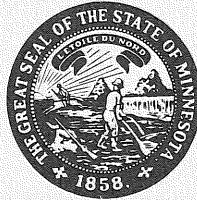




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# LAKE SEDIMENT GEOCHEMICAL SURVEY OF COOK COUNTY, MINNESOTA



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# **LAKE SEDIMENT GEOCHEMICAL SURVEY OF COOK COUNTY, MINNESOTA**

**By: M. K. Vadis and D. G. Meineke**

**Minnesota Department of Natural Resources  
Division of Minerals**

**Report 138-2**

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# LAKE SEDIMENT GEOCHEMICAL SURVEY OF COOK COUNTY, MINNESOTA

By  
M. K. Vadis and D. G. Meineke

## ABSTRACT

A geochemical survey of organic-rich lake sediments was conducted over a major portion of Cook County, Minnesota, as part of a program to evaluate the mineral potential of Cook County for land management purposes. A further goal was to gain additional information on the applicability of organic-rich lake sediments for reconnaissance geochemical exploration surveys.

The survey collected 608 samples from an area of approximately 945 mi<sup>2</sup> (2448 km<sup>2</sup>) from 253 lakes underlain by rocks of the Duluth Complex, North Shore Volcanic Group, and the Rove Formation. Unashed samples were analyzed by atomic absorption for Ag, Co, Cu, Pb, Ni, Zn, Fe, and Mn by using a 4M HNO<sub>3</sub>/1M HCl leach and for As by using a concentrated HNO<sub>3</sub>/30% hydrogen peroxide leach. Organic content was estimated by loss-on-ignition (LOI).

Results of the survey indicate that the chemistry of the bedrock geology is reflected in the element concentrations of the organic-rich lake sediment. This suggests that the lake sediment should also reflect mineralization under favorable chemical, geologic, and hydrologic conditions. The observations and suggestions described are based only on the analytical methods used and may differ with other chemical techniques.

A statistical analysis of the data indicates that Fe and Mn demonstrate a positive relation to all trace elements and that As, Co, Fe, and Mn show a negative relation to LOI. Element ratios were not justified due to non-proportional parameter relations, and univariate regression residuals or inorganic concentration conversions based on LOI did not significantly normalize the raw data for the effects of or relation to Fe, Mn, or LOI.

No positive relations were observed between the trace elements and LOI, suggesting that organic complexing does not play a major role in the concentration of trace elements in the lake sediments of the survey area. Furthermore, the negative relation of some elements to LOI indicates that these elements may be concentrated in the inorganic fraction of the lake sediment.

A non-proportional and approximately exponential relation was exhibited between the trace elements and Fe, Mn, and LOI. A proportional, approximately exponential relation was demonstrated between Fe and Mn and also between the trace elements. It is suggested that these relations are not related to chemical processes, such as scavenging and coprecipitation, which tend to enhance the trace element concentrations, but rather are a function of the relative abundance of the elements in the glacial and bedrock geologic environment.

A number of anomalous regional trends and significant multi-element anomalies were revealed by this survey including several within the expanded borders of the Boundary Waters Canoe Area. This expansion took place subsequent to the completion of this survey.

Some factors that should be considered in the interpretation of this survey for mineral potential purposes include relative trace element mobility, glacial dispersion, variation of trace element background with bedrock lithology, and increase in lake sediment element concentrations with increase in lake area.

## INTRODUCTION

Cook County is a sparsely populated area in extreme northeastern Minnesota bounded by Lake Superior on the south and Ontario, Canada, on the north (Fig. 1). Cook County has experienced minerals exploration for many decades, resulting in the location of numerous mineral occurrences including Fe, Cu, Ni, Co, Ti, V, and other metals (Gladen, McKenna, and Meineke, in preparation). None of these, however, have, as of yet, resulted in a viable mining operation.

The Division of Minerals of the Minnesota Department of Natural Resources manages and administers approximately 15 percent of the mineral lands in Cook County; these are scattered throughout most of the county. A regional geochemical reconnaissance survey of organic-rich lake sediments based on previous research (Meineke, Vadis, and Klaysmat, 1976, 1977a, 1977b, 1977c, 1977d, and 1979; Meineke, Butz, and Vadis, 1977) was undertaken by the Division of Minerals in a substantial portion of Cook County as part of a program to evaluate the mineral potential for land management purposes. An added purpose was to gain further knowledge regarding the applicability of organic-rich lake sediment analyses for exploration geochemical purposes in Minnesota. Recently completed lake sediment surveys by the Geological Survey of Canada in Ontario adjacent to Cook County provide additional data that may have implications for the area covered by this survey (Hornbrook and Coker, 1977; Coker and Shilts, 1979).

The lake sediment sampling described in this report was conducted in 1976-1977 over the area shown in Figure 1. The area includes all areas outside of the Boundary Waters Canoe Area (a U.S. government wilderness area), as the boundary of the BWCA existed before its expansion effective in January, 1979, except the Gunflint Corridor in northwestern Cook County, the Grand Portage Indian Reservation (GPIR), and a small portion of the county east of the GPIR (Fig. 1). The various expansions to the BWCA are also illustrated on the plates that accompany this report. Samples collected from the expanded area before its inclusion in the BWCA are included in this report. All lakes (253) within the area containing acceptable sample material were sampled.

The samples were chemically analyzed at the Division of Minerals under the direction and supervision of A. W. Klaysmat, Research Scientist. Subsequently, computer-supported, statistical analyses were performed on the data to identify relationships and characteristics of the elemental data and other survey parameters that would assist in the interpretation of the survey for mineral potential purposes.

## GEOLOGY AND PHYSIOGRAPHY

The geology of Cook County ranges in age from the Archean to the Pleistocene. The bedrock geology includes Archean, Middle Precambrian, and Late Precambrian (Keweenawan) rocks while the Pleistocene is represented by glacial deposits covering approximately 95 percent of the bedrock. The lithologic and structural character of the Precambrian bedrock as well as Pleistocene glaciation have determined the physiography of Cook County.

### Precambrian Geology

The bedrock geology of Cook County as adapted from Green (1972, revised 1978) is shown on Plate 1. It is dominated by Late Precambrian rocks, as the only Archean units present are the Saganaga Tonalite (sgt) and metavolcanic rocks (gst) in extreme northwestern Cook County. To the south and east of the Archean terrain, the Animikie Group sediments of Middle Precambrian age unconformably overlie the Archean rocks. The Animikie Group includes the basal Kakabeka Quartzite (not shown on Plate 1 because of scale), the Gunflint Iron-formation (gif), and the Rove Formation (rag). The Animikie Group in Cook County is correlative with the Pokegama Quartzite, Biwabik Iron-formation, and the Virginia Formation 50 miles to the southwest in St. Louis County, with the Duluth Complex intervening.

The remainder of Cook County is mainly divided between Keweenawan intrusives (including the Duluth Complex) and volcanics with their associated sediments. The Puckwunge Sandstone (ps) is the basal Keweenawan unit unconformably overlying the Rove Formation (rag) in the eastern part of the county. Overlying the Puckwunge Sandstone (ps) is the North Shore Volcanic Group with its interflow sediments (nss), some of which are not definable on Plate 1 because of scale. The North Shore Volcanic Group and Middle Precambrian Animikie Group have been extensively intruded by Keweenawan rocks including the Duluth Complex and Logan Sills (ld) (Plate 1). The Keweenawan intrusives in Cook County range from troctolite to granophyre in composition.

A compilation of numerous mineral showings and occurrences in Cook County described in the literature plus data from additional field surveys, is in preparation by Gladen, McKenna, and

Meineke. The most numerous mineral prospects in the county are vanadium-bearing, titaniferous magnetites and occurrences of weak Cu-Ni mineralization in the Duluth Complex, the vast majority of which occur in the Gunflint Corridor (Fig. 1).

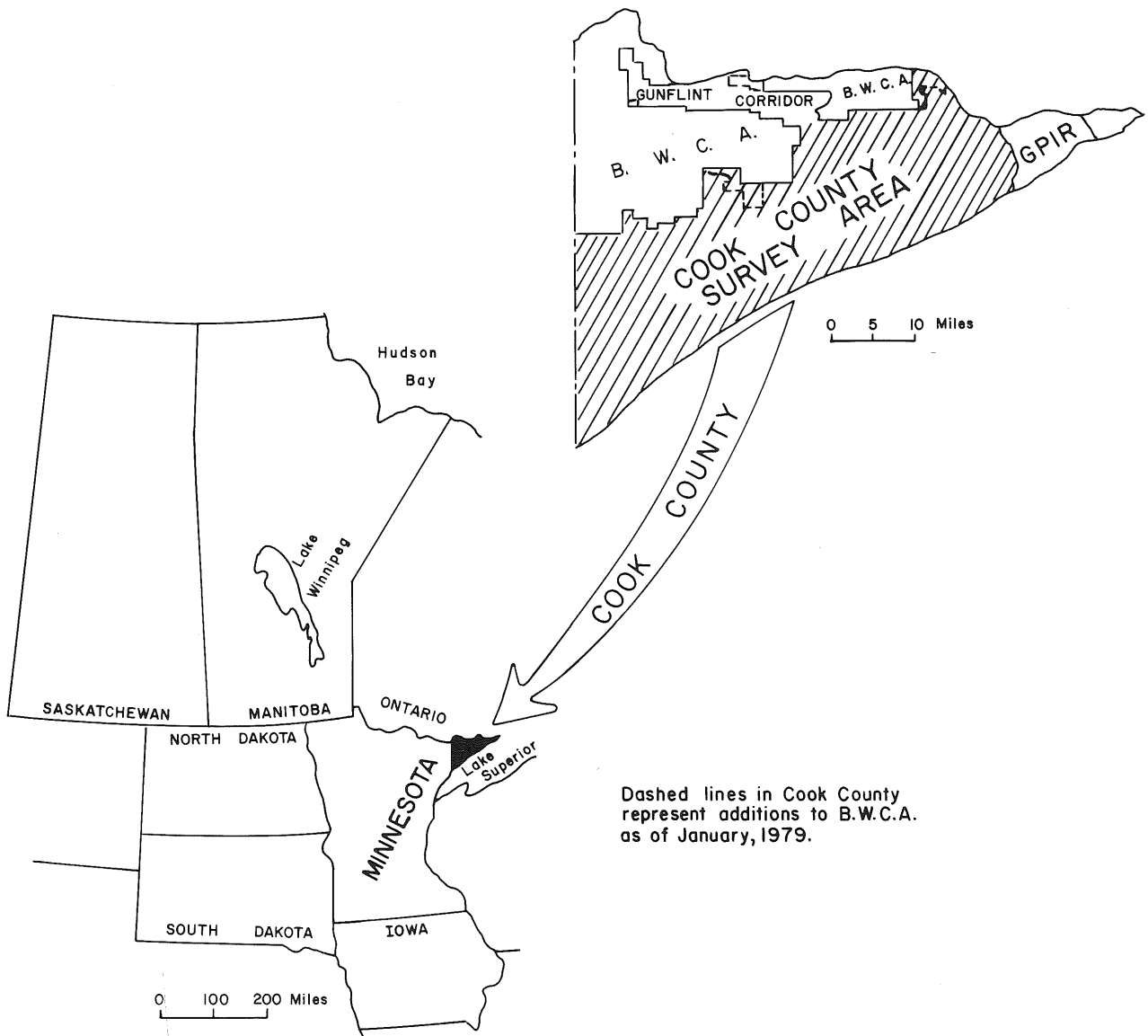


FIGURE 1: Location map of Minnesota, Cook County, and lake sediment survey area.

### Glacial Geology

The glacial geology has a profound effect on the applicability of lake sediment geochemistry since the glacial drift should reflect the nature of the underlying bedrock. Furthermore, the character of the drift will affect the nature of the groundwater and its movement as well as the migration of metals from their bedrock source to the lake sediments. Accordingly, the glacial geology of Cook County was examined and is presented here in some detail.

Cook County was in the path of continental ice masses that moved out of the Hudson Bay lowlands of Canada and has probably undergone numerous ice invasions. Present day glacial deposits, however, contain evidence from only two Wisconsin period glaciers (Sharp, 1953): The Rainy lobe (Elftman, 1898) and the Superior lobe (Leverett, 1929). The Rainy lobe moved into Cook County from the north-northeast and the Superior lobe moved from the east-northeast along the Lake Superior basin. Figure 2 is a composite map illustrating the major phases of these glaciers (after Wright, 1972b). A simplified sequence of Wisconsin Stage glaciation in Cook County and northeastern Minnesota is as follows (Wright, 1972b; Wright and Watts, 1969):

**St. Croix Phase**—The Rainy lobe advanced from the north-northeast and followed a southwest course relatively parallel to the present Lake Superior shoreline (Fig. 2). The Superior lobe moved from the northeast and followed the Lake Superior trough. The end of this phase is a general deglaciation and retreat of the Rainy and Superior lobes.

**Automba Phase**—This phase is marked by a readvance of the Superior lobe and Rainy lobe. The Superior lobe readvance produced the Highland moraine (Fig. 2). At the eastern end, this moraine is joined by the Vermilion moraine of the Rainy lobe (Fig. 2) near Isabella in Lake County, 15 miles west of Cook County. Northeast from the interlobate confluence the two moraines become obscured. The two lobes apparently moved together, side by side, and the accumulation of debris and lateral ice movement was negligible in the Cook County area. The Rainy lobe retreated northward from its terminus at the Vermilion moraine while the Superior lobe retreated far enough into the Lake Superior basin to produce sizeable proglacial lakes at its margins, which deposited clayey and silty sediments.

**Split Rock and Nickerson Phases**—The Superior lobe readvanced during these two phases. The till from these phases is red and clayey, probably from the incorporation of proglacial lake sediments that formed after the retreat of the Superior lobe during the Automba phase. The clayey drift from these phases apparently does not extend very far north of the present shoreline of Lake Superior into Cook County. Figure 3 (adapted from Goebel, 1979) illustrates the distribution of Rainy and Superior lobe drifts in Cook County.

The Rainy and Superior lobe drifts in the Cook County lake sediment survey area appear to be very similar and consist of a nearly continuous mantle of brown, stony till with a sandy matrix. Boulders in the drift are generally composed of granophyre, intermediate igneous rocks, gabbro, diabase, taconite, jasper, iron-formation, greenstone, granite, porphyritic granite, syenite, gneiss, schist, amygdaloid, felsite, rhyolite, basalt, basalt porphyry, argillite, graywacke, sandstone, and quartz pebble conglomerate (Grout, 1959). Boulders are common, attaining a long dimension of up to 15 feet, and often reflect the bedrock lithology. The drift thickness does not usually exceed 15 feet and, in many areas, is only a few feet, although thicknesses of 90 feet and greater are observed locally (Grout, 1959).

The principal results of glacial erosion in Cook County are polishing, striations, grooves, chattermarks, friction cracks, and small, joint-controlled excavations on ice-scoured rock outcrops. Large features include whalebacks, glaciated bedrock hills and ridges, and basins and valleys excavated in the bedrock (Sharp, 1953; Grout, 1959).

The clayey till of the Split Rock and Nickerson phases of the Superior lobe is thought to have covered a narrow strip of land along the southern boundary of Cook County. Till from these phases is a red to pink clayey material, much of which is covered by younger, red, lake clays. The red, clayey till probably extends in a belt approximately three to five and one-half miles wide along the southern boundary of Cook County. None of the lakes sampled for this survey are thought to occur over the clayey material.

The glacial drift of the survey area shows many compositional variations reflecting the nature of the underlying or nearby bedrock. This fact coupled with the relatively thin cover and apparent high permeability of the drift suggests that it should be an excellent environment to reflect bedrock trace element chemistry and economic mineralization through geochemical exploration techniques.

## Physiography

Two of the physiographic areas of Minnesota, the Border Lakes Area and the North Shore Highland described by Wright (1972a), occur in Cook County (Fig. 4). The nature of the bedrock as well as the glacial activity occurring there have resulted in a hilly terrain with local relief up to several hundred feet. The elevation varies from 602 feet at Lake Superior to 2301 feet at Eagle Mountain in the west-central part of the county, the highest elevation in Minnesota.

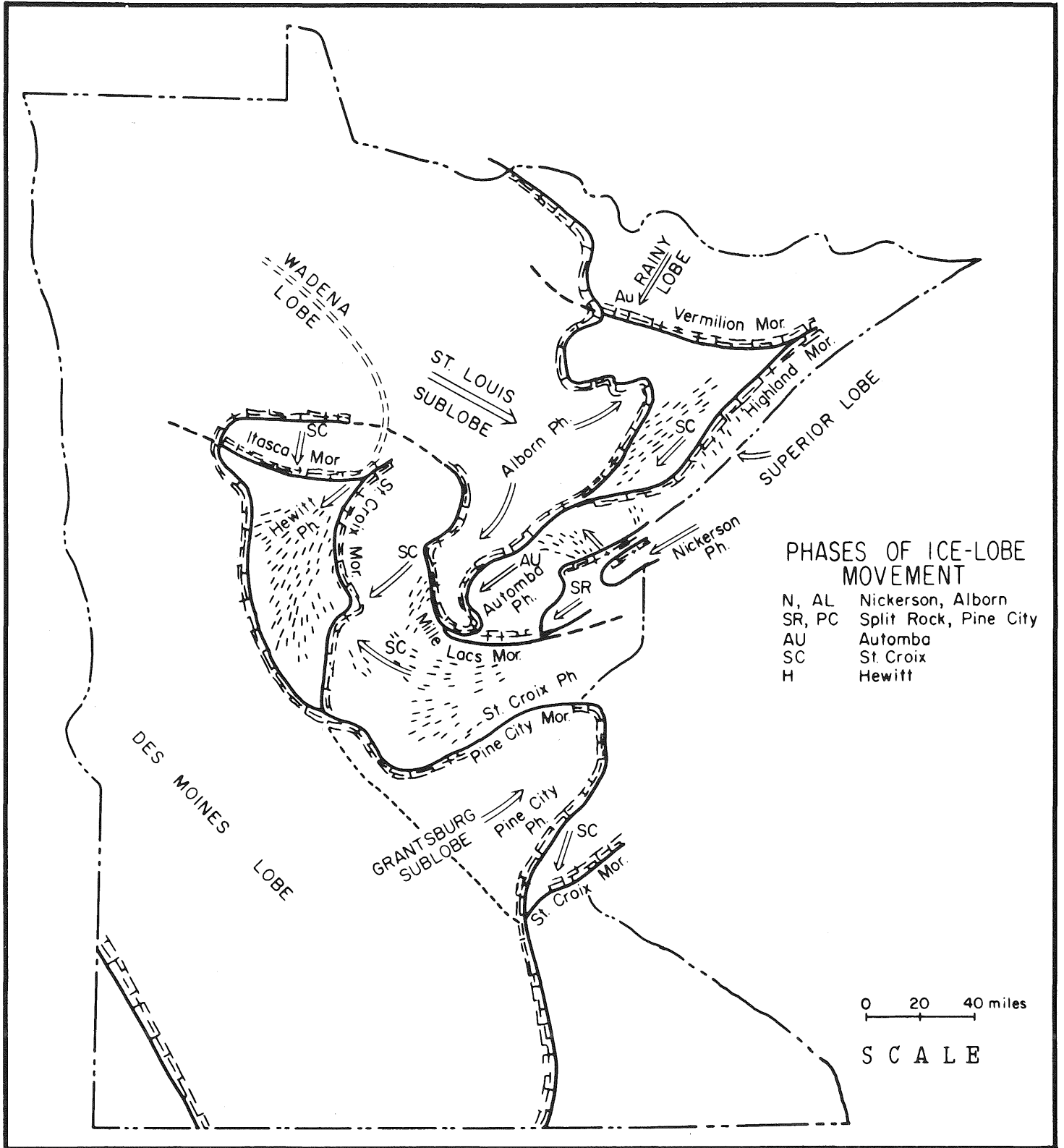
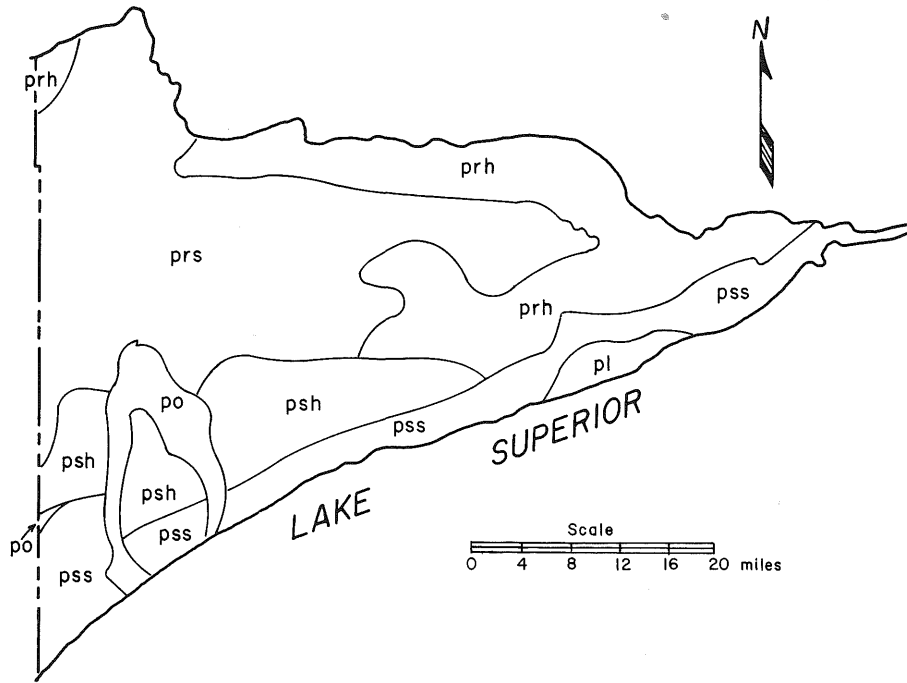


Figure 2: Composite map showing main phases of Wisconsin glaciation in Minnesota. (From Wright, 1972b)





### EXPLANATION

	REDISTRIBUTED DRIFT
<span style="border: 1px solid black; padding: 2px;">pl</span>	GLACIAL LAKE DEPOSITS
<span style="border: 1px solid black; padding: 2px;">po</span>	OUTWASH
	LATE WISCONSIN DRIFT
	<u>SUPERIOR LOBE</u>
<span style="border: 1px solid black; padding: 2px;">pss</span>	SMOOTH TO UNDULATING MORAINE
<span style="border: 1px solid black; padding: 2px;">psh</span>	PITTED TO HILLY MORAINE
	<u>RAINY LOBE</u>
<span style="border: 1px solid black; padding: 2px;">prs</span>	SMOOTH TO UNDULATING MORAINE
<span style="border: 1px solid black; padding: 2px;">prh</span>	PITTED TO HILLY MORAINE

FIGURE 3: Quaternary geology of Cook County (adapted from Goebel, 1979).

