Report 308

PLATINUM, PALLADIUM AND GOLD DISTRIBUTION IN B-HORIZON SOILS IN THE NORTHWESTERN PART OF THE DULUTH COMPLEX, MINNESOTA

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the United States Geological Survey

Minnesota Department of Natural Resources
Division of Minerals

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Platinum, Palladium, and Gold Distribution in B-Horizon soils on the Northwestern part of the Duluth Complex, Minnesota

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B-horizon soil samples were collected at 1385 sites along roads, rivers and lakeshores by the USGS during 1971 - 1975 at a depth of 30-45 cm. The <80 mesh fraction was analyzed in 1993 for Pt, Pd, and Au on behalf of the MDNR-Minerals by Bondar-Glegg & company Ltd Ontario, Canada using a fire assay lead collection direct current plasma atomic emission spectroscopic technique. An interpretation of this data as well as data from USGS analyses will be presented by the authors as a USGS bulletin (in preparation).

Precious-metal concentration ranges in these B-horizon soils are shown below:

Pt concentration range: <5 through 75 ppb - 9.6% (134) of samples ≥5 ppb

Pd concentration range: <1 through 140 ppb - 26% (360) of samples ≥ 3 ppb

Au concentration range: <1 through 156 ppb - 41% (568) of samples ≥ 1 ppb

Histograms for Pt, Pd, and Au are shown in figures 5A.. through 5C... Seven selected percentiles for these metals are shown in Table 1. Correlation coefficients between the three elements are relatively low ranging from 0.15 to 0.37 (Table 2). The corresponding scatter diagrams are shown in figures 6A. through 6C.

Platinum anomalies in soils occur primarily as a discontinuous linear pattern along the Duluth Complex contact extending also into the Biwabik Iron Formation to the south of Babbitt. A more discontinuous pattern occurs along a series of aeromagnetic-highs extending from the Bald Eagle Intrusion southwestward to Basset Lake which is also characterized by Fe, Mg, and Cu anomalies. In addition, a cluster of Pt anomalies occurs in the aeromagnetically complex Big Lake area. A close areal relationship is evident between the Pt and Pd anomalies even though the Pt-Pd correlation coefficient is only 0.37. A less pronounced Pt-Au spatial relationship is also evident although the correlation coefficient in this instance is only 0.15. Spatial distribution patterns of Palladium anomalies is similar to that of Pt with the exceptions that the anomalies do not extend into Biwabik Iron Formation or the Big Lake area. Instead a linear pattern occurs to the north of Big Lake extending southeastward toward Greenwood Lake. Gold anomalies also occur primarily along the Duluth Complex contact. A higher proportion of the anomalies occur in the northern part of the study area however. In addition, an E-W trending lineament occurs to the east of Babbitt.

Low-grade Cu-Ni mineralization occurs along the basal zone of the complex averaging 0.66% Cu with a Cu/Ni ration of 3.3:1. Plots of soil Cu reflect the known mineralization well with the exception of the Dunka Road deposit. A progressive decrease in anomaly intensity can be seen southwestward along the contact corresponding to the increase in overburden thickness.

Fourteen of the 21 DDH's with a combined PGE+AU>450 ppb Dahlberg 1987 and Dahlberg et. al. (1989) coincide with Pt, Pd or Au anomalies or anomaly combinations. The remaining 7 DDH's cluster to the north of an inferred E-W trending fault (Dahlberg, 1987) separating the South Kawishiwi and Partridge River intrusions. They may relate to combined Pt+Pd anomalies about 1.5 mi. to the southwest. Significant mineralization was noted in several cores from this area with >1 % Cu; 3.2' of >11,100 ppb Pd; 6' of 8,300 ppb Pt; 7' of 13,100 ppb Au; 10' of 34 ppm Ag (Severson and Barnes, 1991). Visible gold was reported in DDH D-13 in a shear zone at a depth of 34' (H. Dolence, personal communication).

PLATINUM, PALLADIUM AND GOLD DISTRIBUTION IN B-HORIZON SOILS IN THE NORTHWESTERN PART OF THE DULUTH COMPLEX

INTRODUCTION

The Duluth complex encompasses approximately 6500 km^2 of late to Upper Precambrian (1.1 Ga) anorthositic, troctolitic, gabbroic, granodioritic and granitic intrusive rocks (Phinney, 1972) in northeastern Minnesota. The study area of this report (Fig. 1) incorporates approximately 1798 km^2 in the northwestern part of the Duluth complex between latitude 47°20'00" - 47°55'00" and longitude 91°30'00" - 92°20'00" within St. Louis and Lake counties.

The climate in this part of the Duluth complex is markedly continental with annual precipitation ranging from 66 cm to 79 cm. About 40 percent of this occurs as snow. Average annual temperatures are in the 38-40° F. The topography is primarily bedrock controlled in the general 360 to 485 m range.

Pleistocene glacial materials mantle the area to a greatly varying depth. These are the parent materials of the sampled B-horizon soils.

The area is extensively forested with pines, spruce, fir, aspen, and birch.

