Precious- and Base-Metal Mineralization in the West-Central Vermilion District, Portions of St. Louis, Lake, and Cook Counties, Northeastern Minnesota

U.S. GEOLOGICAL SURVEY BULLETIN 1984

Field work done in cooperation with the Minnesota Geological Survey

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By HENRY V. ALMINAS, JOHN B. MCHUGH, and
E.C. PERRY, JR.

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Geochemical study of west-central Vermilion district indicates widespread precious- and base-metal mineralization; striking similarities exist with Archean lode gold deposits in Ontario

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Precious- and Base-Metal Mineralization in the West-Central Vermilion District, Portions of St. Louis, Lake, and Cook Counties, Northeastern Minnesota

By Henry V. Alminas, John B. McHugh, *and* E.C. Perry, Jr.[1]

Abstract

The west-central Vermilion district encompasses an irregularly shaped area of northeastern Minnesota, some 66 kilometers (41 miles) long and from 5 kilometers (3 miles) to 16 kilometers (10 miles) wide. It extends from Lake Vermilion in the west to Moose Lake in the northeast. The area sampled encompasses some 568 square kilometers (226 square miles) within St. Louis, Lake, and Cook Counties, Minnesota.

The sampled area is centered on the Archean greenstone belt of the Vermilion district. This belt consists predominantly of mafic metavolcanic and associated rocks that were intruded on both the north and south by major granitoid bodies. Adjacent to the granitoid bodies, the rocks are metamorphosed to the amphibolite facies; elsewhere they have mineral assemblages characteristic of greenschist-facies metamorphism. Approximately 90 percent of the Ely Greenstone rocks are of basaltic composition; the remainder consist of intermediate to felsic volcanic rocks, hypabyssal intrusive rocks, banded iron-formation, chert and metasedimentary rocks.

Pleistocene glacial materials consisting of till, outwash, and lacustrine deposits, associated with the Wisconsin episode of glaciation, cover the area. Soils developed from these glacial materials were sampled for this study, in cooperation with the Minnesota Geological Survey. These A-horizon soils were analyzed for 31 elements by spectrographic methods and for ppb-level gold by an atomic-absorption spectroscopic technique.

This study indicates the presence of two major areas within the west-central part of the Vermilion district that are mineralized with respect to precious and base metals. The more pronounced one is centered on Lake Vermilion, located at the west end of the study area. Here the gold contents of the soils are as high as 1.1 ppm and the gold is associated with Ag, Cu, Ti, Co, Pb, Zn, Cr, Ni, La, V, and Y. A pronounced zonation is evident: Pb, Zn, and Co occur in the northern part of the anomaly, Ag and the remainder of the base metals occur in the central part, and gold in the central and southern parts. Mineralization is restricted primarily to the felsic volcaniclastic units in this area. A pronounced anomalous aeromagnetic high, apparently related to that of the Lost Lake syenitic, granitic, and lamprophyric intrusive bodies immediately to the west of Lake Vermilion, shows a good spatial correlation with the mineralization. Minor outcrops of the intrusive rocks also occur immediately to the east of Lake Vermilion.

The second gold-bearing area is located in the east end of the study area between Fall and Jasper Lakes. Here the gold is associated with Cu, Ti, Mn, Ag, Co, Mo, Ni, Sc, Zn, and V. Zonation in this anomaly is less evident and the Ag association much less pronounced. This area is characterized by higher Pb, Zn, and Mo concentrations than that at Lake Vermilion. Lamprophyric and syenitic intrusives are present in the central part of this mineralized area, and essentially coextensive with it is a pronounced aeromagnetic anomaly.

The two geochemical anomalies indicate that widespread precious- and base-metal mineralization occurred in the Vermilion district. This mineralization appears to be related to the buried epizonal granite and syenite in the Lake Vermilion area as well as to lamprophyric rocks intruded into the Lake Vermilion Formation and Ely Greenstone during the Algoman orogeny. Northeast-trending faults also appear to be controlling factors in localizing the mineralization—especially in the eastern part of the greenstone belt.

These geochemical anomalies probably indicate the presence of near-surface gold-bearing disseminated and vein-type ore bodies. Striking similarities are evident between the geologic, structural, and geochemical features of the Vermilion district and comparable features described by A.C. Colvine and others relative to the Archean lode gold deposits in Ontario.

A Cr-Mg-Ni-Co anomaly centered on Little Long Lake is associated with the presence of mafic and ultramafic intrusives and is characterized by the presence of abundant sulfides. Some outcrop samples collected within the Little Long Lake area have platinum and palladium concentrations as high as 0.15 and 0.10 ppm respectively. This anomalous area is believed to hold some potential for the occurrence of economic concentrations of the platinum group elements.

INTRODUCTION

The west-central Vermilion district is in northeastern Minnesota, bounded by lat 47°45′00″–48°00′00″ N. and long 91°30′00″–92°22′30″ W. (fig. 1). It encompasses an

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irregularly shaped area some 66 km (41 mi) long and from 5 km (3 mi) to 16 km (10 mi) wide extending from Vermilion Lake in the west to Moose Lake in the northeast. The area sampled encompasses some 568 km^2 (226 mi^2) and is centered on the Archean greenstone belt within St. Louis, Lake, and Cook Counties. The general geology of this district has been described by Sims (1976).

The field work was done as a cooperative project between the U.S. Geological Survey and the Minnesota Geological Survey in the years 1970 and 1971. The analytical data were entered and stored in the U.S. Geological Survey's computer storage system (RASS) (VanTrump and Miesch, 1977). A table format listing of the data was published in 1981 (Grimes and Alminas, 1981) and 1989 (McHugh and others, 1990).

The climate in the Vermilion district is markedly continental: annual precipitation ranges from 66 cm (26 in.) to 79 cm (31 in.), and about 40 percent of the precipitation occurs as snow. Elevations in the area are in the 360 m (1,200 ft) to 485 m (1,600 ft) range, and the topography is bedrock controlled. The drainage system is youthful; dendritic and rectangular drainage patterns predominate. The vegetation is typical of the extreme southern part of the boreal forest within the downstream shield country of northeastern Minnesota. At this time, most of the tree cover is trembling aspen and jack pine.

Pleistocene glacial materials consisting of till, outwash, and lacustrine deposits, associated with the Wisconsin episode of glaciation, cover the area. These are the parent materials of the soils sampled in this study.

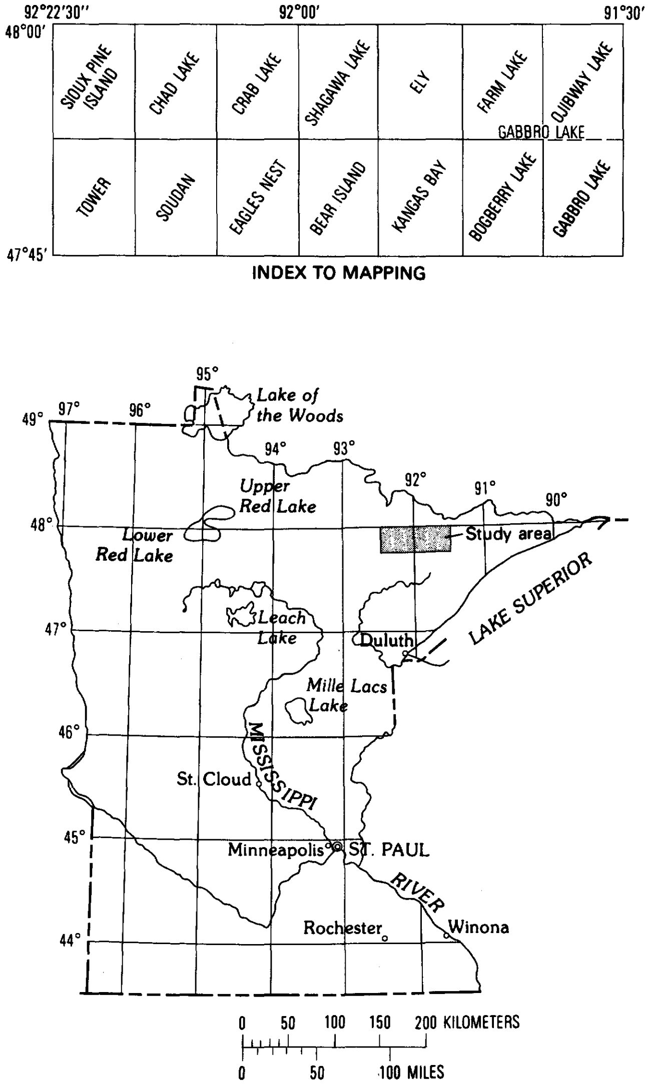


Figure 1. Index map of west-central Vermilion district, in northeastern Minnesota.

GEOLOGY

The sampled area is centered on the Archean greenstone belt of the Vermilion district (Sims, 1976). This belt is composed of mafic metavolcanic and associated rocks that are intruded on both north and south by major granitoid bodies. Except adjacent to a granitoid body, where the rocks are metamorphosed to the amphibolite facies, the rocks have mineral assemblages characteristic of greenschist-facies metamorphism.

Approximately 90 percent of the Ely Greenstone, the major rock unit in the area (Sims, 1985), consists of metabasalts. (Plates 1 and 2 of this report include a geologic base from Sims (1985) as well as names of local geographic features.) The remaining units comprise metamorphosed intermediate-felsic volcanic rocks, hypabyssal intrusive rocks, banded iron-formation, chert, and metasedimentary rocks.

The west end of the sampled area is predominantly underlain by rocks of the Lake Vermilion Formation, which conformably overlies the Ely Greenstone to the south and southwest of Tower, Minn. The Lake Vermilion Formation consists of a feldspathic quartzite member, a metagraywacke-slate member, a volcaniclastic member, and a mixed metagraywacke-felsic conglomerate member.

East of Shagawa Lake, some samples were collected from soils over the Knife Lake Group. Here the Knife Lake Group overlies the Ely Greenstone and is in turn overlain by the Newton Lake Formation. In this area, the Knife Lake Group consists mainly of gray to green slates, phyllites, and metagraywackes containing graded beds.

The Newton Lake Formation, the youngest important unit within the sampled area, occupies the area to the north of Shagawa and Fall Lakes. It consists dominantly of mafic, metavolcanic rocks and is divided into two informal members—a mafic metavolcanic member (to the west of Newton Lake) and a felsic volcanic member (to the east of Newton Lake).

The mafic metavolcanic member consists of pillow and massive metabasalt and meta-andesite flows, and fine- to medium-grained metadiabase (Sims, 1972). The metadiabase and metabasalt are associated with several small, differentiated sill-like bodies of mafic to ultramafic composition. The largest of these—some 3 mi long and 600 ft thick—occurs to the north of Ely, Minn., at Little Long Lake (Green, 1972).

The felsic volcanic member consists predominantly of felsic to intermediate metavolcanic rocks. Most of these rocks are pyroclastic deposits whose mineral and chemical compositions correspond to andesite and dacite (Green, 1972).

Small bodies of syenitic rocks, lamprophyres, and lesser granitic rocks are present in the Vermilion district—especially in the western part. Sims and Mudrey (1972) noted that the syenitic rocks form small, generally discordant plutons ranging in composition from diorite to syenite. These plutons intrude the Lake Vermilion Formation and the Ely Greenstone and are generally discordant on a large and small scale to structures in the wall rocks, indicating emplacement subsequent to or during the late stages of regional deformation. These intrusive rocks are characterized by positive magnetic anomalies. Sims and Mudrey (1972) further noted that the lamprophyres are spatially associated with the syenitic plutons.

The Vermilion fault separating the rocks of the Vermilion batholith from the Vermilion district is probably the major fault structure within the sampled area. Easterly and northeasterly trending high-angle faults, probable branches of the Vermilion fault, dominate the structural setting. A set of north-northeast-trending faults is nearly equally well developed.

This fault system has been defined by P.K. Sims as a classic example of a dextral transcurrent fault in an Archean terrane (Sims and others, 1987). He indicated that this fault system consists of anastomosing fault strands, each of which shows a dextral movement. The aggregate horizontal movement on this fault system is 17–19 km (10.5–11.8 mi) (Sims, 1976). The subsidiary complementary faults have sinistral movement, showing lateral offsets of as much as 7 km (4.3 mi). Sims has noted further that the faults of both sets are ductile shear zones characterized by mylonitization and locally by silicification.

Hudleston (Hudleston and others, 1988) indicated that the deformation in the Vermilion district can be characterized as one of transpression: oblique compression between two more rigid lithospheric blocks to the north and south.

SAMPLE COLLECTION

A-horizon soil samples were collected at 754 localities along roads, rivers, and lakeshores. Outcrop samples were collected at 91 of these localities within 6.7 m (22 ft) of soil sites and have the same latitude and longitude parameters as the corresponding soils.

The A-horizon soils were collected immediately below the turf at an average depth of 10 cm (4 in.). These soils are generally a fine, organic-rich material containing few rock fragments and ranging in color from black through brown to dark red.

Outcrop samples were collected as grab samples and generally incorporated substantial weathered surface 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, using a wide jaw setting. All the soils were then sieved through an 80-mesh (177-μm opening) sieve, and an 84-g (3-oz) container of the fine fraction was saved for analysis.

Outcrop samples were crushed in a jaw crusher and ground in a vertical grinder to approximately 150 μm (micrometers).

ANALYTICAL METHODS

Element concentrations in rock and soil samples were determined by a semiquantitative spectrographic method described by Grimes and Marranzino (1968). Results of these spectrographic analyses are reported within geometric intervals having the boundaries of 1,200, 830, 560, 380, 260, 120, and so on in parts per million, but are shown in the histogram illustrations by approximate geometric midpoints, such as 1,000, 700, 500, 300, 200, 150, and 100. Precision of a reported value is approximately plus or minus one interval at the 68-percent confidence level (Motooka and Grimes, 1976). Table 1 lists the elements analyzed for and the lower limits of detection for this technique.

Gold content of the soils was determined using an atomic-absorption spectroscopic method as follows: A 10-g sample is roasted for 1 hour at 700 °C; gold is then extracted

Table 1. Elements analyzed for and lower limits of detection of semiquantitative spectrographic analytical technique

[Fe, Mg, Ca, Ti in percent; rest in parts per million]

Fe (pct.)	0.05	Be	1.	Sb	100.
Mg (pct.)	0.02	Bi	10.	Sc	5.
Ca (pct.)	0.05	Cd	20.	Sn	10.
Ti (pct.)	0.002	Co	5.	Sr	100.
		Cr	10.	V	10.
Mn	10.	Cu	5.	W	50.
Ag	0.50	La	20.	Y	10.
As	200.	Mo	5.	Zn	200.
Au	10.	Nb	20.	Zr	10.
B	10.	Ni	5.	Th	100.
Ba	20.	Pb	10.		

with hydrobromic acid–0.5 percent bromine solution and MIBK (methyl isobutyl ketone). Electrothermal atomic-absorption spectroscopy, using background correction, is used to determine gold to 0.001 ppm (1 ppb) (O'Leary and Meier, 1986).

STATISTICAL DISTRIBUTION OF NINE SELECTED METALS

Statistical parameters of eight selected metals (Ag, Co, Cr, Cu, Mo, Ni, Pb, and Zn) were determined by spectrographic methods and one (Au) by atomic absorption spectroscopy. These metals were selected on the basis of their importance within the geochemical association characterizing mineralized materials within this district. For purposes of statistical calculations, the qualified values of these metals, and other elements associated with them, have been converted to numerical values. The L values were converted to a value equivalent to one reporting interval below the lowest reported value for each respective element. The N values were converted to a value equivalent to three reporting intervals below the lowest reported value for each respective element. Table 2 shows the conversions.

Table 2. A listing of elements and the respective conversions of N and L values for the purpose of statistical calculations

[No unqualified values occurred for As, Au, Bi, Cd, Sb, and Sn; and thus these data were eliminated. L, detected but below value shown; N, not detected at value shown]

Element	L value	N value
Ag	0.7	0.2
B	7.0	2.0
Be	.7	.2
Co	3.0	1.0
Cr	7.0	2.0
Cu	3.0	1.0
La	15.0	5.0
Mo	3.0	1.0
Nb	15.0	5.0
Pb	7.0	2.0
Sc	3.0	1.0
Sr	70.0	20.0
Y	7.0	2.0
Zn	150.0	50.0

Gold contents in the 754 Vermilion district A-horizon soil samples range from <1 ppb through 1,100 ppb. A histogram of the values (fig. 2) shows a strongly positively skewed population. The geometric mean is 1.4 and the geometric deviation is 3.5 (table 3). The gold contents at six selected percentiles are shown in table 4.

Table 3. Statistical parameters for Au, Ag, Co, Cr, Cu, Mo, Ni, Pb, and Zn in soils from west-central Vermilion district

[Au is in ppb; other elements in ppm]

Element	Minimum value	Maximum value	Geometric mean	Geometric deviation
Au	<1	1,100.	1.38	3.5
Ag	0.2	5.0	0.22	1.56
Co	1.0	50.0	8.95	1.82
Cr	5.5	3,000.0	101.69	2.24
Cu	3.0	300.0	23.22	2.09
Mo	1.0	50.0	1.06	1.42
Ni	5.0	1,000.0	33.87	1.96
Pb	1.0	300.0	13.51	2.05
Zn	50.0	1,000.0	58.80	1.66

Silver contents in the Vermilion district A-horizon soil samples range from <0.5 through 5 ppm. A histogram of the values (fig. 2) shows a strongly positively skewed distribution. The geometric mean is 0.2 and the geometric deviation is 1.6 (table 3). The silver contents at six selected percentiles are shown in table 4.

Copper contents in the 754 Vermilion district A-horizon soil samples range from <5 through 300 ppm. A histogram of the values (fig. 2) shows a bimodal distribution with modes at the 20 and 50 ppm classes. The geometric mean is 23.2 ppm and the geometric deviation is 2.1 (table 3). The copper contents at six selected percentiles are shown in table 4.