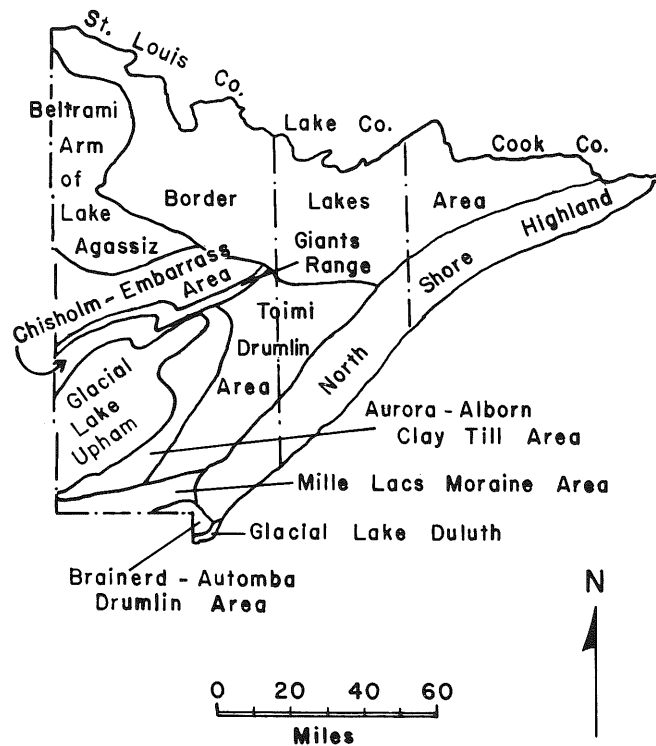


FIGURE 4: Physiographic areas of northeastern Minnesota (adapted from Wright, 1972a).

In the northern portion of the Border Lakes Area, the glacial activity resulted in differential erosion of bedrock, producing patterns of lakes and ridges that trend east-west. A pattern of streams probably existed in this area in preglacial time (Ver Steeg, 1947), but the stream valleys were locally deepened by the glacial ice. Most of the lakes in the northern portion of the county are located in long, narrow bedrock depressions, many of which were localized by dams of glacial drift in preglacial valleys. Within approximately five miles of the Canadian border, the lakes are the result of erosion of the relatively weak slates of the Rove Formation and resistant ridges formed by southward dipping Logan Sills (Plate 1). South of the Rove Formation, over the Duluth Complex in the Border Lakes Area, the lakes are generally shallower than the lakes over the Rove Formation as a result of less prominent differential erosion. The southern portion of the Border Lakes Area is covered by a thicker mantle of glacial drift, and the lake basins there were commonly formed by ice blocks (An Inventory of Minnesota Lakes, 1968).

The North Shore Highland area (Fig. 4), mostly underlain by southeastward dipping Keweenaw volcanics (Plate 1), is characterized by short streams (10-15 miles long) which lead directly to Lake Superior (Wright, 1972a). Few lakes are located adjacent to the Lake Superior shoreline. The boundary between the North Shore Highland and the Border Lakes Area is the toe of the Highland moraine (Figs. 2 and 4).

## SEDIMENT SAMPLING TECHNIQUE

Organic-rich lake sediment samples were collected with a specially designed core sampler, fabricated in such a way that samples could be obtained from a desired depth with minimal mixing of the sediment and that characteristics of the sediment could be easily determined by visual examination. The sampler consists of a thin walled, transparent, plastic tube, 5 cm in diameter and 47 cm long, which is retained in an outer steel pipe by a threaded plastic cutting tip. A valve is located at the top of the outer steel pipe to retard sample loss during retrieval of the sampler. Twenty pounds (9 kg) of weights are located near the top of the sampler to increase sampler penetration. Three equally spaced fins at the top of the sampler assist in maintaining a vertical attitude while lowering the sampler. The sampler yields, except for compaction, a relatively

undisturbed, vertical section of the sediment. Metal contamination is completely avoided as the sample only contacts the plastic portions of the sampler.

In use, the sampler is lowered by a rope, and, when returned to the surface, the plastic cutting tip and plastic liner tube containing the sample are removed. The nature and color of the sample are determined by examining the sample in the transparent tube. The top two inches (5 cm) of sample are discarded to avoid both recent contamination of the lakes, or redox reactions near the sediment-water interface, and to collect a generally reduced sample (Timperley and Allen, 1974). Typically, 10-20 cm of sample is retained in the plastic sample tube per sample run. Approximately one kg of sample was collected from each sample site, which usually required three to eight sampling runs. A composite sample was thus collected, and each sample site represents a sample area. The sample should not be greatly affected by seasonal variations in lake water chemistry.

Water color, water depth, shoreline vegetation, topography, glacial deposit type(s), general slope of the surrounding area, boulder type(s), and rock type(s) in outcrop were recorded for each sample site when available. The degree of H<sub>2</sub>S scent, gyttja quality, color, and texture of the sample were also recorded for each sample. At some sample sites, the surface water and sediment pH and Eh were made with a Beckman Expand-Mate meter and temperature was recorded.

Depending upon access to a lake, sampling was conducted from a boat, canoe, rubber raft, or helicopter. Sample sites were selected to include major bays and basins within a lake and usually were at or near the greatest depth within these areas. An electronic depth finder was used to locate the deeper areas and to determine water depth at each sample site. Sample density amounted to approximately one sample per 1.5 square miles (3.9 sq. km). The sample locations with sample numbers are shown on Plate 11.

## **SAMPLE PREPARATION AND CHEMICAL ANALYSIS**

The organic-rich lake sediment samples were oven dried at less than 80° C for 48 hours. Oven drying of the samples results in their becoming extremely hard; consequently, they were disaggregated with a stainless steel rolling pin and then ground to -80-mesh (177 micron) with a Braun pulverizer equipped with ceramic plates. (Samples collected subsequent to this survey are being prepared by the use of freeze drying equipment, which usually obviates the need for oven drying and pulverization.)

The -80-mesh sediment samples were leached for analysis of Ag, Co, Cu, Ni, Pb, Zn, Fe, and Mn by placing 1000 mg of sample in a solution of 10 mls of 4M HNO<sub>3</sub> and 10 mls of 1M HCl for two hours at 90° C. This solution was then diluted to 100 mls, filtered, and analyzed by using either a Perkin-Elmer model 303 or 603 atomic absorption spectrophotometer. This leach method has been found to provide the greatest and most consistent contrast of anomaly over background of several techniques tested (Meineke, Vadis, and Klaysmat, 1976).

For As, 500 mg of -80-mesh sample was leached in a solution of one ml of concentrated nitric acid and 2 mls of 30 percent hydrogen peroxide overnight at room temperature and then for another six hours at 70° C. Next, 50 mls of 6M HCl was added, and the solution was brought to 100 mls with deionized water and analyzed for As by using an arsine generator and atomic absorption. Loss-on-ignition (LOI) was determined by igniting 1000 mg of -80-mesh sample at 500° C. There is a direct proportional relationship between LOI and organic carbon in organic-rich lake sediment (Coker and Nichol, 1975).

The analytical detection limits are given in Table 1. The number in parentheses is the value used in reporting an analysis below the detection limit. The determination of analytical variability was accomplished by two methods. The first method was to analyze a cut from a precision lake sediment sample with each batch of twenty samples. This precision sample is a large, homogeneous sample that was prepared by the same method used for lake sediments and was thoroughly blended so a homogeneous sample was obtained. This precision sample is of the same sample type so as to obtain the same sample-acid matrix. The Analytical Precision was calculated from these precision sample analyses at the 95 percent confidence level using the "t" distribution. The second method used for determination of analytical variability was reanalysis of randomly selected samples followed by statistical comparison. For As, 34 randomly selected samples were reanalyzed, and for the other elements, 27 samples were reanalyzed. The analytical precision was calculated by a method adapted from Garrett (1969 and 1973) and is shown in Table 2. Most Ag values were below the detection limit for the sample weight used; therefore, analytical precision was not calculated.

The complete analytical data for the 608 samples are given in the Appendix.

TABLE 1: Analytical Detection Limits

Element	Detection Limit
Ag	1 ppm (<1)
As	.1 ppm (<.1)
Co	1 ppm (0)
Cu	1 ppm (<1)
Ni	1 ppm (<1)
Pb	5 ppm (0)
Zn	1 ppm (<1)
Mn	1 ppm (<1)
Fe	.01% (0)

TABLE 2: Analytical Precision for Cook County Lake Sediment Samples

Element	Analytical Precision From Precision Samples	Analytical Precision From Reanalyzed Samples
As	±19.9%	±24.7%
Co	±78.7%	±82.5%
Cu	±28.8%	±23.0%
Ni	±31.5%	±46.8%
Pb	±62.8%	±88.6%
Zn	±17.4%	±17.1%
Fe	±37.1%	±41.8%
Mn	±10.9%	±17.5%
LOI	±12.8%	...

## STATISTICAL ANALYSIS

A statistical analysis of the elements, LOI, and other parameters was conducted to identify various relationships and characteristics that may assist the interpretation of the survey for mineral potential purposes. The parameter distributions were examined for normality compared to lognormality to determine whether log-transformation was necessary to linearize the relationship of lognormal data prior to scatter diagram, correlation, regression, and residual analysis. Various statistical parameters of the elements were compared for the three major bedrock geologic subdivisions of the survey area to determine if the bedrock chemistry was reflected in the lake sediments. Inter-element and other parameter relations were examined by correlation coefficients, scatter diagrams, and interval scatter diagrams.

### Analysis of Data Distribution

An analysis of the total data set was performed to determine if the elements and certain other parameters such as LOI approximate a lognormal or a normal distribution. For the analysis of normality versus lognormality, a combination of statistics such as the mean, variance, skewness, and coefficient of variation along with visual examination of histograms and cumulative frequency distributions were used. This analysis was done to determine if the data should be log-transformed prior to correlation, regression, residual, and scatter diagram analysis in order to linearize any possible relationships.

The range, arithmetic mean, standard deviation, coefficient of variation, and median for the elements, LOI, and water depth are given in Table 3. The histograms and cumulative frequency distributions for As, Co, Cu, Ni, Pb, Zn, Fe, and Mn are shown on Plates 3-10 (in pocket on the back cover), and for LOI on Figure 5.

It was concluded from this analysis that the elements Co, As, Cu, Pb, Ni, Zn, Mn, Fe, and water depth at the sample site approximated a lognormal distribution, and these parameters were log<sub>10</sub> transformed for subsequent statistical analysis. LOI appeared to more closely approximate a normal distribution, and, therefore, no log-transformation was necessary for subsequent analysis.

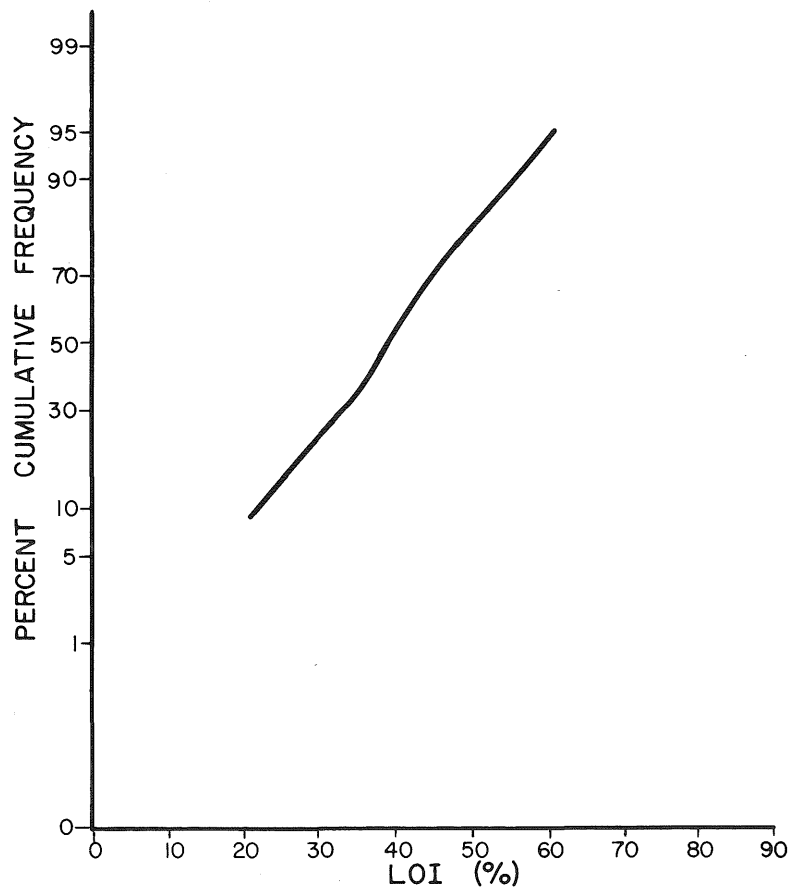
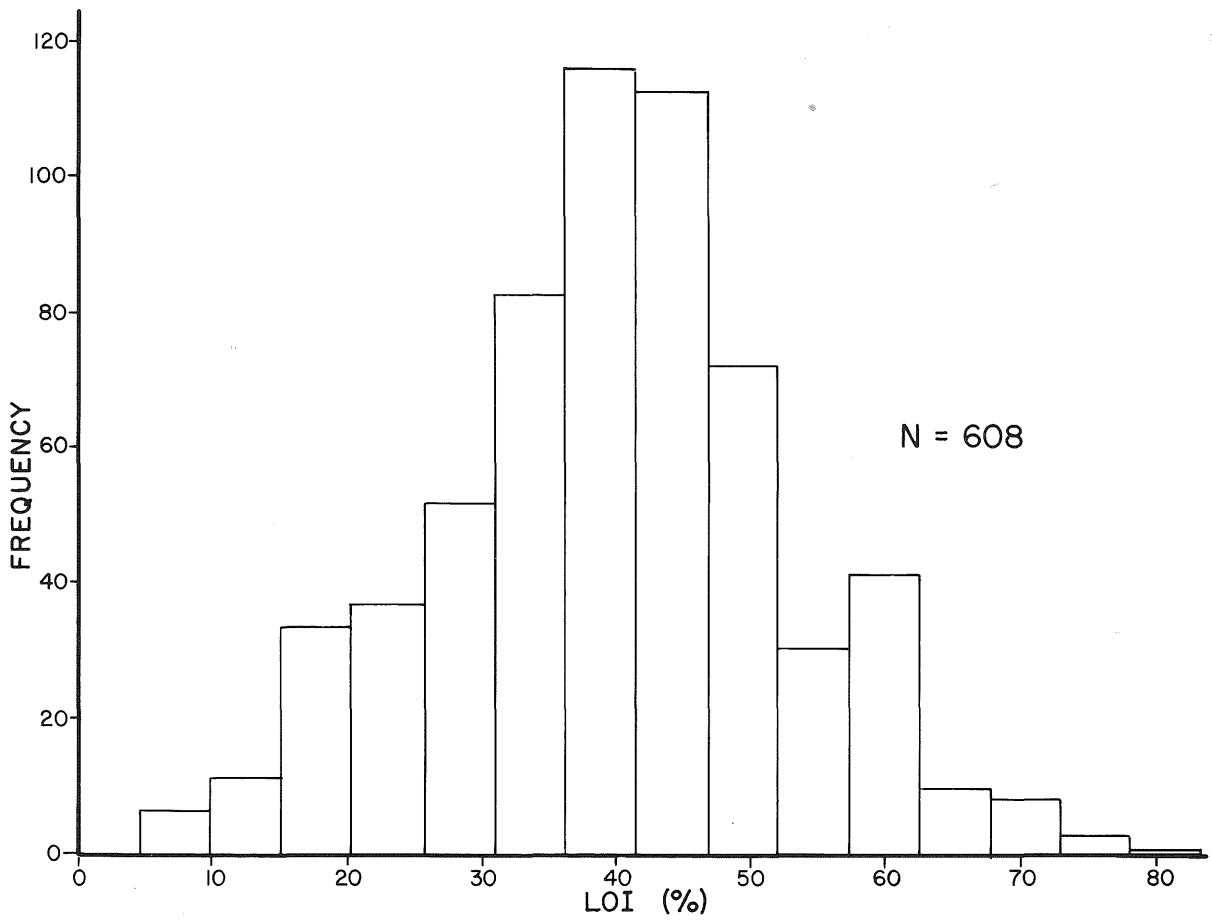


FIGURE 5: Histogram and cumulative frequency distribution of loss-on-ignition (LOI).



TABLE 3: Distribution Statistics of the Element Concentrations, LOI, and Water Depth

Element	Range	Arith. $\bar{x}$	$\log_{10} \bar{x}^*$	Std. Dev.	C.V.%**	Median
As (ppm)	2-20	1.97	1.40	2.30	117	1.2
Co (ppm)	0-41	12.3	10.3	7.3	59	10
Cu (ppm)	7-550	60.1	48.8	50.5	84	49
Ni (ppm)	2-86	22.5	19.4	12.6	56	20
Pb (ppm)	0-35	9	9	6	67	10
Zn (ppm)	26-528	95.0	87.1	43.2	45	88
Fe (%)	.02-7.8	1.57	1.10	1.23	78	1.28
Mn (ppm)	15-1100	195	152	136	70	164
LOI (%)	4.72-81.49	39.02	...	12.59	32	39.10
Water Depth (ft)	1.5-108	14.4	10.2	14.5	...	10

NOTE: N=608

\*Calculated from  $\log_{10}$  transformed data and antilogged for the arithmetic mean values shown. All other statistical parameters shown were not calculated from  $\log_{10}$  transformed data.

\*\*Coefficient of Variation, % = Std. Dev.  $\times$  100/Arith.  $\bar{x}$

### Relation of Bedrock and Lake Sediment Chemistry

The lake sediments should reflect variations in the bedrock chemistry to be useful as indicators of possible economic mineralization and favorable geologic units. Therefore, the relation of metal concentrations in the lake sediments to the three major geologic subdivisions in the survey area were investigated.

The three major bedrock geologic subdivisions are (1) the North Shore Volcanic Group, (2) the Duluth Complex, and (3) the Rove Formation, based on Plate 1 and shown on Plates 3-10. The general lithologies of the subdivisions are described on Plates 3-10, with a more detailed description given on Plate 1.

The Duluth Complex within the survey area consists of mafic to felsic intrusive rocks, and the North Shore Volcanic Group, as depicted on Plates 3-10, includes the North Shore Volcanic Group on Plate 1 plus Keweenaw mafic to felsic intrusives other than the Duluth Complex. The Rove Formation is pervasively intruded by diabase (Logan) sills.

Table 4 shows the range, arithmetic mean,  $\log_{10}$  mean, standard deviation, coefficient of variation, and median of the lake sediment element data for each geologic subdivision. From Table 4 it is apparent that a distinct difference in element concentrations exists between the geologic subdivisions. The relative differences in the element concentrations are typical for the lithologies represented by each geologic subdivision (Hawkes and Webb, 1962; Levinson, 1974). Figure 6, a frequency distribution for Ni, further illustrates the difference in concentration levels between the geologic subdivisions. Cumulative frequency distributions for Ni and other elements indicate that an approximately lognormal population exists for each bedrock geologic subdivision, and the distribution for each geologic subdivision is parallel or subparallel for the same element.

It is apparent from the foregoing that the bedrock chemistry is reflected in the lake sediment of the Cook County survey area. Similar observations have been described for a survey 50 miles west of Cook County (Meineke, Vadis, and Klaysmat, 1976) and for a survey in Ontario immediately north of Cook County (Coker and Shilts, 1979).