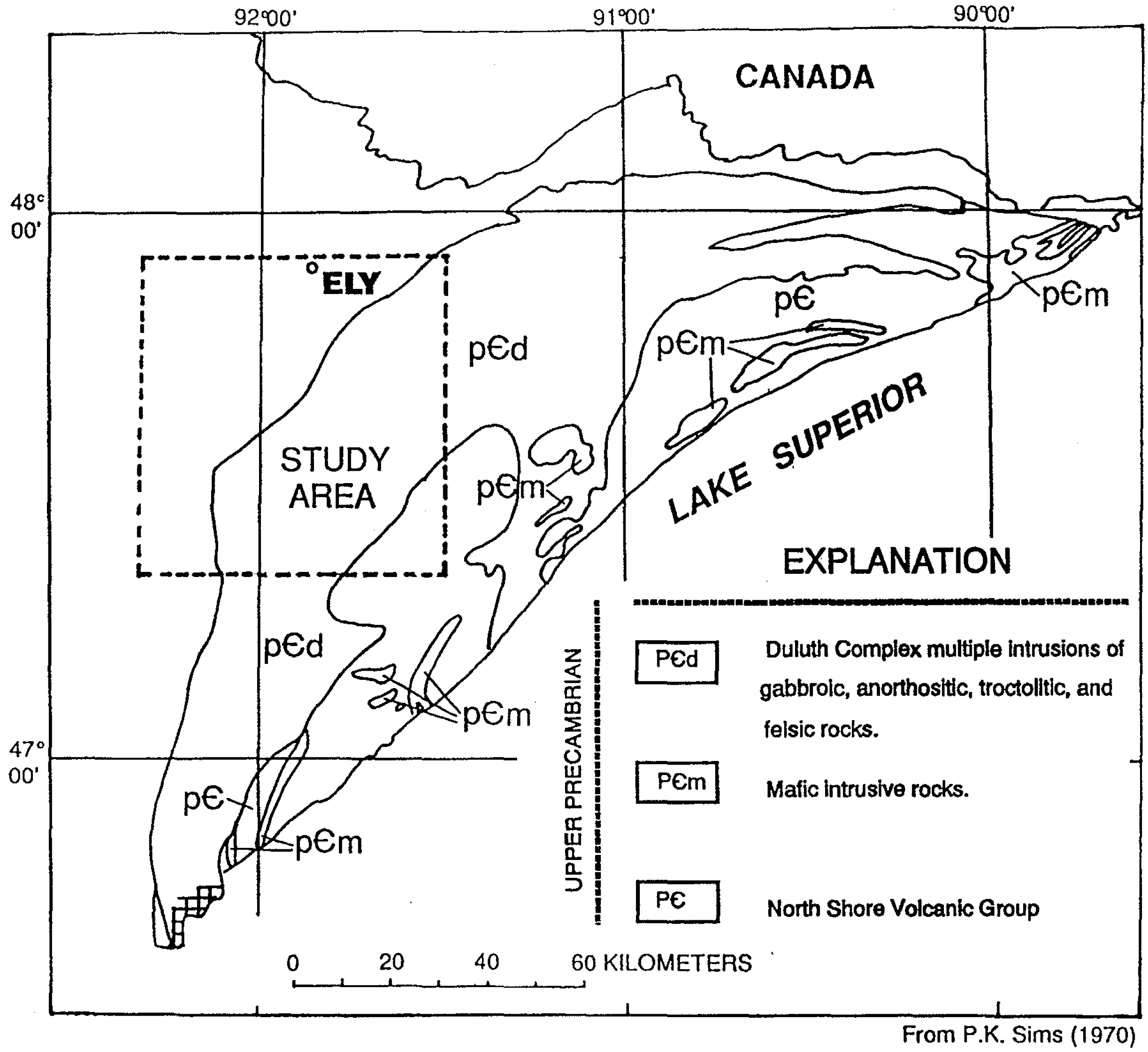

Figure 1. Index map of the study area in the northwestern part of the Duluth Complex, northeastern Minnesota.

GEOLOGY

The Duluth Complex encompasses approximately 6500 km^2 of late to Upper Precambrian anorthositic, troctolitic, gabbroic granodioritic and granitic intrusive rocks (Phinney, 1972). It is exposed sporadically along an arcuate belt extending from Duluth north toward Ely and then north-northeast toward Hovland, Minnesota (Sims, 1970), (Weiblen and Morey, 1975).

The complex is underlain to the north and west by older Archean granite-greenstone and middle Proterozoic metasediments The contact separating the older rocks from those of the Duluth Complex is generally sharp and well defined. Weiblen and Morey indicate that because of a shallow regional dip to the southeast an extensive section of Keweenawan rock is exposed between the basal contact and Lake Superior thus providing a unique opportunity for the study of a total magmatic system.

This system, however, is but a small part of a much larger terrain, the Midcontinent Gravity High, extending as a narrow linear belt as far south as southern Kansas. The name is derived from a large positive gravity signature. This structural feature is interpretable within a framework of pre-Keweenawan tectonics (Weiblen and others, 1972a) and Keweenawan rifting processes (Chase and Gelmer, 1973). The area studied for this report investigates all of the Hoyt Lakes - South Kawishiwi area and a

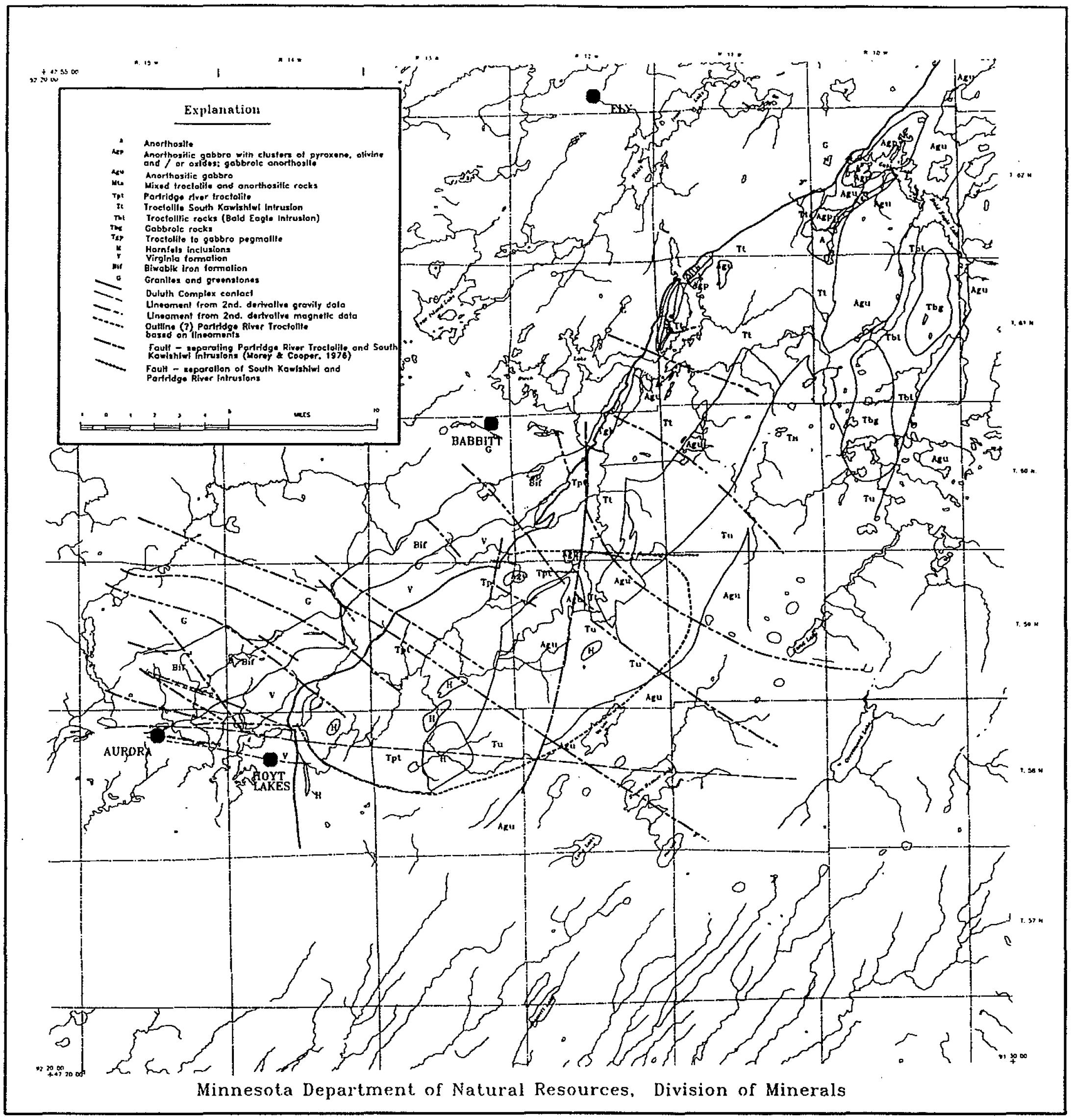

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Figure 2. Simplified geology of the northwestern part of the Duluth Complex, northeastern Minnesota.

small portion of the Boundary Water Canoe Area, as defined by Weiblen and Morey (1975) as well as some adjacent areas to the east.

