GEOLOGICAL, GEOPHYSICAL AND GEOCHEMICAL SURVEYS OF LAKE, ST. LOUIS AND COOK COUNTIES, MINNESOTA FOR THE 1980 DRILLING PROJECT

Minnesota Department of Natural Resources
Division of Minerals

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GEOLOGICAL, GEOPHYSICAL AND GEOCHEMICAL SURVEYS OF LAKE, ST. LOUIS AND COOK COUNTIES, MINNESOTA FOR THE 1980 DRILLING PROJECT

Introduction

This project was initiated as a result of funding from the 1980 Minnesota legislature to perform bedrock core drilling for mineral potential determination and to further the geologic knowledge of the State of Minnesota. The data in this report consists of geochemical, geophysical and geological surveys conducted by the Division of Minerals of the Minnesota Department of Natural Resources in Cook, Lake and St. Louis counties for the purpose of locating bedrock core drilling sites.

The areas surveyed were selected geochemical anomalies from regional lake sediment surveys previously conducted by the Division of Minerals and from magnetic anomalies from aeromagnetic data derived by the Minnesota Geological Survey (Chandler and Walton, 1981). Agency policy parameters placed on the selection of core drilling sites included that there must be at least 50% state trust fund or tax-forfeited county mineral ownership; that sites should not be near already defined economic mineralization, and that drill sites must be located in or near the Duluth Complex but outside of the Boundary Waters Canoe Area. The areas where geochemical, geophysical, or geological surveys were conducted are shown on Figure 1.

The geological, geochemical and geophysical surveys conducted in Cook, Lake and St. Louis counties resulted in the selection of a number of drill sites in Lake County, of which two were drilled during January to March, 1981. Of two holes drilled in the Fools Lake area (Sec. 12, T59N, R11W), the first hole intersected an oxide gabbro with thin zones of up to 30% iron and titanium oxide, and the second hole contains traces of sulphide mineralization. A third hole drilled northeast of Toimi near Crest Lake (Sec. 10, T57N, R11W) intersected a banded troctolite with thin zones of oxide. The oxide zones in this drill hole frequently contain 5% total sulfides and up to 40% oxides assaying .22%-.25% copper and 9%-14% titanium oxide. Disseminated sulfides occur throughout the troctolite. These drilled anomalies represent portions of magnetic anomalies defined by aeromagnetic surveys conducted by the Minnesota Geological Survey. Few, if any, outcrops are known to occur over these anomalies, and the drill holes represent the first known sample of rock producing these anomalies. The results of these drill holes are significant, particularly the drill hole near Crest Lake, and suggest that further investigation may be productive.

This report consists of a presentation of the data, and no attempt to interpret the findings is made. Plates 1 through 12 contain the geophysical, geochemical and geological results obtained during this survey.

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General Geology

The area encompassed in this survey forms an arcuate-shaped zone lying between Duluth and Pigeon Point along Lake Superior and extending inland nearly to Ely (Fig. 2). The regional geology is Keweenawan, consisting of intrusive and extrusive rocks of the Duluth Complex and North Shore Volcanic Group, respectively. Both have been intruded by mafic hypabyssal rocks.

The Duluth Complex is a large, dominantly mafic, igneous body consisting of multiple intrusive phases originating in a tectonically unstable environment. Most of the mapped intrusions or rock units in the complex can be related to one of three series: the anorthositic, troctolitic, or felsic series. Exceptions to these series are a suite of oxide-rich gabbros (Nathan's Layered Series), hornfels inclusions of metasedimentary or igneous rocks, minor ultramafic rocks, and later, mafic dikes and sills.

