

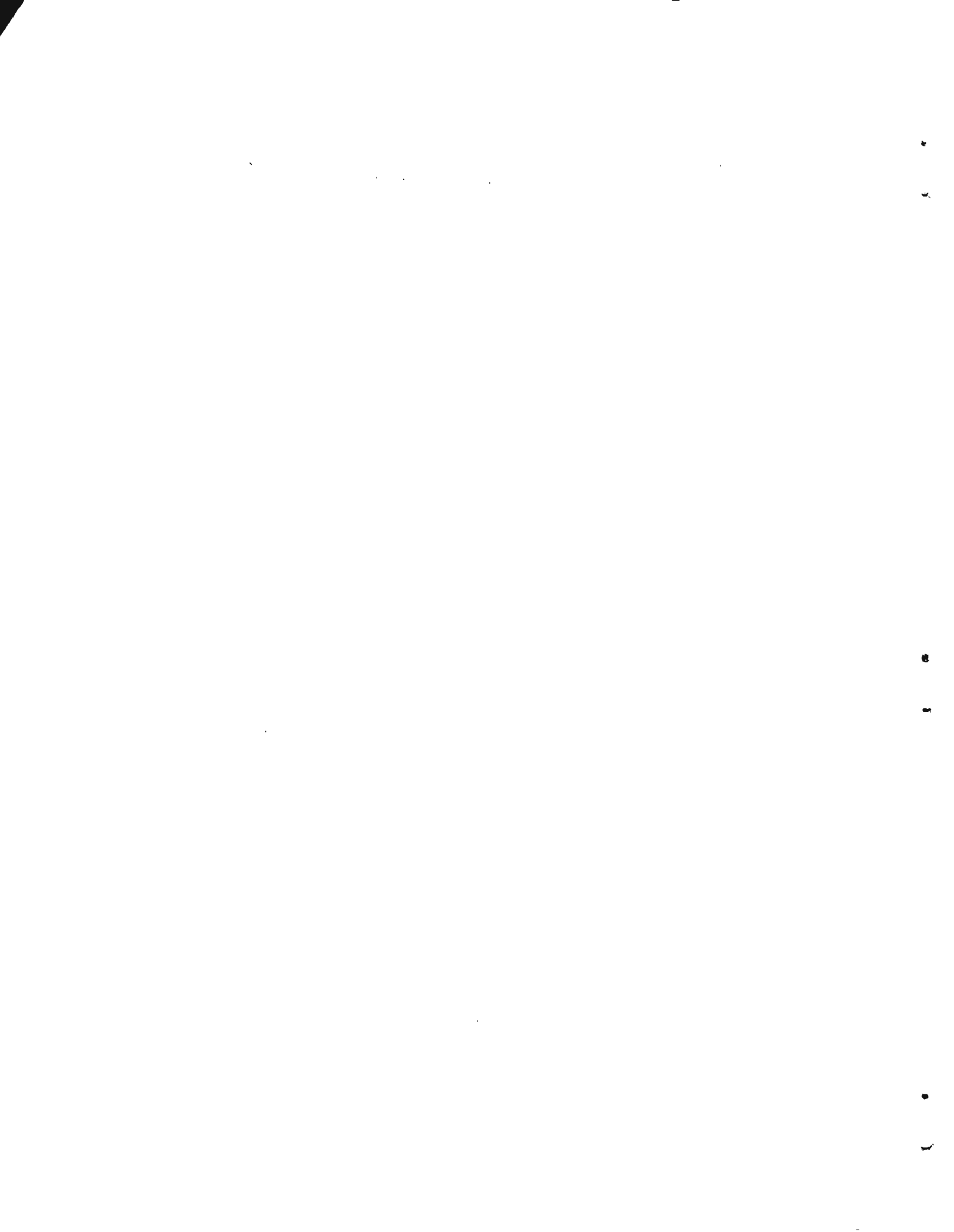
APPLICATIONS OF TREND SURFACE ANALYSIS
AND GEOLOGIC MODEL BUILDING TO MINERALIZED
DISTRICTS IN ALASKA

MIRL Report #11

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ABSTRACT

The Mineral Industry Research Laboratory, University of Alaska, has investigated the application of computers and statistics to mineral deposits in Alaska. Existing programs have been adapted and new ones written for the computers available at the University.

The methods tested are trend surface analysis and geologic model making. An existing coefficient of association program was converted to Fortran IV, but was not applied to an Alaskan problem. A trend surface is a mathematically describable surface that most closely approximates a surface representing observed data. In geologic model making, regression analysis is used to determine what geologic features are significant as ore controls. Coefficient of association compares samples to each other on the basis of a variable being present or absent.