Detailed mapping of a part of the Hoyt Lakes - Kawishiwi area was conducted by Green and others (1966) and associated petrographic studies by Phinney (1969) and Weiblen (1965).

This work has documented the presence of anorthositic - gabbroic rocks as well as several varieties of anorthositic rocks. These include poikilitic gabbroic anorthosite, norite anorthosite, and oxide-rick anorthosite (Phinney, 1969). The area is underlain predominantly by rocks of the troctolitic - gabbroic series belonging to one of four series: The Bald Eagle Intrusion, the South Kawishiwi Intrusion, a dike-like intrusion extending between Omaday and Gabbro Lakes, and the Partridge River Intrusion.

The Bald Eagle Intrusion is a funnel-shaped body, in the northeastern portion of the study area, consisting of two rock types. The central portion consists of and olivine gabbro which is rimmed by an outer zone of troctolite (Weiblen, 1965). This intrusion has well defined contacts and petrologic evidence indicates that flow, rather than gravity settling, was responsible for the development of layering present here.

The second unit belonging to the troctolitic-gabbroic series is the South Kawishiwi Intrusion. It occurs at the base of the Duluth Complex and is bounded to the north and west by older Precambrian rocks. In the east it either intrudes or is in fault contact with rocks of the Duluth Complex anorthositic series.

The South Kawishiwi Intrusion has been subdivided into three units on mineralogic and textural differences. These are, bottom to top, a contact zone, an augite-bearing troctolite and an upper troctolite unit.

Inclusions of anorthositic rocks, iron-formation and metasedimentary and basalt hornfels are relatively widespread in the South Kawishiwi intrusion. These inclusions are especially widespread in the contact zone. The contact zone is also characterized by extensive sulfide mineralization

The dike-like intrusion extending between Omaday and Gabbro Lakes is approximately 4 km long and 1 km wide and consists of an inner zone of pegmatitic gabbro and an outer zone of interlayered troctolite and olivine gabbro (Phinney, 1969).

In the south, the Partridge River Intrusion, consists of at least seven subhorizontal igneous units along its 24 km strike length (Hauck, 1994). Starting at the base of the Complex and working upward, Hauck describes the units as follows:

Unit 1. sulfide-bearing heterogeneous troctolites with variable sedimentary hornfels inclusions;

Unit 2. homogeneous troctolite with a persistent ultramafic base;

Unit 3. mottled-textured troctolites with distinctive olivene oikocrysts;

Units 4.-7. all consist of homogeneous troctolites with a basic ultramafic member

MINERALIZATION

Widespread sulfide and oxide mineralization occurs along the western margin of the Duluth Complex (Fig. 3). Hauck (1994) indicates that the copper-nickel sulfide resources here are estimated at 4.4 billion tons of 0.66% copper with a Cu:Ni ratio of 3.3 to 1. The sulfides occur primarily as disseminations in the basal units of the South Kawishiwi and Partridge River intrusions. The sulfide mineral assemblage predominantly consists of pyrrhotite, chalcopyrite, cubanite, and pentlandite.

The predominant oxide minerals are ilmenite and magnetite with smaller amounts of other spinels. Hauck et. al. have classified the oxide occurrences into three types:

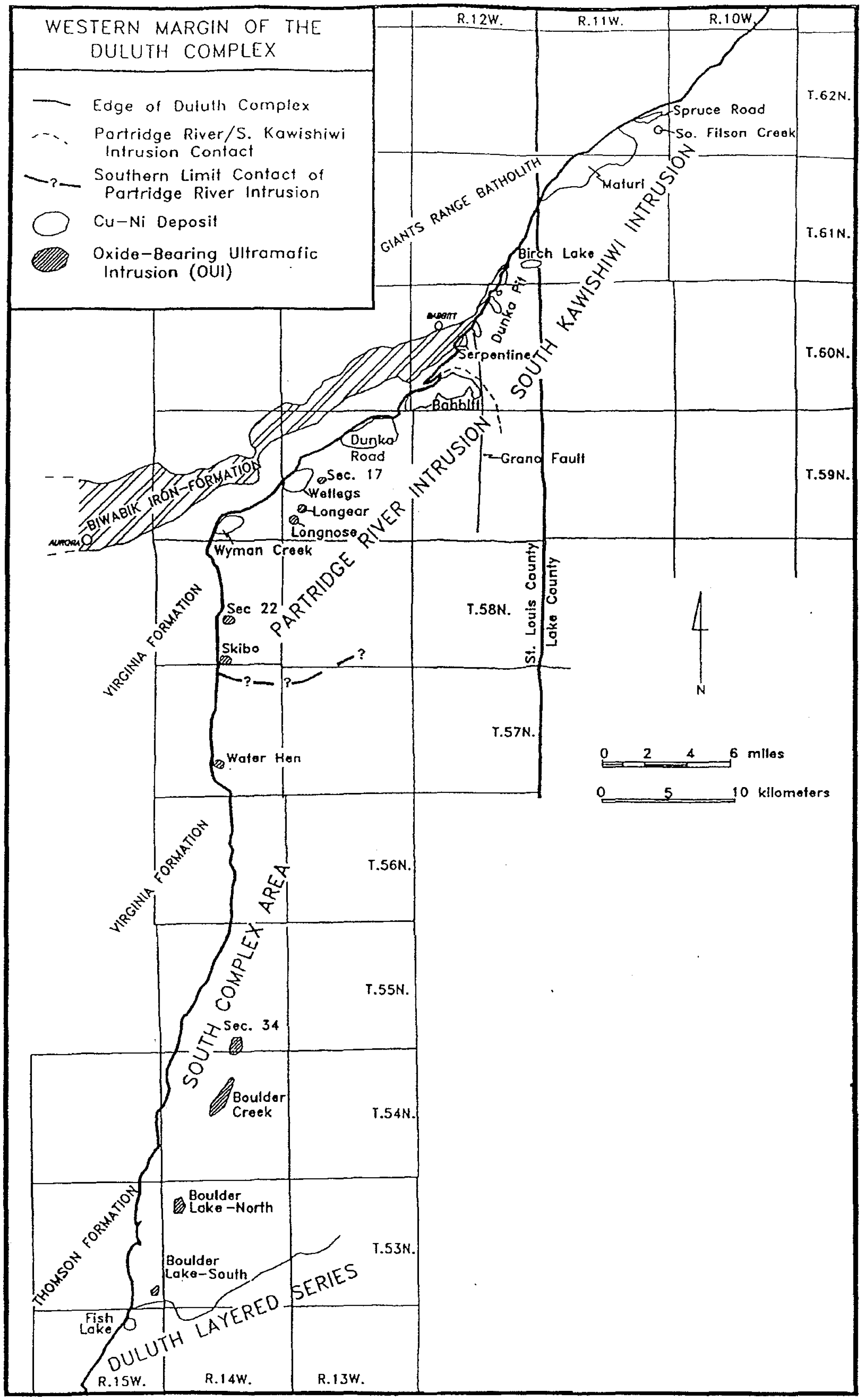
Type 1. banded or layered, oxide-rich metasedimentary inclusions in mafic and ultramafic rocks;