Molybdenum is not widespread in this area. Only 2.9 percent of the collected samples have concentrations equal to or greater than the sensitivity (5 ppm). Molybdenum

Table 4. Six selected percentiles for Au, Ag, Co, Cr, Cu, Mo, Ni, Pb, and Zn in soils from west-central Vermilion district

[Au is in ppb; other elements in ppm]

Element	Percentiles					
	50	75	85	90	95	99
Au	1.0	3.0	4.0	6.0	13.5	55.0
Ag	0.2	0.2	0.2	0.2	0.7	2.0
Co	10.0	10.0	15.0	15.0	20.0	40.0
Cr	100.0	150.0	150.0	200.0	500.0	1,500.0
Cu	20.0	50.0	50.0	70.0	70.0	150.0
Mo	1.0	1.0	1.0	1.0	1.0	7.0
Ni	30.0	50.0	70.0	70.0	100.0	175.0
Pb	15.0	20.0	20.0	20.0	30.0	70.0
Zn	50.0	50.0	50.0	150.0	200.0	500.0

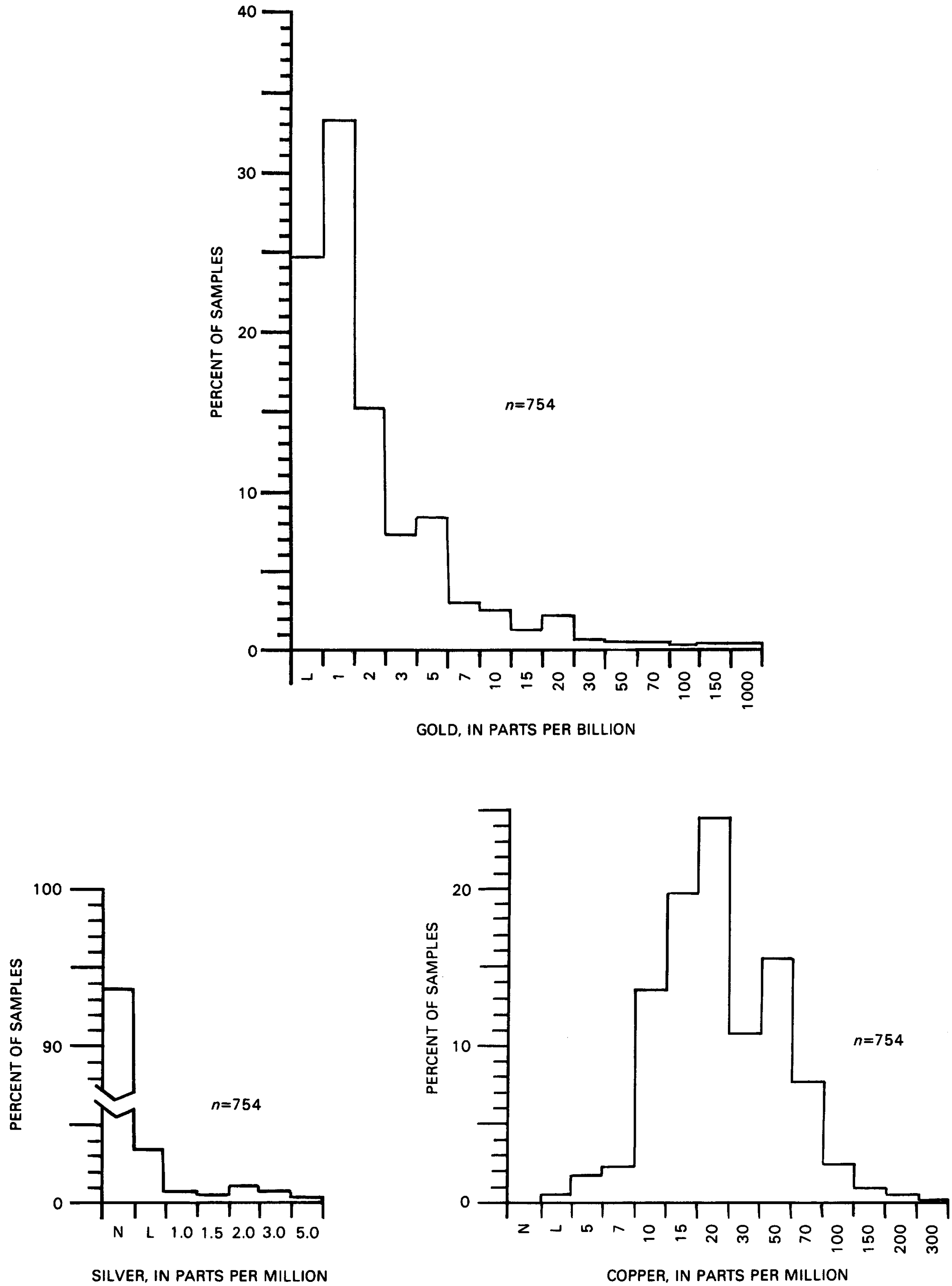


Figure 2 (above and following pages). Histograms showing frequency distribution of A-horizon soil metal contents in west-central Vermilion district. L, value less than lowest standard; N, metal not detected.

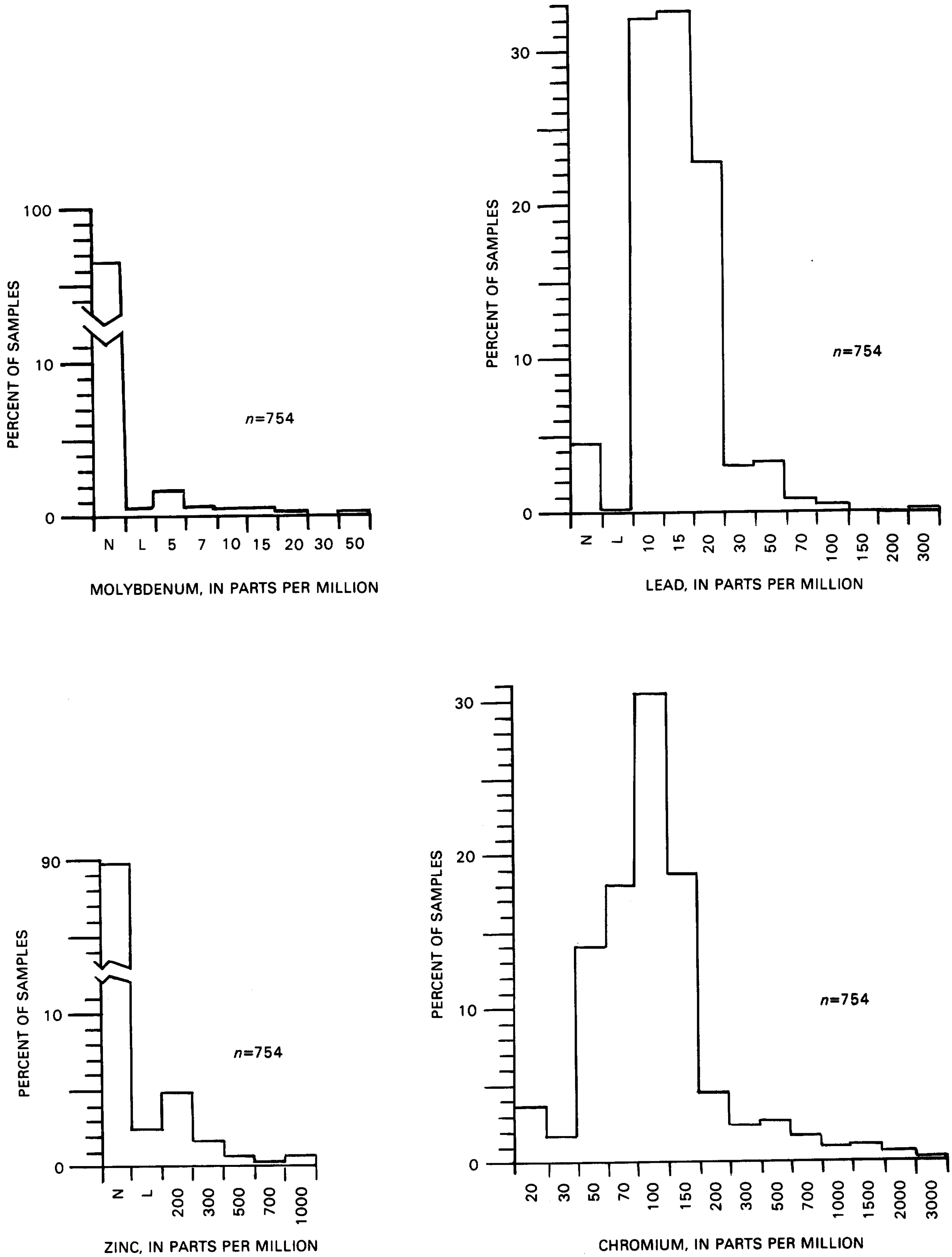
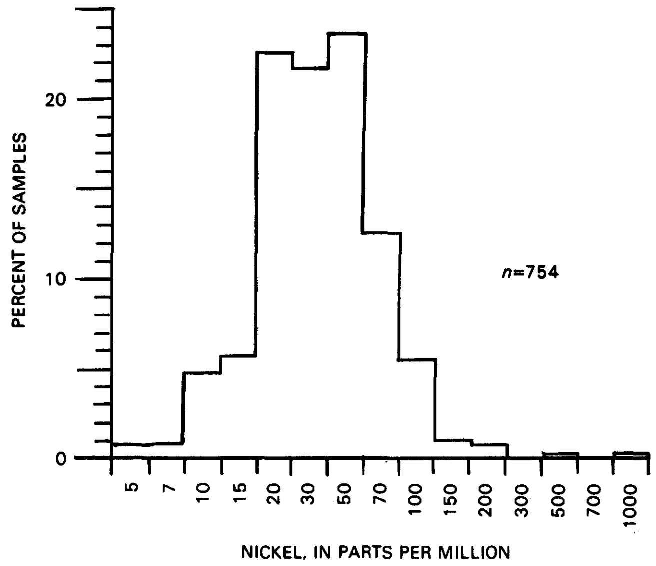
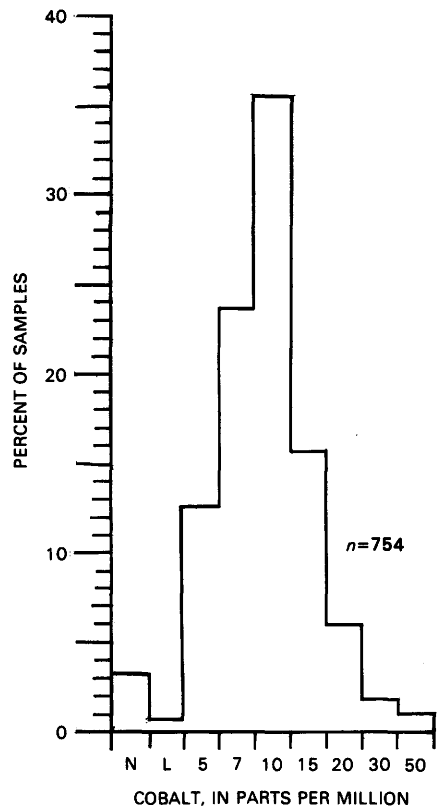


Figure 2 (above and facing page)—Continued. Histograms showing frequency distribution of A-horizon soil metal contents in west-central Vermilion district. L, value less than lowest standard; N, metal not detected.





concentrations range from <5 through 50 ppm. A histogram of the values (fig. 2) shows a strongly positively skewed distribution. The geometric mean is 1.0 and the geometric deviation is 1.06 (table 3). The molybdenum contents at six selected percentiles are shown in table 4.

Lead is detectable in most of the samples, but concentrations are generally low level, ranging from <5 to 300 ppm. A histogram of the values (fig. 2) shows a positively skewed quasi-normal distribution with the preponderance of values in the 20 through 50 ppm range. The geometric mean is 13.5 and the geometric deviation is 2.0 (table 3). The lead contents at six selected percentiles are shown in table 4.

Zinc is detected in these samples at sensitivity level (200 ppm) in only 8 percent of the samples. Zinc concentrations range from 200 through 1,000 ppm. A histogram of the values (fig. 2) shows a strongly positively skewed distribution with a slight mode at the 200 ppm class. The geometric mean is 58.8 and the geometric deviation is 1.7 (table 3). The zinc contents at six selected percentiles are shown in table 4.

Chromium is widespread in the area. Chromium was detected at a concentration ≥20 ppm in the soils from all the sample sites. The concentrations range from 20 through 3,000 ppm. A histogram of the values (fig. 2) shows a positively skewed quasi-normal distribution with most of the values occurring in the 50 through 150 ppm classes. The geometric mean is 101.7 and the geometric deviation is 2.2 (table 3). The chromium contents at six selected percentiles are shown in table 4.

Nickel, like chromium, was detected in every soil collected within the area at a concentration ≥5 ppm. The concentrations range from 5 through 1,000 ppm. A histogram of the values (fig. 2) shows an essentially normal distribution with the majority of the values occurring in the 20 through 50 ppm classes. The geometric mean is 33.9 and the geometric deviation is 2.0 (table 3). The nickel contents at six selected percentiles are shown in table 4.

Cobalt was detected in the soils at nearly all of the sample sites, but the concentration range (5–50 ppm) is very restricted relative to chromium and nickel. A histogram of the values shows an essentially normal distribution with the majority of the values in the 7–10 ppm classes (fig. 2). The geometric mean is 9.0 and the geometric deviation is 1.8 (table 3). The cobalt contents at six selected percentiles are shown in table 4.

NATURE OF SOIL GEOCHEMICAL PATTERNS

Soil geochemical patterns in the Vermilion district are in part residual and in part hydromorphic. Hydromorphic patterns are seen especially clearly in areas of bedrock sulfide occurrence. Here ground-water solution of metals is enhanced by oxidation of the sulfides. The pattern displacement occurs primarily as a result of lateral ground-water diffusion and is minor relative to the sample-site density.

Little evidence of glacial displacement can be seen in the geochemical patterns within the modern A-horizon soils in the Vermilion district. This is especially true for ore metals that are related to sulfides. Displaced sulfides were present at one time but have been oxidized, and the associated metals have been mainly transported out of the region by surficial water in solution.

Heavy-mineral concentrates derived from soil samples in the Vermilion district, collected within an area of intense copper mineralization, contained essentially no copper sulfides. Copper contents in the A-horizon soils here, as opposed to the derived heavy-mineral concentrates, were generally higher by a factor of 10 or greater.

Soil leaching is pronounced in this environment, as can be seen from a rough calculation of soil metal loss/gain, performed on 85 paired rock/soil samples collected throughout the Vermilion district:

Element	Percent of rock metal content present in soil
Fe	80.9
Mg	63.6
Mn	88.0
Cu	46.4
Co	25.1
Cr	88.7
Ni	37.7
Pb	270.0
Zn	89.9

Sulfide-related metal depletion within mineralized areas increases substantially over the cited figures. This loss is uneven from sample site to sample site and is dependent on a number of variables, including nearness to the water table, the topographic and geologic settings, and the presence of sulfides in the bedrock. This uneven retention of trace metals creates somewhat subdued and erratic data.

MODE OF CALCULATION

REM (relative element magnitude) program (VanTrump and Alminas, 1978) calculations are used in the following discussion. A brief description of the nature of these calculations follows:

REM program calculations are performed on an area basis rather than on an individual site basis. This means that all sample sites falling within an area defined by the user are included in these calculations.

These calculations are performed on the basis of two parameters for each of the elements within the selected elemental suite. The first of these, the intensity factor, is derived by dividing the mean of all anomalous values of a given element within the defined area by its respective threshold value:

$$\text{Intensity factor (I)} = \frac{\text{Mean of all anomalous values in cell (M)}}{\text{Cell threshold value (T)}}$$

The second, the area factor, is derived by dividing the number of sample locations within the defined area ("cell") that contain anomalous levels of this element by the total number of sample locations within this area:

$$\text{Area factor (A)} = \frac{\text{Number of anomalous sites within cell}}{\text{Total number of sample sites within cell}}$$

These two values are multiplied for each element, and the product is the individual element magnitude:

$$\text{Individual element magnitude (IEM)} = \text{I}\times\text{A}$$

All individual element magnitudes are summed, to give the total anomaly magnitude of the cell:

$$\text{Anomaly magnitude (AM)}=(\text{IEM})_1+(\text{IEM})_2+(\text{IEM})_x$$

In addition, each individual element magnitude is divided by the anomaly magnitude of the cell, and the quotient is expressed in percent. This is the relative element magnitude.

$$\text{Relative element magnitude (REM)}= \frac{(\text{IEM})}{(\text{AM})}\times 100$$

DISTRIBUTION OF METALS

Copper

Copper contents ≥70 parts per million in the Vermilion district A-horizon soils are considered anomalous. This estimate is based on the frequency distribution of the district's soil copper values as well as the soil copper values found over known copper-mineralized areas in other parts of northeastern Minnesota and the Upper Peninsula of Michigan. On this basis, anomalous copper contents are found in 88 of the 754 samples collected within the area or 11.7 percent of the total population. Most of these anomalous sites occur within two areas: that of the Lake Vermilion anomaly in the west and that of the eastern anomaly to the east of Fall Lake.

Thirty-nine (44.3 percent) of the anomalous sites are clustered in the Lake Vermilion area within a window delineated by lat 47°45′00″–47°53′24″ N. and long 92°06′00″–92°22′30″ W. (See pl. 1.) The anomalous sites within this window occur predominantly over the graywacke member (Alg) and the felsic volcaniclastic member (Alf) of the Lake Vermilion formation.