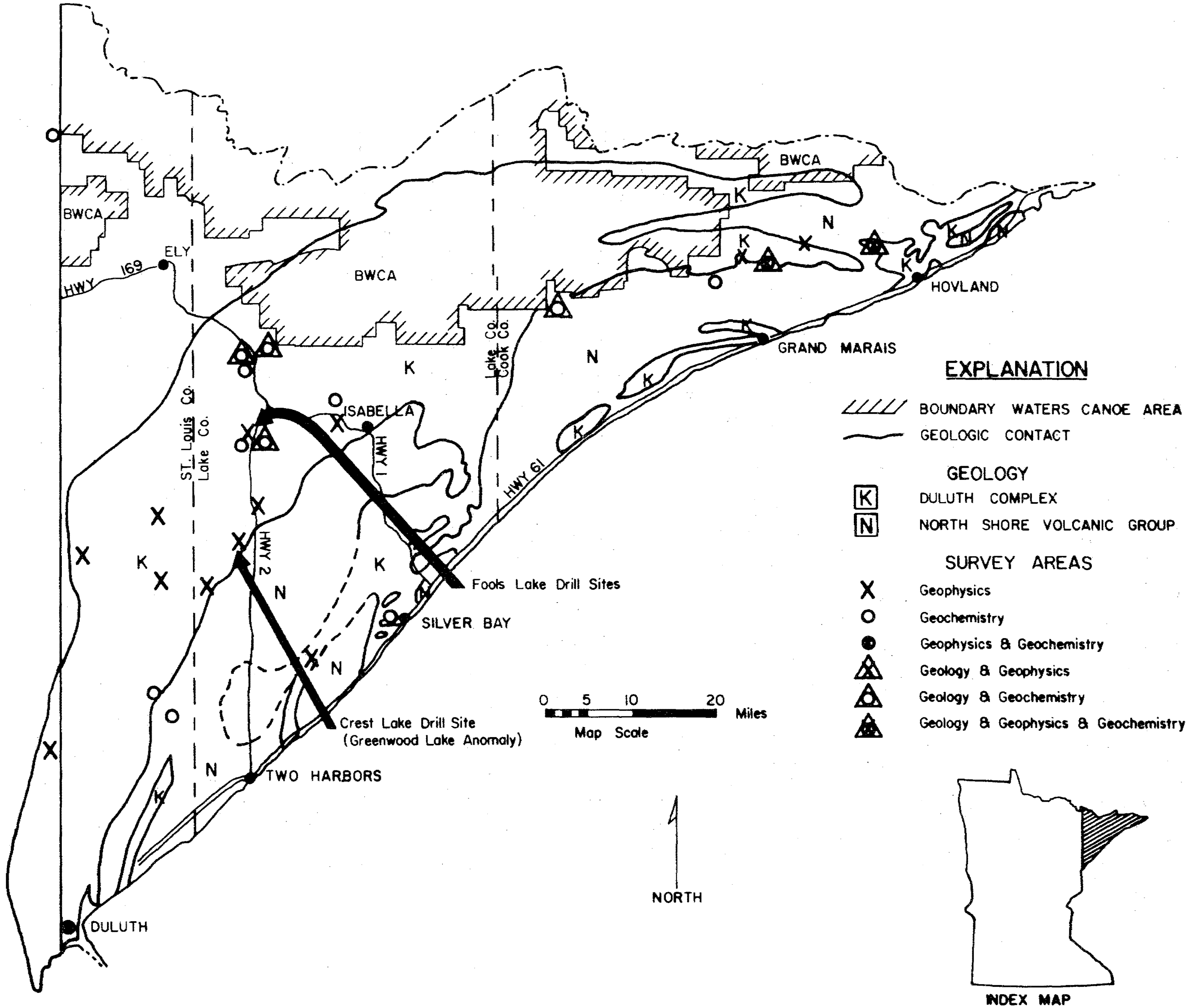

FIGURE 1: LOCATION MAP SHOWING AREAS SURVEYED AND DRILL HOLE LOCATIONS

The anorthositic series occurs as a central cap to the complex and appears to be a distinct suite of rocks that was intruded by the troctolitic series. The distribution of mappable inclusions and their association with faults in the Hoyt Lakes-Kawishiwi area suggest that they are remnants of a cover of anorthositic rocks that was disrupted during the emplacement of troctolitic intrusions. All rocks in the anorthositic series are plagioclase cumulates, by definition, exhibiting igneous lamination to some degree. The anorthositic series is more restricted in composition than the troctolitic series, being distinguished by subtle differences in intercumulate mineralogy and textures. Individual varieties can be traced from outcrop to outcrop on a kilometer scale but form irregular outcrop patterns and are commonly interrupted by "igneous breccia textures."

The troctolitic series forms the basal and upper contacts of the complex and hosts the sulfide mineralization of interest at the base. A number of individual phases of the troctolitic series have been mapped including the Bald Eagle, South Kawishiwi, Partridge River Troctolite, and Powerline Gabbro.

The basal contact zone rocks of the troctolitic series are a heterogeneous zone of noritic, troctolitic, pyroxenitic and peridotitic rock, frequently with numerous xenoliths of metasedimentary and igneous rocks. The troctolitic series overlying the basal contact zone exhibits considerable variety in composition; however, augite-bearing troctolite and augite troctolite are most abundant and are gradational with olivine gabbro, augite-free troctolite, and anorthositic troctolite.

Ferrogabbro and peridotite, sometimes with significant oxides, occur in some areas of the troctolitic series. Troctolitic series rocks overlying the basal contact zone sometimes have a well-defined modal layering that is very discontinuous and can seldom be traced from one outcrop to another. Most minerals in this series exhibit a narrow range of chemical composition and do not appear to vary systematically with stratigraphic position.

Rock types associated with the felsic series include granophyre, adamellite, syenodiorite and ferrogranodiorite, granophyre being most abundant. These occur as irregularly shaped masses in the anorthositic and troctolitic series, occurring principally along the contact between the two series and as intrusive dikes. In the Finland-Beaver Bay area and Gunflint corridor, felsic rocks tend to overlie troctolitic rocks; however, felsic rocks cannot be presently assigned unequivocally to specific intrusions or to either of the major series.

The layered series of Nathan which occurs in the central part of the northern prong of the Duluth Complex does not appear to be associated with either of the major series. In general, this series consists of a sequence of conformable sheetlike bodies that have been interrupted by minor cross-cutting stock and dikelike bodies. Overall, this series is gabbroic but it contains a number of oxide- and olivine-rich units, both sheet-like and stock-like.

Ultramafic rocks are uncommon in the Duluth Complex in comparison to other large mafic intrusive bodies. Known occurrences include those at Bardon Peak, the Water Hen intrusion, and several bodies in the Boulder Lake area. They are characterized by olivine and clinopyroxenes in the intermediate range as well as abundant magnetite-ilmenite in some instances.

The North Shore Volcanic Group is a plateau lava sequence occupying a major portion of the region overlying the Duluth Complex and locally underlying it. While it resembles other plateau lava groups, both physically and chemically, it is much more variable than some. The most abundant lava type is tholeiitic olivine basalt of several types, frequently porphyritic, although quartz tholeiites are common. Intermediate lava types include andesite, trachyandesite and intermediate quartz latites, nearly all porphyritic. Felsic lavas are anomalously abundant for a simple differentiation sequence and are quartz latite and rhyolite in composition. Interflow conglomerates are uncommon and interflow sediments, while not uncommon, form a small part of the overall stratigraphic column.