Trend surfaces were computed for dips and strikes of geologic features (veins, faults, bedrock) for Southeastern Alaska, the Chichagof district, and the Hyder district. Results for the first two are presented as maps. Trend surfaces and residual maps were prepared for geochemical data from the Slana district, Alaska. A mineral occurrence model was made for a portion of the Craig Quadrangle, and potential values were computed for cells in the area. Appraisals of potential values by five geologists are compared with those of the model.

An IBM 1620 multiple regression program is included.

ACKNOWLEDGEMENTS

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Thanks are given to Mr. Philip R. Johnson of the Arctic Environmental Engineering Laboratory for the use of his multiple regression program and for his helpful discussions.

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INTRODUCTION

The computer, as is well known, has made possible the handling of large amounts of data, generally through statistics. Geology has always been capable of generating much larger quantities of data than could be handled, and in the past, analyses have necessarily been based on largely qualitative rather than quantitative considerations. Computer programs have been and are being written and applied to many phases of geology, and in the fall of 1966, the Mineral Industry Research Laboratory began a study of some of these. The study has been conducted in three stages. Stage I, the gathering of data, is a continuing process. Stage II is the development of new programs and the adaptation of existing ones to computers available at the University of Alaska. Stage III is the exploration of applications to mineral deposits in Alaska, especially in Southeastern Alaska. All three stages are inter-related, that is, if it is desired to test a new application, more data may have to be abstracted from the literature and a new program written or adapted.

So far, three main applications have been tried. Two of these involve trend surface analysis, and the third, geologic model making.

Trend Surfaces

A trend surface is a mathematically describable surface that approximates a surface representing observed data. If the equation that is to be used to describe the surface is

stated, then it is possible, by the method of least squares, to compute the surface that most closely approximates the original data. Thus if a simple linear equation in three unknowns is chosen:

$$Z = a + bX + cY$$

in which X and Y are coordinates north or south and west or east, and Z is something measured at those coordinates, the coefficients a, b, and c, are chosen so that only one plane surface is generated. This plane surface is the one for which

$$\sum (Z_1 - Z)^2 \text{ is minimum, where:}$$

Z_1 = computed value on the plane at a coordinate

Z = observed value at that coordinate

Such a plane of course is the simplest type of trend, and might well describe the distribution of sediment size on the continental shelf (Miller, Kahn, 1965).

Similarly, a quadratic equation can be chosen:

$$Z = a + bX + cY + dX^2 + eXY + fY^2$$

having the same property of least squares, or a cubic equation:

$$Z = a + bX + cY + dX^2 + eXY + fY^2 + gX^3 + hXY^2 + iX^2Y + jY^3$$

Such equations up to sixth degree have been computed in the present study. It may also be desirable to transform the data, e.g., take logarithms, squares, or square roots, and to then compute the surfaces. The higher the degree of the equation chosen, the more closely the surface generated can approximate the surface defined by the original data, since more inflections can be included. It must be kept in mind, however, when viewing trend surface maps that the pattern does not approximate

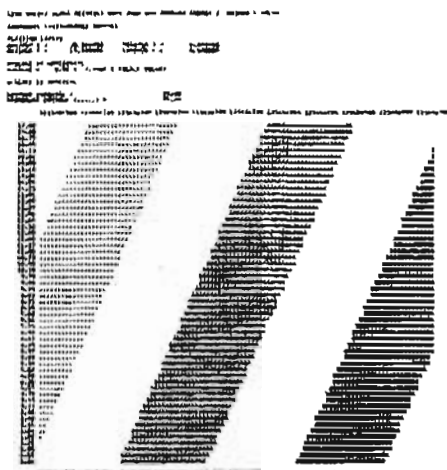
the true surface in areas away from the data points. If this were not so, it would be possible to apply trend surface analysis to an area and extend the trend without limit. Actually, negative and positive values, without physical meaning, often occur near the edges. Contours near the borders therefore, should be disregarded, unless it is known that adequate data were available there.

There immediately become apparent two general applications of trend surface analyses. (a) By computing a surface that varies gradually, local sharp variations are eliminated or at least subdued. This allows regional trends to be traced and projected. (b) If the computed values are subtracted from the observed values, or the trend surface from the actual surface, regional effects are removed, leaving accentuated anomalies. This removal of the regional trend has been applied for a long time to geophysical data; trend surfaces allow a refinement of the method previously unknown.

In making a trend map, the computer first computes Z values between the observed data points utilizing the equation produced. These values are then automatically contoured and the computed values subtracted from the observed values to give residuals. The residuals are contoured by hand. Figure 1 shows six trend surface maps made by the IBM 360 Model 40.