The copper content frequency distribution of the 224 sample sites falling within the window (fig. 3*A*) is similar to that of the population as a whole (fig. 2). Within this area Cu is associated with Ti, Ag, Co, La, V, and Y (fig. 4). The relative elemental standings (VanTrump and Alminas, 1978) within this association are as follows:

Element	REM value
Ag	23.0
La	21.7
Y	20.8
Ti	17.2
Co	10.6
V	6.7

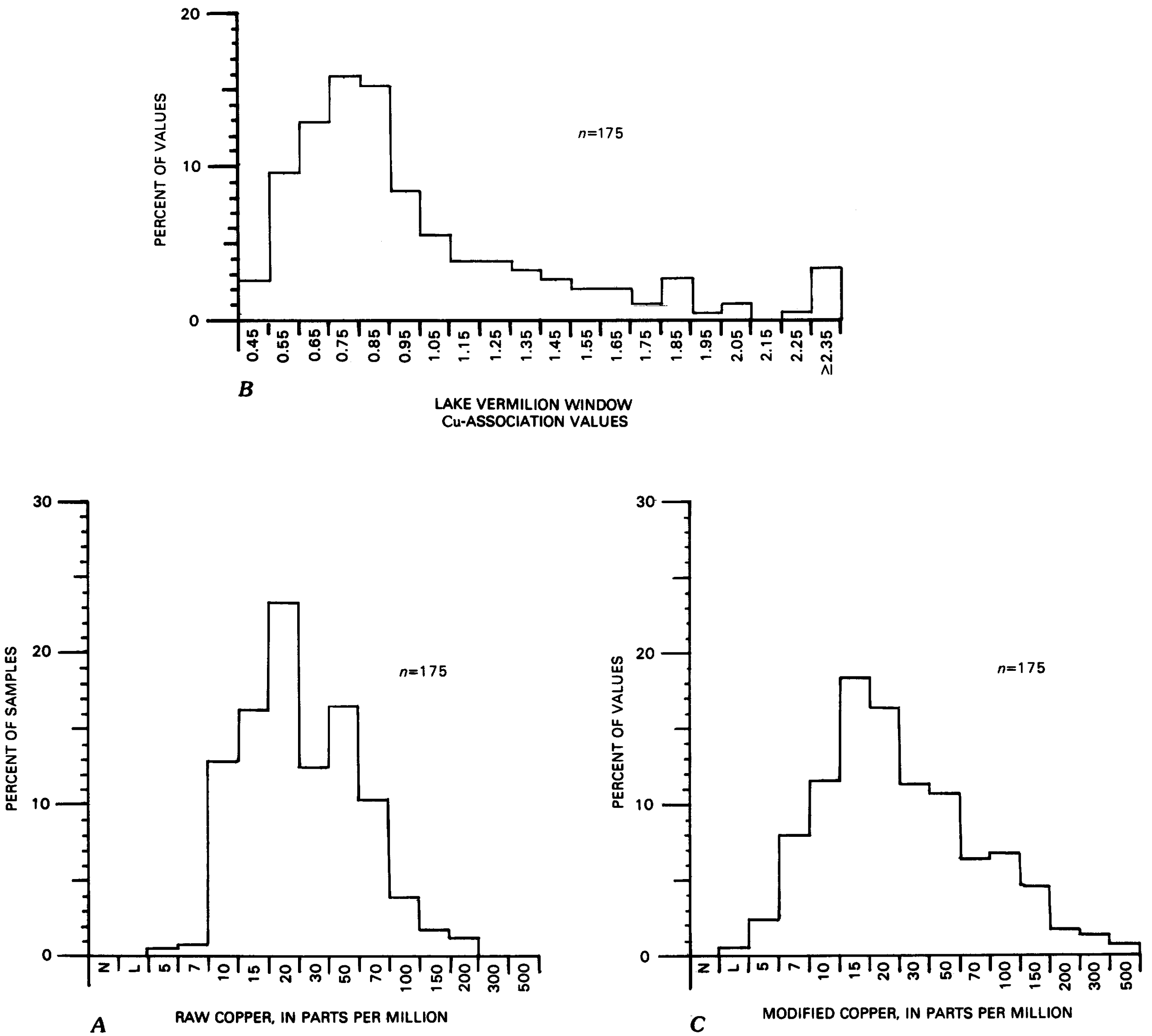


Figure 3. Histograms showing frequency distributions of *A*, raw copper values; *B*, copper association values; and *C*, modified copper values within the Lake Vermilion (western) window. L, value is less than the lowest standard; N, metal not detected.

Their respective correlation coefficients with Cu are as follows:

	Ti	Ag	Co	La	V	Y
Cu	0.19	0.36	0.22	0.16	0.19	0.30

The correlation coefficient between raw copper values and the association as a whole is r=0.40.

A combination of the above-listed copper-related elements was used as an aid in interpreting the copper content data, which were somewhat subdued and sporadic owing to high copper mobility within the weathering environment combined with the variability in sample-site settings. In this approach, the raw copper values are modified by a multiplier representing the degree of association present at each given sample site:

Modified Cu (ppm)=Raw Cu (ppm)×Cu association

This value is formulated in such a manner that the absence of the associated elements at a site will give a value <1, the presence of the association at the site at a preset level will give a value of 1, and the presence substantially above the preset level will give a value >1. As a result, the modified Cu values will be decreased if the association value is <1, remain the same if the value is 1, and be increased if the value is >1. Frequency distributions of modified Cu values as opposed to raw values (for the window area) are shown in figure 3. The degree of Cu value modification can be seen in

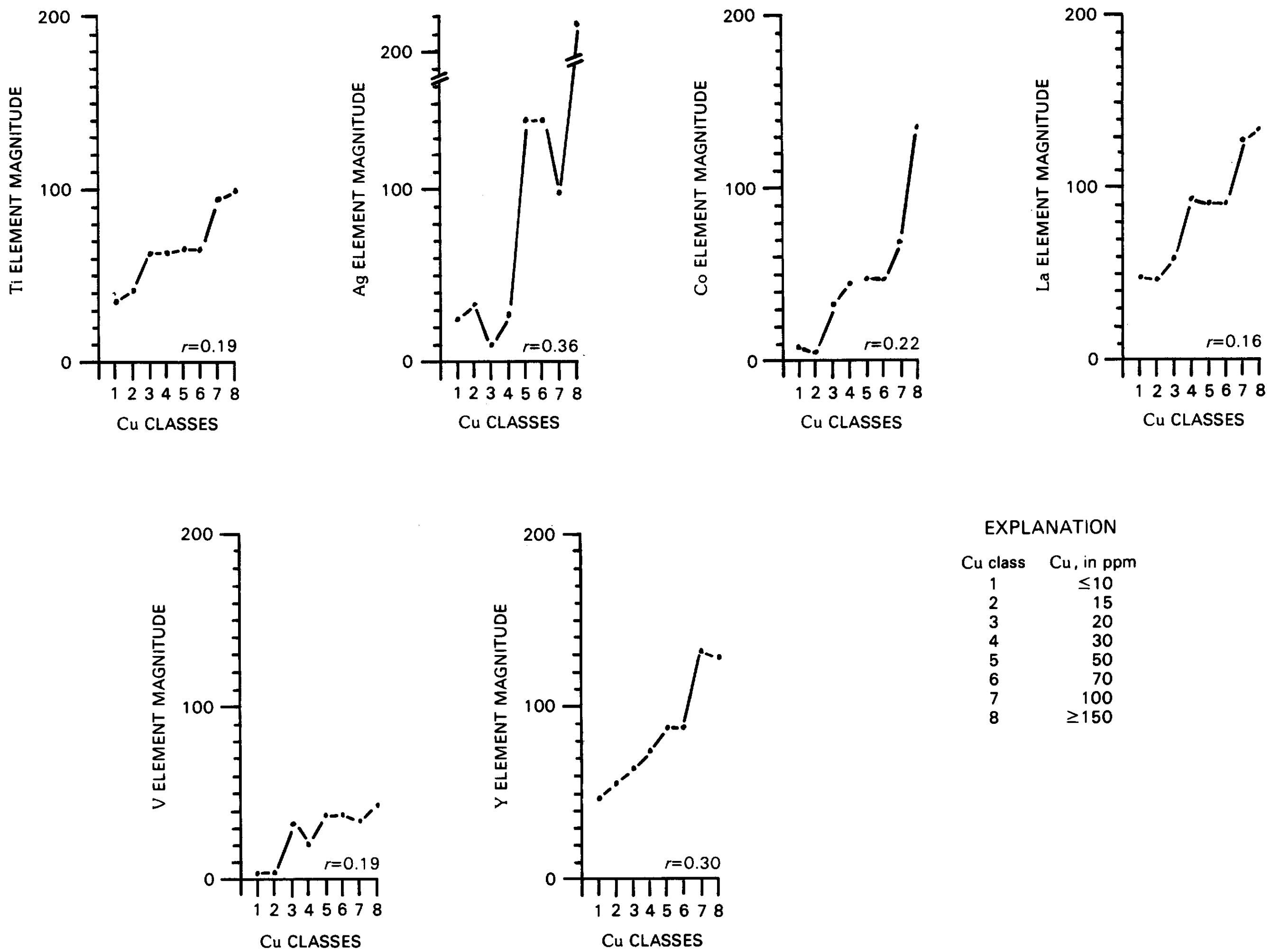


Figure 4. Graphs showing degree of copper association with Ti, Ag, Co, La, V, and Y within the Lake Vermilion (western) window. Association is shown on basis of copper content classes (1-8) relative to element magnitude values (Van Trump and Alminas, 1978). The number "r=x.xx" indicates correlation coefficient between raw copper values and those of each respective element.

the scatter diagram shown in figure 5, where the modified copper values are plotted against raw copper values in percent of the raw Cu value classes. Here, it can be seen that of the modified copper values, most are increased in the raw copper classes of 50 and above and decreased in the classes of 30 and below. The correlation coefficient between the modified and raw Cu values is r=0.89.

In the geographic sense, the modified copper values fill in and extend anomalies that are sporadic on the basis of raw copper values and delineate some areas that do not appear on the raw value plot. A symbol plot of the Lake Vermilion window Cu-association factor is shown in figure 6, that of Cu values modified on the basis of this association is shown in figure 7, and a raw copper plot appears as figure 8. The modified copper contours shown on plate 1 were based on the Lake Vermilion Cu-association from long 91°52′30″ to 92°22′30″ W.

In the eastern portion of the map area, the sample sites with anomalous copper contents can be characterized by a window defined by lat 47°55′12″–47°58′12″ N. and long 91°30′00″–91°47′24″ W. (See pl. 1.) The copper at these sites is associated with a broader range of elements, including Fe, Ti, Mn, Ag, Co, Mo, Ni, Sc, V, and Zn (fig. 9) and has an inverse relationship with Sr.

The copper content frequency distribution of the 137 sites falling within this window (fig. 10A) is quite similar to that of the population as a whole (fig. 2). The relative elemental standings within this association are as follows:

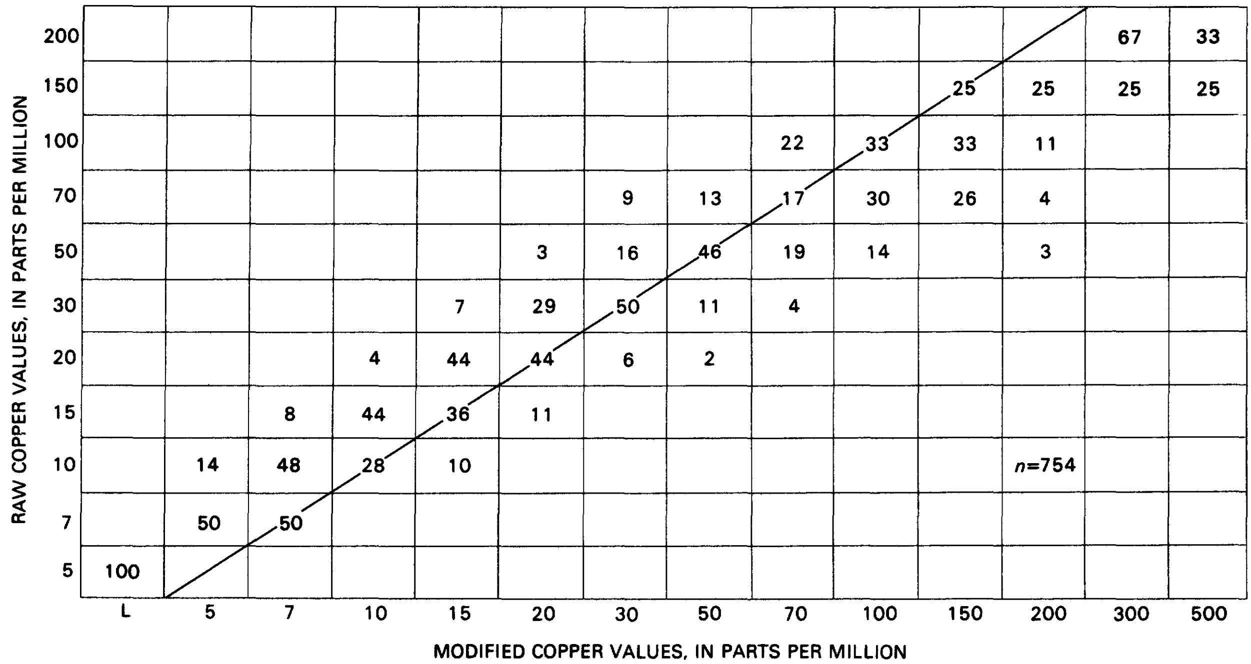


Figure 5. Scatter diagram showing kind and degree of copper value modification resulting from multiplication of raw copper values by the Lake Vermilion window Cu-association factor. Numbers indicate percent of samples within each raw copper content class.

Element	REM value
Fe	15.5
Ti	14.3
Zn	11.8
Sc	11.5
Ni	10.7
V	9.3
Mn	9.1
Mo	7.1
Co	6.2
Ag	4.4

Their respective correlation coefficients with Cu are as follows:

	Fe	Ti	Mn	Ag	Co	Mo	Ni	Sc	V	Zn
Cu	0.31	0.16	0.35	0.15	0.46	0.17	0.35	0.25	0.33	0.29

The correlation between the raw copper values and the association as a whole is r=0.41.

A modification of the eastern window copper values in a manner identical to that described in the preceding paragraphs but using the eastern association factor produces a modified copper content frequency distribution as shown in figure 10*C*. For comparison, a frequency distribution of the raw eastern window copper contents is shown in figure 10*A*. The kind and extent of raw copper content modification are shown in the scatter diagram in figure 11 and a plot of the eastern window copper-association values is shown in figure 12. The modified copper values progressively increase relative to the raw copper values in the raw copper classes above 30 ppm. The correlation coefficient between the modified and raw copper values is r=0.87. The areal distribution of these modified values is shown by a symbol plot in figure 13. The modified copper contours shown on plate 1 were based on the eastern copper association from long 91°30′00″ to 91°52′30″ W.

A comparison of figures 7 and 13 shows that the western association and the eastern association modified copper values delineate much the same areas within the Vermilion district. This co-incidence is believed to indicate that the anomalous copper concentrations in both parts of the map area result from a similar type of mineralization. The more intense and continuous nature of the copper anomaly in the western area and its more restricted association are believed to indicate that this mineralization occurred closer to the present erosional surface than that in the east. The elemental range of the association in the east is broader, but the copper

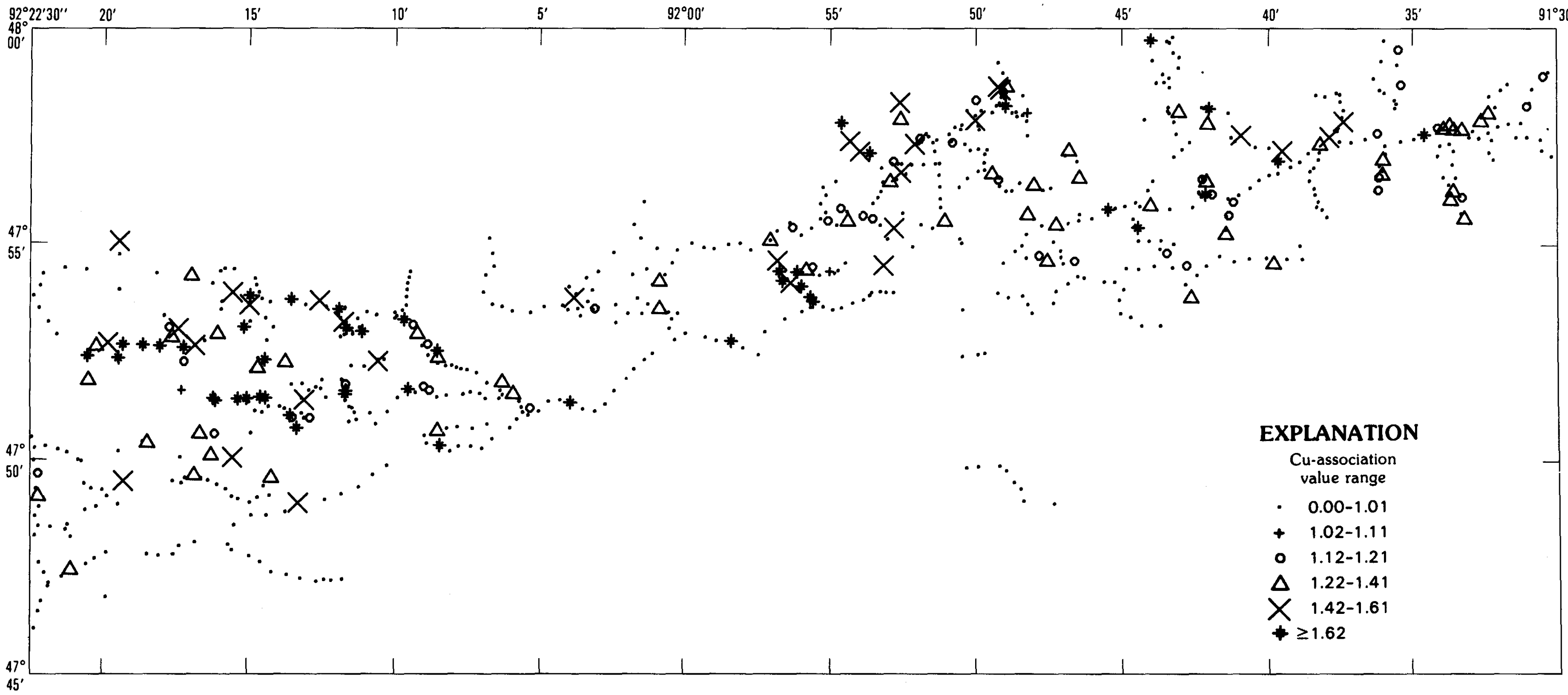


Figure 6. Plot of Lake Vermilion window Cu-association values. In that values are recalculated, they are without units.