Keweenawan hypabyssal, mafic dikes and sills occur throughout the region in rock units bordering the Duluth Complex, in the Duluth Complex itself, and in the North Shore Volcanic Group. These mafic intrusives are diabases or olivine diabases and appear to represent two distinct magmatic episodes, both in time and composition. However, the detailed relationship of these intrusives to the Duluth Complex and the North Shore Volcanic Group has not been established.

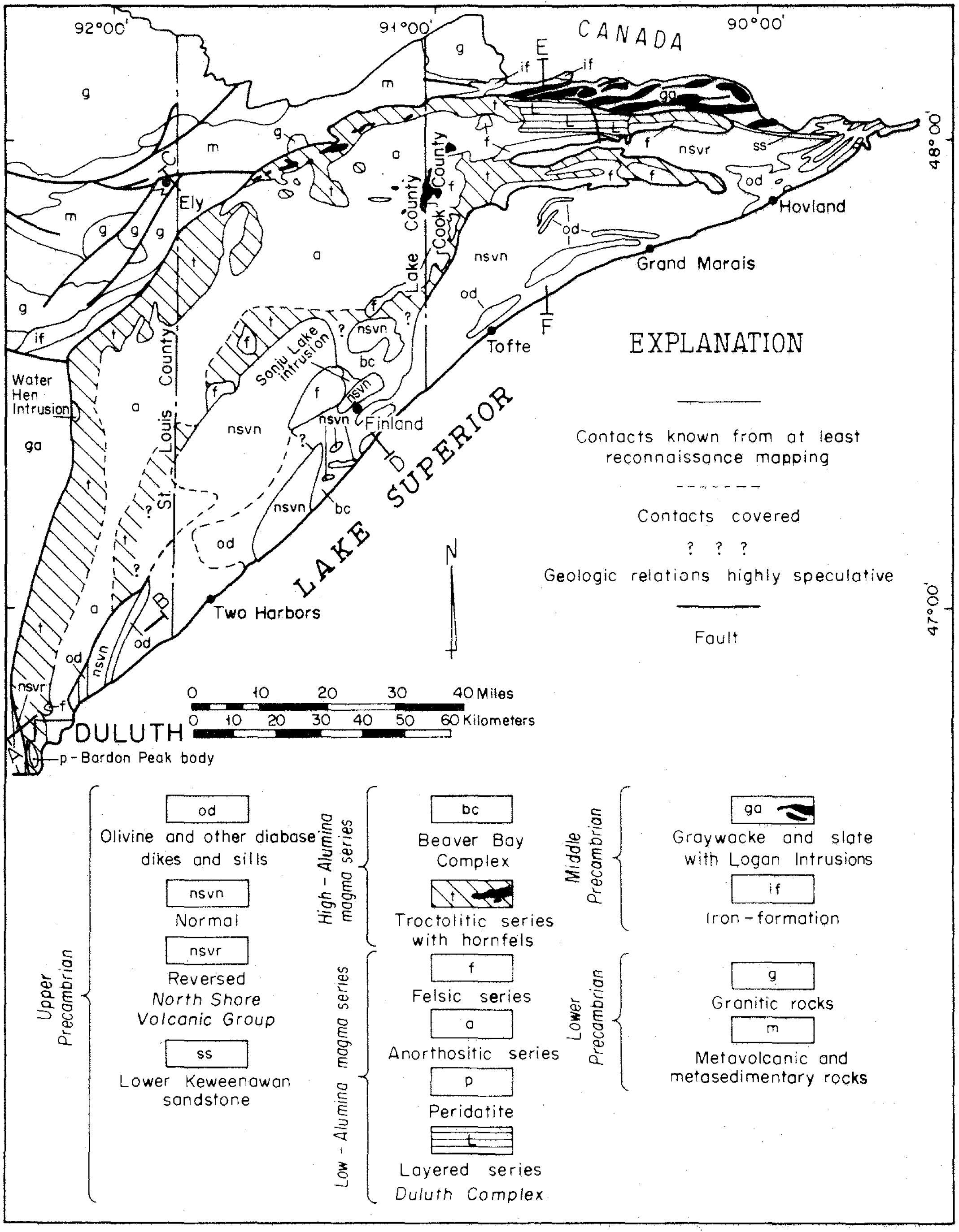

FIGURE 2: GEOLOGIC MAP OF SURVEY AREA (After Weiblen and Morey, 1980)

The Duluth Complex and associated North Shore Volcanic Group are considered to be associated with the northeastern extension of the Mid-Continent Gravity High. Models proposed for the origin of the North Shore Volcanic Group and associated intrusive Duluth Complex include the development of several separate basins of accumulation of lavas along a tensional zone with associated underlying intrusives (White, 1972a; Green, 1977); a rift widening to the north from a pole of rotation in New Mexico, completely filled by mafic mantle derived rock (Chase and Gilmer, 1973); or developed as a result of rotated fault blocks in a zone of crustal tension making room for large intrusive bodies under an underlying cover of volcanic rocks (Weiblen and Morey, 1980).

Plate 12 illustrates the general geology of the Greenwood Lake magnetic trend.

Geophysical Methods

Areas for geophysical ground follow-up were selected from airborne magnetic surveys flown under the supervision of the Minnesota Geological Survey (Chandler and Walton, 1981). Selection of an area for ground follow-up was generally made by locating relatively small, high amplitude, magnetic anomalies from the airborne magnetic data. The ground surveys were conducted using electromagnetic and magnetic instrumentation.