Type 2. banded or layered oxide segregations (cumulates) in mafic rocks;

Type 3. discordant oxide-bearing Ultramafic Intrusions with semi-massive oxide zones

Platinum group elements have been noted in several zones along the western contact of the Duluth Complex. Hauck (1994) defines these as:

1. stratabound zones with sulfides at Dunka Road;
2. structurally controlled zones within massive sulfide ore at the Babbitt deposit;
3. stratabound/structurally controlled oxide/sulfide zones at Birch Lake;



From: S.A. Hauck, 1994

Figure 3. Copper-nickel sulfide ore bodies and oxide-bearing ultramafic intrusions along the western margin of the Duluth Complex, northeastern Minnesota.

4. structurally controlled zones with sulfides at South Filson Creek;
5. a stratabound zone with semi-massive oxides at Fish Lake.

SAMPLE COLLECTION

B-horizon soil samples were collected at 1385 localities along roads, rivers and lakeshores (Fig. 4) by the USGS in the time period 1971 - 1975. These samples were collected at a depth of 30 to 45 cm. Although variable from site to site, these soils are generally fine to medium grained with a low to moderate organic content and range in color from yellow through red to light brown. Characteristically the B-horizon soils contain higher concentrations of Fe and Mn oxides than A-horizon soils, have a substantially lower organic content, and are coarser with a greater content of fragmental rock material.

SAMPLE PREPARATION

The soil samples were oven-dried overnight at 100°C in the original Kraft paper containers. Extremely clay-rich samples were disaggregated in a jaw crusher. All of the soils were then sieved through an 80-mesh (177-μm opening) sieve, and a 84-g (3-oz) container of the fine fraction was saved for analysis.

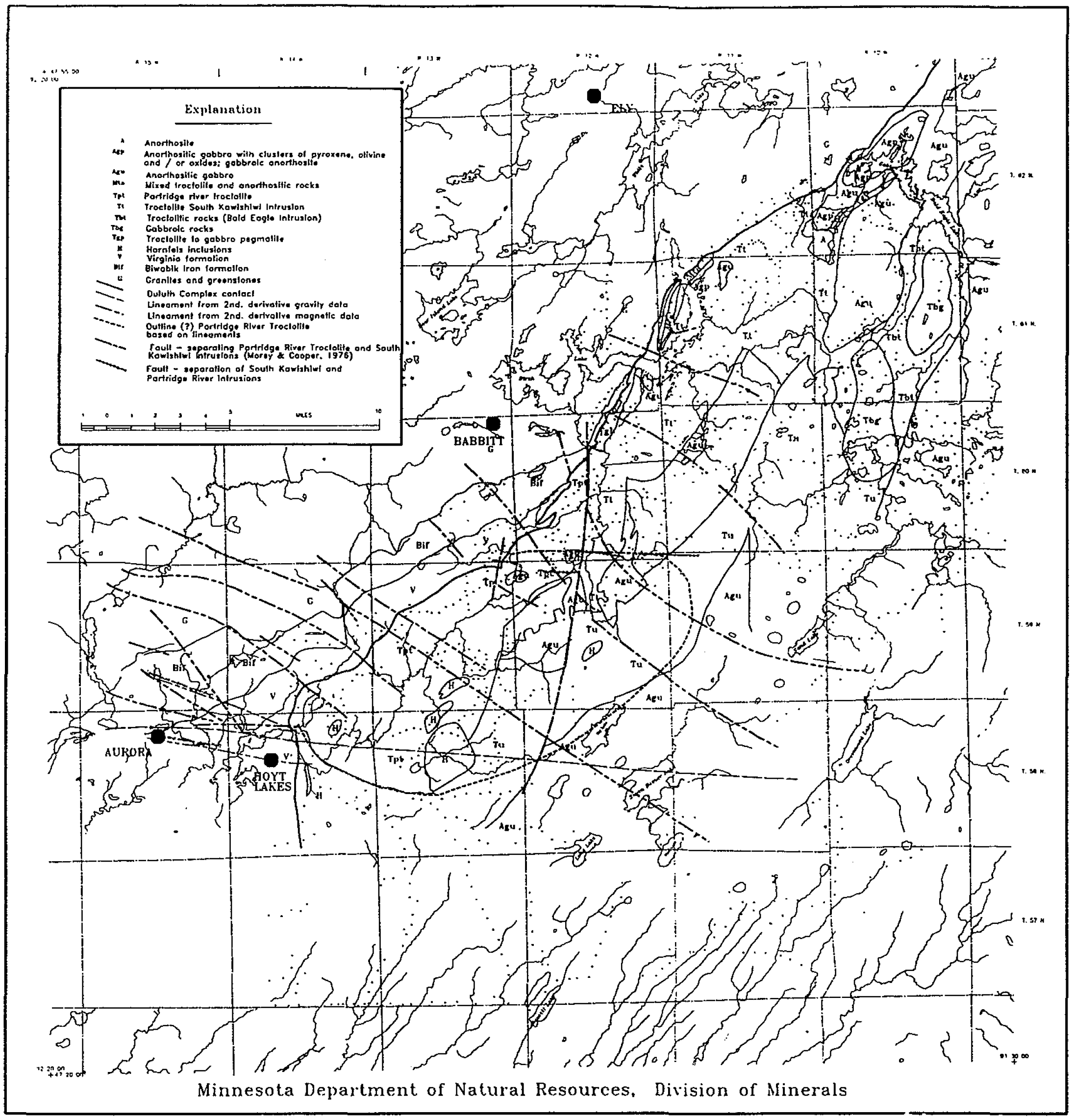


Figure 4. Plot of 1385 B-horizon soil sample sites in the northwestern part of the Duluth Complex, northeastern Minnesota.

ANALYTICAL TECHNIQUES

The Pt, Pd, and Au analyses were performed by the Bondar-Clegg & Company Ltd., Ontario, Canada under contract to the Minnesota Department of Natural Resources, Minerals Division.