### Correlation and Inter-Parameter Relations

Correlation coefficients were calculated for the total data set (N = 608) using a univariate linear model (Table 5). Elements that approximate a lognormal distribution, except LOI which is normally distributed, were  $\log_{10}$  transformed prior to correlation. Similarly,  $\log_{10}$  transformation was used for the elements in constructing scatter diagrams.

In addition to the elements and LOI, other quantitative parameters were correlated, such as water depth at the sample site, lake acreage, sediment and water pH, and sediment and water temperature. Data for pH and temperature were available, however, for only approximately 10 percent of the samples and sample sites. The correlation coefficients (Table 5) of pH and temperature indicate a nonexistent to weak and inconsistent relationship. There is, however, a -0.47 correlation between sediment temperature and water depth.

A relationship does exist between lake acreage and the elements (Table 5), which is apparent but diffuse on scatter diagrams. The negative relation between lake acreage and LOI (-0.52) indicates that larger lakes contain less organic material than smaller lakes, which is in agreement with field observations.

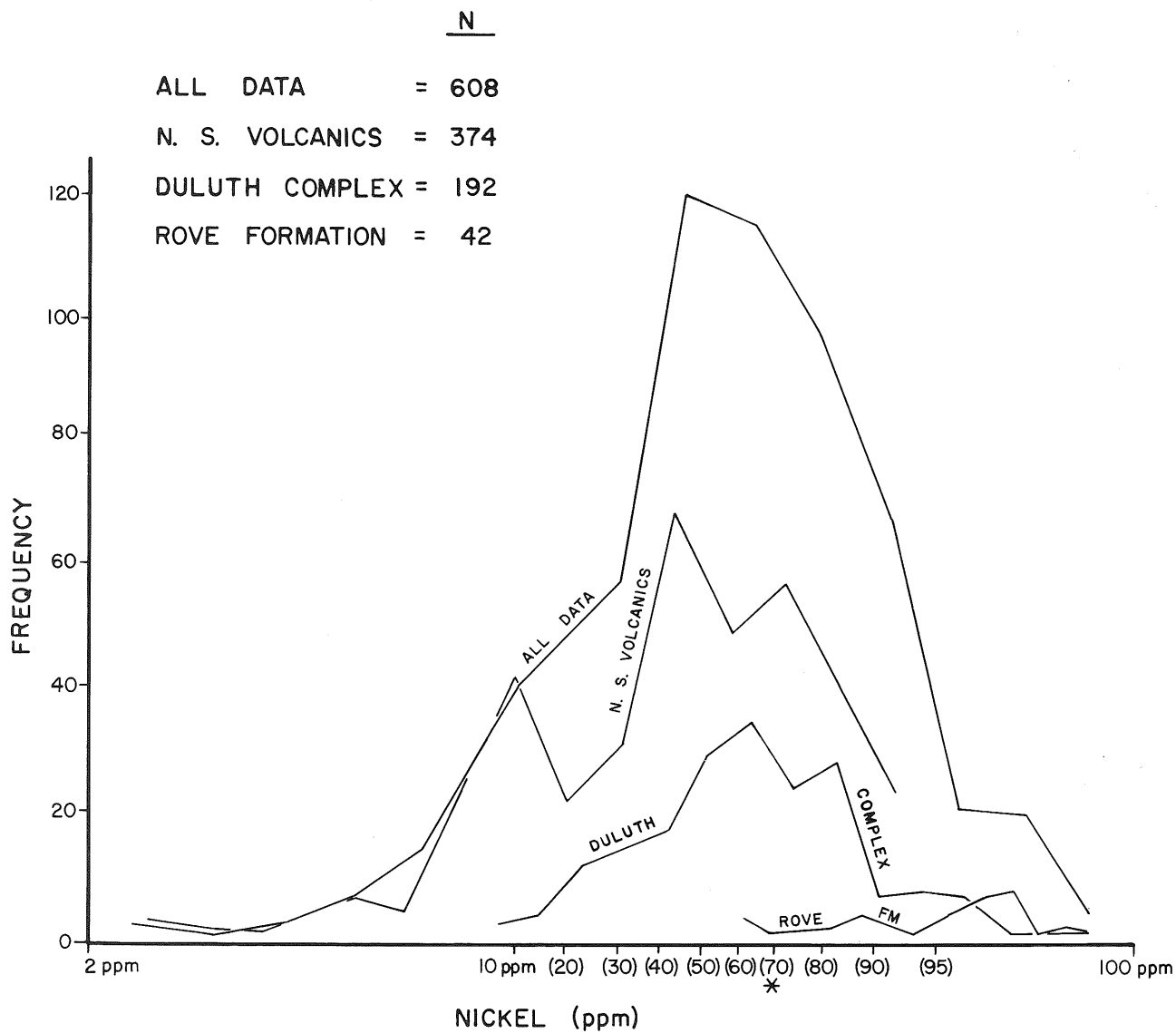


FIGURE 6: Frequency distribution of nickel in lake sediment for all survey data and for three major bedrock geologic subdivisions.

TABLE 4: Distribution Statistics of Lake Sediment Element Data Segregated by Major Bedrock Geologic Subdivisions

Element	Rock Type	Range	Arith. $\bar{x}$	Log <sub>10</sub> $\bar{x}$ *	Std. Dev.	C.V.%**	Median
As (ppm)	Dul. Comp.	2-8.2	1.43	1.16	1.20	84	1.2
	Volcanics	.2-20	1.79	1.33	1.97	110	1.2
	Rove Form.	1.2-20	6.14	5.02	4.03	66	5.4
Co (ppm)	Dul. Comp.	3-41	13.7	12.0	7.5	55	11
	Volcanics	0-33	10.6	8.8	6.5	61	9
	Rove Form.	9-30	20.7	19.8	5.5	27	22
Cu (ppm)	Dul. Comp.	18-550	70.5	56.9	71.5	102	57
	Volcanics	7-205	52.2	42.9	34.5	66	44
	Rove Form.	14-158	84.0	75.8	35.7	43	72
Ni (ppm)	Dul. Comp.	8-86	24.4	22.4	10.8	44	23
	Volcanics	2-41	18.6	16.4	8.7	47	17
	Rove Form.	21-85	49.0	46.5	14.9	30	53
Pb (ppm)	Dul. Comp.	0-20	8	9	6	75	10
	Volcanics	0-35	9	9	6	67	10
	Rove Form.	5-25	15	14	6	40	15
Zn (ppm)	Dul. Comp.	30-302	102.1	94.1	43.3	42	94
	Volcanics	26-528	89.3	81.8	43.3	49	82
	Rove Form.	40-175	112.9	108.3	30.9	27	112
Fe (%)	Dul. Comp.	.13-7.8	1.68	1.31	1.12	67	1.46
	Volcanics	.02-7.73	1.36	.92	1.14	84	1.06
	Rove Form.	.19-2.95	2.95	2.47	1.52	52	2.89
Mn (ppm)	Dul. Comp.	24-1100	210	168	144	68	185
	Volcanics	15-765	183	140	131	72	147
	Rove Form.	59-576	226	193	130	57	205

NOTE: Dul. Comp. (N=192), Volcanics (N=374), Rove Form. (N=42)

\*Calculated from log<sub>10</sub> transformed data and antilogged for the arithmetic mean values shown. All other statistical parameters shown were not calculated from log<sub>10</sub> transformed data.

\*\*Coefficient of Variation, % = Std. Dev. × 100/Arith.  $\bar{x}$

TABLE 5: Correlation Matrix for Cook County Lake Sediment Survey (N=608)

	Water Temp.	Water pH	Sed. Temp.	Sed. pH	Acre	LOI	Mn	Fe	Zn	Pb	Ni	Cu	Co	As
Depth	-.28	.17	-.47	.00	.48	-.26	.52	.54	.52	.22	.33	.41	.40	.22
As	-.22	.00	.00	.00	.37	-.42	.41	.44	.28	.36	.39	.22	.32	
Co	-.30	.37	-.14	.22	.42	-.36	.54	.66	.60	.33	.73	.61		
Cu	-.33	.22	.00	.30	.35	-.10	.49	.62	.59	.26	.63			
Ni	-.28	.32	-.10	.10	.45	-.36	.46	.60	.57	.32				
Pb	-.41	.00	-.22	.10	.20	-.22	.35	.36	.28					
Zn	-.10	.37	.00	.10	.36	-.14	.63	.68						
Fe	-.35	.24	-.17	.14	.49	-.37	.78							
Mn	-.14	.17	-.10	.00	.48	-.32								
LOI	.17	.10	.00	.14	-.52									
Acreage	-.30	.30	.00	.14										
Sed. pH	.10	.00	.14											
Sed. Temp.	-.10	.17												
Water pH	.10													

NOTE: All data log<sub>10</sub> transformed prior to calculation of correlation coefficients, except LOI.

Tenhola and Lummaa (1979) and Kauranne (1979) have reported that lake size has a considerable effect on element concentrations based on an organic-rich lake sediment survey conducted in eastern Finland. Their survey indicated that for small lakes (length <1000 meters) the Zn, Cu, Pb, Ni, and U concentrations are greater than for large lakes (length >1000 meters), but approximately the same for Co and lower for Mn.

Results of a previous survey indicate that As, Co, Ni, Pb, Mn, and Fe are higher in lakes larger than 640 acres than in lakes less than 160 acres in size (Meineke, Vadis, and Klaysmat, 1976). Cu was higher in small lakes and Zn approximately the same in both size lakes. This survey indicates a general tendency for higher concentrations in large lakes (>640 acres) which is opposite to that described by Tenhola and Lummaa (1979).

An analysis of the data from Cook County was done for small lakes ( $\leq 320$  and  $\leq 640$  acres) and large lakes (>320 and >640 acres) (Tables 6 and 7). The means of the elements (Tables 6 and 7) are greater for large lakes, and LOI is greater in small lakes. These results are similar but more consistent than those previously described for the Lake Vermilion-Ely area of Minnesota (Meineke, Vadis, and Klaysmat, 1976), and are again opposite, except for LOI, to those reported by Tenhola and Lummaa (1979) in eastern Finland. The sample preparation and analytic methods used in the Cook County survey are identical to those used by Meineke, Vadis, and Klaysmat (1976), but are substantially different than those used by Tenhola and Lummaa (1979) (ashed sediment and hot 6M HCl leach). Therefore, the differences may be attributed to the sample preparation and chemical techniques.

The rather weak correlation and diffuse relations demonstrated by scatter diagrams (not included in this report) suggest that ratios or residuals would not significantly normalize the element data for the effect of lake size. Furthermore, the diffuse nature of the relationship suggests that there are other factors also controlling the elements, and, therefore, ratios or residuals based on lake area may lead to results that are less representative of the bedrock chemistry than the raw element data. It is suggested, however, that the increase in element concentration with increase in lake area (Tables 5, 6, and 7) should not be ignored in the evaluation and interpretation of the data presented in this report.

The LOI correlation (Table 5) indicates a weak, negative relation with As, Co, Ni, Fe, and Mn. The scatter diagrams (not included in this report) also indicated a weak but possibly significant negative relation, except for Ni where the relation is erratic. This negative relation suggests that these elements, to some degree, are preferentially accumulating in the inorganic fraction of the lake sediment and further suggests that organic complexing may not play a major role. This supports the observation discussed previously for lake area in that the element concentrations increase and LOI decreases with lake size (Tables 5, 6, and 7).

Univariate, linear correlation coefficients (Tables 8 and 9) were calculated for both the small and large lakes and indicate a somewhat weaker relation for most parameters than Table 5, but both lake size classes have a similar relation. One of the major exceptions is Cu with a positive (0.40) relation to LOI for large lakes (Table 9).

Mn and Fe demonstrate a weak to moderate relation to the other elements (Table 5), and Fe and Mn themselves are strongly correlated (0.78). The scatter diagrams also demonstrate that a significant relation exists between Fe and the trace elements, especially Co, Cu, Ni, and Zn. A similar relation to that for the total data (Table 5) occurs for small and large lakes (Tables 8 and 9); however, the relation is generally weaker for the large lakes as compared to the small lakes. This observation may suggest that if scavenging and coprecipitation of the trace elements by Fe and Mn hydroxides are occurring, they would be more predominant in small lakes, which are generally shallower and, therefore, more oxygenated at the sediment water interface. However, the Fe and Mn increase directly with lake area (Tables 5, 6, and 7) and similarly the metals also increase. Therefore, as discussed previously, the net effect is an increase in the element concentrations with increasing lake size. In exploration geochemistry, anomalous concentrations of Fe or Mn can create falsely anomalous trace metal values, which must be recognized when interpreting the data. The normalization of the effect of Mn and Fe on the trace elements will be considered in the section that follows.

As, Co, Cu, Ni, Pb, and Zn display a weak to moderate relation to one another (Table 5), which may not necessarily indicate a bedrock geologic association, because of their common relation to Fe, Mn, and LOI; i.e., their mutual relationship may result from the chemical processes which transported the elements from their source and deposited them in the lake sediment. Common bedrock geologic associations are apparent, however, in Table 5, such as Co-Ni (0.73) and Cu-Ni (0.63), and it was demonstrated previously that the lake sediment in the survey area does reflect the underlying bedrock chemistry.

TABLE 6: Distribution of Lake Sediment Element Concentrations and LOI for Lakes  $\leq 320$  and  $>320$  Acres

SMALL LAKES ( $\leq 320$ acres, N = 457)					
Element	Range	Arith. $\bar{x}$	Std. Dev.	C.V.%**	Log <sub>10</sub> $\bar{x}$ *
As (ppm)	.2-20	1.58	1.89	120	1.18
Co (ppm)	0-41	10.8	6.7	62	9.0
Cu (ppm)	7-550	56.0	54.3	97	44.3
Ni (ppm)	2-86	19.8	10.8	54	17.2
Pb (ppm)	0-35	8	6	74	9
Zn (ppm)	26-528	89.0	44.7	50	81.1
Fe (%)	.02-7.8	1.32	1.17	89	0.9
Mn (ppm)	15-1100	170	134	79	130
LOI (%)	4.76-81.49	42.64	11.27	26	...

LARGE LAKES ( $>320$ acres, N = 151)					
Element	Range	Arith. $\bar{x}$	Std. Dev.	C.V.%**	Log <sub>10</sub> $\bar{x}$ *
As (ppm)	.4-20	3.20	2.93	92	2.38
Co (ppm)	2-35	17.0	6.9	41	15.5
Cu (ppm)	22-205	73.6	34.0	46	66.7
Ni (ppm)	8-85	31.2	13.7	44	28.6
Pb (ppm)	0-25	11	6	50	11
Zn (ppm)	46-200	113.9	32.0	28	109.3
Fe (%)	.19-5.95	2.33	1.10	47	2.06
Mn (ppm)	82-595	272	111	41	251
LOI (%)	4.72-64.63	28.18	9.77	35	26.22

\*Calculated from log<sub>10</sub> transformed data and antilogged for the arithmetic mean values shown. All other statistical parameters shown were not calculated from log<sub>10</sub> transformed data.

\*\* Coefficient of Variation, % = Std. Dev.  $\times$  100/Arith.  $\bar{x}$

TABLE 7: Distribution of Lake Sediment Element Concentrations and LOI for Lakes  $\leq 640$  and  $>640$  Acres

SMALL LAKES ( $\leq 640$ acres, N = 533)					
Element	Range	Arith. $\bar{x}$	Std. Dev.	C.V.%**	Log <sub>10</sub> $\bar{x}$ *
As (ppm)	.2-20	1.85	2.19	118	1.33
Co (ppm)	0-41	11.7	7.2	62	9.7
Cu (ppm)	7-550	59.2	53.1	90	47.1
Ni (ppm)	2-86	21.6	12.5	58	18.5
Pb (ppm)	0-35	9	6	71	9
Zn (ppm)	26-528	93.3	45.0	48	85.1
Fe (%)	.02-7.8	1.46	1.21	83	1.01
Mn (ppm)	15-1100	185	136	73	143
LOI (%)	4.76-81.49	40.51	12.27	30	...

LARGE LAKES ( $>640$ acres, N = 75)					
Element	Range	Arith. $\bar{x}$	Std. Dev.	C.V.%**	Log <sub>10</sub> $\bar{x}$ *
As (ppm)	.4-16	2.92	2.82	97	2.07
Co (ppm)	5-33	16.9	5.9	35	15.9
Cu (ppm)	22-205	69.1	25.6	37	65.0
Ni (ppm)	8-62	29.6	10.6	36	27.6
Pb (ppm)	0-20	11	5	48	10
Zn (ppm)	58-173	108.7	24.4	22	105.9
Fe (%)	.19-5.95	2.38	1.10	46	2.10
Mn (ppm)	82-595	268	113	42	246
LOI (%)	4.72-64.63	28.72	9.53	33	...

\*Calculated from log<sub>10</sub> transformed data and antilogged for the arithmetic mean values shown. All other statistical parameters shown were not calculated from log<sub>10</sub> transformed data.

\*\*Coefficient of Variation, % = Std. Dev.  $\times$  100/Arith.  $\bar{x}$



TABLE 8: Correlation Coefficients of Lake Sediment for Lakes  $\leq 320$  and  $> 320$  Acres

	SMALL LAKES ( $\leq 320$ acres, N = 457)			LARGE LAKES ( $> 320$ acres, N = 151)			
	Fe	Mn	LOI	Fe	Mn	LOI	
As	.35	.32	-.22	As	.37	.26	-.49
Co	.61	.47	-.22	Co	.58	.39	-.20
Cu	.61	.46	.00	Cu	.32	.10	.00
Ni	.54	.39	-.22	Ni	.41	.14	-.20
Pb	.32	.32	.00	Pb	.20	.10	-.24
Zn	.66	.59	.00	Zn	.47	.42	.00
Fe	...	.76	-.24	Fe	...	.51	-.20
Mn	...	...	-.20	Mn	...	...	.00

NOTE: All data  $\log_{10}$  transformed prior to calculation of correlation coefficients, except LOI.

TABLE 9: Correlation Coefficients of Lake Sediments for Lakes  $\leq 640$  and  $> 640$  Acres

	SMALL LAKES ( $\leq 640$ acres, N = 533)			LARGE LAKES ( $> 640$ acres, N = 75)			
	Fe	Mn	LOI	Fe	Mn	LOI	
As	.44	.40	-.39	As	.26	.20	-.49
Co	.64	.50	-.32	Co	.53	.45	-.14
Cu	.63	.49	.00	Cu	.00	-.22	.40
Ni	.59	.45	-.33	Ni	.10	-.10	-.26
Pb	.36	.35	-.17	Pb	.20	.20	-.50
Zn	.69	.62	-.10	Zn	.17	.32	.00
Fe	...	.77	-.33	Fe	...	.47	.00
Mn	...	...	-.30	Mn	...	...	.00

NOTE: All data  $\log_{10}$  transformed prior to calculation of correlation coefficients, except LOI.

Linear correlation coefficients (Table 10) were calculated for each of the three bedrock geologic subdivisions described in the previous section (Table 4). The relations in Table 10 are somewhat variable between bedrock type but are generally similar to the total data (Table 5). Frequently, the correlation coefficients in Table 10 are somewhat greater than Table 5, which may result from less scatter of the data when considering the individual bedrock geologic subdivision. A clustering of geologic subdivisions was observed on the total data scatter diagrams (not included in this report).

### Normalization of the Effects of Fe, Mn, and LOI

As discussed in the previous section, Fe and Mn demonstrate a sympathetic, positive relation with the trace elements, which may result from scavenging and coprecipitation by Fe and Mn hydroxides. Scavenging and coprecipitation of trace elements by Fe and Mn hydroxides have been discussed by Hawkes and Webb (1962) and Levinson (1974, 1980) and have been described for lake sediment by others (Coker, et al., 1979, p. 445). In an organic-rich lake sediment survey conducted in Saskatchewan, it was concluded, however, that Fe and Mn hydroxides do not play a dominant role in scavenging trace elements (Hornbrook and Garrett, 1976).

The normalization of the effect of Fe, Mn, and LOI on the element concentrations was investigated, the objective being to suppress the effect of chemical processes that may tend to concentrate these elements, thereby enhancing the reflection of the bedrock chemistry and also to reduce false anomalies caused by the effect of these processes.

Two major statistical techniques used to normalize lake sediment data are ratioing, i.e., Cu/Mn, Zn/Fe (Coker and Nichol, 1975, 1976; Jackson and Nichol, 1975), and regression residuals (Spilsbury and Fletcher, 1974; Davenport, et al., 1975; Hornbrook and Garrett, 1976). These were examined and evaluated for the Cook County survey, but multivariate residuals, which may deserve consideration due to the observed multielement relations, were not attempted. In the analysis that follows, a number of parameter characteristics emerge that should aid in the interpretation of organic-rich lake sediment geochemical data.