Initial ground follow-up was performed using a Geometrics model G-836 Unimag proton magnetometer and a Ronka EM-16 to screen anomalies and to accurately locate geophysical grid locations. If an anomaly fell upon an existing road or trail, the Ronka EM-16 was not used; instead, lower frequency EM methods were used.

Subsequent to geophysical grid preparation or station flagging along an existing road or trail, measurements were made using an Abex MAX-MIN II and/or Crone CEM and a Geometrics Unimag. The Crone CEM was operated in the horizontal shootback configuration using 300-foot coil separation and as a vertical loop fixed transmitter configuration. The MAX-MIN unit was used in the horizontal loop mode with a 400-foot coil separation.

The results from the geophysical surveys are shown on Plates 1-6.

Geochemical Methods

Determination of areas for geochemical follow-up were based on data derived from reconnaissance lake sediment geochemical surveys previously conducted in northeastern Minnesota by the Division of Minerals (Meineke, Vadis and Klaysmat, 1976; Vadis and Meineke, 1980, 1981). Locations of areas of geochemical follow-up sampling are shown on Figure 1. The geochemical follow-up surveys consisted of sampling near-shore lake sediments, "B" horizon soil, and clastic and organic stream sediments, with consideration given to the probable glacial directions and glacial material encountered in each area. The analytical methods listed below are detailed in the appendix.

The lake sediment samples consisted of organic-rich, lake center material collected with a specially designed sampler. These samples were analyzed for Ag, As, Co, Cu, Ni, Pb, Zn, Fe, Mn, and loss-on-ignition (LOI) by analytical methods AN-3, 14, and 15 (see appendix for complete description of analytical methods).

The near-shore lake sediment samples were clastic or organic materials taken in 1'-3' of water where these samples should be in contact with ground water percolating into the lake. Any metal ions carried in the ground water would probably be precipitated or sorbed by the sediment as the ground water enters the lake because of changing chemical conditions. These samples were analyzed for As, Co, Cu, Ni, Pb, Zn, Fe, Mn, LOI and, in some cases, Ag by AN-3, 14, and 15 (see appendix).

In some areas, "B" horizon soil samples were taken from shovel-dug pits to be analyzed for As, Co, Cu, Ni, Pb, Zn, Fe, and Mn by AN-3, 14, and 15 (see appendix).

Stream sediment sample types include clastic samples from the bottom of the stream, organic samples from the stream bottom, and organic stream bank samples. The organic stream bank samples were collected from below the water level in the bank of the stream and consisted mainly of decomposed and undecomposed organic material. Stream sediments were analyzed for As, Co, Cu, Ni, Pb, Zn, Fe, Mn and, if organic, loss-on-ignition (LOI) by AN-3, 14 and 15 (see appendix).

Results of Surveys

Geophysical Results

Greenwood Lake Anomaly (Snake) (Plate 1) (T57N, R11W, S31 and 32) (T57N, R11W, S10 and 11) (T57N, R12W, S33) (T58N, R10W, S19)

The long, sinuous, magnetic feature which runs on the east side of Greenwood Lake then to the southwest was investigated in four locations (Plate 1). These areas showed a broad, low amplitude magnetic signature and weak EM response with the EM instruments used. A drill hole was located in Section 10 of T57N, R11W along this magnetic trend in an area which produced a weak EM response (see Plate 1 for location).

Fools Lake Area (Plates 3 and 4) (T59N, R11W, S12)

The aeromagnetics from this area are characterized by a relatively high amplitude, magnetic anomaly of relatively small areal extent (Plate 3).

Five grid lines were cut over this anomaly after preliminary ground magnetometer and Ronka EM-16 reconnaissance lines were run. Contoured magnetic data and magnetic profiles along the grid lines indicating northeast trending anomalies are shown on Plate 3. Relatively weak conductive zones are indicated by the EM data from this grid (Plate 4). The EM anomalies do not correspond well with the magnetic anomalies, except that it appears that the conductive zones seem to flank the magnetic anomalies on the north and south. These are interpreted as being the edges of a rather wide, weakly conductive zone responding to EM.

Two drill hole sites were selected in this area: one over the magnetic high and the second hole on an indicated conductor along the northern edge of a magnetic zone. The latter hole was to determine if a wide, weak conductor exists or if the conductors indicated by the EM data represent separate conductors. Unfortunately, the capability to drill an angle hole in this area was not available.

Isabella Anomaly (Plates 5 and 6) (T60N, R9W, S2)

The anomaly in this area appears as a relatively intense, magnetic response over a relatively small areal extent on the aeromagnetic contour map (see Plate 6). Four grid lines were cut in this area following ground verification of the aeromagnetic anomaly with a magnetometer and Ronka EM-16. The ground magnetics along the grid lines are profiled and contoured on Plate 5. The magnetic response indicates depths of greater than 100 feet. Some very weak conductive zones are indicated by the electromagnetics from this grid.

T55N, R9W, S7; T58N, R12W, S29; T63N, R1W, S25, 35, 36; T63N, R1E, S31; and T63N, R1W, S36; T63N, R1E, S20 (Plate 2)

The anomalies in these areas appear as relatively intense, magnetic responses over relatively small areas on the aeromagnetic surveys. Each of these areas was surveyed with ground electromagnetics and magnetics showing a magnetic response and weak to no electromagnetic responses. Some of these areas may deserve further investigation.