The Pt, Pd, and Au were determined by a fire assay lead-collection direct current plasma atomic emission spectroscopic technique by the Bondar-Clegg & Company Ltd.. In this technique a 30 g sample is mixed with a lead oxide based flux in a fusion crucible. An 8 mg Ag inquart is added to the mixture. This mixture is fused at 1050° C for 45 minutes. The fusion melt liquid is poured into a cast iron mold and allowed to cool. The resulting lead "button" is separated from the glassy slag and heated at 800° C on a magnesium crucible. The lead is absorbed leaving a precious metal bead. This bead is digested in Aqua Regia (3:1 HCl:HNO) and the metal concentrations within the solution are determined by direct current plasma emission.

STATISTICS

Platinum concentrations in the 1385 B-horizon soils range from < 5 ppb to 75 ppb. Pt was detected, at a concentration of ≥5 ppb in 134 or 9.6% of the samples. A histogram of the platinum values is shown in Fig. 5A. Palladium concentrations in these soils range from < 1 ppb through 140 ppb. Pd was detected at a concentration of ≥3 ppb in 360 or 26% of the samples. A histogram of the palladium values is shown in Fig. 5B. Gold

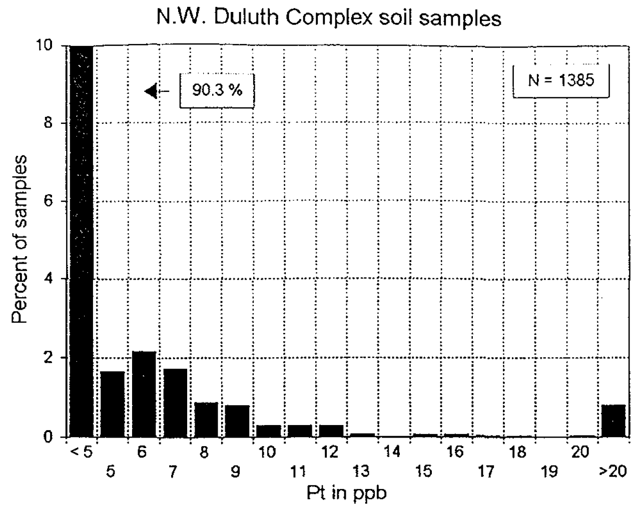


Figure 5A. Platinum content distribution in 1385 B-horizon soils

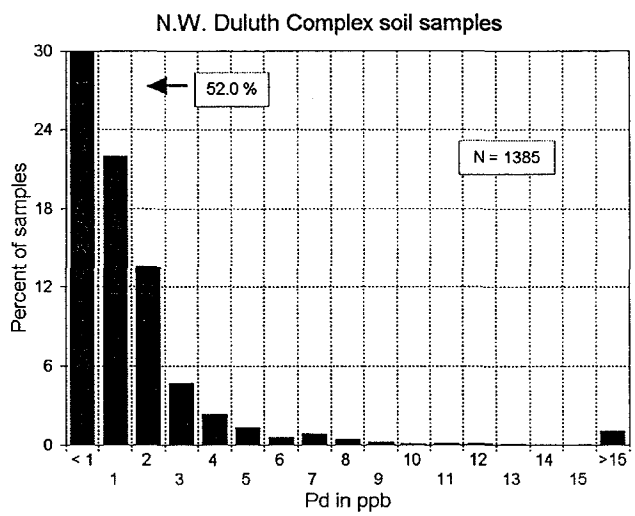


Figure 5B. Palladium content distribution in 1385 B-horizon soils.

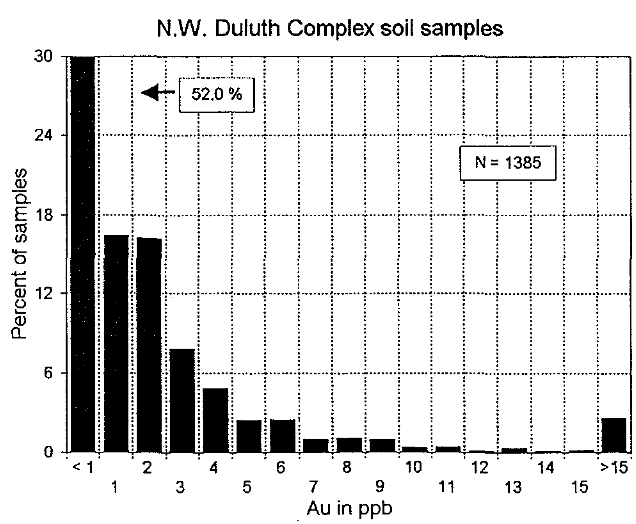


Figure 5C. Gold content distribution in 1385 B-horizon soils.

concentrations range from < 1 ppb through 156 ppb. It was detected at a level of ≥1 ppb in 568 or 41% of the samples. A histogram of the gold values is shown in Fig. 5C. Seven selected percentiles for Pt, Pd, and Au are shown in table 1 (below).

Table 1. Seven selected percentiles for Pt, Pd, and Au in 1385 B-horizon soils shown in ppm.