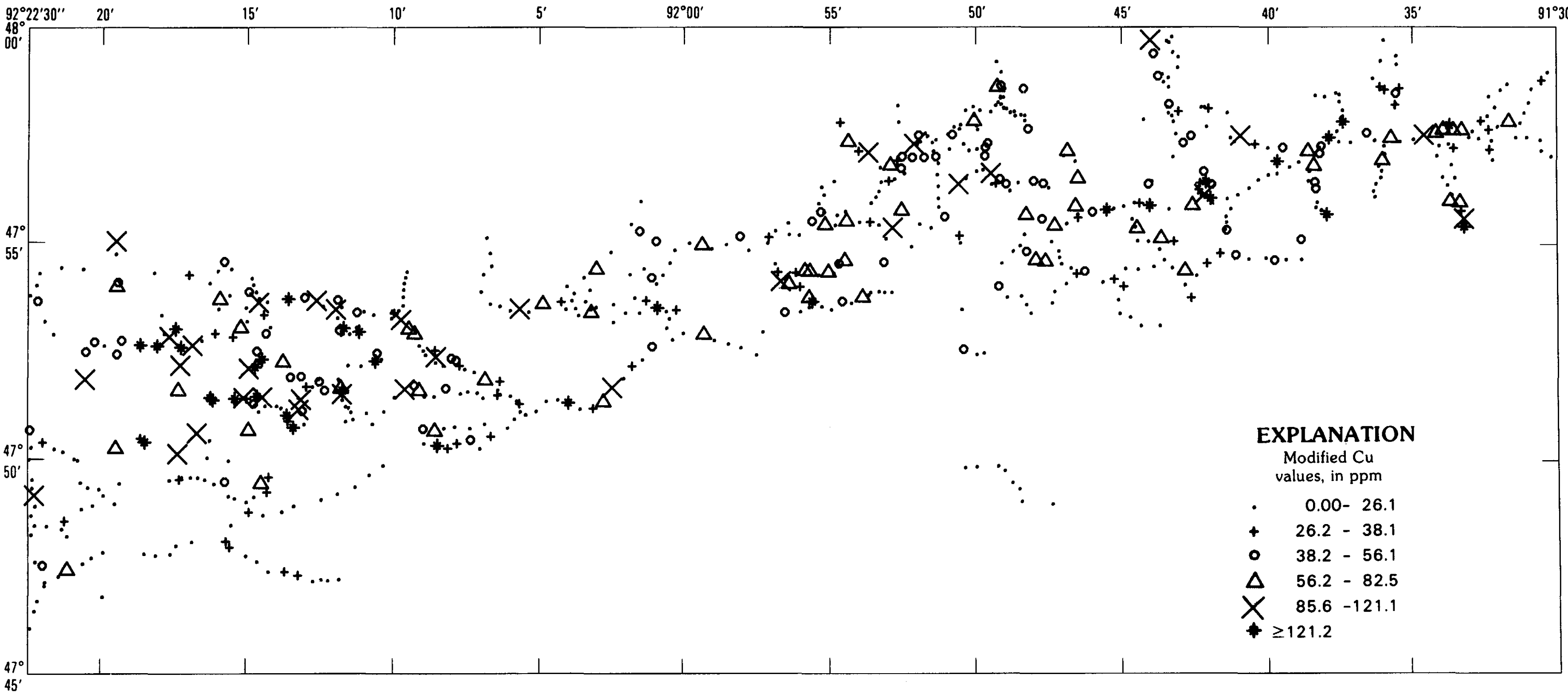


Figure 7. Plot of modified copper contents of A-horizon soils from west-central Vermilion district, northeastern Minnesota. Values are modified by the Lake Vermilion window Cu-association.

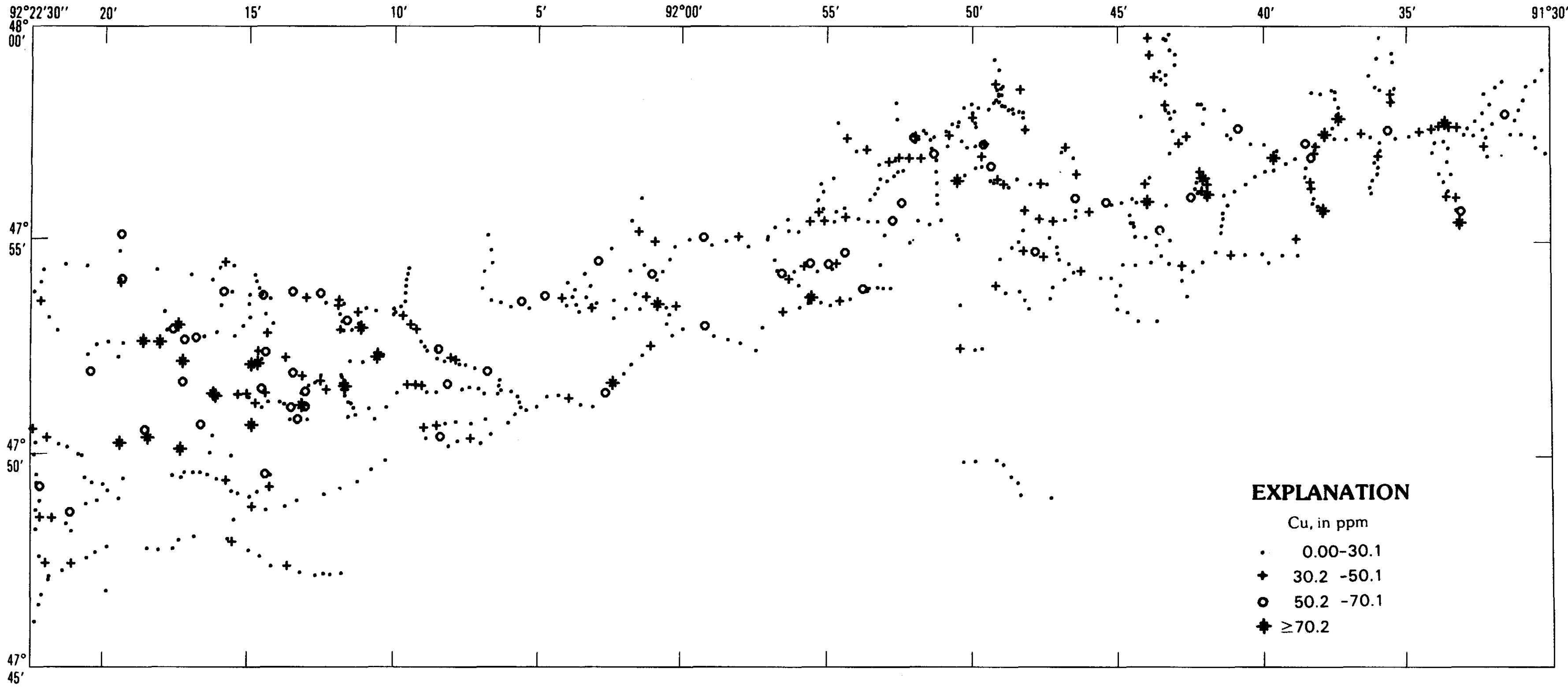
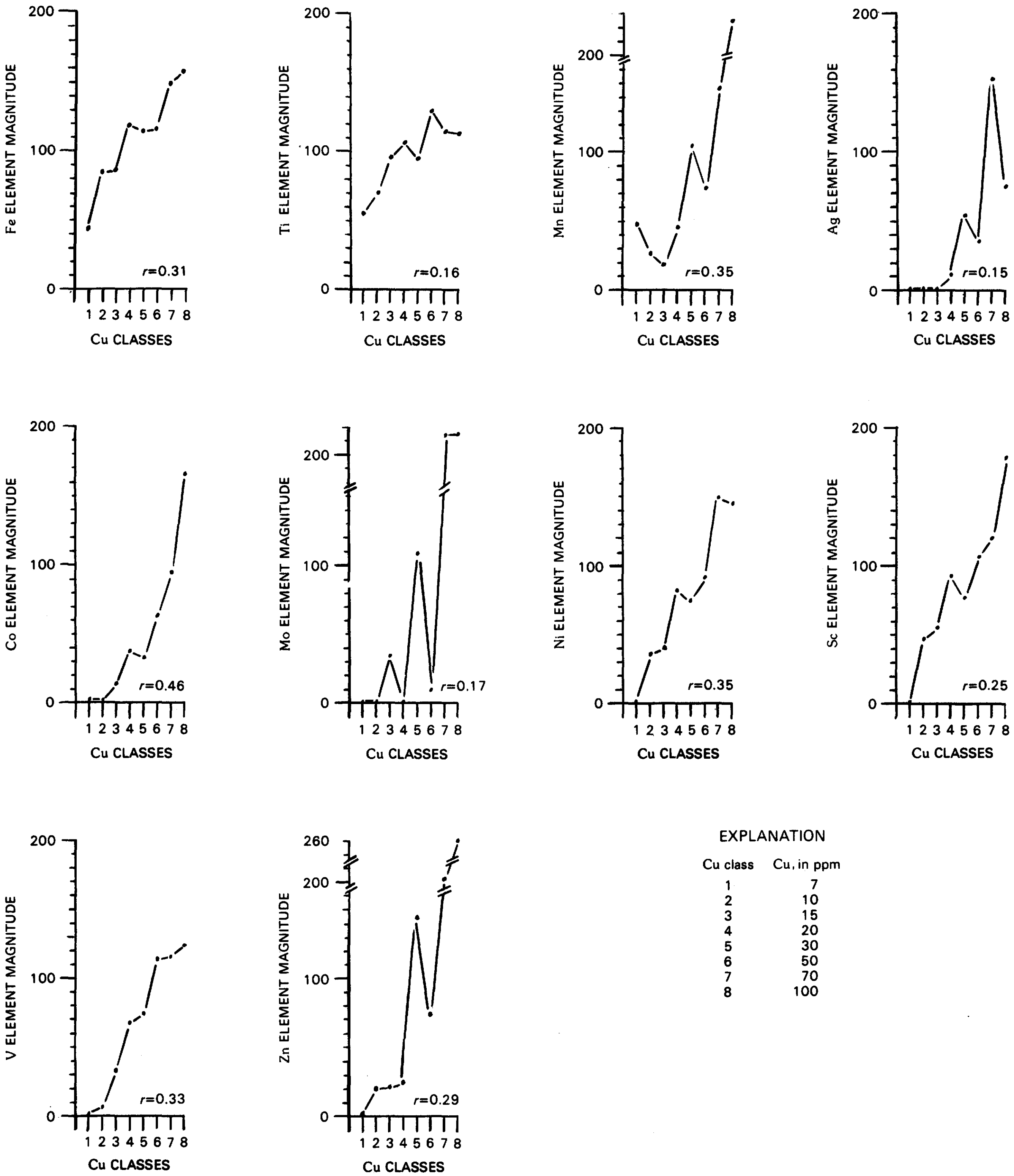


Figure 8. Plot of raw copper contents of A-horizon soils from west-central Vermilion district, northeastern Minnesota.



EXPLANATION

Cu class	Cu, in ppm
1	7
2	10
3	15
4	20
5	30
6	50
7	70
8	100

Figure 9. Graphs showing degree of copper association with Fe, Ti, Mn, Ag, Co, Mo, Ni, Sc, V, and Zn within eastern window. Association is shown on basis of copper-content classes (1-8) relative to calculated element magnitude values (VanTrump and Alminas, 1978). The number "*r*=x.xx" indicates correlation coefficient between raw copper values and those of each respective element.

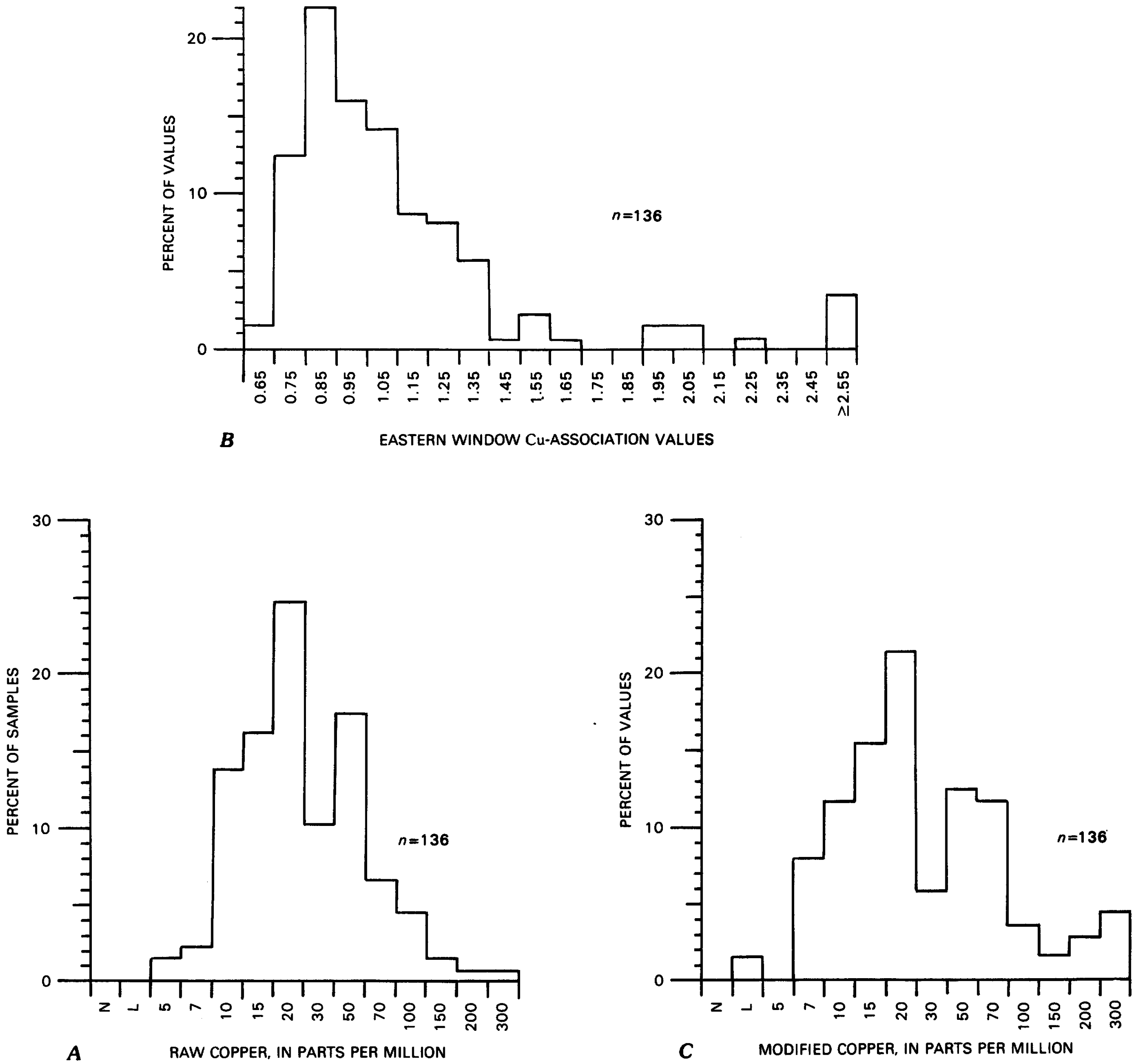


Figure 10. Histograms showing frequency distributions of *A*, raw copper, *B*, copper association, and *C*, modified copper values for eastern window.

anomaly is generally less intense and much more sporadic. In addition, some relationships between the anomalous sample sites and major east-west-trending faults can be noted.

In both anomalous areas, the surficial geochemical patterns probably indicate precious- and base-metal disseminated and vein-type deposits at depth, with the Lake Vermilion one being the shallower of the two.

Gold

Gold occurs in anomalous concentrations within the A-horizon soils in the Vermilion district predominantly over the felsic volcaniclastic member (Alf) of the Lake Vermilion Formation in the west end of the belt and the upper member of the Ely Greenstone in the east (fig. 14 and pl. 1). The most

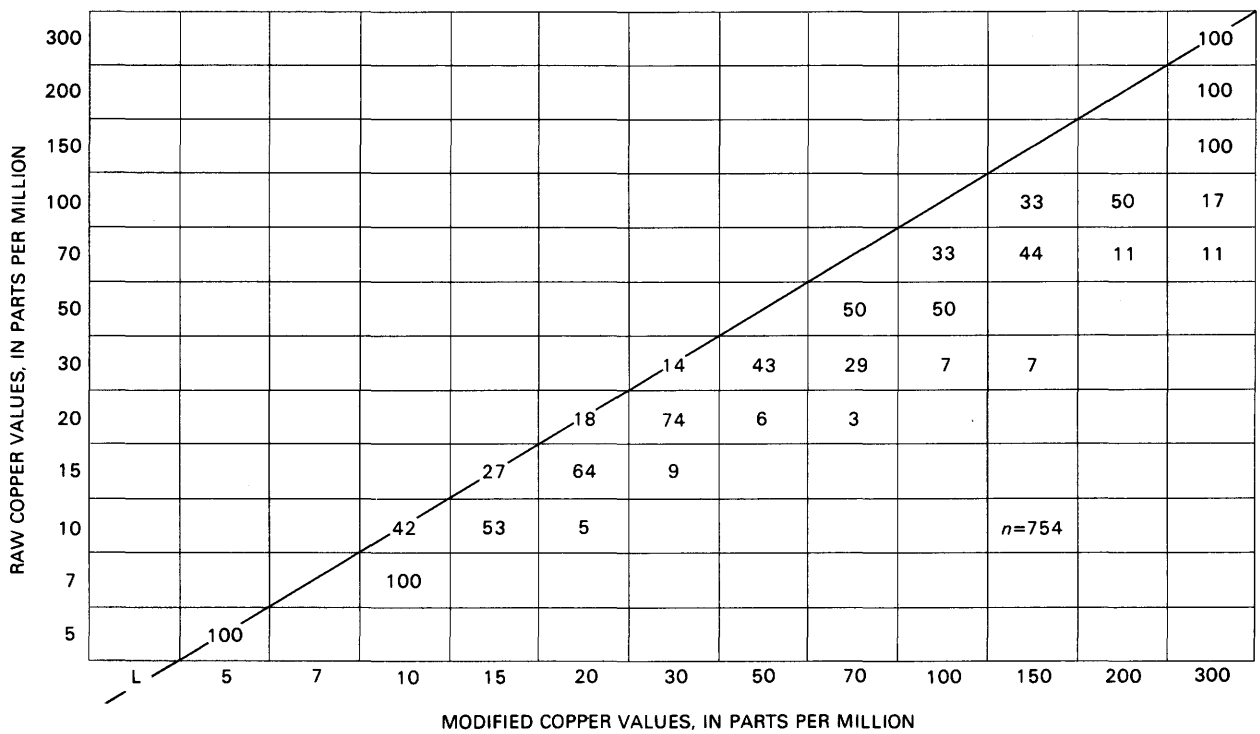


Figure 11. Scatter diagram showing kind and degree of copper value modification within eastern window resulting from multiplication of raw copper values by the eastern window Cu-association factor. Numbers indicate percent of samples within each raw copper content class.

extensive and intense gold anomaly occurs in the west end of the Vermilion district and is centered on Lake Vermilion. Here the gold is associated with Ag (fig. 15) and the Lake Vermilion Cu-association (Ti, Ag, Co, La, V, Y) (fig. 7), and less directly with Pb (fig. 16), Zn (fig. 17), Co (fig. 18), Ni (fig. 19), and Cr (fig. 20). A zonation is evident: Pb, Zn, Co, Ni, and Cr occur in the northern part of the anomalous area, Cu and Ag in the central part with Au overlapping the Ag zone and extending southward to the Soudan mine area.

A smaller gold anomaly occurs immediately to the east of the Lake Vermilion anomaly (pl. 1) to the north and northeast of Gafvert Lake. Here the gold is not associated with silver or the base metals of the Lake Vermilion Cu-association. This area is characterized by a zinc anomaly, however.

A second minor gold anomaly occurs at the west end of Shagawa Lake near Longstorff Bay. Here the gold anomaly is closely related to a silver anomaly and a Lake Vermilion Cu-association anomaly.

Two major gold soil anomalies are evident in the east end of the Vermilion district. The first of these is centered on Madden Lake, and most of the gold-rich sample sites occur to the northwest of the lake. Farther east, gold occurs in the immediate vicinity of and to the north of Ojibway Lake.