Geochemical Results

Thirteen areas were followed up with detailed sampling of soils, streams and lakes, based upon results from the regional lake sediment survey. These results are shown on Plates 7 to 11. All of these follow-up areas were dropped from current considerations either due to inability to determine the bedrock source of the anomalies or because anomalies led to non-state controlled mineral land, although some areas may deserve further investigation. The following is a brief description of the findings of the geochemical follow-up surveys.

Tom Lake (Plate 11)

Soil, stream sediment and near-shore lake sediment samples were collected from this area as follow-up investigation. The lake sediments in this area contain anomalous amounts of Cu, Zn, As, and Co. The near-shore lake sediments are randomly anomalous in Cu, Pb, and Zn while soil samples from the area are randomly anomalous in Zn and Cu. No clear bedrock source for the anomalous geochemical samples was located, but this area merits further investigation.

Circle and Musquash Lakes (Plate 10)

Soil, stream sediment and near-shore lake sediment samples taken did not indicate a source or direction of the anomalous Ag in the lake sediments. This source may be remote from the Circle and Musquash lakes area.

Two Island, Dick and McDonald Lakes (Plate 10)

The lake sediments from these lakes are anomalous in Zn with some samples anomalous in Ni, Cu and As as well. Near-shore lake sediment samples indicate high Zn values in McDonald Lake, particularly along the southern shore. This area may deserve further investigation.

Sawbill Lake (Plate 11)

Lake sediment in this lake is anomalous in Cu, Ni, Zn, As, and Co. Soil, stream sediment and near-shore lake sediment samples collected did not indicate a possible source for this anomaly. Due to the proximity of this area to the Boundary Waters Canoe Area, sampling could be done only a short distance in the up-ice direction from this lake.

Bear and Bean Lakes (Plate 8)

These lakes were anomalous in Cu and Pb, but near-shore lake sediments did not indicate a possible bedrock source or source direction.

Mitawan and Grouse Lakes (Plate 9)

This area is anomalous in As, Cu, Pb, and Zn. Some of the near-shore lake sediment samples showed high Cu values, particularly on the southern end of the lakes and may justify further consideration of this area.

Pequaywan Lake (Plate 7)

The lake sediment from this lake is anomalous in As, Co, Cu, Ni and Zn, although stream and near-shore lake sediments do not indicate a bedrock source for these anomalies.

Meander Lake (Plate 7)

Near-shore lake sediments did not reflect mineralization suggested by lake sediments, and a possible bedrock source was not indicated.

Chris and Schafer Lakes (Plate 7)

The anomalies in the lake sediment from these lakes consist of Co, Cu, Ni and Pb. Cu and Ni are somewhat above background values in the near-shore lake sediments, and a limited number of soil samples from this area indicate that Cu and Ni values increase in an up-ice direction from these lakes. This area may deserve further consideration.

Sand Lake (Plate 9)

The lake sediment from this lake is anomalous in Co, Ni and Zn. The near-shore lake sediment samples and "B" horizon soil samples indicate a trend up-ice for Ni and, to a lesser degree, Cu from the lake, particularly in the area of the northern portion of the lake. This direction is toward an area which is apparently not state-controlled mineral land, and the area was dropped from consideration.

Beaver Hut Lake (Plate 8)

This lake is anomalous in Cu and Ni in the lake sediment, and some variation in the metal values from near-shore lake sediment samples was noted. A possible trend of weakly anomalous values exists toward the northeast portion of the lake but was not followed.

Harris Lake (Plate 8)

The lake sediment in this lake is anomalous in Co and Ni. Near-shore lake sediments from the southern portion of this lake show anomalous Ni concentrations, and some soil samples south of Harris Lake indicate anomalous Ni concentrations. The area south of Harris Lake may not be state-controlled mineral land; therefore, this area was dropped during this project but deserves further investigation.

August Lake (Plate 8)

The lake sediment from this lake is anomalous in Co and Ni. The soil and stream sediment samples indicate anomalous Ni north and east from August Lake which is up-ice. Weiblen (1965) reports a rock analysis of .5% Cu and .05% Ni several miles northeast from August Lake. Land in this direction appears not to be state-controlled, and this area was, therefore, dropped from present investigation but merits further work.

Geological Reconnaissance

Geological reconnaissance was performed in a number of areas in an attempt to determine the source of anomalous base metal values in lake sediments. Preliminary surveys included checking of outcrop and glacial erratic boulders along the shorelines of Harris, August, Beaver Hut and Sand lakes looking for sulfide-bearing outcrop or boulders. Later surveys in these areas involved detailed reconnaissance south of Harris Lake and northeast of August Lake, again looking for evidence of sulfides in either bedrock or float.

Beaver Hut and Harris lakes lie in the South Kawishiwi intrusion near its eastern border, and the area examined in the August Lake area lies on the western edge of the Bald Eagle intrusion, both of which are in the troctolitic series. Sand Lake lies in the anorthositic series near its eastern border, although it should be noted that boundaries between series in this area, and others, are probably arbitrarily located. There was no outcrop on the Sand Lake shoreline, but the majority of numerous boulders were troctolitic or anorthositic Duluth Complex rocks, both of which could be associated with the troctolitic series.

Results of these surveys were largely negative as no evidence of base metals was observed in outcrop other than a few specks of sulfides, probably pyrrhotite. The only mineralization noted in boulders was in greenstone boulders and in two gossanous gabbro boulders found south of Harris Lake, one weakly mineralized and the other strongly mineralized. Soil geochemical samples taken in the vicinity of these boulders were not anomalous. The greenstone boulders found in these areas frequently contained iron sulfide mineralization but showed little evidence of other base metal sulfides.