At the outset, scatter and interval scatter diagrams of Fe, Mn, and LOI plotted against trace elements were evaluated. An analysis of the scatter diagrams is necessary because the correlation coefficients (Table 5) in themselves may indicate false relations that result from

TABLE 10: Correlation Matrix of Lake Sediment Survey Data Segregated by Major Bedrock Geologic Subdivision

	R*/As	N†/As	D††/As	R*/Co	N†/Co	D††/Co	R*/Pb	N†/Pb	D††/Pb	R*/LOI	N†/LOI	D††/LOI
Depth	.45	.22	.14	.53	.42	.26	.32	.20	.14	-.26	-.30	.00
As	...	...	...	.69	.26	.14	.00	.30	.28	-.46	-.35	-.24
Co	.69	.26	.14	...	...	...	.17	.26	.33	-.37	-.36	.00
Cu	.26	.17	.10	.40	.59	.52	.20	.17	.33	.00	-.10	.24
Ni	.62	.22	.35	.78	.71	.60	.20	.28	.10	-.14	-.30	.00
Pb	.00	.30	.28	.17	.26	.33	...	...	...	.00	-.20	.00
Zn	.41	.26	.22	.51	.57	.62	.45	.26	.20	.00	-.17	.10
Fe	.55	.46	.26	.69	.66	.52	.37	.32	.28	-.22	-.39	.00
Mn	.60	.45	.37	.57	.57	.42	.32	.35	.30	-.28	-.36	-.17
LOI	-.46	-.35	-.24	-.37	-.36	.00	.00	-.20	.00	...	...	...
Acreage	.32	.30	.32	.14	.58	.00	.36	.17	.00	-.32	-.50	-.48

NOTE: All data log<sub>10</sub> transformed prior to calculating correlation coefficients, except LOI.

\* R = Rove Formation (N=42)

† N = North Shore Volcanic Group (N=374)

†† D = Duluth Complex (N=192)

TABLE 10 Continued

	R*/Mn	N†/Mn	D††/Mn	R*/Fe	N†/Fe	D††/Fe	R*/Zn	N†/Zn	D††/Zn	R*/Ni	N†/Ni	D††/Ni	R*/Cu	N†/Cu	D††/Cu
Depth	.87	.47	.54	.75	.51	.56	.73	.50	.48	.56	.28	.24	.42	.37	.42
As	.60	.45	.37	.55	.46	.26	.41	.26	.22	.62	.22	.35	.26	.17	.10
Co	.57	.57	.42	.69	.66	.52	.51	.57	.62	.78	.71	.60	.40	.59	.52
Cu	.40	.48	.46	.33	.66	.46	.70	.58	.54	.54	.61	.57	...	...	...
Ni	.55	.49	.36	.56	.58	.44	.66	.58	.45	...	...	...	.54	.61	.57
Pb	.32	.35	.30	.37	.32	.28	.45	.26	.20	.20	.28	.10	.20	.17	.33
Zn	.75	.64	.55	.56	.66	.70	...	...	...	.66	.58	.50	.70	.58	.54
Fe	.68	.80	.77	...	...	...	.56	.66	.70	.56	.58	.44	.33	.66	.46
Mn	...	...	...	.68	.80	.77	.31	.64	.55	.55	.46	.36	.40	.48	.46
LOI	-.10	-.37	.00	-.10	-.32	.00	.20	-.14	.14	.00	-.32	.00	.20	.00	.17
Acreage	.52	.55	.32	.30	.59	.22	.44	.46	.10	.00	.54	.17	.32	.41	.14

NOTE: All data log<sub>10</sub> transformed prior to calculating correlation coefficients, except LOI.

\* R = Rove Formation (N=42)

† N = North Shore Volcanic Group (N=374)

†† D = Duluth Complex (N=192)

spurious values, data clustering, or the effect of more than one variable (Chapman, 1976). Interval scatter diagrams as used here are scatter diagrams where each point represents a number of data points and, in effect, more clearly depict the trend of a two-parameter relationship. Fe, Mn, LOI, and other parameters (on the X-axis) are divided into intervals, and the mean of the corresponding trace elements for each data point within the interval are calculated and plotted as the ordinate value. The use of interval scatter diagrams for geochemical data has been previously demonstrated by Coker and Nichol (1976). The trend of the points on an interval scatter diagram is often very similar to a least square regression line fit to the total data.

All elements were log<sub>10</sub> transformed for the scatter and interval scatter diagrams to linearize the relationships for ease of evaluation. LOI was not transformed as it displays an approximate normal distribution. The relation between two lognormal parameters or a lognormal and a normal parameter is exponential. If lognormal data are not transformed (Figs. 7B and 8B), the data plot

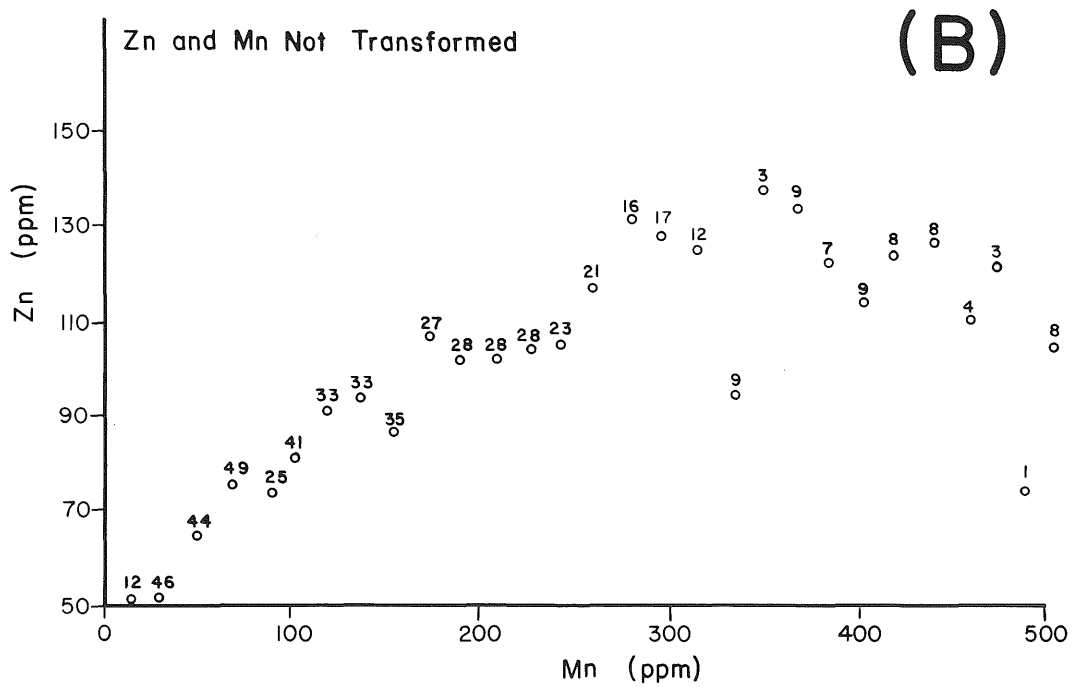
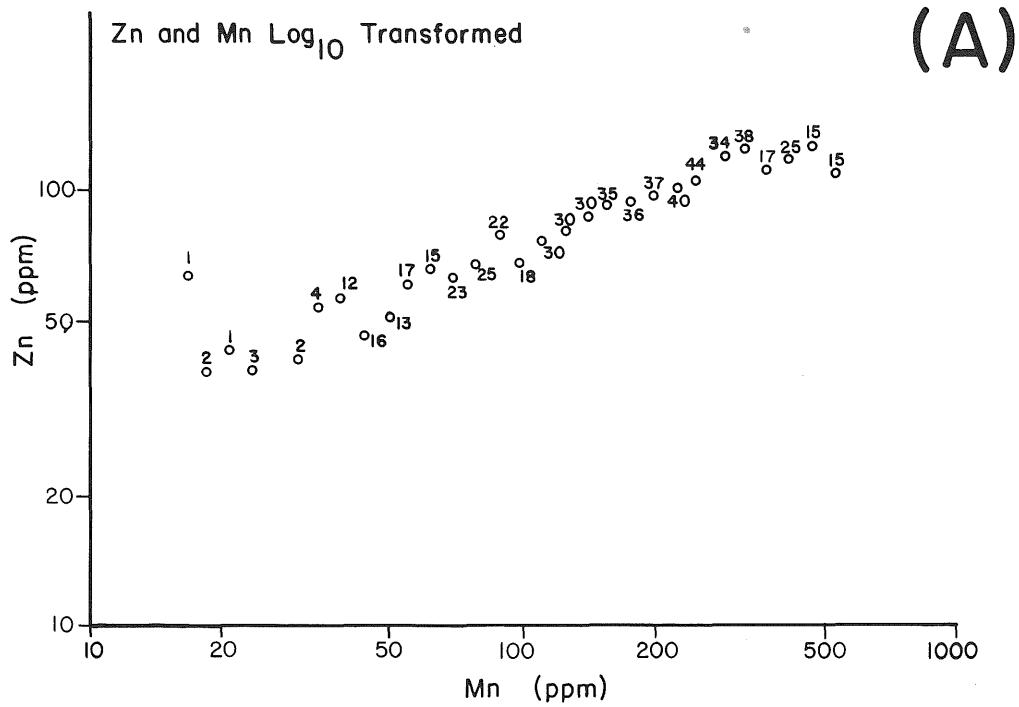


FIGURE 7: Interval scatter diagrams of Zn and Mn. Numbers represent sample frequency of plotted point for each interval.

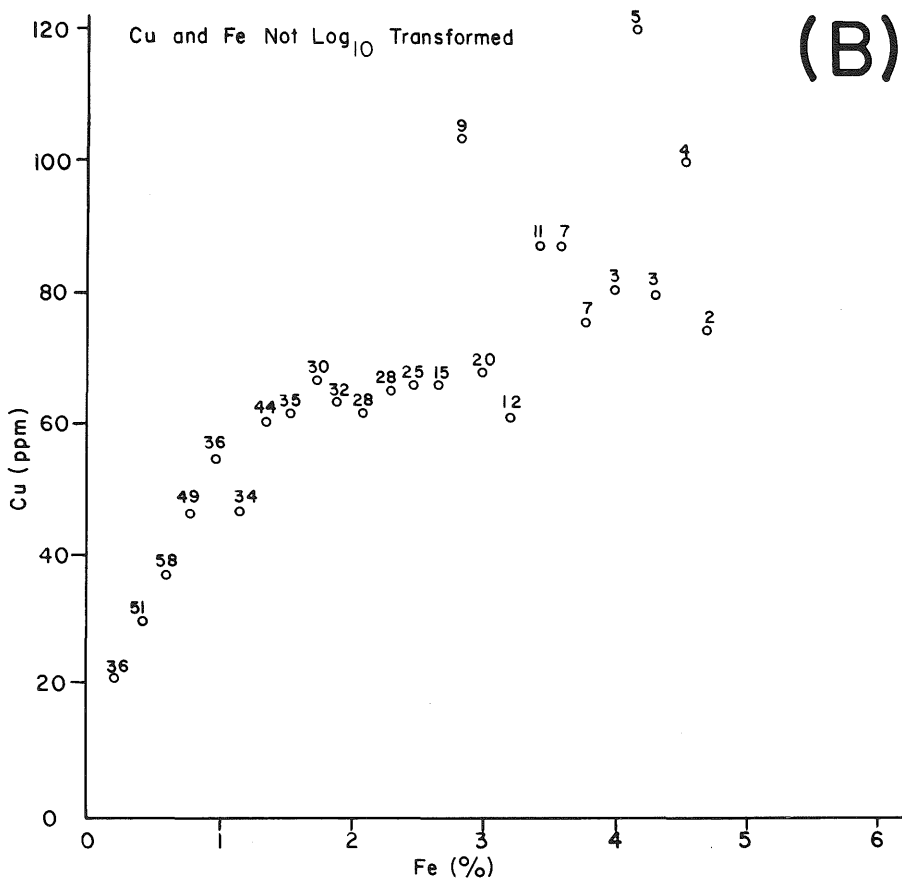
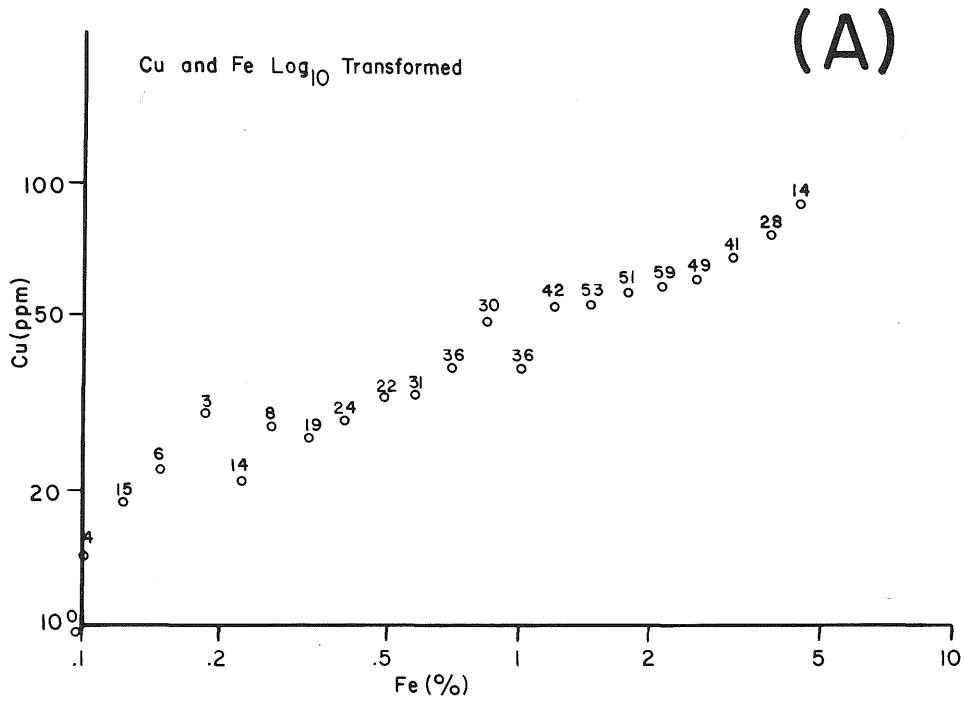


FIGURE 8: Interval scatter diagrams of Cu and Fe. Numbers represent sample frequency of plotted point for each interval.

has an exponential curve, unless the parameter displays both an exponential and proportional relation. As a result, the scatter in the data that has not been  $\log_{10}$  transformed may lead to a false interpretation of changes in the mathematical relationships over the range of parameter values; that is, the exponential curve including the data scatter may falsely appear to display major breaks or inflections. The upper interval scatter diagrams on Figures 7A and 8A, which are  $\log_{10}$  transformed, demonstrate that the relationship between these parameters is approximately exponential. If the relation is both exponential and directly proportional, the untransformed data will plot as an approximately straight line.

Composite interval scatter diagrams of the three major bedrock geologic subdivisions (Table 4) were also evaluated for the relation between Fe, Mn, and LOI to the trace elements. An analysis of the composite diagrams was done in order to determine whether the relationship demonstrated by the total data was consistent with that for each bedrock subdivision. Ratios or residuals cannot be justified to normalize the data if inconsistencies exist between the bedrock subdivisions.

The analysis of the survey data by the techniques described indicate that Cu, Ni, Pb, and Zn do not demonstrate a significant relationship to LOI. However, these metals, especially Cu, Ni, and Zn, do have a pronounced positive relation with Fe and Mn (examples shown on Figs. 7 and 8); the Fe relation is generally stronger and more consistent than Mn. Co and As (Fig. 9A) displayed a positive relation with Fe and Mn and a negative relation with LOI (Co shown on Fig. 12A); the Fe relation was again generally stronger and more consistent than Mn. Fe and Mn also have a negative relation with LOI.

Based on these observations, ratios and residuals were considered to normalize the effect of the Fe and Mn on other trace metal values. It was decided that ratios or residuals would not be used to represent parameters unless they indicated a significant improvement over the raw element data. This is because they may represent a less accurate reflection of the bedrock chemistry than raw element data when multi-parameter relations, known and unknown, are present. This is especially true if their use does not demonstrate a significant normalization of the data.

Two major criteria were used in making this determination. First, the variability in the raw element data resulting from Fe, Mn, and LOI influences was compared to that for ratios or residuals. For example, the scatter diagram on Figure 9A indicates that samples that fall along the trend of points plotted would represent an equivalent relative reflection of As in the bedrock source, providing this relation represents a scavenging or coprecipitation of As by Fe hydroxides. Fe creates a variability of approximately 1.2 ppm (0.8 to 2.0 ppm) in the As data (Fig. 9A) for the range of 0.2-3.0 percent Fe. The percent of the As data in the range of 0.8-2.0 ppm can be determined from a histogram or cumulative frequency distribution and compared to the percent of the data variability from ratios or residuals. Approximately 60 percent of the As data falls in the range of 0.8-2.0 ppm. For the residual of As-Fe (Fig. 9B), the range of variability is approximately -0.4 to +0.5 which represents 70 percent of the data on a histogram. Because the As-Fe residual did not improve the data variability, it was not used to represent the As data for interpretation of survey results. Further discussion on residuals is presented later.

The second criterion for evaluating the use of ratios or residuals was a composite interval scatter diagram of the three major bedrock geologic subdivisions similar to Figure 9B, but points were plotted for each geologic subdivision. An analysis of the composite diagrams was done to determine whether the relationship demonstrated by the total data ratios or residuals was consistent with that for each bedrock subdivision and to determine if the ratios or residual variability was created by a clustering effect of the geologic subdivisions. Clustering may increase the ratio or residual variability of the total data, but the variability may be less for each geologic subdivision compared to the raw data variability for each subdivision. If the low ratio or residual variability is common to all geologic subdivisions, ratios and residuals may significantly normalize the data, even though the total data ratio or residual variability is high.

As noted previously, the trace elements display an exponential relation to Fe, Mn, and LOI (Figs. 7, 8, and 9). The exponential relations observed were generally mathematically consistent, but it was also observed that ratios along the trend of the data (or a curve fit to the data) decreased with increase in parameter concentration, as would be expected for a non-proportional, exponential relation. An example of this observation is shown on Figure 10, where "Line A" has been fit to the data shown on Figure 8A. As discussed previously for As, the trend of the data represents an equivalent relative reflection of the trace element in the bedrock source if its raw data concentration has been influenced by Fe or Mn scavenging or coprecipitation. Therefore, any normalization technique applied to the data should yield equivalent normalized values along the regression line, which can be accomplished with univariate residuals. If, however, the two parameters display a proportional relation, their ratios would be equal along the regression line, as shown by a hypothetical "Line B" on Figure 10. In this case, ratios could be used to normalize the