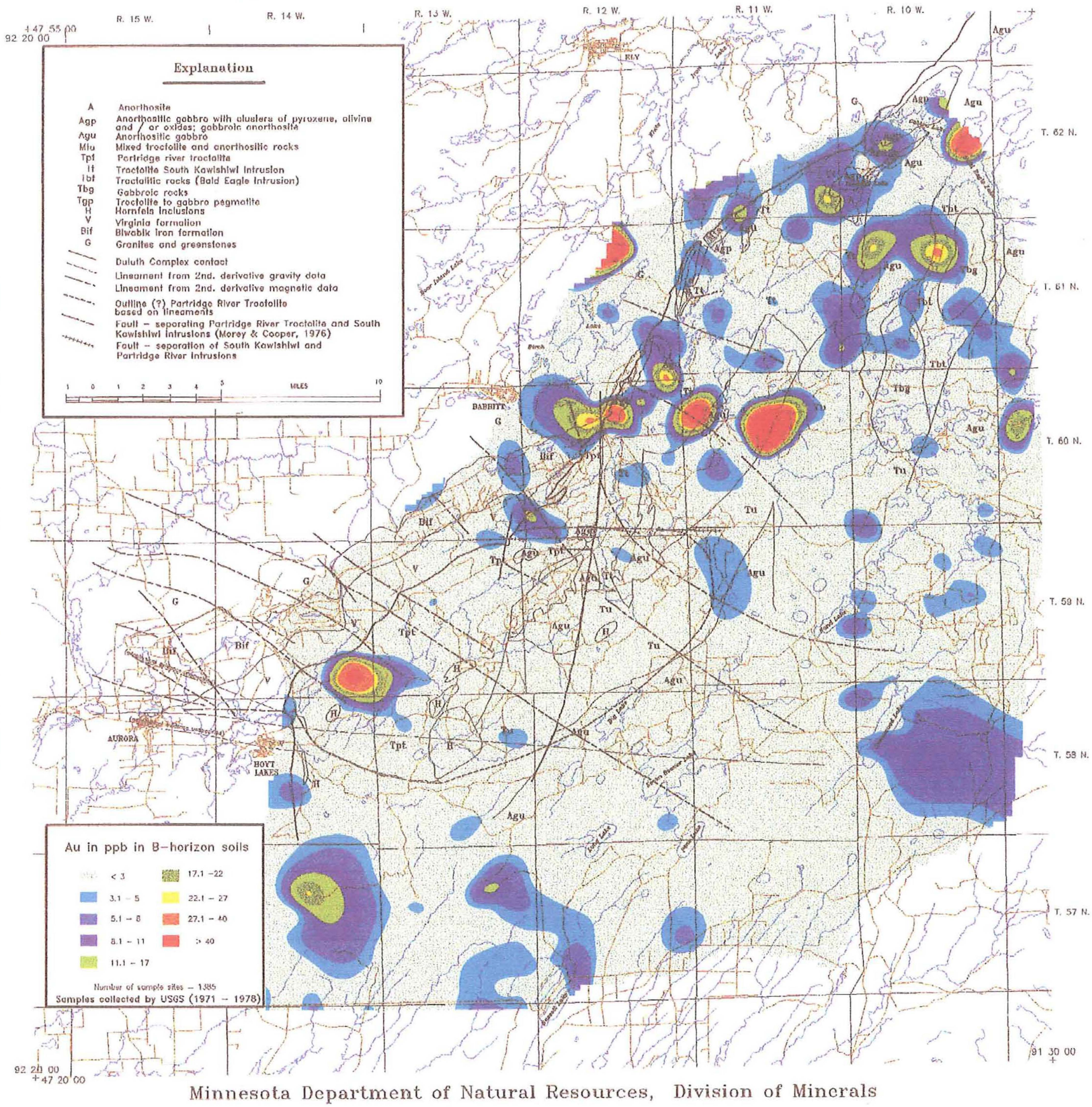
Element	No.	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Pt	1385	<5	<5	<5	<5	7.0	9.0	18.0
Pd	1385	<1	<1	2.0	3.0	5.0	8.0	16.0
Au	1385	<1	1.0	2.0	5.0	8.0	16.0	31.0

Correlations coefficients between the three analyzed elements are relatively low ranging from 0.15 to 0.37 (table 2). The respective scatter diagrams are shown in figures 6A through 6C.

Table 2. Correlation coefficients for Pt, Pd, and Au in 1385 B-horizon soils.

Element	Pt	Pd	Au
Pt	1.0	0.37	0.15
Pd	1385	1.0	0.24
Au	1385	1385	1.0

Gold in B-horizon soils – NW Duluth Complex



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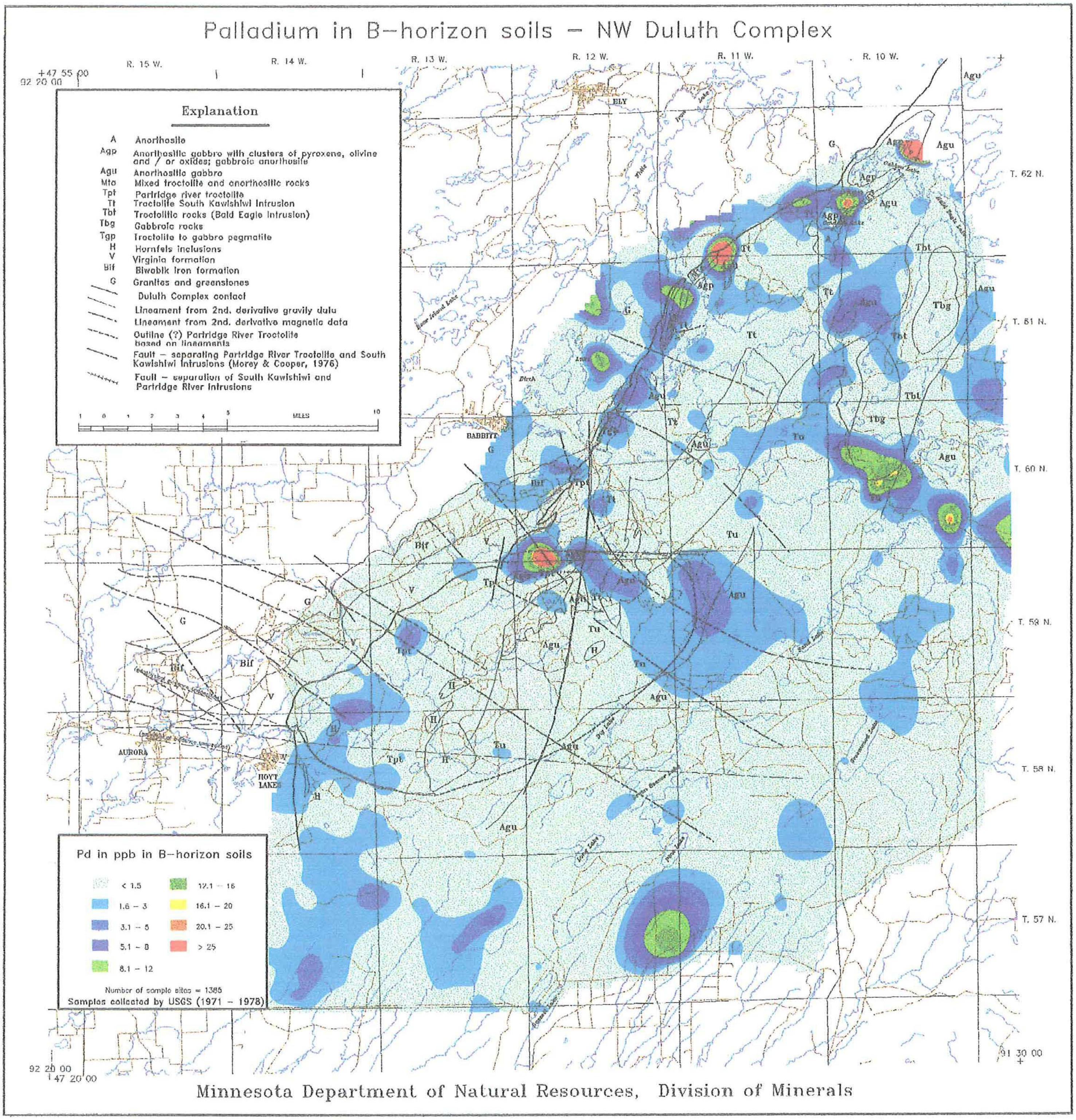
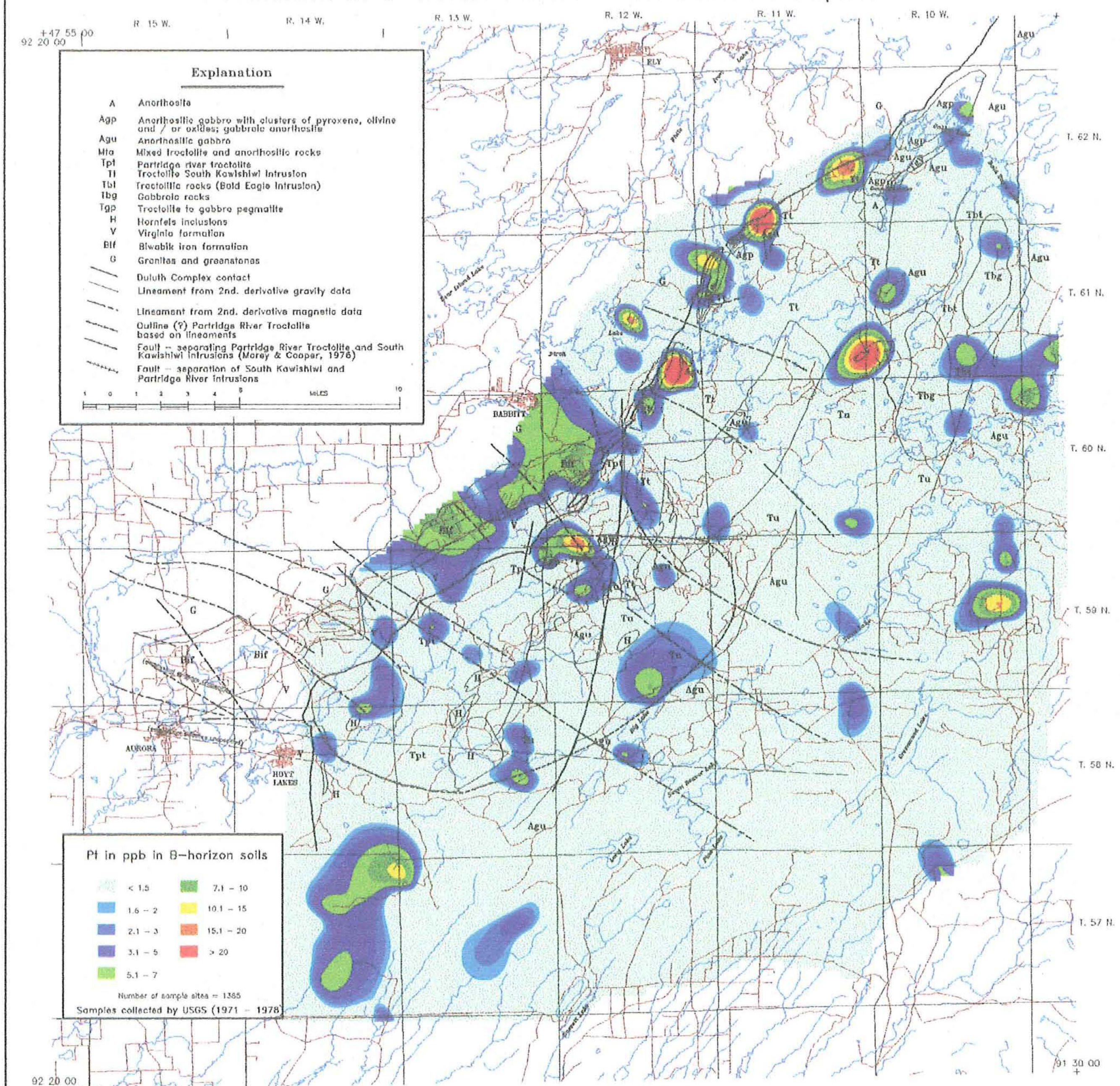