Another area in which geologic reconnaissance was undertaken to inspect the geology associated with an airborne magnetic anomaly was the Musquash and Tom lakes area. A north-south traverse was made across the center of the aeromagnetic anomaly northwest of Musquash Lake. All outcrop seen was granophyre with 3-5% of magnetite. The only variation noted in the geology was that the granophyre appeared to be somewhat coarser and possibly more magnetic in the northern part of the traverse.

Numerous rock outcroppings were noted along and adjacent to the shoreline of Tom Lake consisting of sequences of North Shore volcanics and Duluth Complex rocks. From the southeast shore of Tom Lake northward, they generally consist of granophyre, alternating sequences of volcanic rocks ranging from basalts to rhyolites (latites?), often porphyritic, and occasional intervening intrusive rocks. The intrusive rocks consist mainly of gabbro, olivine gabbro, and olivine-oxide gabbros. Little sulfide mineralization was noted; however, the oxide content of some of the intrusive rocks may reach 20%.

Drilling Results

Sites were chosen for three diamond drill holes: one in the area of the Greenwood Lake Anomaly, and two in the Fools Lake area (Fig. 1). The drill hole S-1 in the Greenwood Lake Anomaly area (Plate 1D) penetrated 113.5 feet of overburden before encountering bedrock. It was necessary to terminate the hole after drilling to 143.3 feet. Drill holes FL-1 and FL-2 in the Fools Lake area (Plate 3) encountered bedrock at 13.3 feet and 29.0 feet and were terminated at 125.5 feet and 65.0 feet, respectively.

Diamond drill logs refined by petrographic studies as well as assays and whole rock analyses are presented below. The petrographic studies and the assays and whole rock analyses by atomic absorption were performed at MDNR laboratories in Hibbing, while assays for platinum and palladium were done by the DC Plasma method at X-Ray Assay Laboratories, Limited, in Don Mills, Ontario.

Drill Logs and Petrography

Geologic Log for DDH S-1

0 -113.5'	Overburden.
113.5'-118.0'	Olivine-bearing oxide gabbro—not cored.
118.0'-123.0'	Olivine-bearing oxide gabbro. Medium-grained, dark gray. Well-foliated, 70°-90° to core axis. Mode: plagioclase, 50%; augite, 30%; olivine, 7%-8%; magnetite-ilmenite, 10%; biotite (including oxybiotite), 2%; total sulfides, 0.2%-0.3%. At the 120.6'-120.9' interval there is a band of finer-grained olivine augite gabbro with the upper contact sharp and normal to the core axis and the lower more gradational and 45° to the core axis.
123.0'-124.0'	Banded sulfide-bearing oxide augite troctolite. Medium-grained, dark gray to black with 0.5"-2" oxide-rich bands 80° to core axis. Upper and lower contact of bands is gradational to fairly sharp. Mode from thin section with a 0.5" oxide band: plagioclase, 30%; olivine, 25%; augite, 20%; biotite, 1%; magnetite-ilmenite, 15%-20%; total sulfides, 4%.
124.0'-128.5'	Oxide gabbro. Medium-grained, dark gray. Foliation is chaotic, varies from 80° to core axis to random. In thin section this interval shows considerable alteration of ferro-magnesian minerals. Mode from thin section: plagioclase, 50%; hornblende, 20%; augite, 15%; biotite, 5%; olivine, 1%; magnetite-ilmenite, 10%; total sulfides, 0.3%-0.5%.
128.5'-136.0'	Banded sulfide-bearing augite-oxide troctolite. Medium-grained, dark gray to black with 0.5"-1" oxide-rich bands. Banding and oxide-sulfide content decrease in lower 3' of interval. Upper and lower contacts of bands are fairly sharp. Foliation is variable, 65°-85° with core axis. The mode of the interval is variable with the ferro-magnesian minerals increasing with the oxide minerals and plagioclase decreasing. Mode: plagioclase, 20%-60%; olivine, 25%-30%; augite, 20%-25%; biotite (including oxybiotite), 1%; magnetite-ilmenite, 15%-30%; total sulfides, 4%-5%.

136.0'-140.0'	Olivine-bearing oxide gabbro. Medium-grained, dark gray to black. Foliation is distinct to strong, 70° to core axis. Mode: plagioclase, 45%-50%; augite, 30%; olivine, 5%-10%; biotite, 1%; magnetite-ilmenite, 10%-15%; total sulfides, 0.2%-0.3%.
140.0'-143.3'	Oxide augite troctolite. Fine- to medium-grained, dark gray. Strongly foliated, 80°-85° with core axis. Contact with overlying unit is fairly distinct, marked by a change in grain size and orientation of foliation. Mode: plagioclase, 15%-20%; olivine, 35%; augite, 25%; chlorite, 1%; magnetite-ilmenite, 20%; total sulfides, 1%.

E.O.H.

The determination of An ratio of the plagioclase was difficult using the Michel-Levy method (Heinrich, 1965) because of fracturing and bending of plagioclase laths. However, most appear to be in the calcic andesite-sodic laboradorite range, varying from An_{45} to An_{52} where a reliable determination was possible.

The sulfide mineralogy throughout the hole was consistently about 75% pyrrhotite including troilite, the remainder being quite evenly distributed between chalcopyrite and cubanite with occasional traces of bornite. Only one possible trace of pentlandite was noted. The majority of the sulfides occur as irregular blebs, frequently heterogeneous in composition, interstitial to and molded on the silicates. Fine veinlets of chalcopyrite occur as fracture fillings and along cleavage planes in plagioclase and, to a lesser extent, in other silicates. Very fine blebs of sulfides also occur as inclusions in silicate minerals.