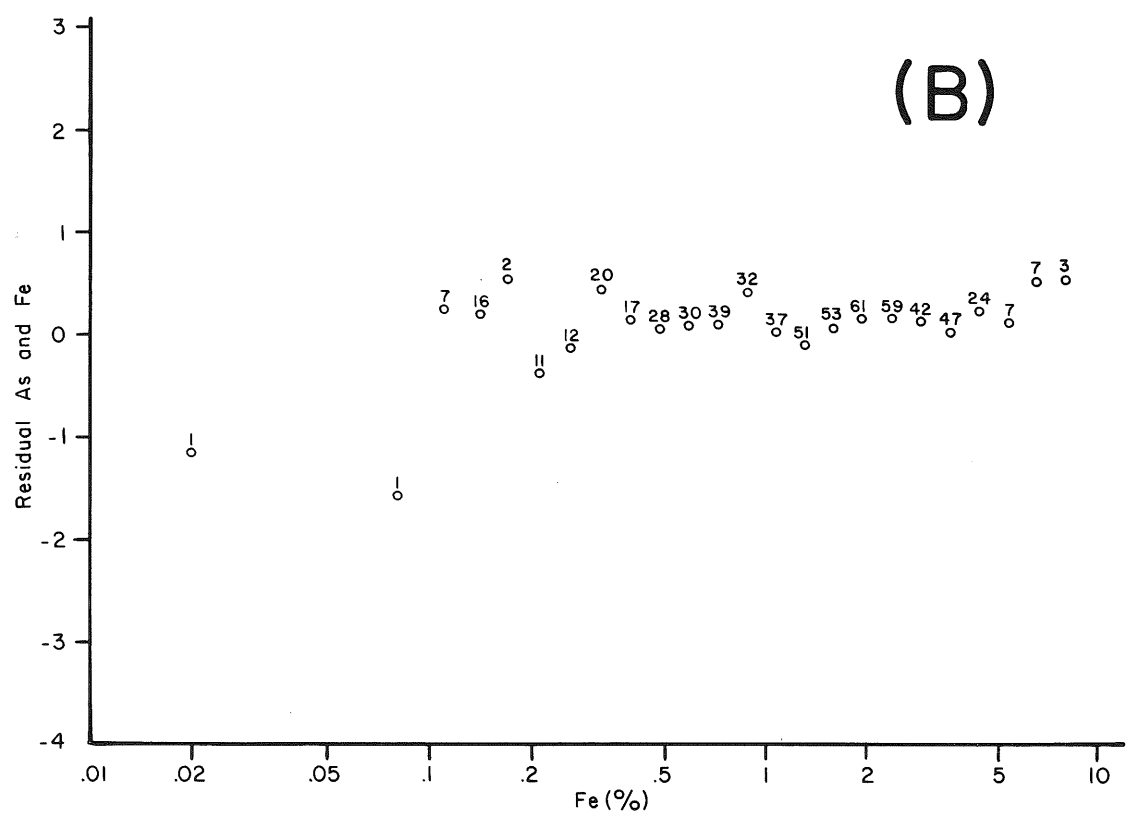
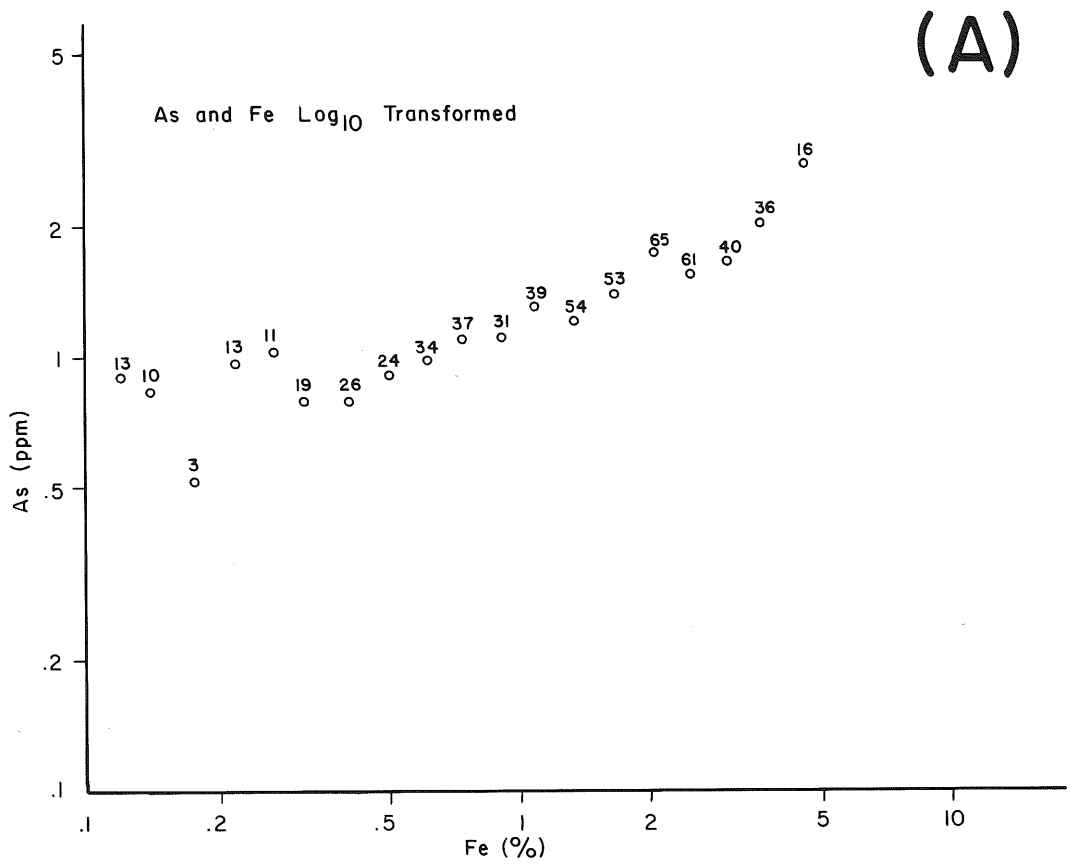


FIGURE 9: Interval scatter diagrams of As and Fe and univariate residual of As and Fe. Numbers represent sample frequency of plotted point for each interval.

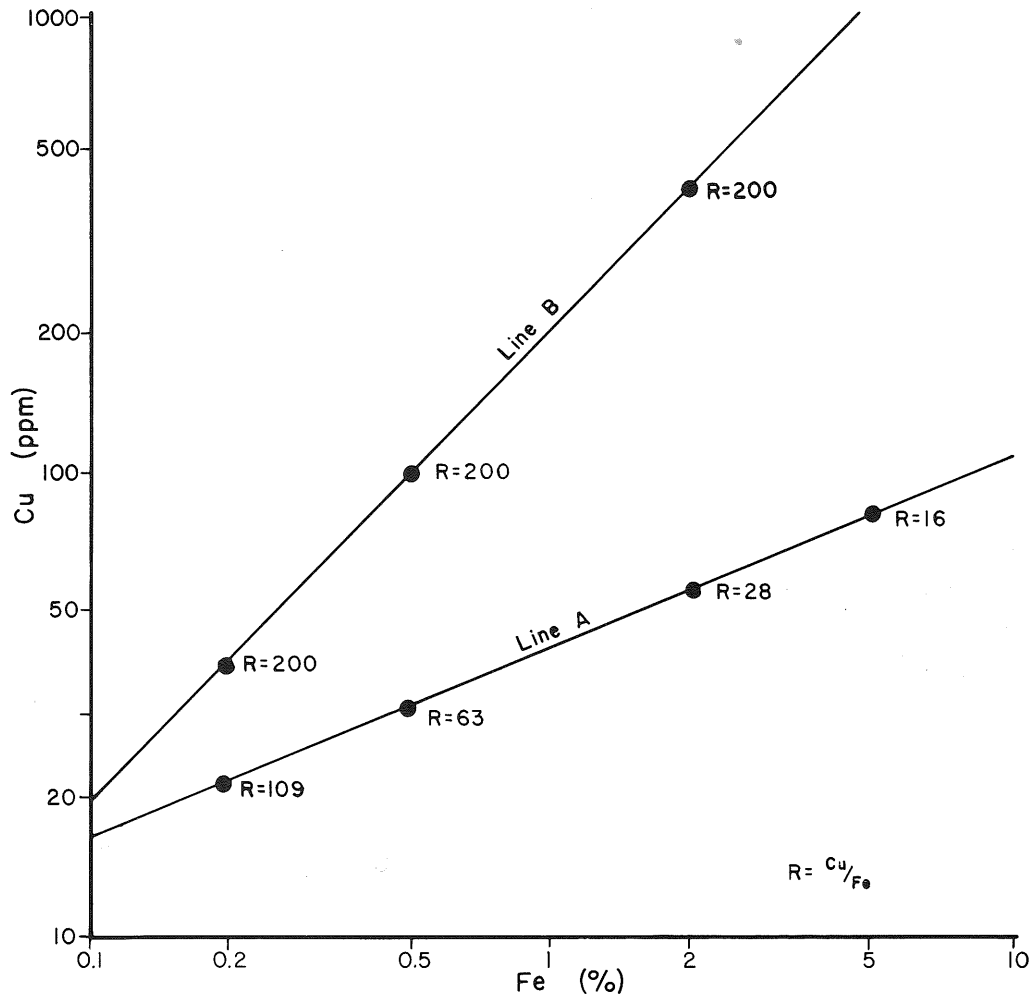


FIGURE 10: Cu/Fe ratios along regression line. Line A is regression line from upper graph on Figure 8. Line B is a hypothetical line representing a proportional relation between Cu and Fe.

data. No proportional relations were observed between Fe, Mn, or LOI and the trace elements; therefore, ratios were not further considered to normalize the effect of Fe, Mn, or LOI. The interrelationship between the trace elements as well as that between Fe and Mn (Fig. 11) is approximately proportional.

An attempt was made to normalize the negative relation of Co and As to LOI by converting Co and As concentrations to the inorganic weight of each sample using the LOI value, i.e.,  $100 \text{ (Co)} / (100 - \text{LOI})$ , where LOI is in percent. The lake sediment samples were not ashed before chemical analysis. This conversion would be similar to analyzing the ashed sample without regard to possible element loss during ignition (Peachey, 1976), and has similarities to ratios but is not directly influenced by the proportionality problem. The scatter diagram for Co to LOI is shown on Figure 12A. The negative relation of Co and LOI (Fig. 12A) was eliminated by conversion of Co to the inorganic fraction (Fig. 12B). However, an analysis of the data variability resulting from the negative relation of the unconverted Co data compared to that of the converted data (\*Co) indicated no significant normalization of the Co data. Similar results were obtained for As.

Finally, univariate residuals were examined for trace element (As, Co, Cu, Ni, and Zn) relationships to Fe and Mn. An effort was made to normalize the negative relation of LOI on As and Co. The residuals did not in all cases normalize the data to the extent where it was a significant improvement over the raw element data, or the bedrock subdivisions did not exhibit a parallel or consistent relation. As a result, residuals were not used to represent or interpret the element data.

In several cases, Fe and Zn for example, the residuals displayed a pronounced bimodal distribution (Fig. 13). A bimodal distribution was displayed by the following residuals: Cu-Fe, Cu-

Mn, Ni-Fe, Ni-Mn, Zn-Fe, Zn-Mn, Mn-LOI, and Zn-LOI. A unimodal distribution was observed for the following residuals: As-Fe, As-Mn, Co-Fe, Co-Mn, Fe-Mn, and Fe-LOI. Parameters such as bedrock subdivision, water depth at sample site, LOI, and lake area were examined in an attempt to determine why this occurred, but the cause could not be identified. An examination of analytical control sample data did not indicate that analytical problems could be the cause.

The bimodal distributions were evident on scatter diagrams of the residuals and once identified could be discerned to some degree on scatter diagrams of the raw element data. It appears that two elongate clusters of data that generally parallel the regression line produce the two residual modes. It is interesting to note that, except for Mn, the elements that displayed a bimodal residual do not have a significant negative relation to LOI, and that all residuals that are unimodal have a positive relation to Fe and Mn and a negative relation to LOI, including Fe and Mn themselves. Nearly identical results have been obtained for a larger survey adjacent to Cook County (Vadis and Meineke, in preparation).

### Discussion and Interpretational Considerations

Statistical analysis was performed for this survey to identify relationships and characteristics of the elemental data and other parameters that would assist in the interpretation of this survey for mineral potential purposes. It was found that the bedrock chemistry is reflected in the organic-rich lake sediments of the survey area, a necessary condition for application of the geochemical method. It was also determined that relationships exist between the trace elements and Fe, Mn, and LOI. This suggests that certain chemical processes may be enhancing the trace element concentrations, thereby producing a variable background and creating false anomalies. However, ratios, inorganic concentration conversions, and univariate regression residuals were unable to

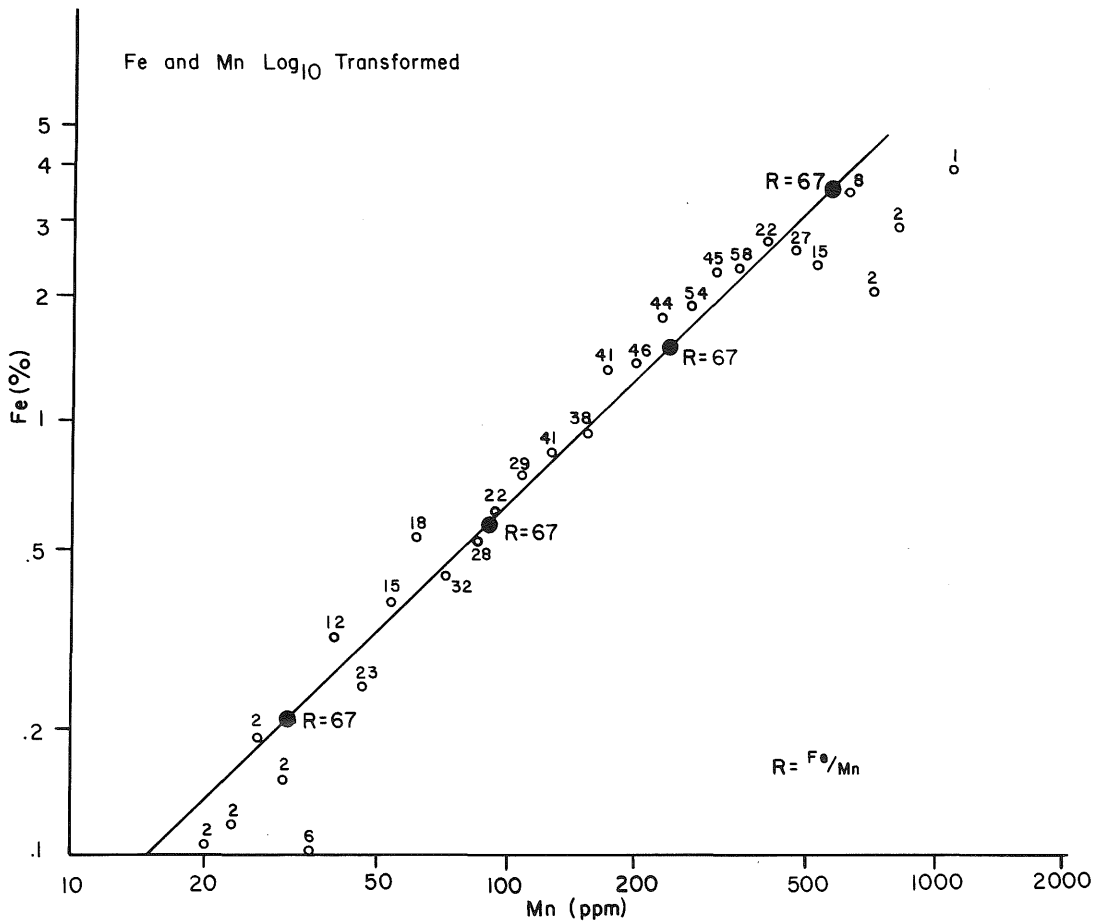


FIGURE II: Interval scatter diagram of Fe and Mn. Numbers represent sample frequency of plotted point for each interval.

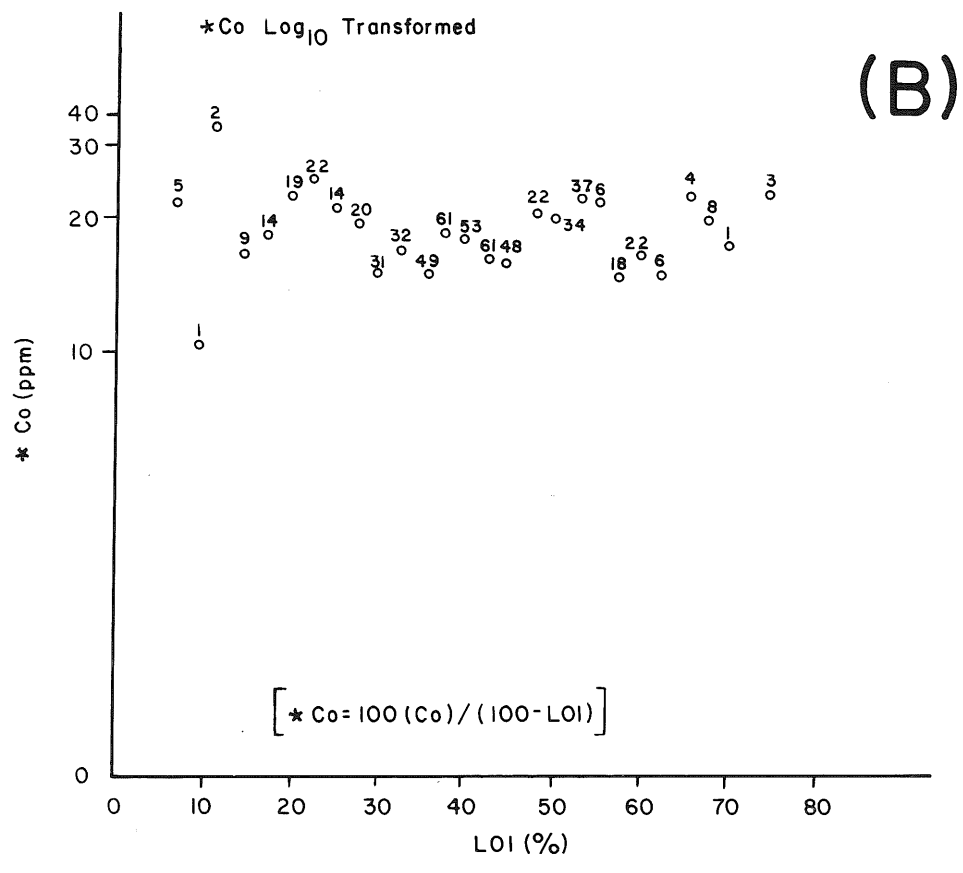
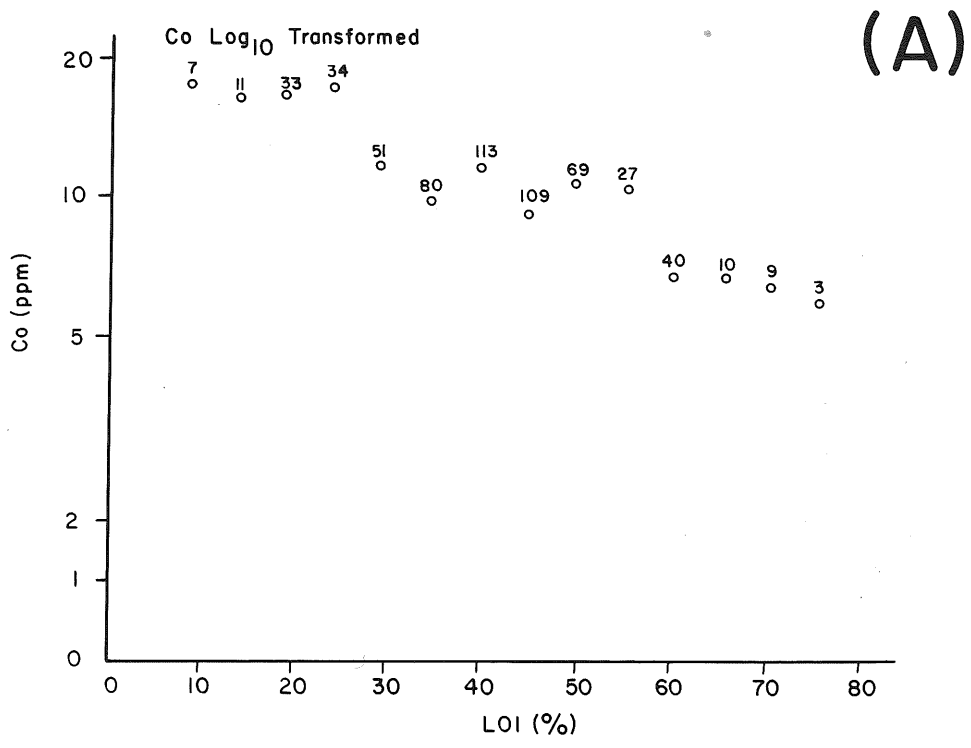


FIGURE 12: Interval scatter diagram of Co and LOI, and Co based on inorganic fraction. Numbers represent sample frequency of plotted point for each interval.

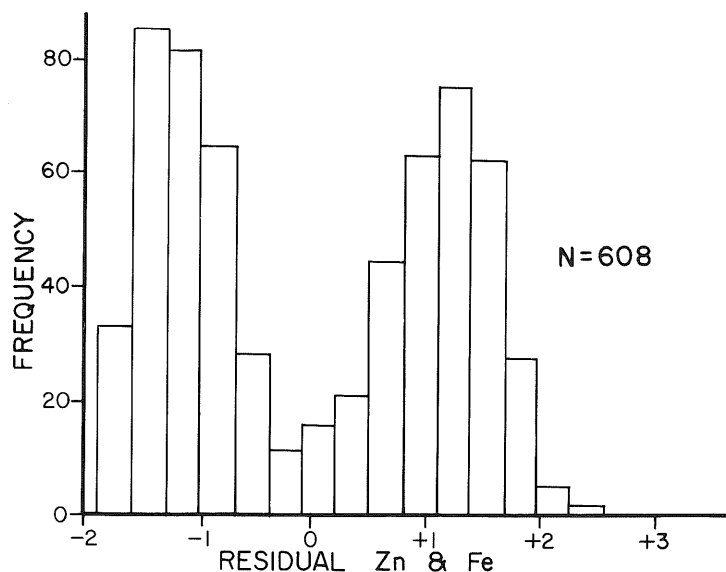


FIGURE 13: Histogram of the univariate residual of Zn and Fe.

normalize the trace element data for the effects of Fe, Mn, or LOI to a degree that demonstrated a significant improvement over the raw trace element data. Therefore, it was concluded that the data should only be used in its raw element form for interpretation. Some of the relationships and characteristics of the data identified by the statistical analysis should, however, assist in the interpretation of this survey.

The mobilization, transport, and deposition of the trace elements involves variable and complex chemical and biological processes (Timperley and Allan, 1974; Nichol, et al., 1975; and Coker, et al., 1979). The element concentrations observed in the lake sediment are a result of Eh, pH, and other chemical and biological factors. Variations in these factors can affect elemental concentrations at any point; i.e., availability at their source, during transit, and at their site of deposition. At the source, the environment may be constantly reducing or oxidizing or alternately oxidizing and reducing, depending upon geologic and hydrologic conditions. As a result, the relative mobilization of the elements, each having their own characteristic mobility at various combinations of Eh and pH, will vary even for mineral deposits of identical elemental and mineralogical composition.