Palladium in B-horizon soils – NW Duluth Complex
R. 15 W.
R. 14 W.
R. 13 W.
R. 12 W.
R. 11 W.
R. 10 W.
T. 62 N.
T. 61 N.
T. 60 N.
T. 59 N.
T. 58 N.
T. 57 N.
Explanation
A Anorthosite
Agp Anorthositic gabbro with clusters of pyroxene, olivine and / or oxides; gabbroic anorthosite
Agu Anorthositic gabbro
Mta Mixed troctolite and anorthositic rocks
Tpt Partridge river troctolite
Tt Troctolite South Kawishiwi Intrusion
Tbt Troctolitic rocks (Bald Eagle Intrusion)
Tbg Gabbroic rocks
Tgp Troctolite to gabbro pegmatite
H Hornfels inclusions
V Virginia formation
Bif Biwabik Iron formation
G Granites and greenstones
Duluth Complex contact
Lineament from 2nd. derivative gravity data
Lineament from 2nd. derivative magnetic data
Outline (?) Partridge River Troctolite based on lineaments
Fault – separating Partridge River Troctolite and South Kawishiwi Intrusions (Morey & Cooper, 1976)
Fault – separation of South Kawishiwi and Partridge River Intrusions
MILES
ELY
BABBITT
AURORA
HOYT LAKES
Pd in ppb in B-horizon soils
< 1.5
1.6 – 3
3.1 – 5
5.1 – 8
8.1 – 12
12.1 – 16
16.1 – 20
20.1 – 25
> 25
Number of sample sites = 1385
Samples collected by USGS (1971 – 1978)
Minnesota Department of Natural Resources, Division of Minerals

Platinum in B–horizon soils – NW Duluth Complex



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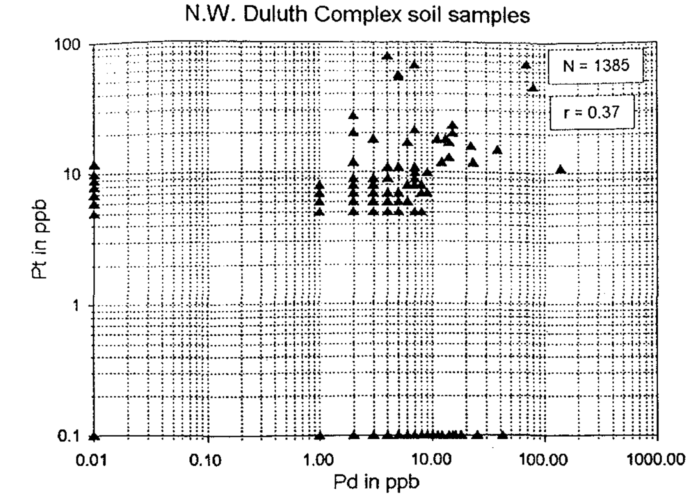

Figure 6A. Scatter diagram showing relationship between Pt and Pd in 1385 B-horizon soil samples