The oxide minerals are quite uniformly distributed between magnetite and ilmenite in a 9:10 ratio in this core. The major occurrence of both is as discrete, disseminated grains or as aggregates of grains, although some exsolution of ilmenite along crystallographic planes in magnetite is present.

A polished thin section taken at the 123.2' interval has a number of very fine-grained, euhedral to subhedral, prismatic crystals with radiating dendritic overgrowths. Presently, it is not known whether they may be defects in the thin section or represent unidentified minerals. However, they do appear to be associated with what appears to be healed fractures in silicate minerals or in close association with oxide or sulfide minerals.

Geologic Log for DDH FL-1

0 - 13.3'	Overburden.
13.3'- 51.5'	Oxide gabbro-hornfels zone. Complex interval containing xenoliths of fine-grained oxide gabbro or oxide basalt that have been recrystallized to varying degrees, reaching the pyroxene hornfels facies near contacts. Color varies from medium gray to dark gray to black. Grain size varies from fine-grained, equigranular, massive, to medium-grained with a massive, felty texture. Contacts vary from sharp and distinct to gradational and indistinct. Fracture at 36.5' at 10° to core axis. Interval from 41.0'-51.5' contains irregularly shaped grains and veinlets of augite. Mode of one xenolith: plagioclase An_{45} (one determination), 25%; augite, 50%; magnetite-ilmenite, 20%-25%; serpentine as fracture filling. Mode of "host" rock: plagioclase (An_{60}), 45%-50%; augite, 25%-30%; magnetite-ilmenite 15%-20%; olivine, trace to 2%.
51.5'-125.5'	Oxide gabbro. Contact with above interval is gradational and evidenced by a gradual increase in grain size. Medium to dark gray, generally medium-grained although minor, locally coarse zones are present. Foliation appears to be very weak although there is a crude parallelism of longer plagioclase laths. Fractures and their angle with the core axis are as follows: 56.5', 35°; 57.5', 20°; 66.5', 30°; 106.0', 10°. Oxide-rich bands occur at 69.5' (2"), 71.7' (1.5"), 77.7'-78.6', and 92.8'-94.1'; contacts vary from sharp to gradational. Xenoliths of oxide basalt or fine-grained oxide gabbro occur at 100.4'-106.9' and 107.9'-109.0'. The upper xenolith is fine-grained at the contacts and medium-grained in the middle. Mode of rock: plagioclase, 60%-70%; augite, 15%-25%; magnetite-ilmenite, 10%-15%; olivine, 0%-4%. Mode of interior of xenolith at 100.4'-106.9': plagioclase, 45%-50%; augite, 35%-40%; magnetite-ilmenite, 15%. Mode

of oxide band at 77.7'-78.6': plagioclase, 35%; magnetite-ilmenite, 40%; augite, 25%; serpentine as fracture filling. Mode of oxide band at 92.8'-94.1': plagioclase, 2%; augite, 65%-70%; magnetite-ilmenite, 25%-30%; chalcopyrite, trace; serpentine as fracture filling.

E.O.H.

It was not possible to make a large number of An determinations in this core because of recrystallization in the upper interval and frequent fracturing and bending of plagioclase laths in the lower interval. Those that were made ranged from An_{45} to An_{67} with the majority falling in the An_{53} to An_{67} range.

The magnetite-ilmenite ratio in this core is variable with ilmenite varying from 10%-30% of the oxides and magnetite from 70%-90%. Most occurs as discrete grains or aggregates of grains although some of the magnetite is titanomagnetite with crystallographically oriented exsolution intergrowths of ilmenite and possibly spinel.

The only sulfides seen in this core were those noted above, although a few minute specks of native copper were noted throughout this core.

Geologic Log for DDH FL-2

0 - 29.0'	Overburden.
29.0'- 34.5'	Boulder; probably the same rock type as the underlying bedrock.
34.5'- 38.0'	Overburden.
38.0'- 65.0'	Anorthositic augite-bearing troctolite. Medium gray, medium- coarse-grained with no apparent foliation. The upper part of the interval is highly fractured with hematite-limonite alteration of olivine. Below 55.0' the rock is quite fresh. Mode: plagioclase (An_{64}), 70%-75%; olivine, 20%; augite, 5%; magnetite-ilmenite, 1%; sulfides, trace.

E.O.H.

Assay and Whole Rock Analyses for Drill Hole #S-1

Assays for Pt and Pd were done by X-Ray Laboratories, Ltd., Don Mills, Ontario, using the DC Plasma method. All other analyses were done by the AA method using a total digestion in MDNR laboratories at Hibbing, Minnesota.