A complete description of the trend program, input, method, and output, for the trend surface program may be obtained by reference to MIRL Report No. 9 (Helner and Geller, 1967).

Some of the literature reviewed suggests the application



1



2



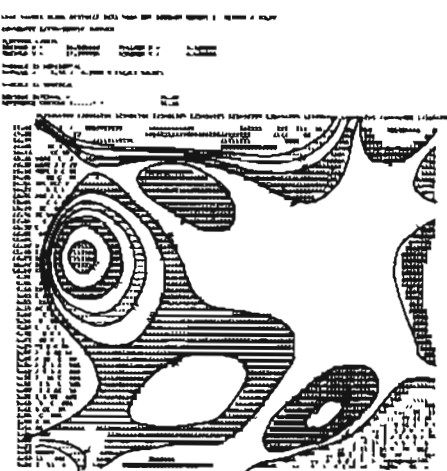
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4



5



6

Figure 1 Example Trend Surface Maps

of trend surface analysis to structural data. After studying this application, some caution is advised. Trend surface analysis is not a cure-all approach for handling data, and least of all for structural data. Structural information is difficult to quantify, and direction data (azimuths) must be carefully handled so as not to change the true picture radically, or even make the data meaningless. For example, the average strike of N 60° W and N 60° E could be due N or due E.

Structural data for Southeastern Alaska, the Chichagof district and the Hyder mining district were gathered and trend surfaces computed. The results of the first two are included in this report. Data available from the Hyder district were not sufficient to produce significant results and that district, therefore, was not included.

Data Gathering

Data on mines in Southeastern Alaska were gathered from several sources. Published and unpublished reference works were consulted first (Cobb, 1959; Cobb, personal communication; Cobb, 1960; Cobb, 1962). Copies of index cards of unpublished State Division of Mines and Minerals reports were also obtained from the Division. The individual properties were then looked up, and pertinent information recorded on cards, one card to each property. The unpublished reports of the Division of Mines and Minerals were also examined and information abstracted and recorded.

Geologic Model Making by Regression Analysis

The Mineral Industry Research Laboratory has investigated the use of regression analysis for selection of target areas. Basically, regression analysis is a mathematical tool which enables the computation of best fitting surfaces to a set of independent variables by the least squares criterion.

The geologist, in picking what he considers to be a favorable place to prospect, is guided by a number of factors. Most of these are geologic, but analysis of past history and geophysical and geochemical tools are also used. Examples of geologic factors, which, on a reconnaissance basis may be taken from aerial photographs or maps, are nearness of intrusive rocks, faults, and type of bedrock. Selections based on such criteria may be biased by the person doing the analysis. Controls for ore in one section of the country with which the geologist is familiar may influence his choice; these controls may or may not be significant in the area being investigated. Another difficulty encountered by an individual is the inability to keep in mind and judge simultaneously more than a few independently varying controls. Means are available for removing personal bias from the selection of search areas, and for keeping track of a large number of variables.

There are two points to remember: (1) A trained and experienced geologist may develop a "nose for ore" that is at times very successful, and (2) a computer simply gives answers based on information furnished to it. Under certain circumstances it can be a valuable complement to the geologist noted

above. It is true that a computer does remove the bias from the choice of an area, but only because it gives 100% literal answers based upon its information. One should heed the advice of E. E. Morison (1966) quoted in Science, "Thus they (earlier machines) set clear limits to man's ineptitude (by breaking down). For the computer the limits, I believe, are not so obvious. Used in ignorance or stupidity, asked a foolish question, it does not collapse; it goes on to answer a fool according to his folly. And the questioner being a fool will go on to act on the reply."

COEFFICIENT OF ASSOCIATION PROGRAM

An existing coefficient of association program by Kaesler, Preston, and Good, (State Geological Survey of Kansas, Special Distribution Publication 4, 1963) written in Fortran II was converted to Fortran IV. This program is designed for computing simple matching coefficients for as many as 70 items with as many as 70 characters or observations in each. It compares samples to each other on a basis of a variable being present or absent (Sokal & Michener, 1958, p. 1417). Although the program has been adapted and is ready for use, it has not been applied to any major problems here. The program is best described by quoting Kaesler, et.al, (1963).

"A number of characters is examined for each sample (preferably 35 or more) and a 2 is recorded for the property or condition if present, a 1 for the property or condition if absent. Each column of data (sample) is then compared with all others, and the number of

character states each column has in common with every other column is recorded. Character states in common are called "matches." If data from two samples from a larger study were

2	1
1	2
1	1
2	2
2	2

the number of matches would be 3. This number of matches is divided by the total number of comparisons (5 in this case) to give the coefficient of association or simple matching coefficient (here $3/5 = 0.6$).