The second major gold anomaly is centered on Garden Lake with gold-rich soil sites forming a halo to the west, north, and east. These two gold areas are considered to be part of the same system.

In the eastern window anomalies, the gold occurs with the eastern Cu-association (Fe, Ti, Mn, Ag, Co, Mo, Ni, Sc, Zn, V) and tends to occur within the areas delineated by this association or immediately peripheral to them. Very little silver is associated with the eastern anomalies and much less Ni, Co, and Cr occur here than in the west. The Pb input here is somewhat lower and the Zn input is much greater than in the Lake Vermilion window anomaly. Marginally more Mo is evident in this area (fig. 21).

A few minor Au and eastern Cu-association anomalies occur over and peripheral to the upper mafic member of the Newton Lake Formation between Shagawa and Newton Lakes.

Silver

Silver contents of the west-central Vermilion district A-horizon soils range from not detected (at a level of 1 ppm) through 5.0 parts per million. Silver was detected in 48 of the 754 soil samples (6.4 percent of the total population). A histogram of the silver content frequency distribution appears in figure 2, and figure 15 plots silver distribution

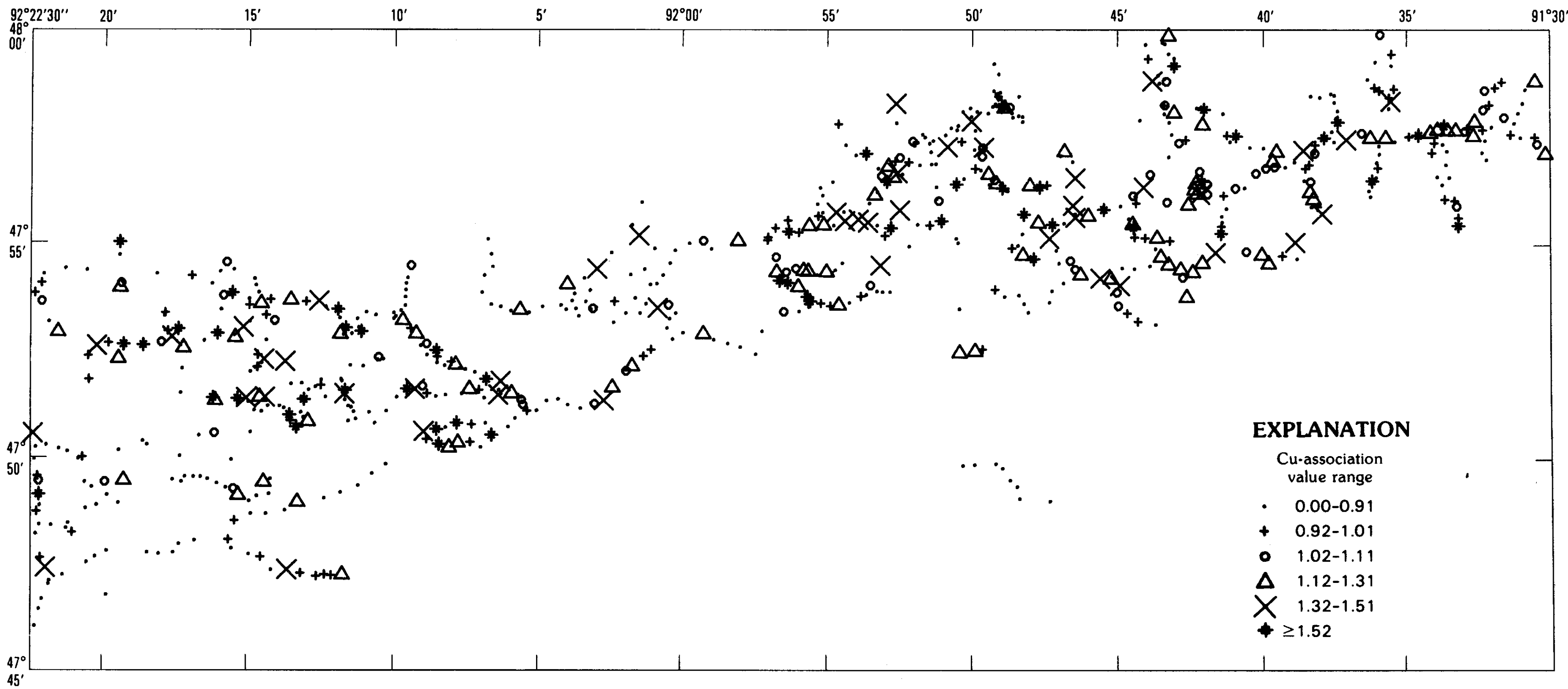


Figure 12. Plot of eastern window Cu-association values. In that values are recalculated, they are without units.

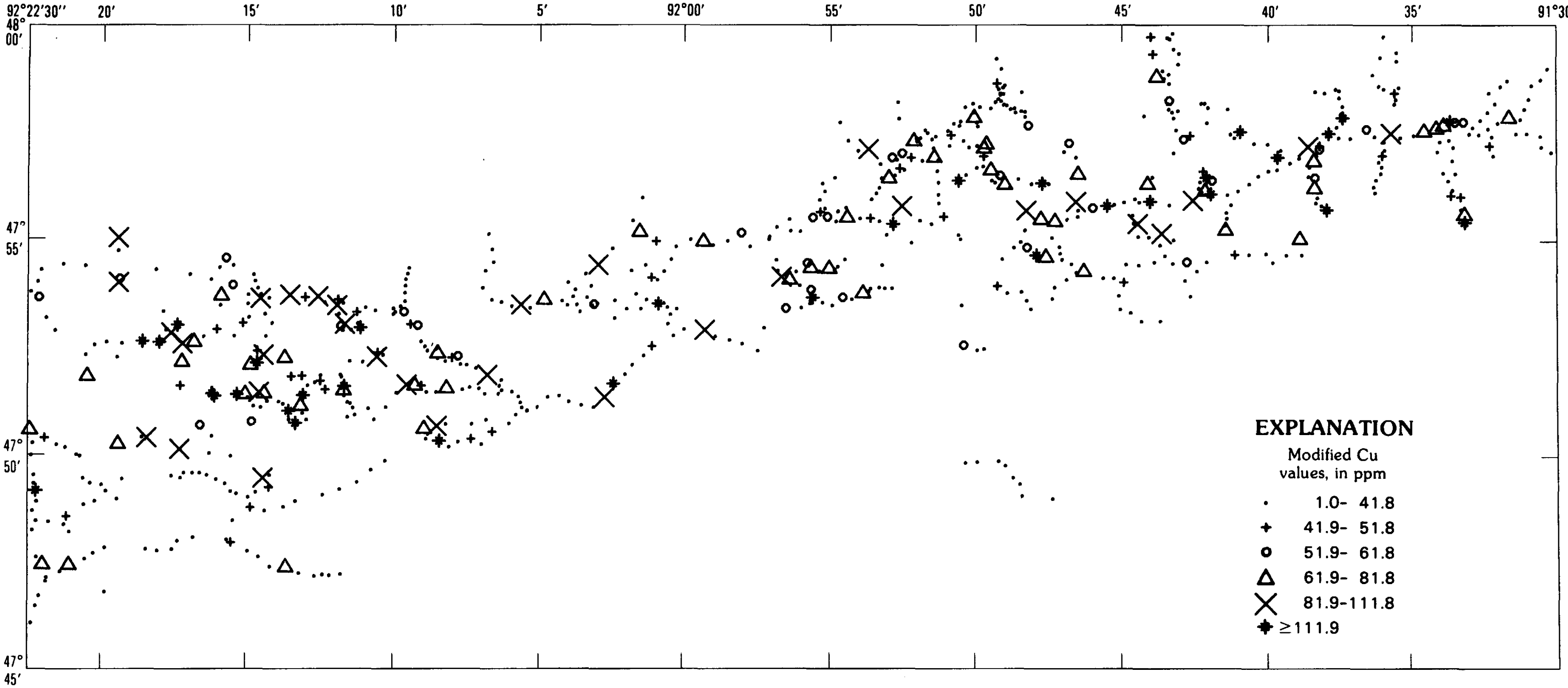


Figure 13. Plot of modified copper contents of A-horizon soils from west-central Vermilion district, northeastern Minnesota. Values are modified by the eastern window Cu-association.

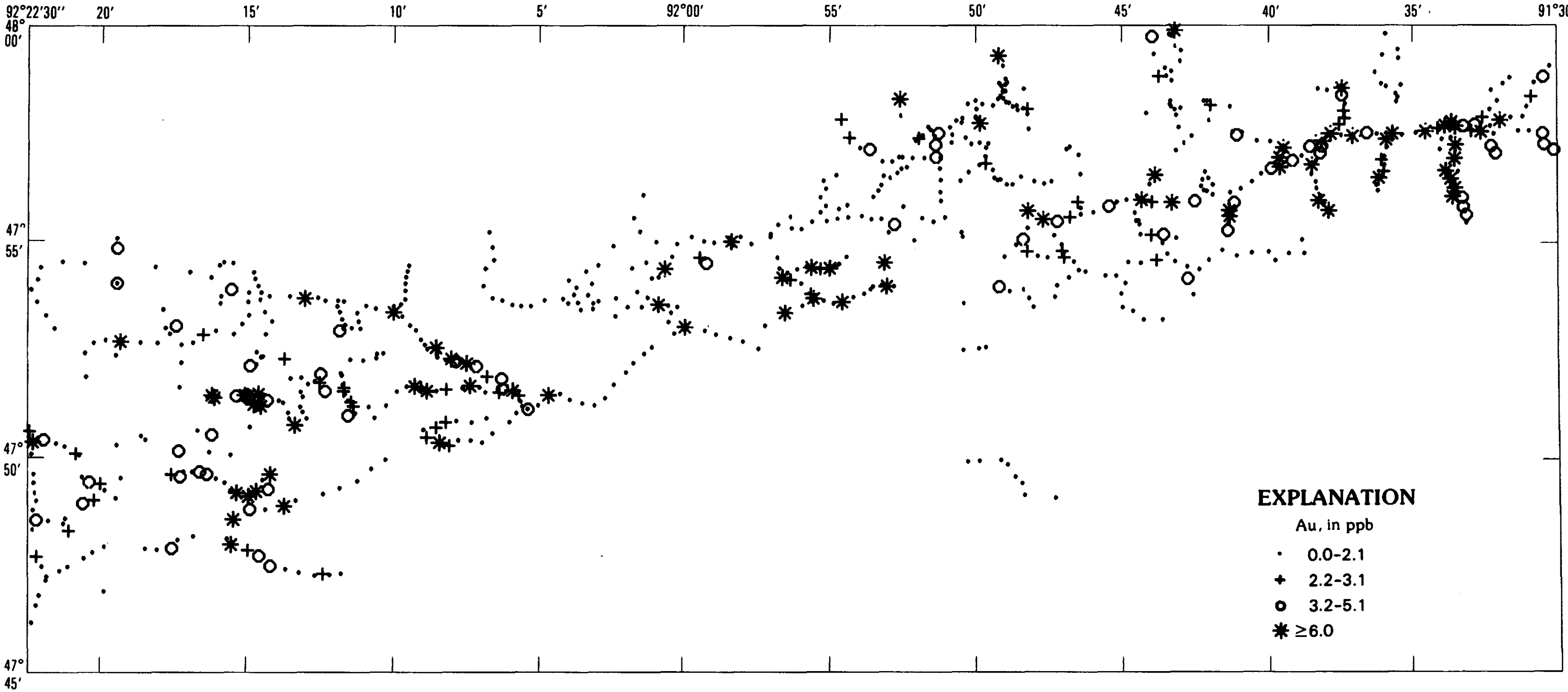


Figure 14. Plot of gold contents of A-horizon soils, west-central Vermilion district.

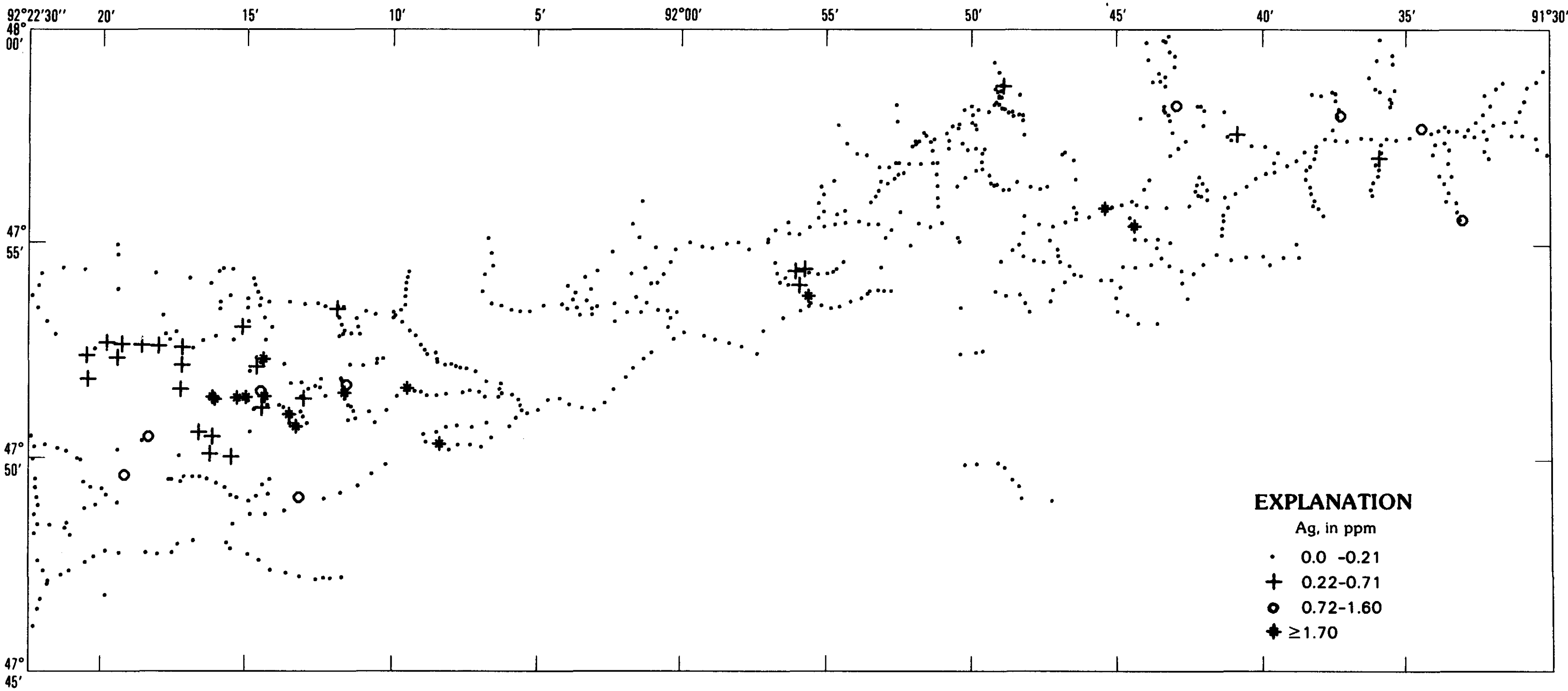


Figure 15. Plot of silver contents of A-horizon soils, west-central Vermilion district.

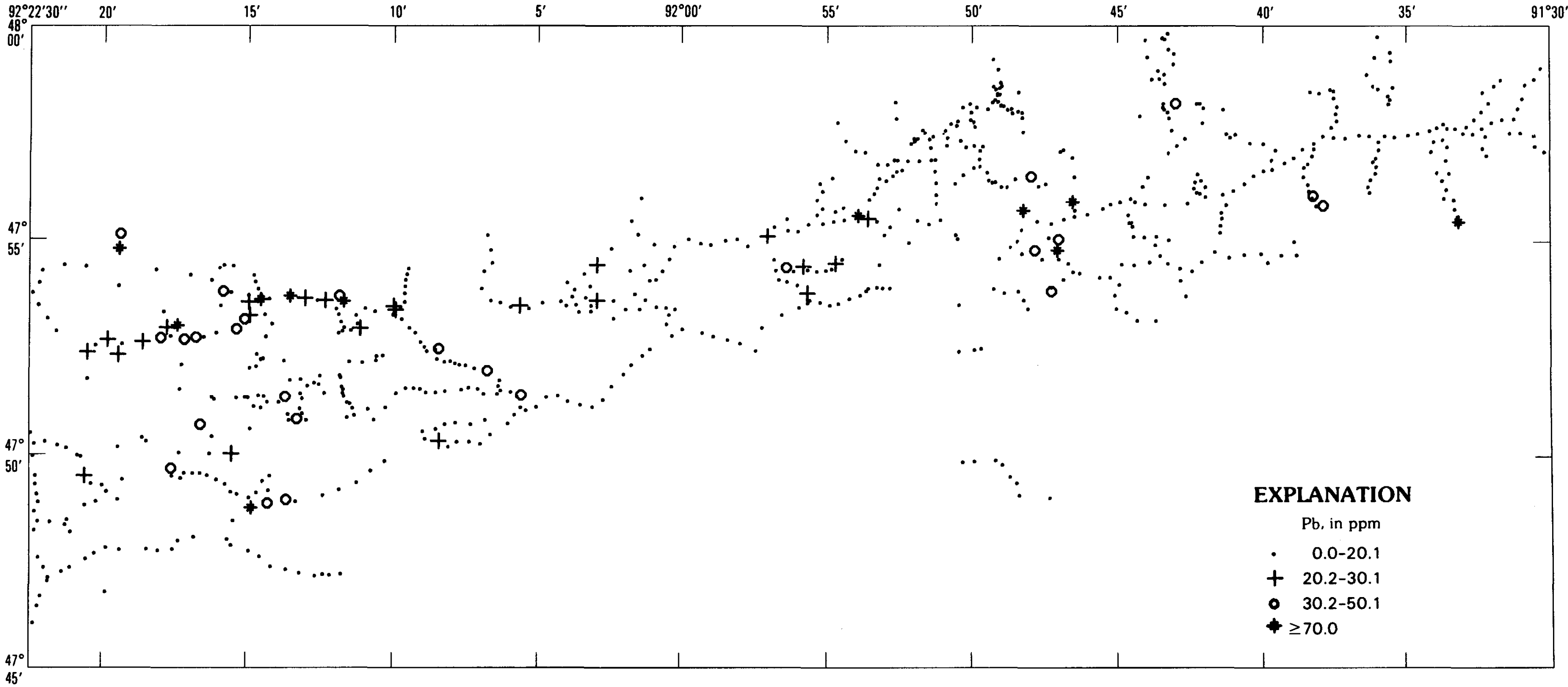


Figure 16. Plot of lead contents of A-horizon soils, west-central Vermilion district.