*** Indicates a Davis tube concentrate analysis.**

Interval (feet)	Ag (ppm)	Au oz/ton	Co (ppm)	Cr (ppm)	Cu (ppm)	Ni (ppm)	Pb (ppm)	Ti (%)	V (%)	Zn (ppm)
118 -123	.01	.009	90	10	410	70	10	5.68	.05	110
123 -124	.6	.006	140	10	2150	60	10	9.34		200
			58.75* Recovery = 20%					15.01*	.36*	
124 -128.5	.01	.008	80	10	350	70	10	4.68	.09	110
128.5-129.5	.6	.007	150	10	2230	50	10	8.68	.09	180
129.5-130.5	.6	.006	160	10	2500	50	10	11.68	.09	180
130.5-131.5	.8	.006	200	10	2500	60	10	14.02	.11	240
			57.53* Recovery = 20%					15.35*	.36*	
131.5-132.5	.4	.004	160	10	2340	50	10	9.34	.07	180
132.5-133.5	.4	.006	140	10	1240	40	10	7.68		170
133.5-135	.01	.006	120	10	1180	100	10	5.68	.07	140
135 -136	.01	.005	120	10	510	40	10	6.68	.05	150
136 -140	.01	.007	120	10	300	50	10	5.00	.05	120
140 -143	.01	.005	130	10	480	40	10	7.34	.07	130

Interval (feet)	Al %	Ca %	Fe %	K %	Mg %	Mn %	Na %	Si %	Pt (ppb)	Pd (ppb)
118 -123	12.09	11.48	19.87	.58	4.84	.19	2.70	52.41		
123 -124	6.42	6.94	34.23	.29	5.5	.27	1.47	36.15	20	5
124 -128.5	10.58	12.43	19.19	.70	4.78	.19	2.68	51.34		
128.5-129.5	6.42	7.73	35.58	.29	6.00	.27	1.54	37.22		
129.5-130.5	5.67	5.88	34.23	.24	6.16	.29	1.13	40.92		
130.5-131.5	4.16	3.30	43.20	.10	6.84	.33	.61	26.95	20	5
131.5-132.5	6.42	7.95	33.13	.31	5.60	.26	1.29	39.36		
132.5-133.5	6.80	10.64	30.64	.36	6.60	.26	1.39	41.07		
133.5-135	9.02	9.67	24.71	.53	5.38	.22	2.01	45.99		
135 -136	9.82	10.75	25.81	.51	4.94	.21	2.14	45.56		
136 -140	9.82	12.15	21.67	.48	5.60	.21	2.17	48.35		
140 -143	8.69	11.76	25.12	.26	6.24	.24	1.86	44.50		

Assay and Whole Rock Analyses
for Drill Hole #FL-1

Analyses were done by the AA method using a total digestion in MDNR laboratories at Hibbing, Minnesota.

Interval (feet)	Ag (ppm)	Au oz/ton	Co (ppm)	Cu (ppm)	Ni (ppm)	Ti (%)	V (%)	Zn (ppm)
13.3- 15.1	2.2	0	100	60	100	13.46	0	260
22.6- 24.6	2.0	0	100	60	180	9.53	0	280
31.9- 33.9	2.0	0	100	100	210	10.66	0	270
41.2- 43.2	2.0	0	100	90	180	8.97	0	240
50.7- 52.7	2.2	0	100	60	120	8.97	0	290
66.6- 68.6	2.2	0	90	60	150	7.85	0	240
77.7- 78.7	2.6	0	110	50	150	11.78	0	330
85.4- 87.4	2.4	0	80	30	140	8.41	0	200
92.5- 94.0	2.2	0	120	50	210	12.90	0	340
100.6-102.6	2.2	0	110	60	140	11.78	0	270
113.6-115.4	2.2	0	70	40	160	6.16	0	160

Interval (feet)	Al (%)	Ca (%)	Fe (%)	K (%)	Mg (%)	Na (%)	Si (%)
13.3- 15.1	8.35	1.65	29.72	1.18	6.83	1.35	
22.6- 24.6	12.13	2.29	24.01	.77	6.43	2.20	36.42
31.9- 33.9	11.07	2.15	25.15	.75	6.27	2.05	33.21
41.2- 43.2	12.66	2.52	23.01	.80	5.87	2.56	39.20
50.7- 52.7	13.68	2.71	26.44	.72	4.94	1.71	34.71
66.6- 68.6	17.42	2.97	21.29	.80	4.68	2.04	32.41
77.7- 78.7	10.47	1.96	34.87	.77	5.74	1.32	32.36
85.4- 87.4	14.51	2.66	20.58	80	4.78	1.28	31.34
92.5- 94.0	8.88	1.71	32.58	.77	6.47	.76	34.28
100.6-102.6	10.77	1.99	30.01	.70	5.64	1.28	36.63
113.6-115.4	20.29	3.47	13.86	.27	3.81	1.98	35.62

Appendix

AN-3: Analysis of Total As In Any Material By AA For Geochemical Exploration

1. Weigh out .50 gm or 1.00 gm of sample in a 250 ml beaker.
2. Add 40 mls concentrated HCl and digest for one hour on the hot plate.
3. After 50 minutes add l gm KI. In the remaining 10 minutes, all the KI should dissolve. Bring to 100 ml volume and filter using 40 Whatman filter paper.
4. Pour off 40 mls of the filtrate into a graduated cylinder and transfer to 125 ml arsenic reaction flask. The sample is now ready for Arsine generation using a sodium borohydrate pellet.
5. Make standards of 2, 4, 10 and 20 ppb; the 40% concentrate HCl and 1% KI

AN-14: Loss-On-Ignition Determination

1. Weigh out 1.000 g sample in porcelain crucible and record weight on sample sheet.
2. Preheat electric furnace to 500° C. Furnace maintains temperature within ±10° C.
3. Place samples in furnace for 30 minutes.
4. Remove samples from furnace. Cool crucible.
5. Weigh ashed sample and record weight on sample sheet.

AN-15: 4M HNO_3 and 1M HCl—Digestion

1.0000 gm sample digested with 10 mls of 4M HNO_3 and 10 mls of 1M HCl. The final volume in the analysis was 100 mls. The sample was digested at 90° C for two hours (a setting of 2 on the hot plate) and then filtered through 40 Whatman filter paper.

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