"When comparing more than 2 samples, one should not use data that show no change of state in a row (Sokal and Sneath, in preparation). The reason for this restriction is obvious if we consider an extreme hypothetical case.

"Suppose that Pennsylvanian cyclothems have been sampled for the following fossils - Olenellus (Cambrian), Strophomena (Ordovician), Polydiexodina (Permian), and Acanthoscaphites (Cretaceous). Because none of these fossils were found, the data would have perfect matches at all localities, and the computed coefficients of association would equal one.

"Similarly, in a mineralogical study of sandstone it generally would be unwise to include quartz because it would normally be present in all samples and would lead to an unjustifiably large coefficient

of association."

The simple matching coefficient indicates the degree of similarity among samples reduced to two states (Kaesler, et.al, 1963).

The equation for the coefficient is:

$$S_{sm} = \frac{m}{n}$$

Where: S_{sm} = the coefficient

m = the number of matches

n = the total number of comparisons

Lack of association is indicated by 0.00, maximum correlation by 1.000.

Sample Problem

The following description, problems, etc. are taken directly from Kaesler, et.al. (1963).

"In an area being investigated ecologically, samples were obtained at 5 stations. Six ostracode species were found in the samples, but not all were present at each station. Using 2 for "ostracode present" and 1 for "ostracode absent," the data are:

<u>Station</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Species					
1	2	1	2	1	2
2	2	1	1	2	2
3	2	1	2	2	1
4	2	1	1	1	1
5	2	1	2	1	2
6	1	2	1	2	2

Here $M = 5$, $N = 6$. (See next page)

A Fortran IV listing follows.

```

      DIMENSION ID(70,70),IZ(70),S(70),T(70)
10  READ(1,11) M,N
11  FORMAT(10X,12,2X,12)
12  AN=N
13  ANI=1./AN
14  DO 140 I=1,N
15  READ(1,61) (IZ(K), K=1,M)
16  FORMAT(10X,70I1)
17  DO 130 J=1,M
18  IF(IZ(J)-1)110,110,120
19  ID(I,J)=-1
20  GO TO 130
21  ID(I,J)=1
22  CONTINUE
23  CONTINUE
24  WRITE(3,151)
25  FORMAT('0' 22X,36HTABLE OF COEFFICIENTS OF ASSOCIATION )
26  DO 290 J=1,M
27  DO 270 K=1,M
28  ISUM=0
29  IF(J-K)200,260,270
30  DO 220 I=1,N
31  ISUM=ISUM+ID(I,J)*ID(I,K)
32  CONTINUE
33  S(K)=ISUM
34  T(K)=0.5*S(K)*ANI+0.5
35  GO TO 270
36  T(K)=1.0000
37  CONTINUE
38  WRITE(3,281) J
39  FORMAT(12X,12HROW NUMBER = ,I3)
40  WRITE(3,286) (T(K),K=J,M)
41  FORMAT(10X,10F7.4)
42  CONTINUE
43  GO TO 10
      END

```

Listing of nomenclature.

M = number of columns.
N = number of rows.
I = row index.
J = column index.
K = dummy column index for comparison with J.
ISUM = number of matches minus number of mismatches.
S(K) = floating point equivalent of ISUM.
T(K) = coefficient of association or simple matching coefficient. K is incremented from J = 1 to M and is punched for each value of J from 1 to M. Diagonal values are set equal to 1.0000.
IZ(K) = input data found on one card, K = 1, 2, ..., M.
ID(J,K) = data matrix stored in core of computer; the 1's have been converted to -1 and the 2's to +1.

LINEAR ELEMENTS OF SOUTHEASTERN ALASKA

Twenhofel and Sainsbury (1958) have studied aerial photographs of Southeastern Alaska and plotted the linears observed on a map with a scale of 25 miles to the inch. They believe that most of the linears represent faults or fault scarps. Their map is reproduced in Figure 2. In the present study, the map was divided into squares 30' wide in an east-west direction, and 15' wide in a north-south direction. The average strike of the linears falling within a circular area of about 240 square miles at each of the corners was determined visually, and this strike value assigned to the coordinate. It should be noted that this average regional strike is not necessarily the same as the strike of the major linears.