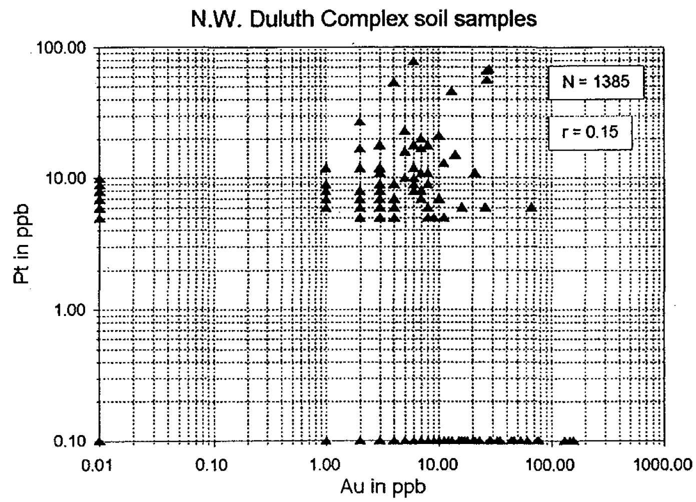

Figure 6B. Scatter diagrtam showing relationship between Pt and Au in 1385 B-horizon soil samples

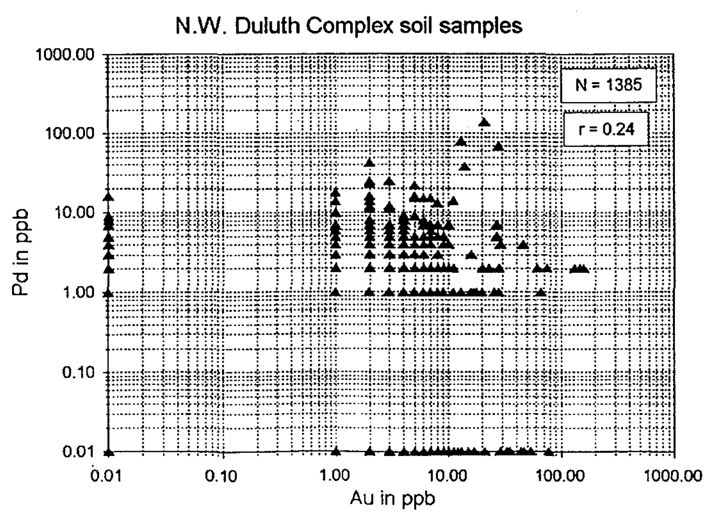

Figure 6C. Scatter diagram showing relationship between Pd and Au in 1385 B-horizon soil samples.

GRIDDING TECHNIQUE

In the Dynamic Graphics technique gridding is a two-step procedure. The first step calculates a Z value for each grid node. The original data are examined on an octant basis. Octants with data points near a grid node are not searched for distant data points nor are they searched to a great distance if two adjacent octants have data points close to a grid node. If no data points are close to a grid node, the gridding technique will search as far as needed to find data points. A grid node will not be estimated if it is beyond the gridding boundaries set by the user; in this case, the grid node will be set to the mean of the grid nodes directly across the boundary. Therefore, the gridding technique avoids estimating spuriously high or low grid nodes. After the data points are selected, they are averaged using a function dependent on inverse distance weighting and angular distribution.

The second step of the gridding technique re-estimates the grid nodes using a biharmonic cubic spline function. This function distributes the second derivative of curvature (or <u>tension</u>) among the grid nodes in order to minimize the sum of the squares of the second derivatives. Isopleth curvature is therefore distributed over the map surface rather than being concentrated around the data points. The spline is fitted to the grid nodes rather than to the data points. As each grid node is re-estimated, a new Z value is calculated for that node using the spline function with the X, Y, and Z values of neighboring nodes as input to the function.

Since the minimum tension technique tolerates the generation of a surface represented by grid nodes that could be drifiting away from the scattered Z values of the original data, a scattered data feedback routine follows each spline re-estimation of each grid node. If the feedback routine finds no scattered data points within one half of the grid cell spacing from a grid node during a 360° sweep, the Z value of the grid node will be the one estimated by the spline function. However, if one data point is within a half-cell distance of a grid node, the Z value at that data point as estimated in relation to the grid nodes is compared to the original Z value. The gridding technique stores the deviation between the original Z value and the gridded Z value from one interation to the next. If that deviation decreases, the Z value of the grid node just estimated remains unchanged. If the deviation increases, the grid node is given a Z value closer to that of the neighboring data point. This re-estimated (or corrected) grid node is one of the input points to the spline function upon re-estimation of a neighboring point. Therefor, corrections are distributed away from the corrected grid node to surrounding grid nodes not having scattered data points immediately neighboring. The gridding technique allows up to 15 data points within one half cell distance of a grid node to be used in the feedback routine. The feedback routine keeps the grid nodes closely related to neighboring data points while allowing the spline function to distribute tension in a rational manner (EarthVision v 1.2, Dynamic Graphics, Inc.).

ELEMENT DISTRIBUTION

Platinum

Platinum anomalies in soils occur primarily as a linear pattern along the Duluth Complex contact extending also into the Biwabik iron formation to the south of Babbitt. A more discontinuous pattern occurs along a pronounced series of aeromagnetic-highs extending from the Bald Eagle intrusion southwestward to Basset lake. In addition, a cluster of Pt anomalies occurs in the aeromagnetically complex Big lake area. A close areal relationship is evident between the platinum and palladium anomalies even though the Pt-Pd correlation coefficient is only 0.37. A platinum-gold spatial relationship is also evident although less pronounced and the Pt-Au correlation coefficient is only 0.15.

Palladium

Spatial distribution patterns of the Pd soil anomalies are similar to that of platinum. The main linear pattern occurs along the Duluth Complex contact. There is no Pd anomaly associated with the Biwabik iron formation however. A secondary linear pattern is associated with the aeromagnetic-high lineament extending from the Bald Eagle intrusion southwestward toward

Basset lake. There is no cluster of Pd anomalies in the Big lake area, as is the case with platinum. Instead, a linear pattern occurs to the north of Big lake extending southeastward toward Greenwood lake.

Gold

As is the case with Pt and Pd, gold anomalies tend to occur primarily along the Duluth Complex contact. A higher proportion of these anomalies, however, occur in the northern part of the study area. The secondary linear anomaly trend, seen in Pt and Pd, is also evident with respect to gold extending along the aeromagnetic-high lineament extending from Bald Eagle intrusion through Basset lake. There is no anomaly cluster in the Big lake area but an east-west lineament occurs to the east of Babbitt.

Bedrock Pd values > 11,100 ppb, Pt values up to 8,300 ppb and Au values up to 13,100 ppb were reported by Severson and Barnes (1991) from the Babbitt Cu/Ni deposits (S28-33, T60, R12). Elevated bedrock Pt, Pd and Au values were earlier reported from the same Birch Lake area (S25, T61, R12)

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