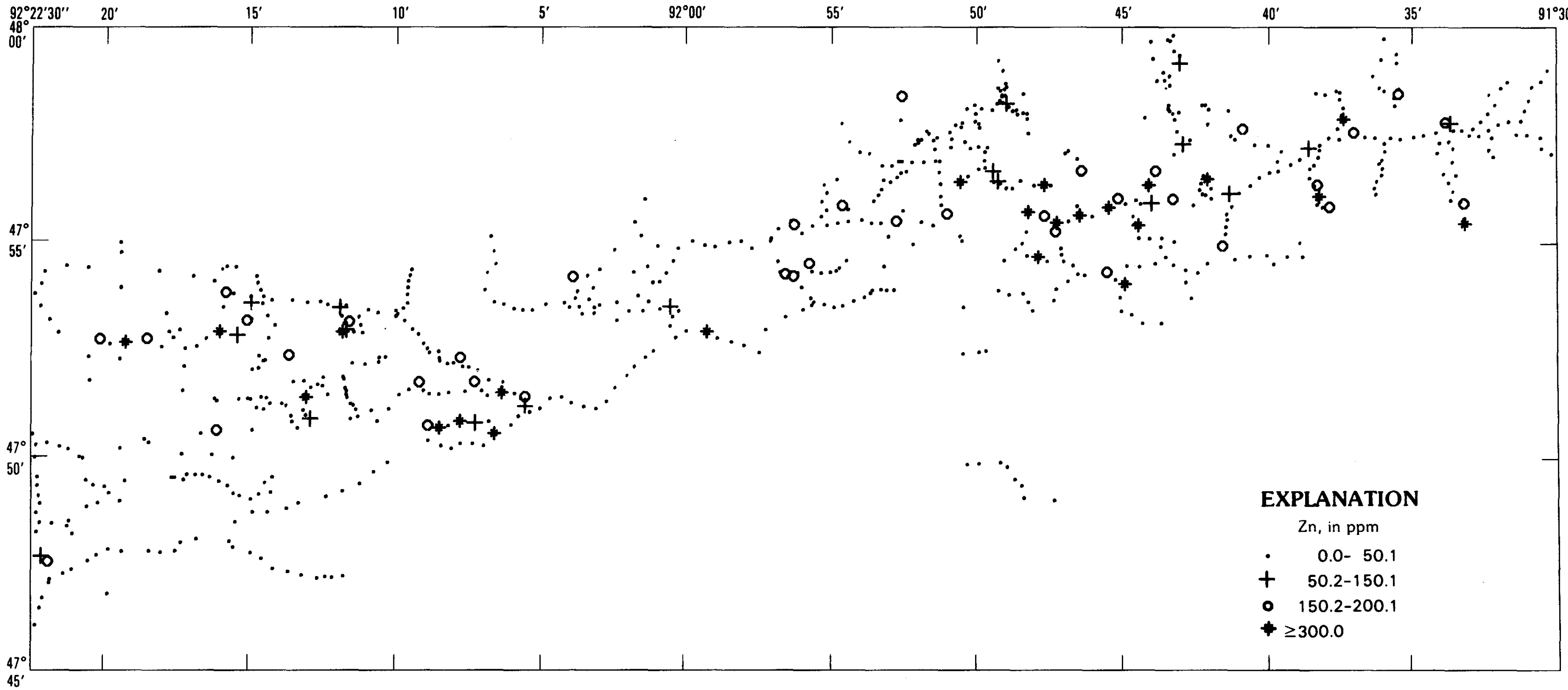


Figure 17. Plot of zinc contents of A-horizon soils, west-central Vermilion district.

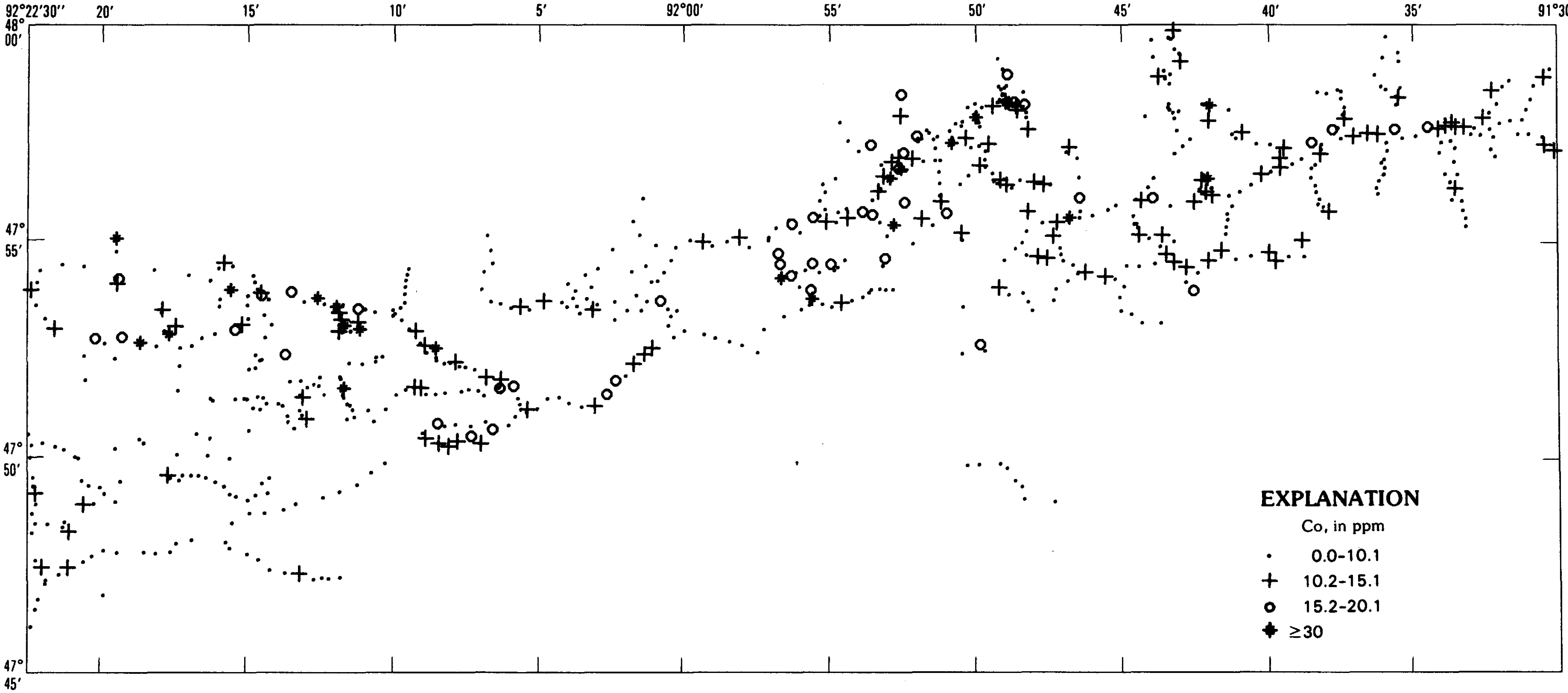


Figure 18. Plot of cobalt contents of A-horizon soils, west-central Vermilion district.

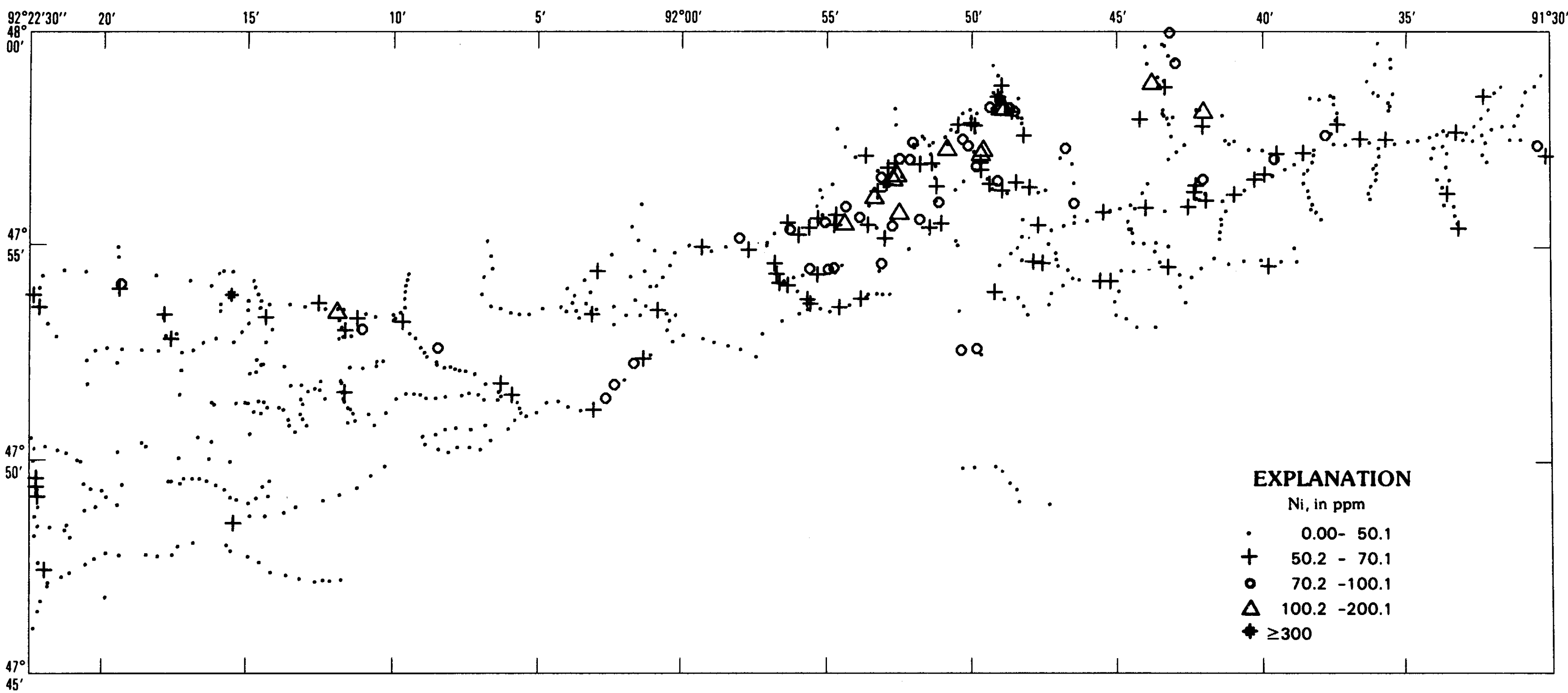


Figure 19. Plot of nickel contents of A-horizon soils, west-central Vermilion district.

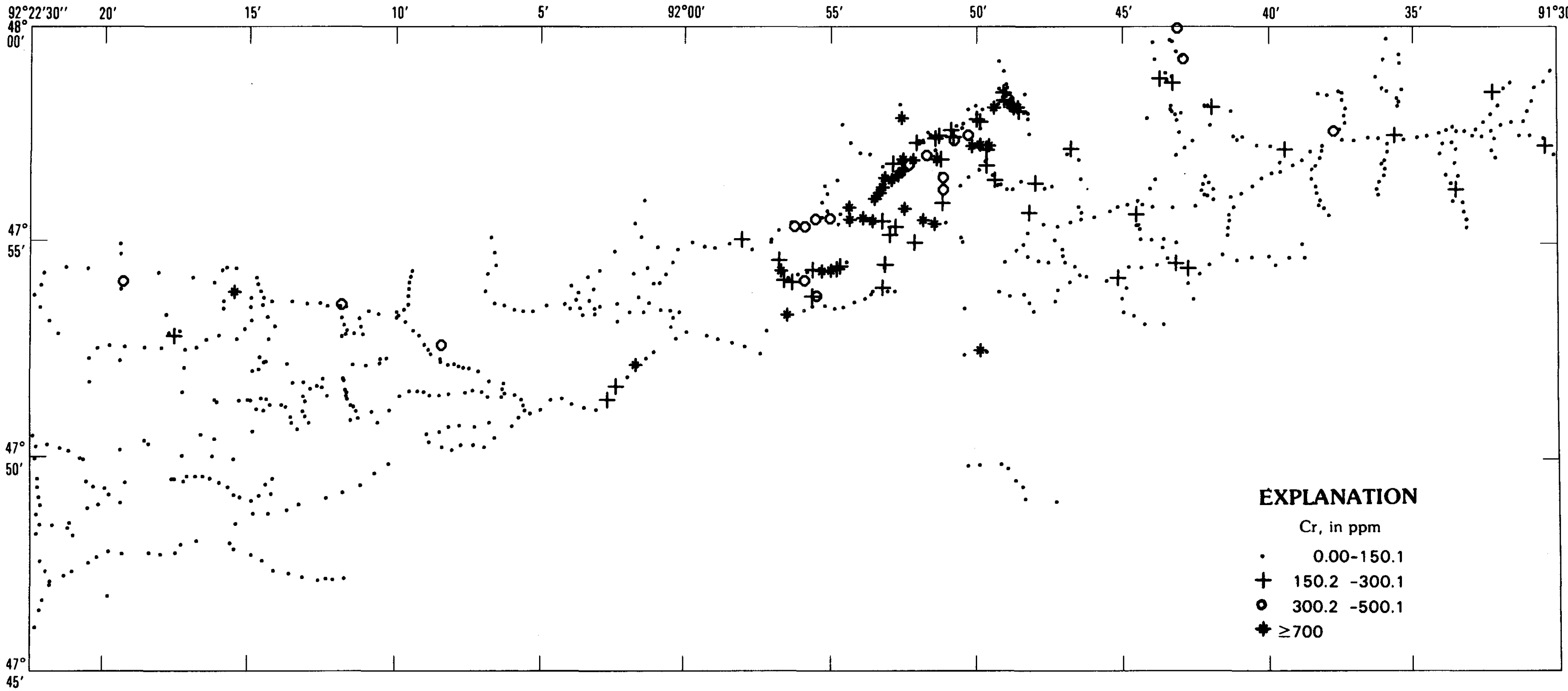


Figure 20. Plot of chromium contents of A-horizon soils, west-central Vermilion district.

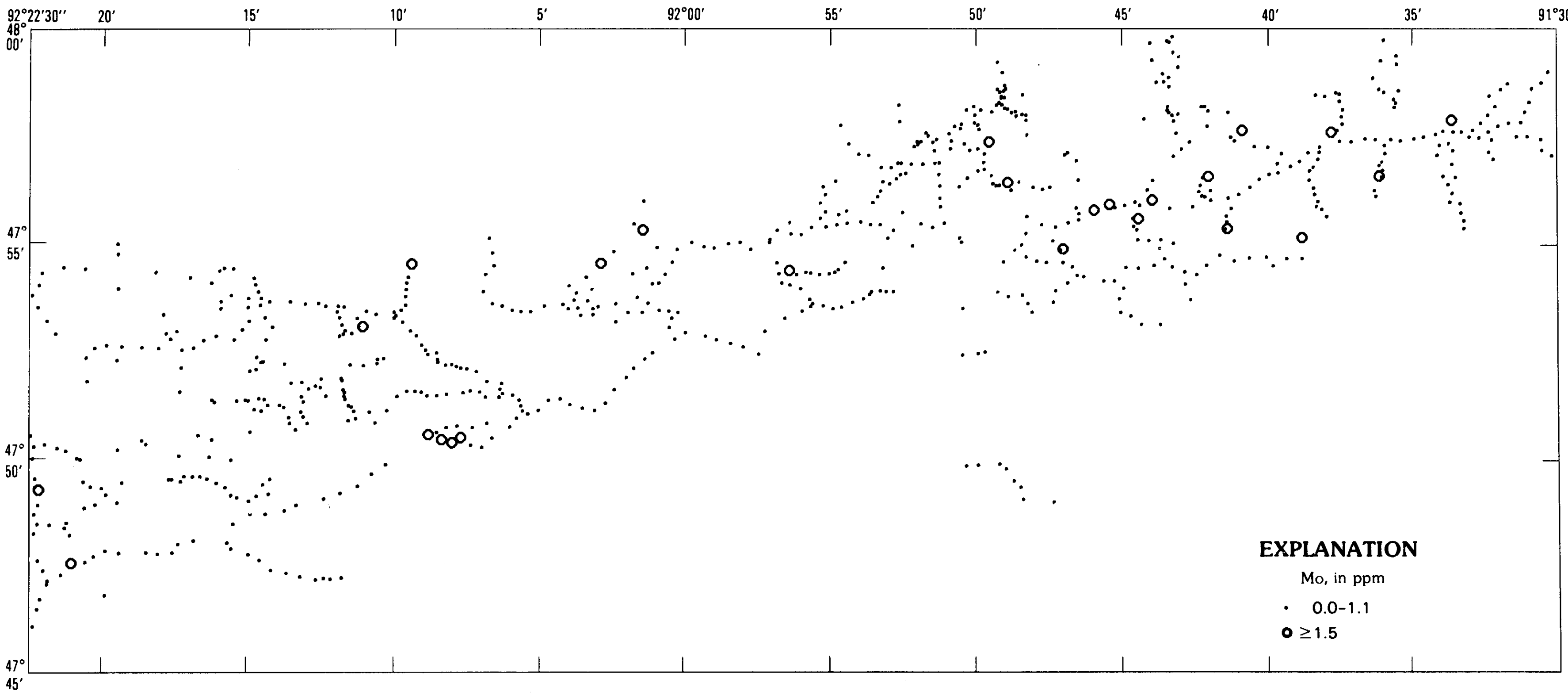


Figure 21. Plot of molybdenum contents of A-horizon soils, west-central Vermilion district.

within the Vermilion district. Any detectable silver in these soil samples is considered anomalous. Thirty-two (66.7 percent) of the soils with anomalous silver contents were collected within the central part of the Lake Vermilion window anomaly—predominantly over the felsic volcaniclastic member (Alf) of the Lake Vermilion Formation. As might be expected, the Cu-Ag correlation coefficient within this area is rather high (r=0.42), as is the Au-Ag correlation(r=0.35). The somewhat lower Au-Ag correlation reflects the north-south Ag-Au zonation.

A cluster of four anomalous sites occurs over the lower mafic volcanic member (Anml) of the Newton Lake Formation to the southwest of Shagawa Lake (pl. 1). This silver is related to a small gold and Cu-association anomaly located here. In addition, this area is transected by the intense, linear Cr-association anomaly associated with the gabbro, diabase, and layered mafic sills of the upper mafic volcanic member of the Newton Lake Formation, which trends northeast-southwest immediately to the north. A small, but intense local high in this belt coincides with the precious- and base-metal anomalies.

The remaining sites with anomalous silver contents occur in the vicinity of the more intense portions of the Garden Lake and Madden Lake precious- and base-metal anomalies.