The results of trend surface analysis are shown in Figures 3 and 4. Figure 3 is a map showing contours of the sixth degree surface. Important and potentially important ore deposits are indicated on this map by stars. These deposits from north to south are:

- Klukwan (iron)
- Berners Bay (gold)
- Eagle River (gold)
- Juneau (gold)
- Funter Bay (nickel, gold)
- Bohemia Basin (nickel)
- Sitka (gold)
- Windham Bay (gold)
- Hyder (gold)

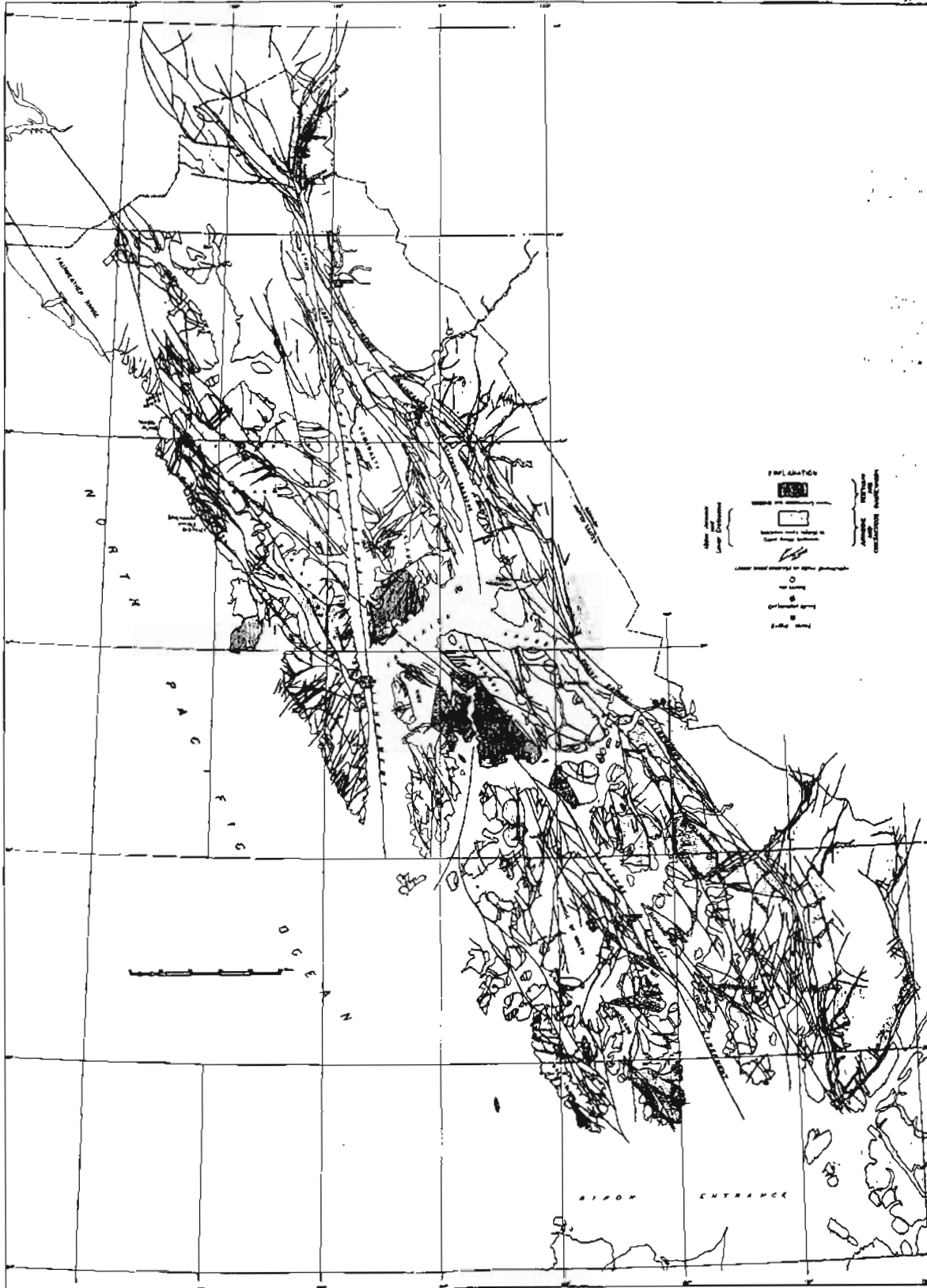


Figure 2 LINEAR TRENDS IN SOUTHEASTERN ALASKA
 Distribution of rocks taken from Baddington and Chapin (1929, Pl. 1, 2). Base map from Tongass National Forest, Alaska, U.S. Dept. Agriculture, Forest Service
 Note: Adapted from plate 2, Bull. Geol. Soc. Am., Vol. 69