The hydrologic, geologic, and resultant chemical conditions under which the mobile elements are transported to the lacustrine environment vary considerably. For example, the elements may be transported via ground or surface water directly to a lake, via groundwater to a stream and finally to a lake, or by numerous other combinations. This array of various combinations of element mobilization and transport mechanisms can have a varying and profound effect on the relative mobilities and the quantity of elements that actually reach the lake. Finally, variable Eh, pH, and other chemical and biological conditions of the lacustrine environment will determine the relative proportions of elements that are deposited in the lake sediment.

The possible combinations of factors affecting the modes of mobilization, transport, and deposition of the elements appear almost infinite. Analysis of the Cook County and other lake sediment data, however, indicates some relative or average consistency to the process. If the operative processes were random or inconsistent, the element concentrations of the lake sediment would not reflect those of the bedrock (Table 4), and common bedrock elemental associations would not be reflected in the lake sediment (Table 5). Furthermore, if organic complexing, scavenging, or coprecipitation by Fe-Mn hydroxides were dominant in the deposition of the trace elements in the lacustrine environment, the concentrations of these elements would be dependent upon these processes and would not reflect the bedrock chemistry, except possibly in the most extreme cases. The failure to significantly normalize the trace element data for the effects of Fe, Mn, and LOI further suggests that these agents do not play a dominant role. In fact, the negative relation of As, Co, Fe, and Mn to LOI indicates that organic complexing does not play a major role in the accumulation of these elements in the lake sediment.

As discussed in the previous section (Normalization of the Effects of Fe, Mn, and LOI), an approximately exponential relationship is exhibited by the various parameters measured for this survey. It was suggested that all parameters that display a lognormal distribution should be  $\log_{10}$  transformed prior to correlation, scatter diagram, and interval scatter diagram analysis in order to avoid misinterpretation of the trends of the parameter relations (Figs. 7 and 8). Figures 7B and 8B may lead to the false interpretation that major breaks or inflections occur. Figures 7A and 8A, however, display a relatively consistent, approximately exponential function for a vast majority of the data.

The exponential relations observed between the trace elements and Fe, Mn, and LOI are not proportional. The relative amounts of the trace elements decrease (ratios decrease) with increase in Fe, Mn, or LOI. An example of the ratio decrease is shown on Figure 14 for Co-Fe and was previously described (Fig. 10). The ratios of the trace elements to Fe, Mn, or LOI themselves display a non-proportional exponential function as shown by the example for Co-Fe (Fig. 14). Therefore, the non-proportional exponential relation between the parameters considered in this survey is consistent.

Similar relations between the trace elements and Fe, Mn, or LOI have been reported for lake sediment surveys in Canada (Garrett and Hornbrook, 1976; Hornbrook and Garrett, 1976; Coker, Hornbrook, and Cameron, 1979), in Finland (Tenhola and Lummaa, 1979), and in Minnesota (Meineke, Vadis, and Klaysmat, 1976). These authors have suggested that the observed relation results from an insufficient amount of the trace elements to satisfy the scavenging, coprecipitation, or complexing capacity of the sediment as the concentrations of organics (LOI), Fe, or Mn increase.

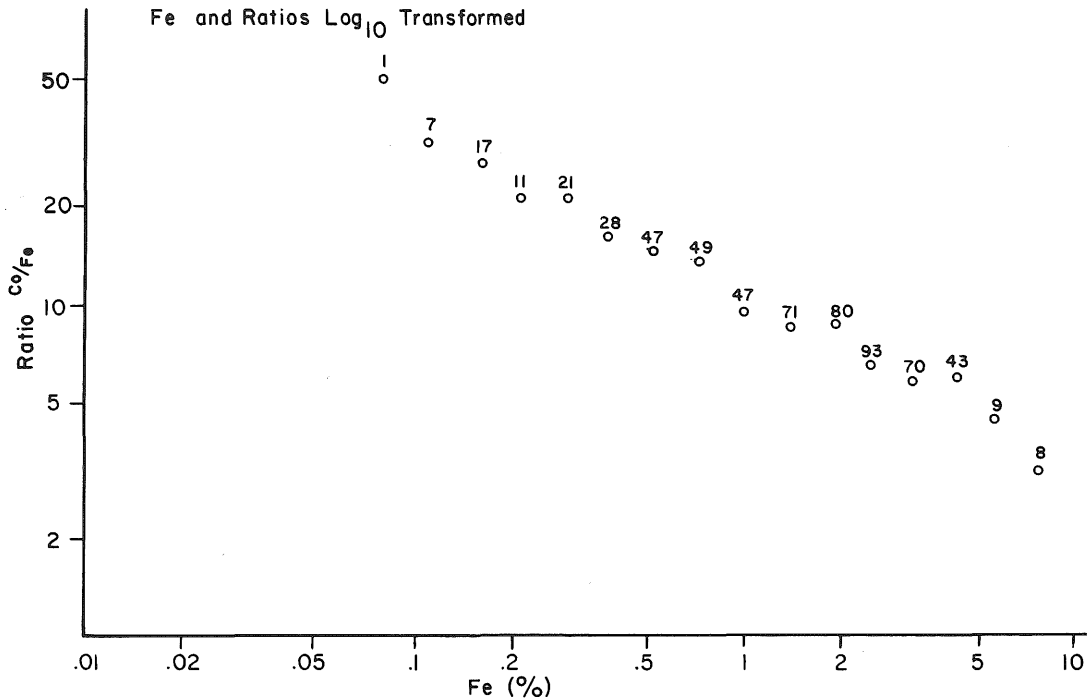


FIGURE 14: Interval scatter diagram of Fe and Co/Fe. Numbers represent sample frequency of plotted point for each interval.

On the other hand, an approximately exponential and proportional relation was observed in the Cook County survey for Fe-Mn (Fig. 11) and between the trace elements themselves (i.e., Ni-Zn, Cu-Zn, Co-Ni, Co-Zn, Cu-Ni, etc.). Therefore, the ability of the lake sediment to reflect the bedrock chemistry, the non-proportional interrelationship between the trace elements and Fe, Mn, or LOI and the proportional interrelationship between Fe and Mn and between the trace elements, suggests that these relations may be a result of the relative crustal abundance of these elements. Elements having a relatively similar crustal abundance display an approximately proportional relation (i.e., Fe-Mn, Cu-Ni, Cu-Zn, Co-Ni, etc.). The non-proportional exponential relation

observed between the trace elements and Fe, Mn, or LOI is the same as that observed for other earth material parameters (i.e., tonnage vs. ore grade, sand size vs. distance downstream). Therefore, it is suggested that the observed non-proportional relationships do not indicate any major effect of scavenging, coprecipitation, or complexing but rather the relative abundance of these elements in the glacial and bedrock geologic environment. This suggestion is, again, further substantiated by the conclusion that ratios, inorganic concentration conversions, and regression residuals did not significantly improve the data. This is not to suggest that Fe-Mn hydroxides, organic complexing, or other agents do not play a role as high concentrations of any scavenging or complexing agent always have the potential to create false anomalies.

The observations and suggestions that have been made are based only on the chemical leach methods used for this survey and could differ with other chemical techniques. The 4M HNO<sub>3</sub>/1M HCl leach used for Co, Cu, Pb, Ni, Zn, Fe, and Mn is a partial extraction that preferentially leaches weakly bonded elements as opposed to strongly bonded elements in the silicate detritus. The objective of this survey was to measure the elements that have been chemically mobilized and transported from their source and deposited in the lake sediment. The leach method used in this survey has been found to provide the greatest and most consistent contrast of anomaly over background of several techniques tested (Meineke, Vadis, and Klaysmat, 1976).

The variability of the chemical and biological conditions in the lacustrine environment are at least partially affected by lake area, lake depth, and LOI (Tables 5, 6, and 7) and are all interrelated with the elements. Although the relation of lake area with the elements is not strong, it does indicate that the element concentrations do increase with lake area (Tables 5, 6, and 7), and the consideration of this factor may be important when evaluating the background or when attempting to delineate lithologic units.

As mentioned previously, the varying Eh and pH and other chemical conditions can have a very significant effect on the mobilization, transportation, and deposition of the trace elements. Furthermore, the varying chemical conditions will have an effect on the relative mobility of each element. An earlier survey found that the mobility of Ni and Zn exceeded Cu's in organic stream bank material near Cu-Ni mineralization in the Duluth Complex west of Cook County (Meineke, Vadis, and Klaysmat, 1977e). In this same area, the lake sediments display a relatively anomalous predominance of Ni, Zn, and Co over Cu even though Cu is the major constituent of the mineralization (Vadis and Meineke, in preparation). Therefore, because of the relative mobilities of the elements, anomalies can be observed that do not appear to have a common elemental association to mineralization.

Furthermore, the proximity of a lake to mineralization may have a pronounced effect on the observed elemental composition of anomalies. A lake in close proximity may reflect only the lower mobility elements in the sediment, the more mobile elements having moved out through streams to other lakes and deposited further away from the mineralization. An excellent example of this mobility phenomenon has been described by Cameron (1977) for a system of streams and lakes in Canada.

The chemistry of each major bedrock geologic subdivision produces its own background levels in the lake sediment (Table 4) and should be considered during interpretation. It is entirely possible that lower concentration anomalies over a lower background may be as, or more, significant than high concentration anomalies over a high background. Anomaly to background contrast must, therefore, be considered.

The sediment chemistry reflects the chemistry of the glacial drift as well as that of the bedrock (Table 4). The exact proportion of each is, of course, difficult to determine and varies depending upon the geologic, hydrologic, and chemical conditions. The effect of glacial erosion and dispersion in lake sediment geochemistry has been reported by Coker and Nichol (1975); Meineke, Vadis, and Klaysmat (1976); and others. The effect of glacial dispersion must be considered, at least locally, for the interpretation of this survey.

## **SURVEY RESULTS AND DISCUSSION**

Symbol maps, using symbols designed and used by the Geological Survey of Canada, were prepared to depict the concentrations of As, Co, Cu, Ni, Pb, Zn, Fe, and Mn (Plates 3-10). The symbols represent ranges of concentrations that were determined by ranges of percentiles of the cumulative frequency distribution for each element, except for Pb (see Plates 3-10). The smallest ranges possible for each element were selected, subject to the constraints of analytical precision (Table 2), in order to reflect variations in the chemistry of the bedrock geology. Twenty percent ranges were selected in all cases, except for Mn, which is 10 percent, so that the median of each range did not drastically overlap other ranges as a result of analytical variability (Table 11). Pb is

shown as increments of 5 ppm and not as percentiles (Table 11 and Plate 7). For Ag, only 13 of the 608 survey samples exceeded the detection limit (1 ppm) and are shown on Plate 2. At high concentrations, the ranges are reduced to illustrate the relation and distribution of the most anomalous samples (i.e., percentiles of 80-95%, 95-99%, and 99-100%). Plate 2 illustrates samples where two or more elements exceed 90 percent cumulative frequency and all Ag above the detection limit as described previously and in Table 11. The element concentrations for any sample can be determined by first locating the sample site and sample number on Plate 11 and referring to the Appendix.

The percentile maps (Plates 3-10) illustrate the effect of the three major bedrock subdivisions on the relative element concentrations in the lake sediments. The North Shore Volcanic Group generally displays lower element concentrations than the Rove Formation and the Duluth Complex, especially for Co, Cu, Ni, and Fe (Plates 4, 5, 6, and 9; see also Table 4). These elements tend to increase in concentration from Lake Superior toward the contact with the Duluth Complex, which may be related to the bedrock chemistry but may be influenced by glacial smearing and/or groundwater movement.

The Rove Formation generally contains higher concentrations of all elements analyzed (Plates 3-10; Table 4), especially As, Co, Ni, and Fe; however, it displays a relatively low variance compared to the North Shore Volcanic Group and the Duluth Complex, as indicated by the coefficients of variation (C.V.%, Table 4). This indicates that the element distributions in the lake sediment over the Rove Formation are statistically stable, which suggests that they may represent only background concentrations. A similar elevation of trace elements in organic-rich lake sediments also occurs over the Rove Formation in Ontario, directly across the border from Cook County (Hornbrook and Coker, 1977).

There are currently no known economically mineable deposits in Cook County although many mineral showings and occurrences have been reported (Gladen, McKenna, and Meineke, in preparation). This vast majority of these are in the Gunflint Corridor (Fig. 1), however, which was not included in this survey. Therefore, the ability of the organic-rich lake sediments to reflect known mineralization cannot be considered in the survey area. However, as previously discussed in this and other sections, the bedrock chemistry is reflected in the lake sediment (Table 4) and, therefore, mineralization should be reflected under favorable chemical, geologic, and hydrologic conditions. The organic-rich lake sediment survey previously mentioned in Ontario (Hornbrook and Coker, 1977) did reflect, with a very weak anomaly, the Great Lakes Nickel Cu-Ni deposit located five miles north of extreme northeastern Cook County. However, this weak anomaly occurs in the only lake in close proximity to the deposit and is up drainage from the deposit. A lake sediment survey (Vadis and Meineke, in preparation) does reflect the Cu-Ni mineralization of the South Kawishiwi River-Birch Lake area of the Duluth Complex 30 miles west of Cook County.

The Duluth Complex generally contains element concentrations intermediate in background to the North Shore Volcanic Group and the Rove Formation (Plates 3-10; Table 4). The Duluth Complex contains some of the most anomalous concentrations, especially for Co, Cu, and Zn (Plates 4, 5, and 8), having the highest contrast above background of all geologic subdivisions considered. Also, the Duluth Complex contains the majority of Ag values that exceed the detection limit, these often being single element anomalies.

TABLE 11: Percent Ranges of Percentiles for Element Concentration Symbol Maps

Element	Percent of Map Symbol Range <sup>1</sup>	Percent Confidence of Range <sup>2</sup>
Ag*	ppm concentration	...
As	20%	95% at range boundary
Co	20%	60% at median of range
Cu	20%	80% at range boundary
Ni	20%	60% at range boundary
Pb†	ppm concentration	60% at median of range
Zn	20%	60% on range boundary
Mn	10%	90% on range boundary
Fe	20%	80% on range boundary

<sup>1</sup>The percentage of the total data represented by each element concentration range (Plates 3-10).

<sup>2</sup>Percent confidence that median of range is within the range boundary or median of adjacent range, based on the "t" distribution, and calculated for the 40-60% interval for 20% ranges, and the 40-50% or 50-60% interval for 10% ranges.

\*For Ag only, 13 of the 608 samples are above the detection limit (1 ppm), and, therefore, a percentile symbol map was not prepared. All ≤ 1 ppm are shown on Plate 2. Twelve samples are 1 ppm and one is 2 ppm.

†Pb values are reported in increments of 5 ppm, and are represented on Plate 7 in this manner.



The most prominent anomalies in the Duluth Complex are the Cow-Bull-Calf Lake area (T63N, R2W, Plate 2), the Greenwood-Cucumber-Devil Fish Lake area (T64N, R1, 2, 3E), and the Sawbill Lake area (T62N, R4W). The anomalies in the Greenwood-Cucumber-Devil Fish Lake and the Sawbill Lake areas demonstrate a relatively anomalous predominance of Ni and Zn as compared to Cu. The anticipated mineralization is Cu-Ni; however, as discussed in the previous section (Discussion and Interpretational Considerations), Zn and Ni do produce anomalies related to Cu-Ni mineralization as a result of their higher chemical mobility as compared to Cu.

The most prominent anomalies in the North Shore Volcanic Group (Plate 2) are located in Tom and Dick Lake areas (T63N, R3E and T62N, R1W). Tom Lake is over a contact between the North Shore Volcanic Group and Keweenawan mafic intrusive rocks (Plate 1).

A large number of sites over the Rove Formation display multi-element anomalies (T64 and 65N), based on the upper 10 percent of the total data (Plate 2). However, as noted previously, these anomalies may only result from an elevated background. The apparently elevated background of the Rove Formation eliminates many of the higher samples in the Duluth Complex and North Shore Volcanic Group from the upper 10 percent of the total data on Plate 2. Because of the difference in background over the major geologic subdivisions, a review of Plates 3-10 indicates other anomalous areas not apparent on Plate 2.

Some of the more interesting anomalies described were included in the expansion of the Boundary Waters Canoe Area effective January, 1979, as shown on Plates 2-10.

## SUMMARY AND CONCLUSIONS

This survey involved the collection of lake sediment samples from 253 lakes encompassing an area of 945 sq. mi. (2448 sq. km). These samples were analyzed for Ag, Co, Cu, Pb, Ni, Zn, Fe, and Mn by atomic absorption techniques and ashed for loss-on-ignition (LOI). The digestion methods used included leaching with 4M HNO<sub>3</sub>/1M HCl for all elements except for As which was leached with concentrated HNO<sub>3</sub>/30% hydrogen peroxide solution. Organic content was estimated by LOI.

Statistical analyses were performed on elemental and LOI data derived from the analytical results on each sample.

A statistical analysis was performed on the Cook County lake sediment data in an attempt to identify relationships and characteristics of the elemental data and other parameters that could assist in the interpretation of the survey for mineral potential purposes. A number of observations and suggestions emerged, which could vary considerably with data derived using different chemical analytical methods than those used in this survey.

The statistical analysis indicated that Fe and Mn display a positive relation with all elements and LOI a negative relation with some elements. Ratios, inorganic element concentration conversions based on LOI, and univariate regression residuals were attempted to normalize the trace element data for the effects of Fe, Mn, and LOI, but it was determined that these normalization techniques did not provide any significant improvement over the element data. Therefore, element data was used in interpretations.

The trace elements displayed a non-proportional, approximately exponential relation to Fe, Mn, and LOI, which results in a decrease of the ratio (trace element/Fe, Mn, or LOI) with an increase in Fe, Mn, or LOI. This non-proportional relation indicated that ratios were not justified for data normalization. Proportional exponential relations were observed between the trace elements as well as between Fe and Mn. It is suggested that these relations are not related to chemical processes that tend to enhance the trace element concentrations but, rather, are a function of the relative abundance of the elements in the glacial and bedrock geologic environment. However, it is suggested that Fe-Mn hydroxides, organic complexing, and other agents do have the potential of creating false anomalies in lake sediments.

The analysis also indicated that the bedrock chemistry is reflected in the element concentrations of the lake sediment, which suggests that mineralization should also be reflected in the lake sediment under favorable geologic, hydrologic, and chemical conditions. The reflection of the different geologic subdivisions in the elemental concentrations in the lake sediments results in a variable background for the survey area, which should be considered in the interpretation of the data for mineral potential purposes.

The element concentrations of the lake sediment exhibited a positive relation to lake area and depth and often a negative relation to LOI. Lake area and depth display a negative relation to LOI, which indicates that these parameters are all interrelated. These observations suggest that lake size, at least in part, is reflected in the chemistry of the lacustrine environment. These relations do not produce a profound effect on the element concentrations, but lake area should at least be

considered along with background or bedrock lithologic variation. Multivariate analysis was not attempted but may deserve consideration because of the multiparameter relations.

It is also suggested that the elemental composition of anomalies may not necessarily represent the major elements of interest at their source as a result of relative chemical mobility of the different elements, and the physical relation of an anomaly to its source may be complicated by the relative mobility of the elements as well as glacial dispersion.

Several significant multi-element anomalies were indicated by this survey, the most interesting of which occur over the Duluth Complex and North Shore Volcanic Group and deserve further consideration in relation to possible mineralization. A number of these interesting anomalies were included in the expansion of the Boundary Waters Canoe Area effective January, 1979.

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# **APPENDIX**

# APPENDIX

SAMPLE NUMBER	SAMPLE DEPTH ft	As ppm	Co ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	Fe %	Mn ppm	LOI %
5001	17	1.2	7	58	15	0	63	1.3	15	48.45
5002	12	1.8	16	45	32	20	57	1.6	164	26.98
5003	11	.8	7	51	22	20	70	1.1	102	58.07
5004	10	.8	10	51	17	20	68	.8	85	57.32
5005	31	2.2	14	58	24	10	106	1.6	155	33.11
5006	23	3.0	10	61	27	20	113	1.8	147	34.18
5007	10	11.6	14	85	28	10	123	1.4	303	48.11
5008	17	1.2	12	65	27	0	106	1.5	135	40.80
5009	17	1.2	11	60	33	0	112	2.1	149	39.97
5010	14	2.4	16	57	42	10	160	3.3	197	29.35
5011	17	1.2	17	64	29	10	121	2.1	216	45.06
5012	17	1.6	14	73	32	0	145	1.6	176	44.50
5013	5	1.6	14	71	26	0	81	1.4	157	48.02
5014	15	1.2	19	98	28	10	134	2.1	193	44.95
5015	27.5	1.8	22	95	25	0	111	2.7	331	47.3
5016	11	1.2	12	94	23	10	81	1.2	85	41.07
5017	8	.6	14	105	24	0	99	1.4	104	40.59
5018	24	2.4	12	84	38	0	134	1.9	186	31.24
5019	62	2.0	11	66	26	0	111	1.8	189	29.81
5020	60	1.8	12	61	26	0	114	2.1	183	28.76
5021	29	1.2	8	43	25	10	100	1.8	119	23.07
5022	35	1.8	14	56	32	10	127	2.9	226	24.63
5023	63.5	2.0	15	68	37	10	133	3.1	232	28.
5024	37.5	5.4	19	56	37	20	117	3.2	291	19.
5025	52.5	5.4	17	62	37	20	117	3.0	222	20.
5026	10	1.2	12	76	18	0	65	.8	55	42.13
5027	7	1.0	11	80	18	0	66	.7	55	41.22
5028	16	2.0	10	98	20	10	113	1.92	300	30.6
5029	27	1.8	16	147	24	15	155	2.63	283	19.
5030	33	2	16	150	23	15	164	2.89	325	23.05
5031	25	2.4	22	141	26	15	155	2.77	387	23.
5032	15.5	1.8	14	161	16	5	95	1.18	181	12.
5033	15	7.2	23	112	23	10	118	2.19	303	12.
5034	19	3	33	182	26	15	178	3.45	542	21.11
5035	23	2.8	31	157	22	15	171	3.28	365	22.
5036	30	2.6	20	55	25	10	123	2.52	236	20.0
5037	17	1.4	23	70	31	10	156	2.45	131	39.6
5038	45	1.8	18	62	27	10	121	2.40	223	41.6
5039	67.5	4	22	71	32	15	128	3.03	322	41.7
5040	52.5	5.2	30	81	35	10	147	4.23	384	31
5041	47.5	6.0	33	70	38	15	124	4.22	447	22
5042	60	6.6	24	70	36	15	131	3.22	386	24.1
5043	65	4.0	11	43	15	15	126	3.58	400	29.2
5044	23	2.4	18	67	33	15	118	2.45	387	15.
5045	27	1.4	23	37	13	10	133	3.15	515	27.
5046	27.5	1.8	19	22	8	5	73	1.74	517	12.7
5047	27	2.0	27	38	18	10	123	2.89	550	27.
5048	37	1.8	25	39	19	15	132	3.10	595	28.