Zinc

Zinc contents in the west-central Vermilion district A-horizon soils range from not detected (N at a level of 200 ppm) through 1,000 ppm. A histogram of the frequency distribution of zinc concentrations in the Vermilion district soils appears in figure 2, and figure 17 is a plot of zinc distribution within the district.

Any detectable zinc in these soils is considered anomalous. Detectable zinc was found in 78 of the 754 soils collected within the Vermilion district (or 10.3 percent of the total population). Fourteen of these sites (19 percent) occur within the Lake Vermilion window Cu-association anomaly. These anomalous sites define a zinc zone just outside the silver zone along the northern margin of the anomaly. A large cluster of anomalous sites occurs to the east of the Lake Vermilion anomaly in the vicinity of Gafvert Lake. This area is also characterized by a gold anomaly. The sites in both these areas occur predominantly over the felsic volcaniclastic member of the Lake Vermilion Formation (Alf) and the upper member of the Ely Greenstone.

A small cluster of sites occurs to the southwest of Shagawa Lake associated with the small precious- and base-metal anomaly occurring there.

Zinc is substantially more abundant within the eastern Cu-association window. Here, zinc in anomalous concentrations occurs at 24 sites, thus accounting for 29 percent of all anomalous zinc sites within the Vermilion district.

Lead

Lead contents in the west-central Vermilion district A-horizon soils range from not detected (at a level of 10 ppm) through 300 ppm. A histogram of the lead content frequency distribution appears in figure 2, and figure 16 is a plot of the lead distribution within the Vermilion district.

Lead contents ≥30 ppm are considered anomalous within the west-central Vermilion district. Lead at this level occurs in 59 (or 7.8 percent) of the soils collected here. Twenty-one (or 35.6 percent) of the anomalous sites occur within the Lake Vermilion Cu-association anomaly. These sites delineate a well-defined lead zone along the north shore of Lake Vermilion. A cluster of anomalous sites also occurs along the south lakeshore.

Some anomalous sites are associated with the precious- and base-metal anomaly to the southwest of Shagawa Lake, and only five anomalous sites occur within the eastern Cu-association window. A cluster of anomalous sites does occur peripheral to the gold-mineralized soils southwest of Garden Lake.

Molybdenum

Molybdenum contents in the west-central Vermilion district A-horizon soils range from not detected (at a level of 5 ppm) through 50 ppm. A histogram of the molybdenum frequency distribution appears in figure 2, and figure 21 is a plot of the molybdenum distribution within the Vermilion district.

Detectable molybdenum was found in 22 of the 754 soils collected within the west-central Vermilion district (or 2.9 percent of the total population). Any detectable molybdenum in these soils is considered anomalous.

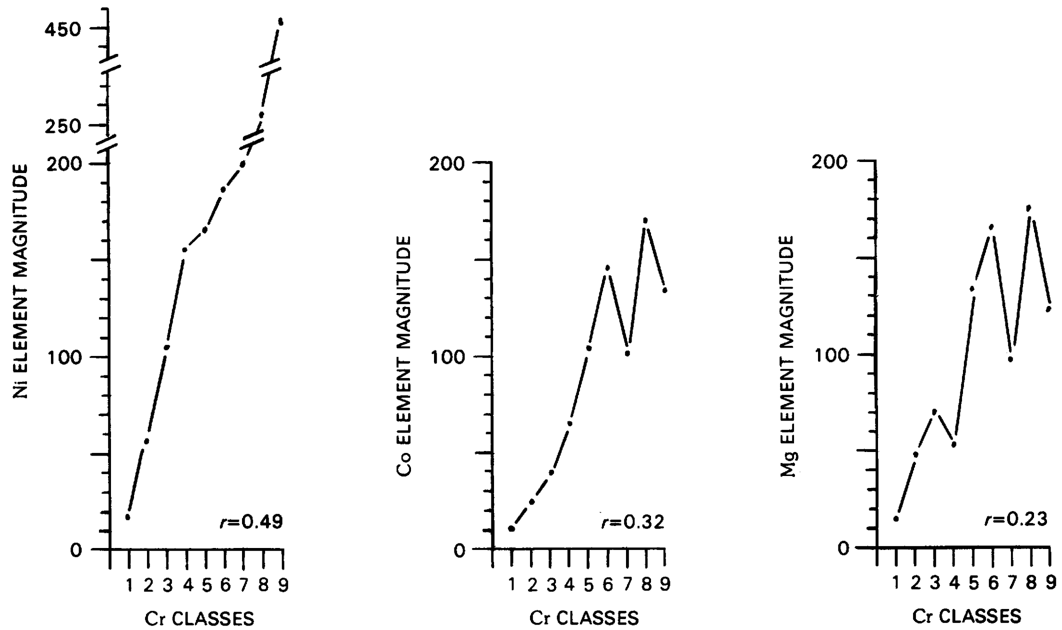
No soils with anomalous concentrations of molybdenum were collected within the Lake Vermilion Cu-association window. A few sites with anomalous molybdenum concentrations occur peripheral to the Gafvert Lake Au-Zn anomalous area to the east of Lake Vermilion.

Nearly half (45.4 percent) of the soils with anomalous molybdenum contents were collected within the eastern Cu-association window.

Chromium

Chromium contents in the west-central Vermilion district A-horizon soils at ≥200 ppm are considered anomalous. On this basis, anomalous Cr concentrations occur at 100 of the 754 sites sampled (or 13.3 percent of the total population).

Seventy-two (72 percent) of the anomalous sites are clustered in the Little Long Lake area within a window delineated by lat 47°53′24″–47°58′48″ N. and long 91°48′00″–91°58′12″ W. (See pl. 2.) The anomalous sites



EXPLANATION

Cr class	Cr, in ppm
1	≤70
2	100
3	150
4	200
5	300
6	500
7	700
8	1000
9	≥1500

Figure 22. Graphs showing degree of chromium association with Ni, Co, and Mg within Little Long Lake window. Association shown on basis of chromium-content classes (1-9) relative to calculated element magnitude values (Van Trump and Alminas, 1978). The number "*r*=x.xx" indicates correlation coefficient between raw chromium values and those of each respective element.

within this window occur predominantly over the gabbros, diabases, and layered mafic sills of the upper mafic volcanic member (Anmu) and the pillow and massive basalts of the lower mafic volcanic member (Anml) of the Newton Lake Formation (pl. 2). The chromium is associated with Mg, Co, and Ni (fig. 22).

The chromium content frequency distribution of the 159 sites falling within the window (fig. 23*A*) indicates a marked increase in values ≥200 ppm relative to the frequency distribution of chromium in the population as a whole. The relative elemental standings are as follows:

Element	REM value
Ni	47.8
Mg	29.3
Co	23.0

The respective correlation coefficients with chromium are:

	Ni	Mg	Co
Cr	0.49	0.23	0.32

The correlation coefficient between raw chromium values and the association as a whole is *r*=0.54.

A modification of the chromium values within the Little Long Lake window in a manner identical to that described in the copper discussion produces a modified chromium content distribution as shown in figure 23*C*. For comparison purposes a histogram showing the frequency distribution of raw chromium within this window is shown as figure 23*A*. The kind and degree of Cr-value modification are shown in a scatter diagram (fig. 24). Figure 25 is a plot of the Little

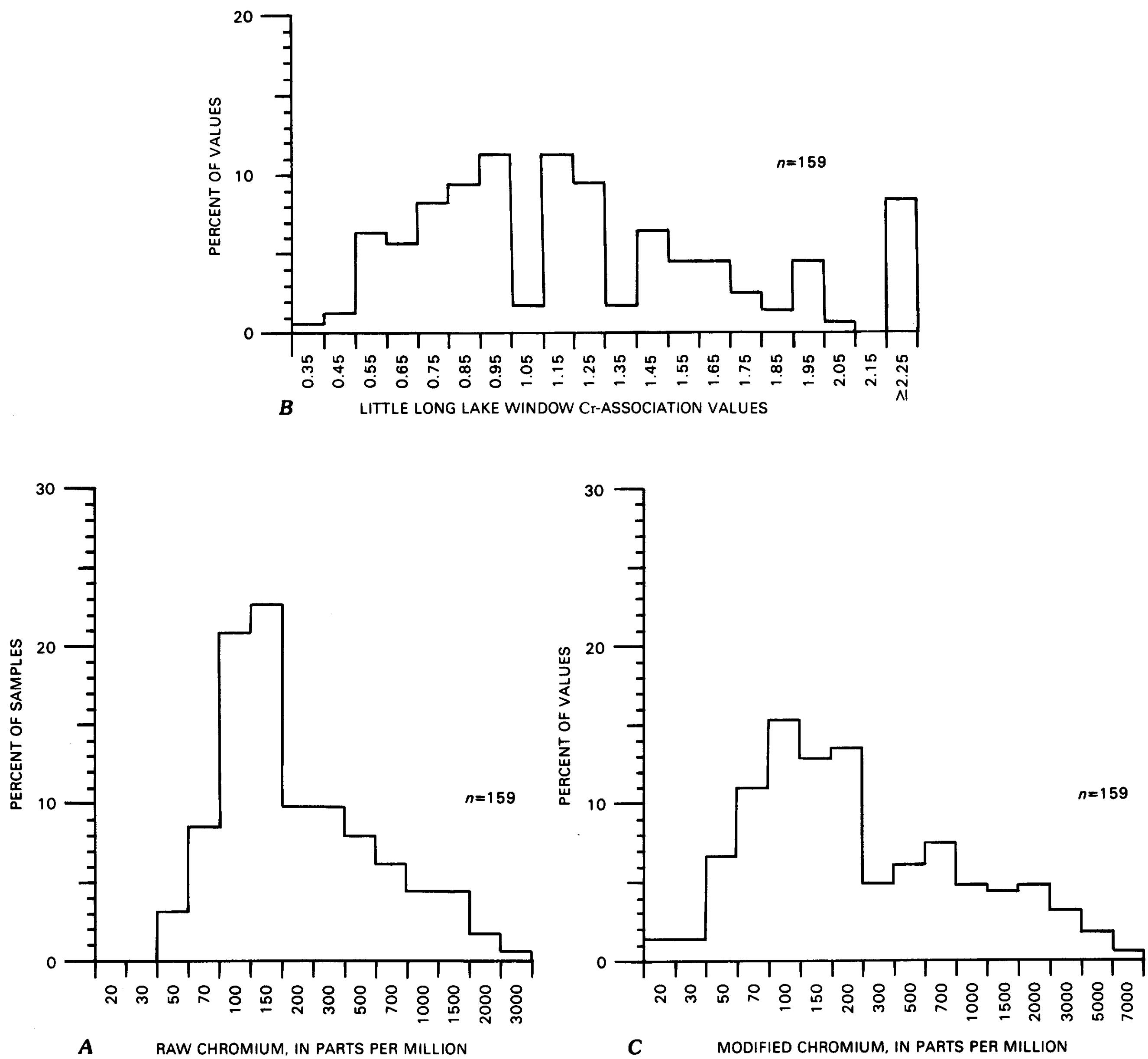


Figure 23. Histograms showing frequency distributions of *A*, raw chromium, *B*, chromium association, and *C*, modified chromium values for Little Long Lake window.

Long Lake window Cr-association values, and figure 26 is a plot of chromium values modified by this association.

Some of the outcrop samples collected within this area contained platinum in concentrations of as much as 0.15 ppm and palladium as much as 0.10 ppm. The kind and extent of chromium content modification are shown by the scatter diagram in figure 22. The modified chromium values progressively increase relative to the raw chromium values in the higher raw chromium content classes. The correlation coefficient between the raw chromium and modified chromium values is r=0.72. Figure 26 shows a symbol plot of the areal distribution of these modified values.

Nickel

Nickel contents in the west-central Vermilion district A-horizon soils range from detected (at a level of 5 ppm) through 1,000 ppm. Nickel contents of ≥70 ppm are considered anomalous in the Vermilion district A-horizon soils.

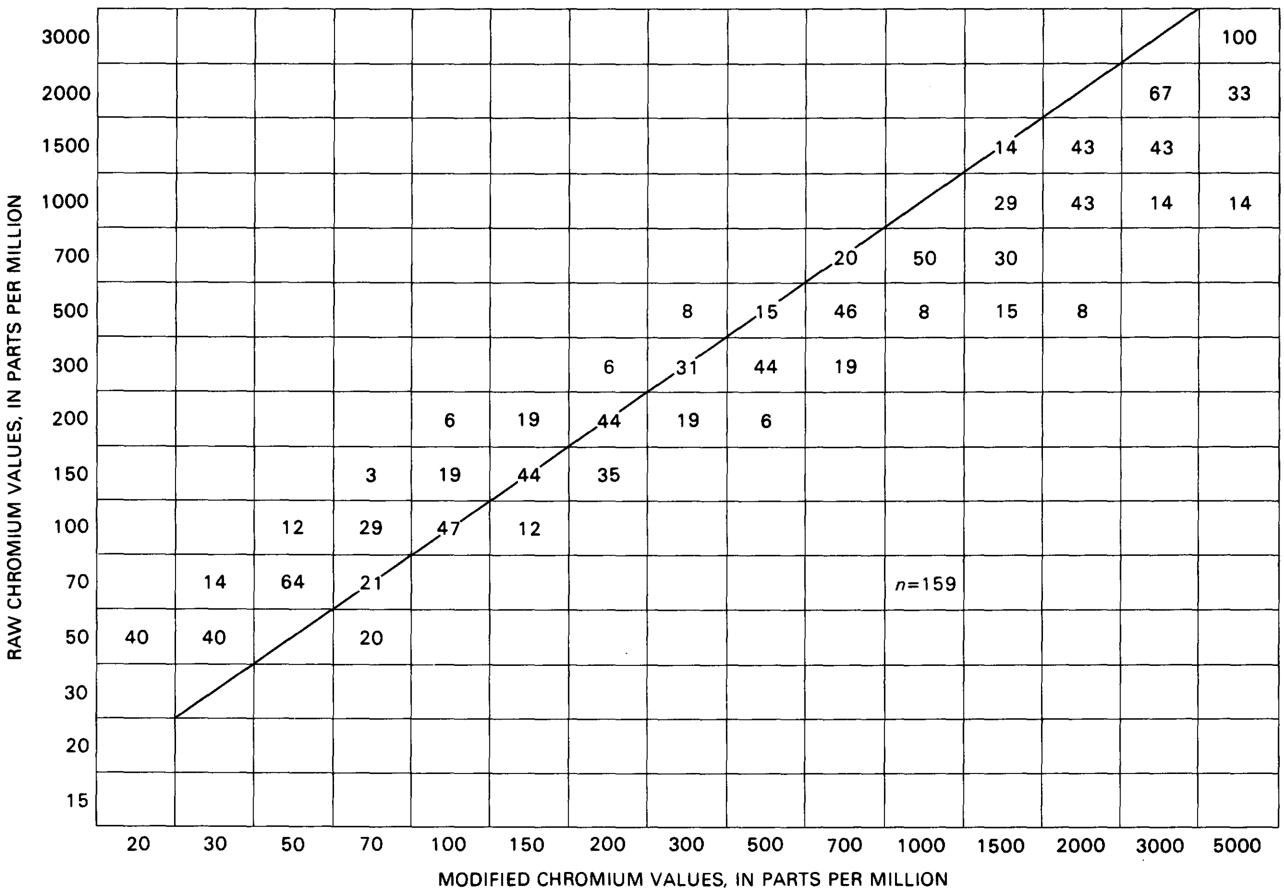


Figure 24. Scatter diagram showing kind and degree of chromium value modification within Little Long Lake window resulting from multiplication of raw chromium values by Cr-association factor. Numbers indicate percent of samples within each raw chromium content class. Correlation coefficient between raw chromium and modified chromium values is r=0.90.

On this basis anomalous Ni concentrations occur at 149 sites (or 19.8 percent of the total population).

The greatest number of sample sites at which soils contain anomalous concentrations of nickel occur within the Little Long Lake window northeast of Shagawa Lake, over rocks of the upper and lower mafic volcanic members (Anmu and Anml) of the Newton Lake Formation. Here, the Ni is associated with Cr, Mg, and Co.

The second greatest concentration of these sites occurs in the eastern Cu-association window along the major east-northeast-trending faults. Anomalous concentrations of nickel are also associated with the northern part of the Lake Vermilion window.

Cobalt

Cobalt contents in the west-central Vermilion district A-horizon soils range from not detected (at a level of 5 ppm) through 50 ppm. Cobalt contents ≥20 ppm are considered anomalous in the Vermilion district A-horizon soils. On this basis, anomalous Co concentrations occur at 67 sites sampled (or 8.9 percent of the total population).

The greatest concentration of samples with anomalous cobalt contents was collected to the northeast of Shagawa Lake over rocks of the Newton Lake Formation. Here, the Co is associated with Cr, Mg, and Ni.

Numerous samples with anomalous Co concentrations were also collected along the northern margin of the Lake Vermilion precious- and base-metal anomaly. Anomalous concentrations of Co also occur associated with the eastern mineralization, though to a much lesser extent.