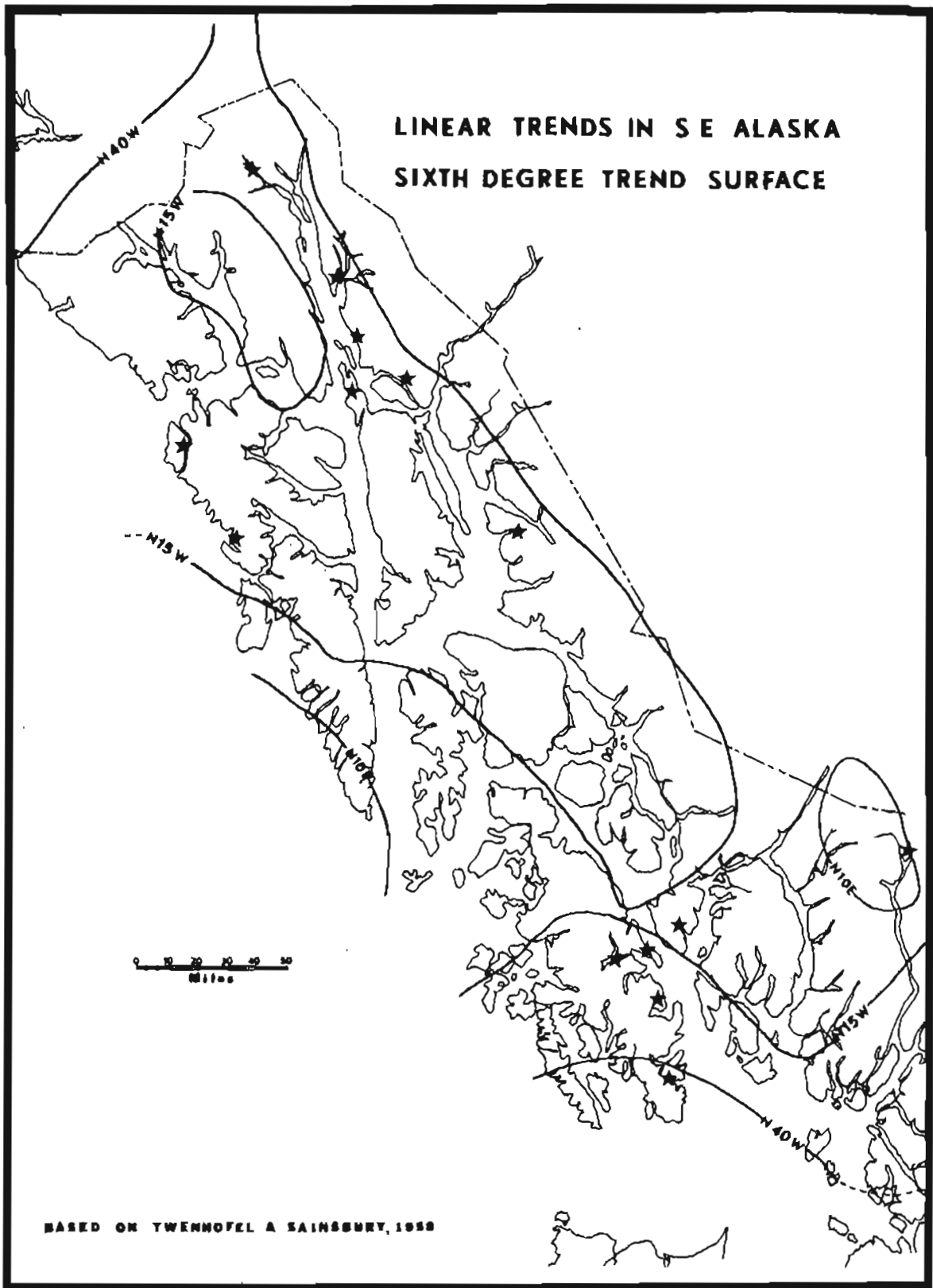


FIGURE 3

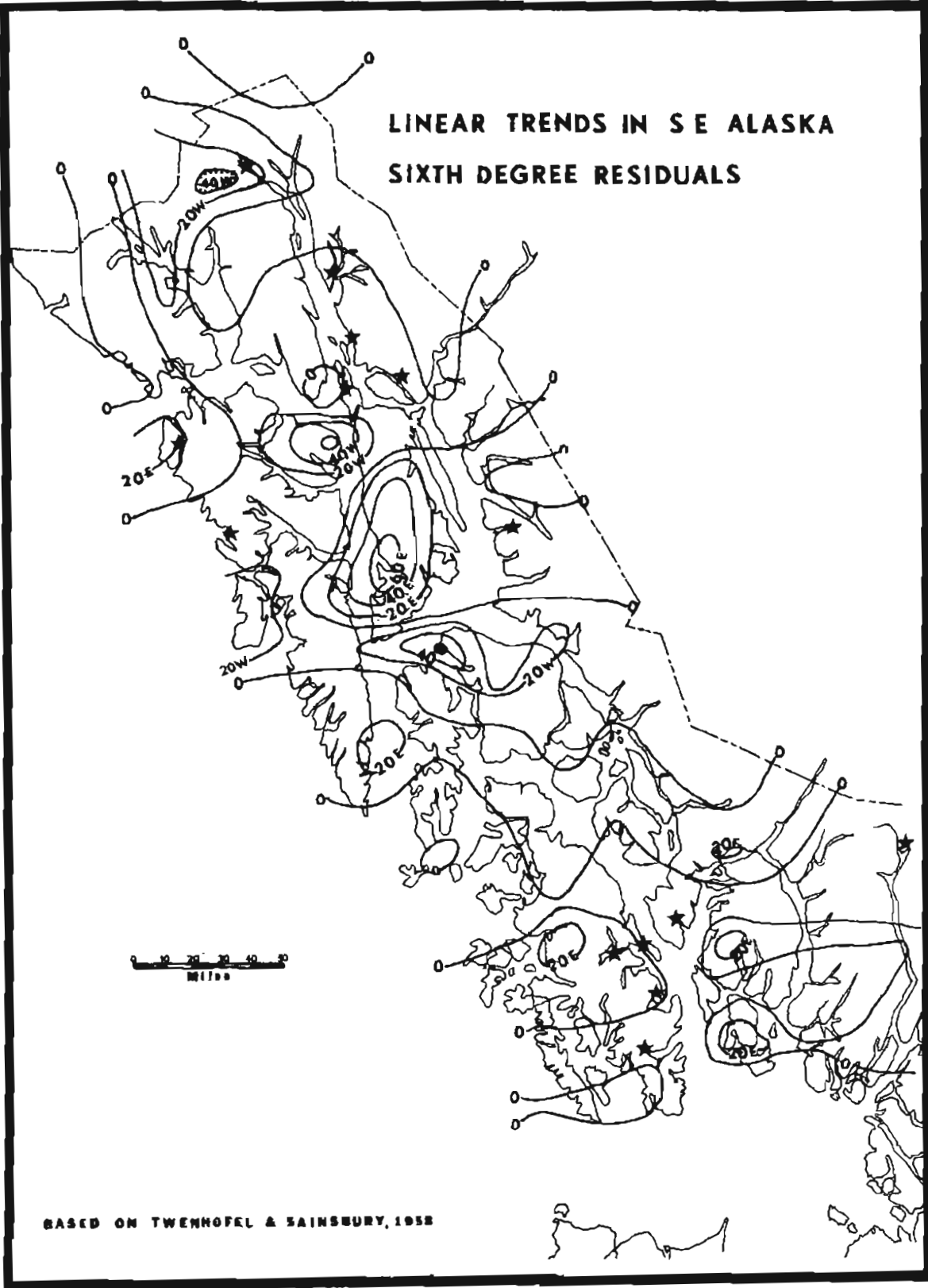


FIGURE 4

Helm Bay (gold)

Kasaan Peninsula (copper, gold)

Jumbo Basin (copper, gold)

Dolomi (gold)

Ross-Adams (uranium)

Aside from the information that the regional trend swings westerly in the north and south, this map tells little about the relationship of mines to structure. Figure 4, the sixth degree residual map, however, indicates that only two deposits, Klukwan and Bohemia Basin, lie in areas of anomalous strike. From this it is concluded that ore deposits in Southeastern Alaska tend to occur along regional trends of lineaments, a conclusion that has been reached on strictly geological information by several workers (e.g., Twenhofel and Sainsbury, 1958, p. 1441).

CHICHAGOF DISTRICT

Twenty-nine mines and prospects, as described in U. S. Geological Survey Bulletin 929 (Reed and Coats, 1942) have been plotted on maps, and various structural data have been analyzed. Trend surface maps from first to sixth degree were made, as well as maps of residuals and original data. The structural elements analyzed are strike and dip of the veins; strike of linears and strike and dip of bedrock. The linears were mapped from aerial photographs; most of them are believed to be faults or fault scarps.

A weakness of the data is that although there are both major producers and undoubtedly worthless prospects, yet there

is very little on which to rank each deposit. The Chichagof mine (\$13 million production) and the Hirst-Chichagof mine (\$2.5 million production) are identified by special symbols on all maps.

Data are presented as contour maps. Note that azimuths read clockwise from west, so that 90° is north.

Strike of Veins

Figures 5, 6, and 7 are plots of original data, fourth degree trend surface, and fourth degree residuals of strike of veins. The map of original data shows that veins are formed in faults that trend westerly in the north, northwesterly in the central map area, and northerly in the east and south. The trend surface map also roughly approximates this pattern. The plot of residual values indicates that in most parts of the area the mineralized veins are on the regional trend, but that south and east of Chichagof, they strike somewhat more westerly (negative residuals). Standard deviation = 22.3° , correlation coefficient = 0.83.