SAMPLE NUMBER	SAMPLE DEPTH ft	As ppm	Co ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	Fe %	Mn ppm	LOI %
5108	22.5	1.2	7	65	17	30	136	1.31	216	50.
5109	35	1.2	9	69	16	25	130	1.45	229	52.90
5110	7	2	5	127	13	25	68	.61	213	42.00
5111	17.5	1.4	5	142	10	20	73	.82	217	44.
5112	5	1	6	35	10	20	56	.59	39	43.84
5113	5	1.2	5	35	11	5	62	.69	52	44.40
5114	20	.8	9	64	15	5	137	.63	102	37.42
5115	27.5	1	11	80	16	20	183	.95	123	40.32
5116	17.5	1.2	8	177	11	5	96	1.22	115	48.6
5117	15	1.4	7	190	16	5	110	1.34	126	47.83
5118	6	.6	8	84	14	20	53	.57	116	45.11
5119	ND	.8	9	94	13	5	54	.53	110	46.63
5120	5	1	7	27	13	5	80	.66	91	68.42
5121	13	.6	9	28	10	5	80	1.18	109	67.95
5122	5	1	7	26	12	10	50	.21	50	37.47
5123	5	1.2	8	25	12	5	52	.26	64	39.83
5124	5	.6	5	27	5	20	93	.45	101	70.02
5125	5	1.2	10	46	16	20	87	1.26	127	41.97
5126	6	1.2	10	47	16	15	88	1.09	118	40.34
5127	5	1.2	10	35	15	20	74	.85	124	36.84
5128	8	1.2	9	35	16	15	95	1.06	135	27.12
5129	ND	1.4	10	34	14	5	90	.99	132	26.98
5130	8	2.2	15	70	22	5	110	1.36	155	37.36
5131	18	1.2	10	61	14	20	100	1.42	196	32.5
5132	13.5	1	12	54	13	10	117	3.45	298	31.6
5133	17.5	1.4	12	65	14	20	126	2.22	278	35
5134	5	.6	9	37	18	5	99	.42	64	59.95
5135	5	1.2	10	44	20	5	104	.48	60	63.61
5136	4	8	4	45	31	10	46	.26	42	40.15
5137	4	2.4	10	46	29	10	42	.29	38	41.52
5138	5	1.2	10	37	30	10	30	.29	41	44.38
5139	4	1	10	37	32	10	35	.34	43	46.05
5140	35	.8	14	46	30	10	160	1.58	306	53.72
5141	27.5	1	13	47	20	5	160	1.57	312	54.13
5142	18.5	13.6	18	97	22	10	91	7.74	387	46
5143	15	15	21	89	25	25	82	7.07	348	59.27
5144	5	1	16	34	25	5	63	.49	71	59.30
5145	5	.6	13	42	24	5	68	.42	68	60.85
5146	4	1.6	15	44	32	10	103	1.23	235	39.14
5147	4	1	15	44	30	10	92	1.32	222	38.71
5148	4	.4	10	28	24	5	39	.21	67	36.38
5149	4	1	14	31	16	5	48	.53	66	38.41
5150	3	1	8	49	24	10	127	1.21	72	43.31
5151	3	1.4	9	51	20	10	129	1.31	77	44.38
5152	7	.6	11	60	25	10	96	1.26	154	45.25
5153	12	.6	12	64	18	5	105	1.42	142	47.22
5154	5	.4	9	27	13	5	66	.28	43	35.78
5155	5	.4	9	25	11	5	73	.15	38	33.98

5049	44	1.8	26	40	22	10	125	3.13	490	29.
5050	42	1.2	23	40	14	10	116	2.35	376	26.
5051	42	4.0	13	48	22	15	131	2.20	423	28.
5052	47	1.2	14	41	13	15	122	2.19	376	30.
5053	36	8.0	11	36	14	15	118	2.00	373	30.
5054	7	5.4	30	55	27	15	117	1.88	275	12.31
5055	7	8.2	26	97	25	15	140	1.95	316	18.95
5056	7	3.0	26	69	21	10	142	1.26	287	21.99
5057	15	1.8	29	56	19	5	71	1.57	181	27.11
5058	18	1.0	24	61	16	5	67	1.28	143	32.35
5059	60	3.2	20	47	17	10	105	2.22	283	15.8
5060	60	1.4	17	58	15	10	96	2.22	165	25.33
5061	55	3.6	21	66	17	15	127	2.50	300	25.7
5062	16	6.8	35	100	48	10	188	2.28	323	50.
5063	22	1.6	20	57	27	15	172	2.48	184	34.5
5064	20	2.8	24	75	35	15	193	2.96	290	35.4
5065	40	3.0	31	68	30	20	200	2.95	295	28.9
5066	27.5	1.4	31	59	25	15	166	2.45	176	35
5067	30	1.4	15	49	16	15	100	1.35	276	37.1
5068	35	1.8	33	62	20	20	137	2.30	253	33.6
5069	25	1.4	22	56	16	10	132	1.81	192	41.5
5070	30	2.6	11	61	22	20	101	1.77	271	40.6
5071	18	1.8	9	55	24	15	124	1.89	185	34.87
5072	14	1.8	10	59	17	10	88	2.03	235	39.00
5073	17.5	2.0	14	63	20	15	112	3.25	315	40
5074	30	1.0	9	45	19	15	67	.99	152	43.54
5075	15	8.0	5	109	30	20	148	.85	129	75.77
5076	17.5	2.6	12	85	17	15	83	3.70	452	57.
5077	20	3.0	10	80	16	10	87	5.18	516	51.99
5078	8	6	6	47	10	5	48	.45	39	36.81
5079	ND	6.0	9	49	11	5	52	.60	37	37.81
5080	8	1.4	6	46	16	10	63	.53	55	46.05
5081	6	.8	7	39	12	15	52	.43	42	43.54
5082	5	.6	6	34	11	20	43	.38	41	45.28
5083	5	.4	8	34	10	5	41	.35	44	47.36
5084	17.5	.6	15	34	12	20	88	1.33	210	46.9
5085	23.5	1	9	42	15	5	117	2.00	256	46.62
5086	15	.4	7	27	7	20	57	.44	115	53.61
5087	10	.4	8	26	5	20	56	.35	99	51.95
5088	6	.4	6	28	11	15	63	.35	46	59.99
5089	6	.4	9	32	20	10	66	.40	52	59.92
5090	14	.6	14	51	21	15	84	1.43	96	52.28
5091	7	.6	10	48	19	20	77	.97	84	52.13
5092	5	.6	5	49	19	5	64	.59	82	56.08
5093	5	.8	7	50	18	10	76	.65	94	58.62
5094	21	.8	12	90	19	20	104	1.65	132	43.15
5095	20	.6	11	86	18	15	113	2.28	160	37.98
5096	18	.4	10	73	12	5	83	1.08	239	41.58
5097	25	.8	10	91	16	15	145	3.05	440	49.02
5098	7	.8	8	83	11	15	92	.86	105	50.71
5099	7	1.8	7	77	10	15	89	.79	122	48.03
5100	6	.4	8	37	8	5	58	.44	63	32.96
5101	6	.6	10	40	8	10	59	.45	64	34.16
5102	4	.8	9	46	10	5	83	.66	106	42.91
5103	4	.8	5	47	7	15	76	.52	81	41.72
5104	15	1	7	38	6	0	85	.84	108	67.52
5105	15	1.2	6	39	7	5	77	.97	123	36.58
5106	16	.8	6	39	9	5	92	.86	139	38.17
5107	15	.6	7	42	10	5	93	.79	128	33.39

ND—No Data.

5156	4	.8	6	20	24	5	77	.54	115	41.37
5157	4	.8	15	27	22	5	81	.70	99	42.73
5158	5	1.2	9	22	19	5	74	.53	114	41.15
5159	4	.4	9	34	14	5	56	.31	55	49.32
5160	ND	.6	13	36	18	5	58	.40	69	49.91
5161	6	1.8	22	89	37	5	528	2.31	256	51.38
5162	6	1.4	21	68	33	5	351	1.96	257	44.70
5163	6	1	24	63	34	10	222	1.87	274	42.23
5164	8	1.2	21	89	39	5	122	1.86	88	50.48
5165	10	1	20	93	39	5	119	1.59	83	50.68
5166	25	1.6	21	66	32	10	96	2.42	274	35.38
5167	25	1.8	16	80	39	5	127	3.35	276	39.32
5168	20	1.8	13	77	41	5	117	3.0	264	24.16
5169	20	1.8	17	45	32	10	140	3.58	260	36.8
5170	15	1.4	10	46	26	5	107	1.77	176	35.25
5171	4	1.0	10	39	30	5	86	.70	70	40.22
5172	4	.8	12	27	22	5	60	.52	53	38.00
5173	ND	.8	16	60	29	5	133	2.60	178	43.77
5174	10	.8	12	57	28	5	130	1.79	165	43.81
5175	19	.4	7	61	19	5	96	1.16	108	60.03
5176	17	.4	10	55	16	5	81	.71	105	58.62
5177	4	.6	9	77	32	10	107	1.60	161	30.84
5178	5	.8	12	74	30	10	110	1.68	197	30.22
5179	5	1.6	8	169	27	10	129	1.80	252	49.27
5180	3	.8	16	34	17	5	62	.54	114	37.98
5181	3	1.6	19	30	21	5	63	.41	62	38.42
5182	3	1.4	13	26	17	5	47	.39	103	27.33
5183	5	1.6	12	26	15	5	45	.42	80	28.63
5184	5	1.4	20	155	25	10	73	.96	66	51.10
5185	5	1	17	156	28	20	75	.80	72	51.45
5186	9	1.2	22	82	23	5	119	4.44	270	50.37
5187	9	1.4	23	43	17	5	134	6.69	261	36.78
5188	10	1.2	17	87	19	5	104	2.65	237	67.22
5189	17	.4	13	103	19	5	83	3.40	241	39.71
5190	22	.6	19	94	15	5	81	2.92	209	38.59
5191	8	1	17	205	23	5	117	1.70	177	64.63
5192	18	.6	14	83	33	5	71	2.83	203	37.19
5193	26	.6	15	83	20	5	79	3.83	267	36.28
5194	15	1.2	21	122	27	5	117	5.95	361	39.2
5195	17	.6	24	99	20	5	78	2.82	251	36.25
5196	5	1.2	16	67	18	5	71	1.58	157	51.31
5197	21	3.4	18	94	26	5	91	1.93	242	44.93
5198	34	1.6	14	70	22	5	73	1.27	144	38.94
5199	43	1.2	14	49	22	5	58	1.05	162	31.11
5200	35	1.6	20	66	22	5	74	1.46	197	31.09
5201	24	2	15	76	26	10	88	2.39	267	33.64
5202	6	.6	16	139	27	5	78	1.24	77	49.56
5203	6	.6	13	131	22	5	71	.91	74	50.59
5204	6	.6	11	127	24	5	73	.81	70	49.38
5205	14	2	18	23	24	10	87	2.21	202	6.65
5206	13	4.4	28	57	33	10	111	2.57	351	19.3
5207	14	2.8	12	67	33	10	173	3.05	425	27.8
5208	13	3.4	19	54	32	10	136	3.20	415	19.5
5209	10	5.8	26	72	62	15	111	3.75	217	21.3
5210	9	6	10	66	34	15	105	1.96	199	14.19
5211	12	1.2	16	70	39	15	113	2.18	206	21.8
5212	11	9	30	66	47	15	110	5.66	294	18.92
5213	10	16	28	67	50	20	102	4.52	266	13.25
5214	8	14.2	22	90	56	20	120	3.97	266	20.7

ND—No Data.

SAMPLE NUMBER	SAMPLE DEPTH ft	As ppm	Co ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	Fe %	Mn ppm	LOI %
5215	8	4.2	18	56	34	15	82	1.50	249	19.48
5216	8	8	24	63	38	15	93	1.81	133	10.33
5217	8	4	16	67	33	20	98	2.17	150	13.41
5218	8	3	18	47	36	15	77	3.61	166	4.73
5219	40	4.4	27	127	64	20	146	3.59	208	25.
5220	34	5.6	24	130	62	25	163	4.07	244	21.
5221	35	4.6	23	128	48	25	147	3.47	203	23.
5222	37	5.6	25	139	56	25	160	4.11	244	20.
5223	34	6	27	158	74	20	175	4.46	266	21.52
5224	35	4.8	22	144	66	20	151	3.50	214	25.
5225	5	4.4	21	74	55	15	113	1.84	165	27.11
5226	5	.6	8	44	28	35	49	.43	76	57.34
5227	4	.4	10	45	23	5	55	.54	80	58.29
5228	5	.8	7	70	27	5	90	.40	58	51.18
5229	6	.6	19	74	32	5	95	.70	65	49.78
5230	4	.8	19	68	29	20	107	.36	63	47.69
5231	6	3.6	20	73	52	15	108	1.61	147	29.07
5232	7	3.2	20	66	44	5	100	1.63	158	25.64
5233	5	1.8	13	50	33	10	67	1.14	89	15.44
5234	5	3.4	16	27	22	5	40	.94	59	4.77
5235	3	11	19	71	58	10	97	2.47	119	32.56
5236	8	11.4	21	81	60	10	80	3.24	132	15.58
5237	ND	6.2	23	88	54	15	116	4.19	217	13.9
5238	22	1.4	14	77	28	15	104	1.75	146	42.1
5239	8	1.6	19	85	35	20	121	1.69	115	49.56
5240	11	1	18	72	23	10	98	1.47	128	50.83
5241	7	1.6	23	90	28	10	118	1.39	104	52.82
5242	20	1.0	16	73	23	20	130	2.50	124	53.9
5243	20	1.4	8	70	28	5	129	2.11	133	48.06
5244	5	1.6	12	50	23	5	63	1.52	200	44.02
5245	3	3.2	13	16	10	15	43	.69	144	46.39
5246	87	9.0	24	119	85	15	166	4.07	548	15.
5247	107	8.4	28	148	59	10	151	5.37	576	22
5248	108	11.4	26	155	62	5	158	5.79	565	23
5249	58	20	27	71	71	10	114	2.92	345	5.36
5250	6	5.2	22	88	36	15	100	1.89	133	16.46
5251	ND	5.0	15	95	47	10	127	.19	175	19.11
5252	7	5.8	19	85	38	10	112	2.25	163	19.13
5253	4	2.0	16	63	53	10	79	1.33	60	37.98
5254	3	2.2	16	61	50	10	80	1.06	71	39.08
5255	1.5	1.8	10	40	21	15	65	.74	61	35.02
5256	1.5	1.6	14	41	27	10	67	1.21	71	33.04
5257	87	5.6	22	54	62	25	91	2.86	350	6.18
5258	95	10.4	28	14	60	20	133	5.91	424	18.
5259	93	7.0	27	123	58	20	139	5.94	480	18.
5260	30	7.0	23	114	55	25	133	3.83	221	20.
5261	34	4.1	22	119	53	20	128	3.65	198	21.
5262	3	2.8	13	15	12	15	44	.87	137	45.91
5263	5	1.4	12	54	23	10	76	1.87	205	38.07
5264	10	.8	10	48	15	5	72	.29	72	43.86
5265	10	.6	7	61	17	5	91	.40	117	48.89
5266	5	.6	4	22	18	10	44	.24	45	36.55
5267	5	2.4	6	30	16	5	56	.75	54	40.81

SAMPLE NUMBER	SAMPLE DEPTH ft	As ppm	Co ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	Fe %	Mn ppm	LOI %
5977	7	.8	7	36	19	0	58	.83	122	31.24
5978	8	1.2	13	45	18	10	120	3.78	448	34.32
5979	20	1.2	7	58	24	10	113	2.10	463	48.20
5980	4	1.2	11	36	22	10	82	1.49	211	41.84
5981	ND	1.0	10	33	22	10	75	.96	173	47.32
5982	ND	1.2	7	32	17	10	93	1.37	624	41.12
5983	35	1.2	10	54	20	10	103	2.38	740	35.0
5984	35	1.0	11	57	22	20	96	1.18	283	40.41
5985	4	.8	12	43	27	10	97	2.15	157	37.55
5986	12	1.0	10	78	22	10	77	2.36	250	36.85
5987	16	.8	9	87	23	10	83	2.12	230	38.14
5988	5	.6	11	41	21	10	93	.65	152	45.40
5989	ND	.6	13	50	20	10	126	4.62	306	50.25
5990	5	.4	9	33	17	0	44	.28	118	40.57
5991	5	.4	7	33	17	10	45	.35	167	45.69
5992	50	1.4	17	58	26	10	102	3.66	321	17.8
5993	25	2.4	18	69	33	10	110	3.28	415	24.0
5994	25	1.6	16	59	31	10	114	3.30	445	22.0
5995	20	.6	13	56	15	0	62	1.69	210	58.02
5996	ND	.2	9	108	17	10	84	1.69	119	76.09
5997	3	.4	6	36	17	0	46	.32	50	37.75
5998	3	1.0	5	31	21	0	43	.41	48	38.54
5999	12	1.8	13	38	26	0	101	1.95	340	16.22
6000	15	1.8	17	63	33	0	148	2.64	450	33.82
6001	25	1.0	18	64	28	0	127	1.90	287	37.59
6002	5	1.2	7	41	15	10	60	.80	72	43.47
6003	ND	1.4	5	36	17	5	64	.53	112	43.57
6004	2	1.2	7	29	16	5	60	.70	164	38.25
6005	2	1.8	7	25	15	5	59	.68	169	38.78
6006	20	.6	11	148	24	10	117	1.54	152	41.9
6007	20	1.0	15	146	23	10	117	1.57	444	42.
6008	18	.6	6	80	17	5	80	.96	80	41.39
6009	8	.6	5	80	15	5	75	.45	58	40.54
6010	9	.8	11	52	19	5	109	2.06	249	42.99
6011	17.5	.8	13	59	18	10	120	2.02	325	42.
6012	5	.6	10	22	14	5	65	.42	62	47.78
6013	6	.4	8	22	14	10	58	.22	50	43.82
6014	5	.6	5	28	10	5	62	.33	38	46.62
6015	5	.6	7	31	9	5	65	.36	37	45.33
6016	9	.6	11	28	14	10	69	.78	168	49.25
6017	8	.6	9	26	13	5	73	.88	162	49.10
6018	4	.6	7	20	9	5	64	.30	73	38.73
6019	6	.6	8	21	9	10	58	.32	67	36.15
6020	5	1.2	6	33	10	10	66	.53	79	45.20
6021	4	.8	8	31	10	5	54	.39	49	38.35
6022	13	1.0	11	57	17	10	126	1.41	166	33.8
6023	11	1.6	14	57	23	10	152	1.94	268	32.1
6024	5	1.2	7	36	18	10	72	.58	122	34.22
6025	4	1.6	9	46	24	10	75	.68	110	37.10
6026	8	2.0	9	50	23	10	85	.91	186	34.89
6027	5	2.0	13	69	34	10	110	1.22	284	41.28
6028	5	2.8	10	63	26	20	100	1.03	245	45.99
6029	6	1.8	11	60	31	20	104	1.13	185	35.32