DISCUSSION

This study indicates the presence of two major (and several smaller) anomalous areas within the Vermilion district that are mineralized with respect to gold, silver, and a copper-related base-metal association. The more pronounced

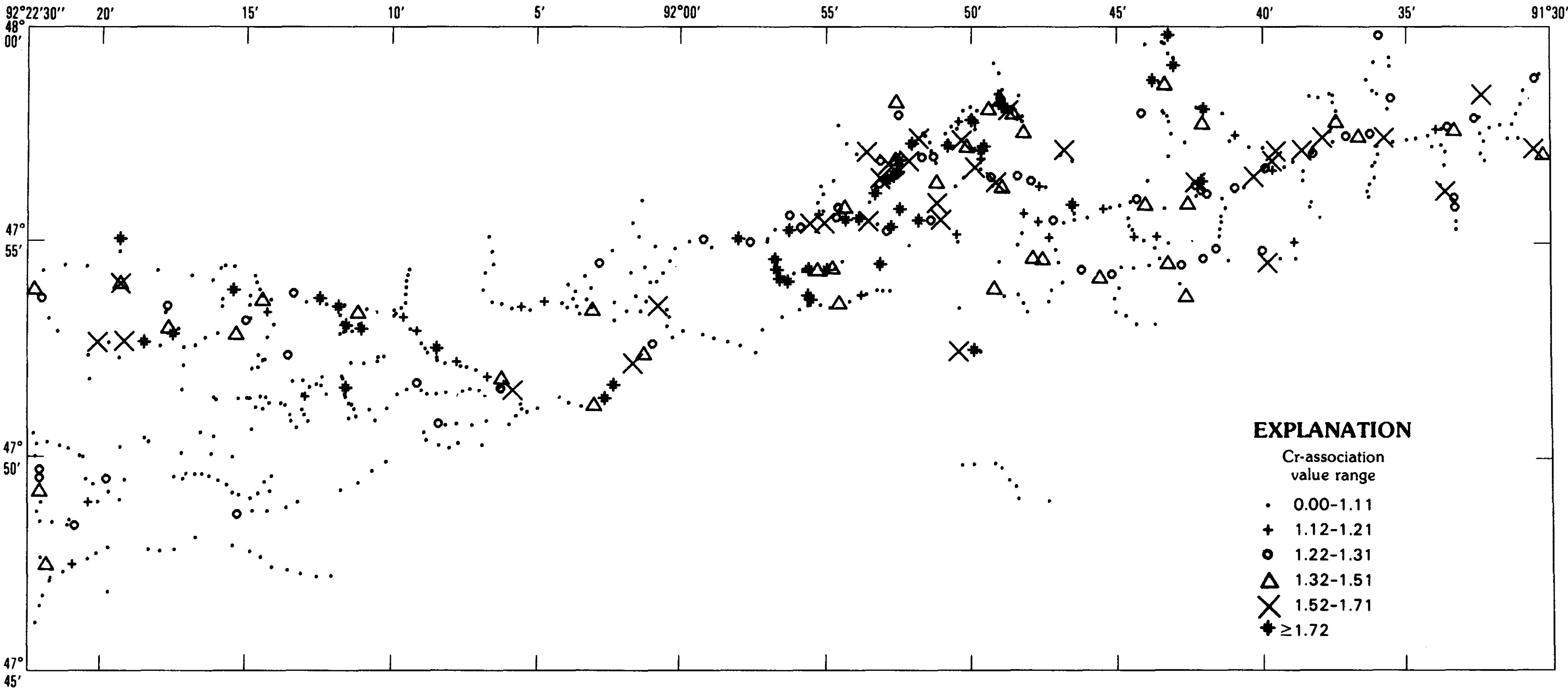


Figure 25. Plot of Little Long Lake window Cr-association values. In that values are recalculated, they are without units.

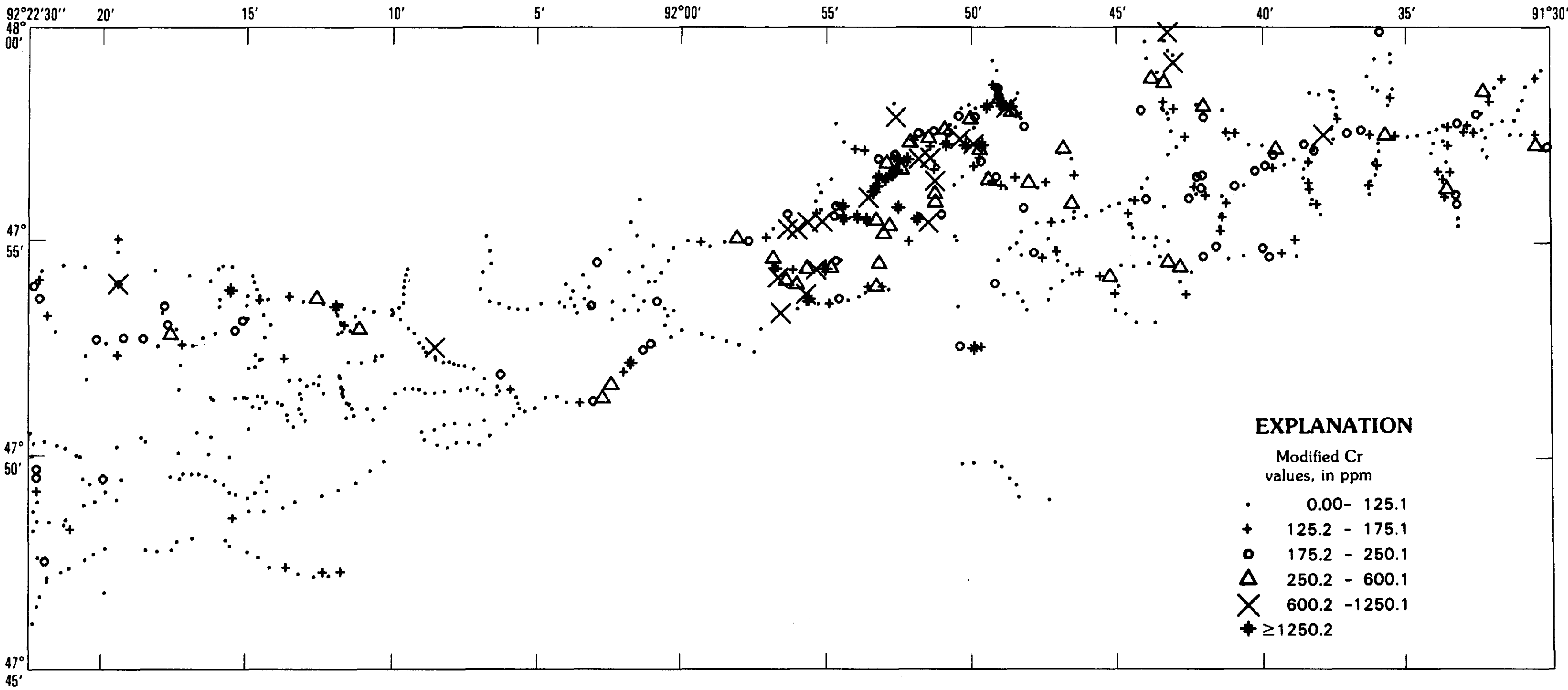


Figure 26. Plot of modified chromium values of A-horizon soils from west-central Vermilion district, northeastern Minnesota. Values are modified by Little Long Lake window Cr-association.

anomaly is approximately 89 km^2 (35 mi^2) in areal extent and is centered on Lake Vermilion (pl. 1), at the west end of the study area and extending beyond the west boundary of the study area. In this area the gold content of the soils is as high as 1.1 ppm, and the gold is associated with Ag, Cu, Ti, Co, Pb, Zn, Cr, Ni, La, V, and Y. A pronounced zonation is evident. Lead (fig. 16), zinc (fig. 17), and cobalt (fig. 18) occur in the northern part of the anomalous area. Silver (fig. 15) and the remainder of the base metals occur in the central part, and gold (fig. 14) occurs in the central and southern parts. The mineralization was restricted primarily to the graywacke and felsic volcaniclastic members of the Lake Vermilion Formation. A pronounced aeromagnetic high anomaly (fig. 27), apparently derived from a buried pluton related to the Lost Lake syenitic, granitic, and lamprophyric intrusive bodies immediately to the west of Lake Vermilion, shows a good spatial correlation with the mineralization. Small outcrops of these intrusive rocks (pl. 1) also occur immediately to the east of Lake Vermilion. The mineralized area is located within a gravity high (fig. 28) within a region that is a general gravity low.

A second major gold-bearing anomalous area is located in the east end of the west-central Vermilion district study area, between Fall and Jasper Lakes, and encompasses some 77 km^2 (30 mi^2). In this area the gold is associated with Cu, Ti, Mn, Ag, Co, Mo, Ni, Sc, Zn, and V. The zonation in this anomaly is less evident and the Ag association much less pronounced than in the Lake Vermilion anomaly. This area is characterized by higher Pb, Zn, and Mo concentrations than that at Lake Vermilion. Lamprophyric and syenitic intrusives crop out in this area as they do in the area of the Lake Vermilion anomaly. A pronounced aeromagnetic high anomaly is essentially coextensive with the geochemical anomaly, and the area is characterized by a relative gravity high within a generally gravity low region.

Smaller gold anomalies occur at Gafvert Lake (just east of Lake Vermilion) and at Longstorff Bay at the west end of Shagawa Lake. The Gafvert Lake gold-anomalous area is underlain by rocks of the upper member of the Ely Greenstone. This area is characterized by a pronounced zinc anomaly (fig. 17) and lack of silver or a base-metal association, although minor Cu-association anomalies occur peripheral to the gold zone. This area is located on a pronounced aeromagnetic high trend and has a gravity setting very similar to that at Lake Vermilion. Lamprophyric intrusive rocks and associated syenitic rocks are present immediately west-northwest of the area.

The Longstorff Bay precious- and base-metal anomaly is compositionally similar to that at Lake Vermilion. Although no specific aeromagnetic anomaly occurs near Longstorff Bay, a lamprophyric intrusive is located some distance to the west near Outlet Bay of Burnside Lake. A few scattered sites with anomalous gold concentrations occur adjacent to this intrusive body.

Anomalous chromium, nickel, and cobalt values in the Vermilion district A-horizon soils occur primarily in the central part of the study area (pl. 2), in a region underlain by the upper and lower mafic volcanic members of the Newton Lake Formation. The anomalous area is not, however, coextensive with the outcrop area of these rock types. Marked north-northwest-trending aeromagnetic anomalies occur in this area, which is characterized by a gravity low. Anomalous concentrations of platinum and palladium were detected in some of the rock samples collected within this area, and some minor gold anomalies occur peripheral to this northwest-trending belt.

The gold, silver, and Cu-association geochemical anomalies indicate widespread precious- and base-metal mineralization in the Vermilion district. The mineralized areas appear to be spatially related to the buried epizonal granite and syenite as well as lamprophyric rocks intruded into the Lake Vermilion Formation and Ely Greenstone during the Algoman orogeny. Northeast-trending faults, probably associated with the late phase of the Algoman orogeny (Sims, 1972) also appear to be controlling factors in the localization of the mineralization–especially in the eastern portion of the belt. These geochemical anomalies probably indicate the presence of near-surface gold-bearing disseminated and vein type ore bodies.

In an evaluation of the precious- and base-metal anomalies within the west-central Vermilion district, it is important to keep in mind that the rocks in northern Minnesota are typical of the Archean greenstone-granite complexes in the Canadian Shield (McGlynn, 1970, p. 44-71). Card (1989) indicated that over the past century the Superior province of the Canadian Shield has produced more than 142 million oz of gold—a production rate that is second only to Witwatersrand. Colvine (1989) stated that virtually all of the gold deposits in the Superior province occur within or immediately adjacent to greenstone belts in rocks ranging in metamorphic grade from subgreenschist to amphibolite. He also noted that all the gold deposits occur within large-scale transcurrent and oblique-shear deformation zones and that the gold is localized in extensional structures within the brittle-ductile portion of the system.

Colvine further suggested that an apparent spatial association of the gold deposits with somewhat older felsic intrusives exists, and more so with the temporally more closely related intrusives of a more alkaline or lamprophyric affinity. He concluded that this gold deposition can therefore be viewed as an expression of a major late Archean tectonic episode.

Striking similarities can be seen between the lithologies, structural setttings, age relationships, nature and localization of felsic intrusive bodies and lamprophyric intrusives, the type of alteration, and geochemical features of the Vermilion district and these same features as described by Colvine and others for the remainder of the Superior province (Colvine

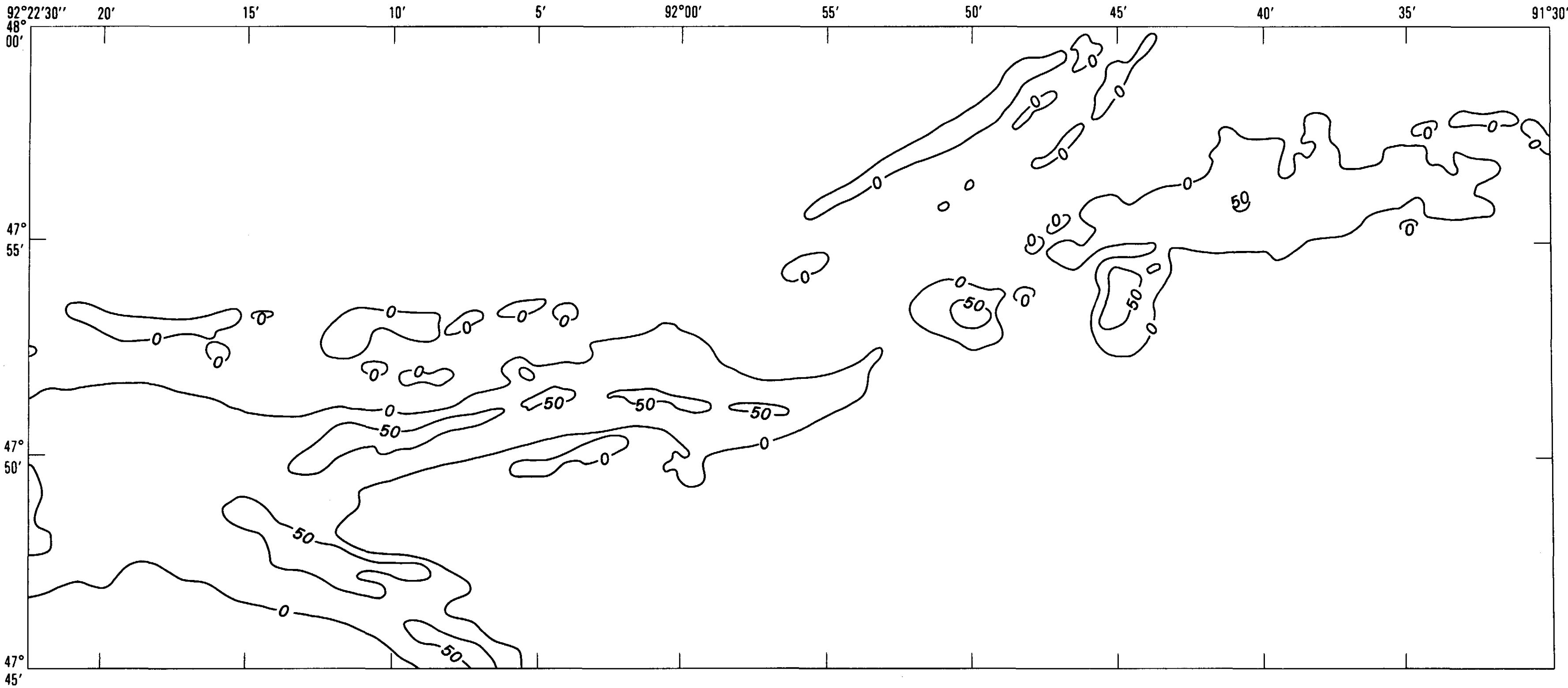


Figure 27. Simplified aeromagnetic contours of west-central Vermilion district, northeastern Minnesota. Contour interval 50 gammas. From Chandler (1983a, b).

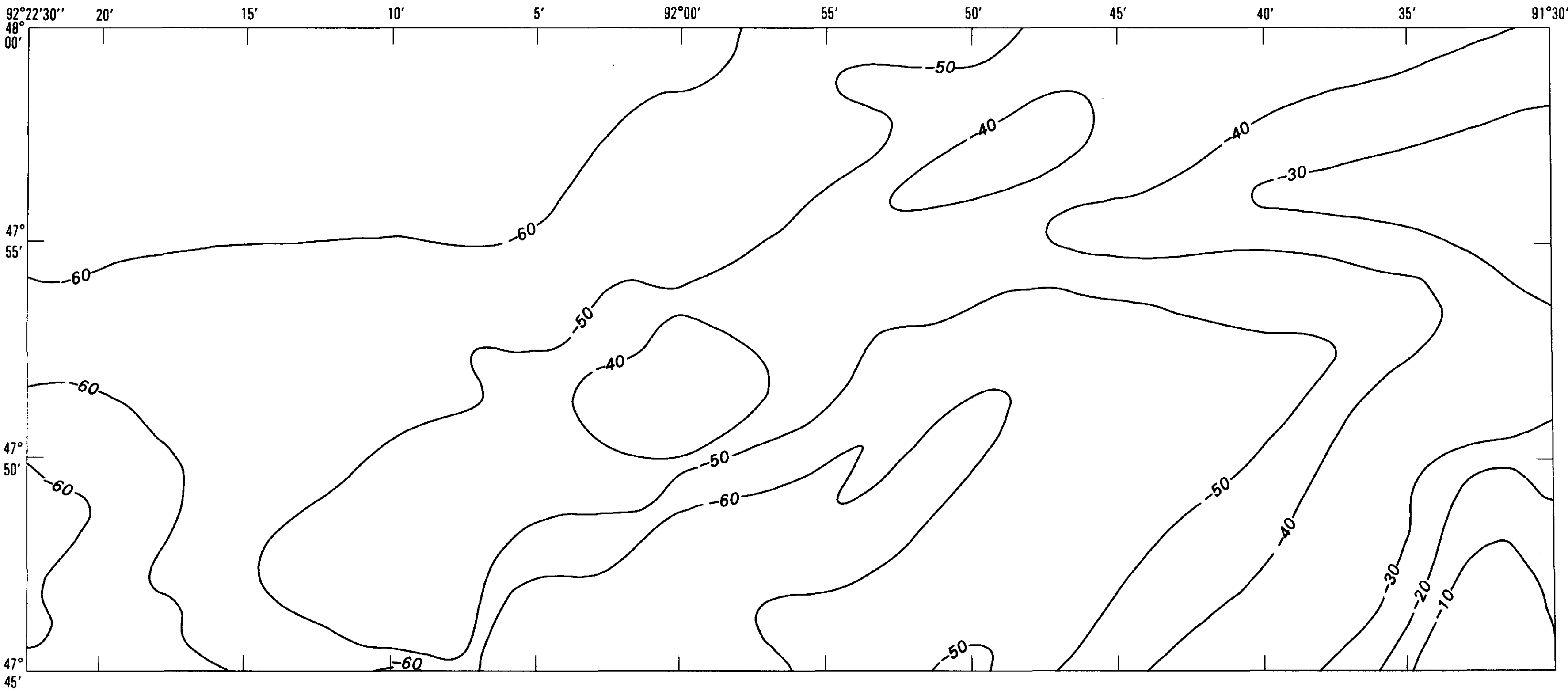


Figure 28. Simplified Bouguer gravity contours for west-central Vermilion district, northeastern Minnesota. Contour interval 10 milligals. From Ikola (1970).

and others, 1988; Colvine, 1989). It is equally important to remember that the west-central Vermilion district represents but a small percentage of the total area within northern Minnesota meeting these parameters.

The Cr-association anomaly, centered on Little Long Lake (pl. 2), encompasses approximately 61 km^2 (24 mi^2). The area is characterized by the presence of small mafic-ultramafic intrusives and fairly abundant sulfides. Platinum and palladium concentrations as high as 0.15 and 0.10 ppm respectively have been found in some outcrop samples collected within this area. This area is believed to hold some potential for the occurrence of economic concentrations of platinum group elements.

The association-based Cu and Cr value modification approach was applied to compensate for the subdued and somewhat erratic data from analyses of the glacial material-derived A-horizon soils. The values derived by this approach tend to fill in sporadic anomalies, eliminate spurious anomalous values, and accentuate anomalies within the Vermilion district.

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