5268	11.5	1.6	12	63	31	10	146	1.60	192	49	6030	10	1.4	11	53	27	10	86	.93	161	32.63	
5269	6	2.2	17	83	49	10	297	2.86	186	49.42	6031	6	3.4	12	70	36	20	102	1.11	181	40.99	
5270	10	1.8	20	54	42	10	172	1.95	179	36.4	6032	6	3.8	14	27	29	20	120	1.17	278	ND	
5271	18	1.2	16	53	41	10	135	2.01	173	37.1	6033	11	4.8	16	26	30	20	141	1.54	378	30.8	
5272	4	1.0	12	31	20	5	50	.50	97	34.63	6034	15	2.4	15	29	30	20	140	1.49	247	33.9	
5273	3	1.2	8	32	22	10	64	.51	133	38.04	6035	14	1.6	41	305	86	20	140	4.04	545	46.	
5274	7	10.0	19	135	41	15	288	2.24	238	30.	6036	27.5	.8	31	370	65	20	154	3.49	449	40	
5275	9	2.0	15	39	22	15	123	2.48	259	20.59	6037	42	1.0	13	85	30	10	91	1.46	212	29.15	
5276	12	1.8	13	52	27	10	94	1.91	308	34.24	6038	25	1.6	31	518	37	20	177	4.18	1100	45	
5277	15	3.4	18	66	32	15	100	2.36	344	19.1	6039	ND	1.4	21	550	36	20	153	2.39	529	41.	
5278	9	1.0	12	32	22	10	87	1.26	208	27.24	6040	15	1.0	36	485	30	20	165	3.00	287	48.	
5279	14	.8	12	44	31	10	121	2.27	326	27.63	6041	15	1.0	29	371	26	20	128	3.50	306	47.	
5280	20	1.0	13	40	30	10	117	2.13	266	29.0	6042	25	1.8	16	109	49	20	94	1.40	320	36.5	
5281	15	1.6	14	54	35	15	146	2.90	385	28.7	6043	30	.8	12	82	25	10	82	1.22	173	31.57	
5282	15	1.8	15	50	24	10	97	1.80	290	39.55	6044	ND	.8	14	76	31	10	83	1.18	216	27.52	
5283	12	2.6	17	72	30	10	61	1.95	253	16.81	6045	25	1.4	11	36	16	10	142	.66	82	33.52	
5284	18	1.6	14	44	22	10	76	1.20	252	38.28	6046	6	.8	15	89	26	10	93	1.92	183	29.68	
5285	25	1.2	13	36	20	10	62	1.11	158	34.89	6047	8	.6	11	26	13	10	100	.95	93	29.93	
5286	5	.6	10	32	14	10	58	.40	49	41.82	6048	6	.6	8	23	36	20	92	.81	421	28.89	
5287	5	.6	9	29	16	10	59	.60	72	40.97	6049	45	.8	10	72	30	10	78	1.24	188	29.96	
5288	3	.6	15	44	26	10	117	2.29	278	40.96	6381	50	.8	7	85	31	10	77	1.04	217	28.87	
5289	3	2.2	9	30	15	10	56	.39	60	42.80	6382	50	.8	9	85	23	5	173	.75	153	33.92	
5290	12	1.4	14	77	31	10	128	2.48	325	35.4	6383	55	1.4	13	58	23	5	106	1.82	140	18.82	
5291	12	1.4	12	85	35	10	142	2.75	405	37.0	6384	50	1.8	10	78	23	5	83	1.53	273	30.93	
5292	12	1.6	15	84	40	0	148	2.71	405	37.66	6385	50	.8	5	80	21	5	75	.93	141	32.24	
5293	11	1.6	16	70	33	20	114	1.59	325	36.9	6386	25	.8	8	79	28	5	86	1.23	157	34.18	
5294	10	1.4	20	84	35	20	134	2.18	430	38.6	6387	10	1.0	8	35	17	5	88	.74	174	33.91	
5295	6	1.2	13	64	27	10	87	1.02	207	42.44	6388	10	1.4	10	40	17	5	108	.67	194	32.47	
5296	12	1.6	18	94	41	0	117	2.08	337	44.73	6389	7	.8	6	39	16	5	78	.63	145	33.77	
5297	17	1.6	15	30	24	20	69	1.89	252	21.09	6390	7	.8	9	46	18	5	99	1.71	189	35.26	
5298	21	2.2	16	38	28	20	84	2.93	325	25.90	6391	10	.6	5	49	20	5	79	.35	70	37.16	
5299	30	1.4	11	40	27	10	79	1.68	207	31.71	6392	12	.6	6	50	21	5	74	.59	113	40.85	
5300	18	2.6	18	45	32	10	87	2.45	313	33.94	6393	14	.8	8	109	24	10	69	.62	100	41.32	
5865	6	1.4	23	73	28	0	113	1.35	242	39.85	6394	10	.8	9	102	25	5	80	.75	117	38.44	
5866	6	.6	39	94	26	0	151	2.28	292	35.64	6395	10	1.0	8	84	22	5	75	.56	142	41.14	
5867	7	.2	23	73	22	0	93	1.33	147	35.52	6396	10	1.0	9	86	24	5	95	.62	131	37.07	
5868	ND	.8	28	107	23	0	190	3.25	218	46.11	6397	15	1.4	18	97	31	10	132	4.60	392	41.7	
5869	10	1.0	26	85	23	0	105	1.33	220	39.72	6398	20	1.4	15	89	30	5	117	3.12	247	35.72	
5870	7	.8	28	72	25	0	112	1.38	239	39.69	6399	12	2.0	14	81	31	10	118	2.28	471	37.4	
5871	10	.8	23	25	11	0	70	.66	97	48.22	6400	ND	1.6	10	46	18	5	71	1.22	230	24.62	
5872	5	.4	21	36	34	0	67	.63	46	42.72	6401	25	1.4	11	69	20	10	96	1.47	230	37.70	
5873	14	1.4	31	105	46	0	292	2.40	128	58.3	6402	25	1.0	10	56	22	5	88	1.13	124	36.49	
5874	10	.8	23	43	23	0	104	1.29	109	42.25	6403	15	.8	10	59	21	5	82	.80	118	35.29	
5875	3	.6	16	39	29	0	60	.52	63	39.16	6598	10	.8	13	95	30	5	78	.28	244	47.36	
5876	9	2.8	13	89	51	0	118	1.47	143	61.60	6599	ND	1.8	ND	ND	ND	ND	ND	ND	ND	ND	44.06
5877	20	1.2	23	62	24	0	98	1.41	167	44.78	6600	13	1.4	20	135	35	10	115	2.10	428	37.	
5878	30	.4	31	38	21	0	148	2.38	258	50.99	6601	15	1.0	16	97	32	15	102	1.84	308	28.3	
5879	8	.6	20	46	28	0	121	1.01	84	44.96	6602	12	1.2	24	121	38	10	122	2.79	465	34.	
5880	25	2.0	27	101	23	10	156	1.66	115	55.	6603	15	1.4	16	64	32	10	75	1.50	222	15.75	
5881	10	1.2	21	86	26	0	102	.77	83	42.97	5894	30	1.2	4	100	12	0	88	2.04	186	56.68	
5882	6	.4	18	55	19	0	77	.60	70	36.36	5895	8.5	.8	0	65	5	0	63	.75	124	58.66	
5883	6	.4	10	28	18	0	68	.46	55	50.03	5896	6	.8	0	41	9	0	82	.55	104	53.68	
5884	36	1.4	26	36	19	0	172	2.47	309	50.00	5897	8	1.2	0	34	5	0	91	.77	38	52.94	
5885	3	3.8	22	33	22	0	85	.98	81	40.11	7059	15	10.8	3	107	14	0	87	1.48	157	54.71	
5972	12	4.2	10	31	25	20	69	1.38	245	28.58	7060	6	2.6	5	53	11	0	67	1.72	546	28.33	
5973	14	3.0	18	36	20	0	72	1.82	250	32.93	7061	7	4.8	4	70	15	0	83	1.78	302	43.91	
5974	11	2.2	12	36	19	1	51	.98	145	31.01	7062	8	3.4	2	102	15	0	77	1.84	222	56.91	
5975	10	2.4	12	44	20	10	49	.84	112	34.64	7063	10	.6	9	68	17	0	87	2.22	219	33.75	
5976	6	1.0	11	41	16	10	64	.87	109	34.81	7064	10	.6	8	73	18	0	105	2.55	232	32.70	

ND—No Data.

ND—No Data.

SAMPLE NUMBER	SAMPLE DEPTH ft	As ppm	Co ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	Fe %	Mn ppm	LOI %
7065	8	1.4	11	122	25	0	108	4.00	278	55.03
7066	8	.6	8	78	18	0	111	3.02	239	36.61
7067	10	2.6	2	31	15	0	94	1.75	272	27.39
7068	8	2.6	6	86	14	0	118	1.74	288	26.02
7069	5	3.0	9	21	3	0	39	.47	111	42.09
7070	5	3.4	7	22	9	7	49	.79	167	45.57
7071	9	2.6	6	29	4	0	52	.65	343	40.95
7076	5.5	2.2	8	59	33	10	124	1.13	245	38.2
7077	5	.8	8	57	33	10	122	1.17	244	37.84
7078	6	2.0	9	52	26	5	113	1.11	241	36.15
7079	20	.8	5	41	9	10	88	.53	144	52.62
7080	6	1.0	4	41	16	5	72	.44	108	53.25
7081	10	.8	5	37	14	10	76	.63	131	51.99
7082	8	2.8	10	62	34	10	104	1.47	204	37.77
7083	10	2.0	13	63	38	10	149	1.98	299	32.8
7084	11	2.6	11	66	38	10	146	2.09	314	33.9
7085	14	3.0	10	67	36	10	154	2.06	299	34.5
7086	12	1.0	9	58	29	10	127	1.98	229	35.10
7087	4	3.4	5	23	12	10	56	.70	147	46.84
7088	3.5	3.8	7	24	15	10	66	.66	112	41.98
7089	12	1.2	6	56	14	10	81	.94	78	44.03
7090	17	1.0	9	52	20	10	91	.60	104	56.47
7091	5	1.0	5	24	11	5	59	.49	54	43.17
7092	5	1.2	6	19	12	5	72	.73	62	43.01
7093	5	1.4	5	22	10	10	54	.38	41	47.83
7104	5	3.4	9	28	24	10	80	1.15	298	38.00
7105	15	3.4	14	36	26	10	88	2.59	423	17.20
7106	12	2.8	13	36	25	15	106	2.92	521	39.3
7107	12	2.6	12	25	20	10	84	1.92	393	18.92
7108	4	5.2	6	23	13	ND	48	.31	54	36.94
7109	4	1.4	5	24	14	15	56	.40	64	39.22
7110	8	.8	3	20	7	5	36	.23	30	49.36
7111	7	.8	4	24	14	5	41	.23	34	49.05
7112	8	1.2	3	28	8	10	46	.22	44	58.53
7113	7	1.4	2	27	7	10	43	.26	46	57.43
7114	1.5	1.8	3	22	12	15	39	.30	44	42.75
7115	1.5	1.8	2	16	4	15	38	.38	40	42.25
7116	5	1.0	1	13	4	5	33	.90	66	28.63
7117	5	1.2	2	13	5	0	36	1.03	62	31.83
7118	12	1.8	6	31	9	10	91	2.42	254	39.97
7119	7	1.8	6	31	9	10	91	1.98	254	36.84
7120	5	1.8	5	30	10	10	60	1.36	424	42.65
7121	6	.8	2	28	12	10	47	.23	36	57.38
7122	7	.8	2	28	7	5	54	.24	85	57.74
7123	4	3.6	7	34	11	10	73	1.29	53	46.75
7124	12.5	1.0	4	18	10	5	125	.99	82	61.72
7125	8	1.2	3	17	11	10	94	.51	82	61.57
7126	4	1.2	4	21	8	5	62	.20	94	41.05
7127	5	1.6	5	30	12	5	72	.50	78	38.56
7128	17	.8	7	29	13	5	86	.30	187	59.12
7129	21	2.8	7	32	9	5	99	1.00	247	59.62
7130	7	1.2	2	22	5	5	43	.20	67	56.32
7147	12	1.6	9	64	13	10	91	3.13	672	44.16

SAMPLE NUMBER	SAMPLE DEPTH ft	As ppm	Co ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	Fe %	Mn ppm	LOI %
7186	4	1.0	5	13	11	5	53	.30	121	43.76
7187	4	2.4	5	12	6	10	54	.10	129	44.81
7194	5	1.0	3	12	6	5	51	.12	32	33.52
7195	6	1.0	1	19	6	5	66	.20	36	33.93
7196	12	2.2	5	27	8	10	132	.50	144	49.88
7197	20	8.4	8	30	10	10	122	2.20	256	49.82
7198	3	.4	2	14	8	5	44	.13	18	38.53
7199	3	.8	2	15	7	5	43	.13	20	37.16
7200	4	1.0	3	11	5	5	26	.60	81	59.11
7201	4	1.4	2	12	8	5	31	.50	105	59.99
7202	12	1.6	18	67	37	5	120	2.90	277	25.05
7203	7	1.2	2	12	8	5	38	.13	49	43.75
7204	7	1.0	3	16	9	5	43	.10	46	44.28
7205	12	2.6	21	86	44	10	158	.60	381	32.16
7206	12	4.4	21	111	50	5	140	3.30	422	36.3
7207	10	4.2	25	89	47	10	150	4.50	439	32.1
7230	10	.6	6	38	16	5	76	1.50	123	42.88
7231	10	.8	7	36	15	5	70	1.00	89	41.02
7232	15	.6	8	48	17	5	94	1.80	114	45.97
7233	11	.6	8	47	20	10	302	7.80	104	43.84
7234	7	1.0	8	37	20	5	87	1.30	133	36.24
7235	8	1.0	9	51	20	10	87	1.15	228	37.89
7236	20	1.6	10	32	18	10	89	2.38	420	61.43
7244	8	1.2	7	44	20	10	71	.93	100	38.20
7250	3	.8	2	11	7	0	48	.34	86	39.84
7251	3	1.2	4	12	10	0	44	.36	93	41.56
7252	3	.8	5	14	9	10	58	.25	88	58.84
7256	3	1.0	5	15	8	0	45	.19	77	58.53
7258	3	.8	3	18	11	10	34	.92	95	34.37
7259	5	.8	4	7	2	10	47	.08	43	51.97
7260	3	1.0	3	25	9	10	74	.75	116	41.75
7261	22	.6	5	16	8	10	115	.22	116	65.80
7262	5	1.2	4	16	2	10	50	.58	206	35.87
7263	12	1.2	3	14	2	0	61	.13	66	39.30
7264	12	1.0	19	67	61	10	143	3.55	399	34.6
7265	14	1.0	10	143	18	10	122	2.68	368	37.
7266	29	.2	16	124	15	10	114	2.46	415	40.2
7272	10	2.0	9	18	14	0	47	1.24	128	8.75
7273	10	2.2	11	31	19	0	75	1.57	201	16.69
7274	8	1.8	12	37	26	10	90	2.22	225	20.45
7275	10	1.6	4	35	17	0	54	.98	170	29.56
7276	10	1.6	9	38	22	10	66	1.14	187	22.28
7277	15	1.6	12	39	26	10	79	2.18	214	17.84
7278	10	4.6	8	56	23	10	46	.54	185	20.47
7279	25	4.6	10	38	24	10	60	1.43	176	17.32
7280	20	2.0	10	40	19	10	71	1.55	213	20.42
7281	18	1.8	12	33	18	10	75	1.72	193	14.87
7282	10	1.4	4	34	13	0	68	1.02	155	27.18
7283	10	1.4	9	27	18	10	87	1.46	175	18.24
7284	17	1.4	8	25	14	10	80	1.41	194	17.05
7285	12	1.6	8	23	15	10	77	1.11	153	16.35
7286	12	1.6	11	33	23	10	108	1.95	196	20.2
7291	3	1.4	3	22	10	10	45	.46	126	35.05

7148	6	1.6	8	64	17	10	89	3.62	765	44.85
7149	5	1.8	8	84	20	10	94	3.70	490	46.81
7150	21	2.0	7	66	14	15	81	2.93	469	43.88
7151	5	1.6	8	60	14	10	73	2.85	495	43.32
7152	5	1.2	6	61	17	10	66	3.08	351	41.15
7153	6	1.0	4	66	14	5	53	3.01	239	45.05
7154	5	1.8	5	66	15	10	71	2.99	235	47.06
7155	3	2.0	28	118	36	10	114	1.84	380	44.6
7156	2	2.4	10	66	18	10	119	1.02	519	47.83
7157	5	1.4	10	75	24	10	108	1.07	516	50.25
7158	5	1.8	10	71	22	10	138	1.18	521	52.89
7159	3	2.4	3	24	8	5	42	.14	40	59.76
7160	4	.6	3	30	9	5	57	.13	43	62.77
7161	5	.6	4	32	9	5	55	.13	43	64.66
7167	15	2.0	9	27	23	10	77	1.30	172	22.69
7168	17	2.0	8	26	21	5	76	1.20	167	23.30
7169	12	2.2	2	16	10	5	112	1.90	214	41.05
7170	10	1.4	3	14	9	5	97	.90	214	35.57
7171	7	1.0	2	19	10	5	65	.30	47	34.76
7172	7	.6	3	24	10	5	58	.30	53	58.08
7173	7	1.2	4	17	11	10	82	.20	75	58.88
7174	10	1.0	4	19	10	5	79	.40	93	60.57
7175	11	.6	4	15	10	5	45	.14	84	66.36
7176	21	.8	4	20	12	5	112	.20	133	74.01
7177	14	.6	3	29	9	5	46	.11	35	49.47
7178	6.5	.8	0	16	8	5	37	.12	23	41.62
7179	7	4.2	5	82	10	5	78	2.70	155	61.94
7180	7	5.2	6	97	12	10	94	6.00	162	66.36
7181	5	.8	3	26	8	5	72	.12	55	51.71
7182	5	.6	3	24	8	5	71	.12	68	49.36
7183	11	1.2	3	13	7	10	68	.20	46	14.24
7184	5	1.4	5	15	9	5	59	.10	85	52.90
7185	5	1.2	3	15	11	5	62	.10	66	48.44

ND—No Data.

7292	17	1.8	6	33	12	10	82	1.26	197	29.55
7293	23	1.2	9	35	15	10	87	1.65	262	28.85
7294	18	1.8	9	46	20	10	103	2.35	258	31.64
7295	15	1.2	9	28	13	10	80	1.89	190	18.69
7299	3	.8	5	15	15	10	64	.28	73	42.92
7300	3	1.6	3	11	10	10	48	.12	45	42.23
7305	10	.8	5	57	16	10	56	.27	44	45.60
7306	12	.4	3	28	18	0	38	.02	33	45.58
7307	12	1.0	4	22	13	10	62	.18	80	60.59
7308	3	1.0	3	25	16	0	45	.11	28	34.62
7309	20	.8	4	33	13	10	128	.78	148	67.10
7310	12	.6	3	31	14	10	139	.46	108	66.82
7311	12	.8	10	38	21	10	151	1.64	162	29.08
7312	3	.4	2	16	7	10	32	.11	19	28.46
7313	3	1.2	7	24	10	0	43	.51	78	33.01
7314	5	.4	8	27	19	0	63	.15	80	59.28
7315	2	20.0	13	48	24	10	59	1.24	172	40.41
7316	18	1.6	10	38	17	0	66	.91	59	48.90
7317	15	.8	11	30	20	0	83	.70	76	58.58
7318	10	.8	12	32	23	0	80	.58	72	57.32
7319	2	1.8	10	22	16	0	62	1.10	525	36.99
7320	2	1.8	7	21	13	0	53	.70	412	32.70
7321	5	1.4	12	24	19	0	57	.65	144	30.80
7322	4	1.0	7	25	10	0	34	.14	24	52.28
7323	8	.6	5	29	10	10	38	.12	35	43.17
7324	14	.6	5	15	13	0	131	.32	147	81.49
7330	2	1.0	4	19	12	0	40	.55	80	32.14
7331	4	1.0	4	22	11	0	44	.40	45	32.01
7333	4	1.2	6	25	11	0	110	.14	31	47.08
7334	6	.8	9	29	18	0	116	2.46	89	37.91
7335	5	1.0	10	31	22	0	40	1.69	95	40.29
7336	3	.8	11	33	21	0	46	.27	24	36.99
7336	3	.8	11	33	21	0	46	.27	24	36.99

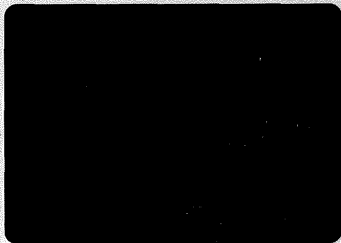
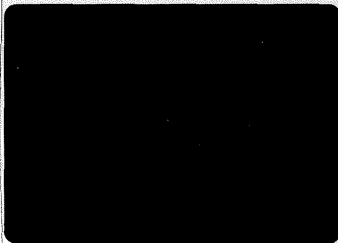
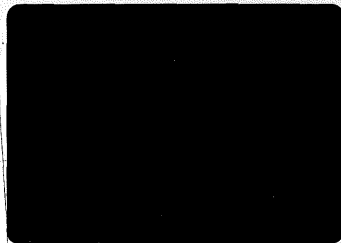
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LAKE SEDIMENT EXPLORATION GEOCHEMICAL SURVEY  
OF COOK COUNTY, MINNESOTA

PLATES 1-6

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LAKE SEDIMENT EXPLORATION GEOCHEMICAL SURVEY  
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PLATES 7-11

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