Dip of Veins

Figures 8 and 9 show the original data and fourth degree trend surface for dip of veins. Most mineralized veins range in dip from 50° to 80° . The plot of residuals, (Figure 10) indicates that there are few deviations from the regional trend. Standard deviation = 11.8° , correlation coefficient = 0.60.

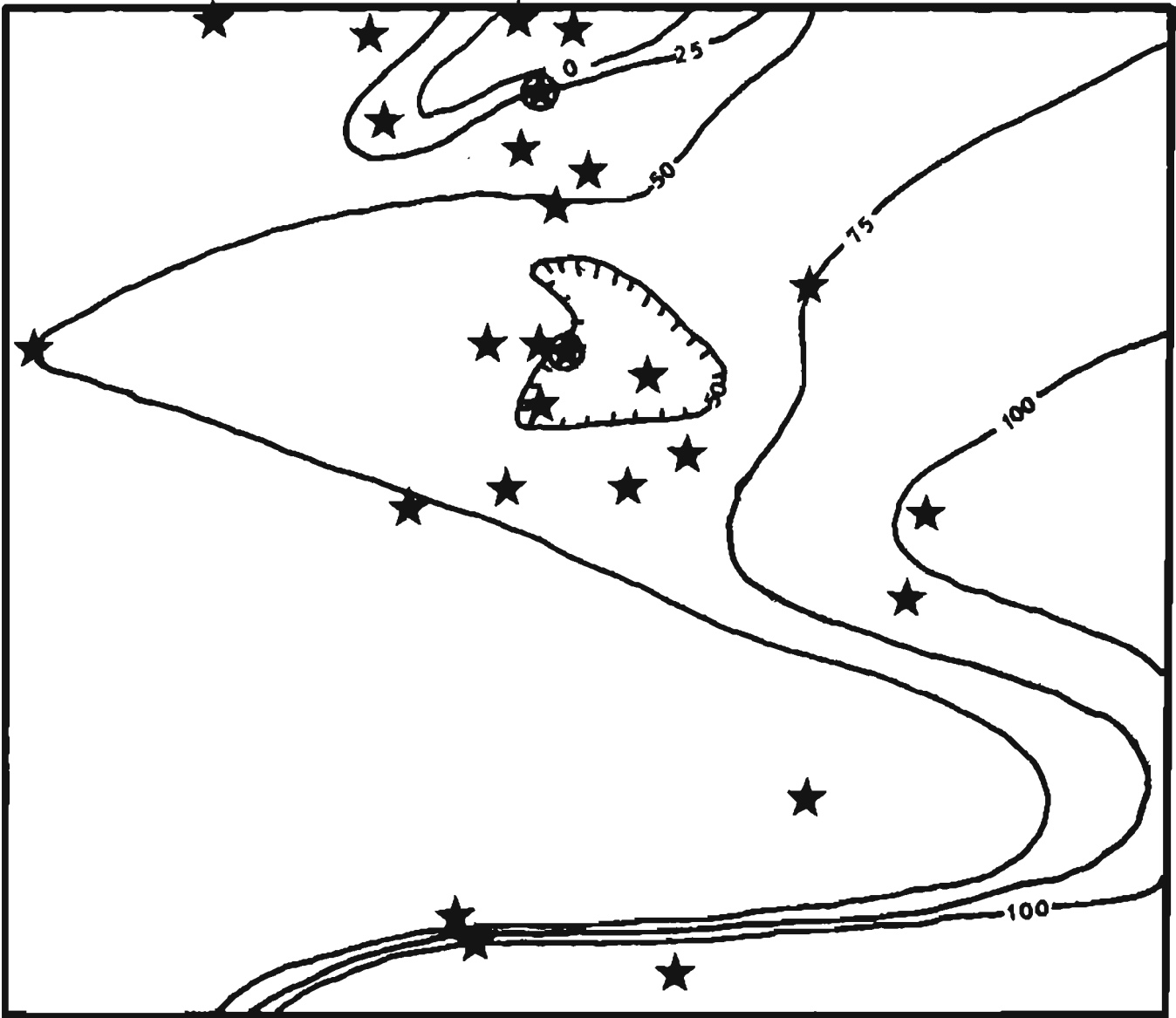


Figure 5 - Strike of Veins, Chichagof District, S.E. Alaska - Original Data

Contour Interval = 25°
 ★ = Mine or Prospect ★⊙ = Major Producer
 Azimuths in degrees clockwise from west.

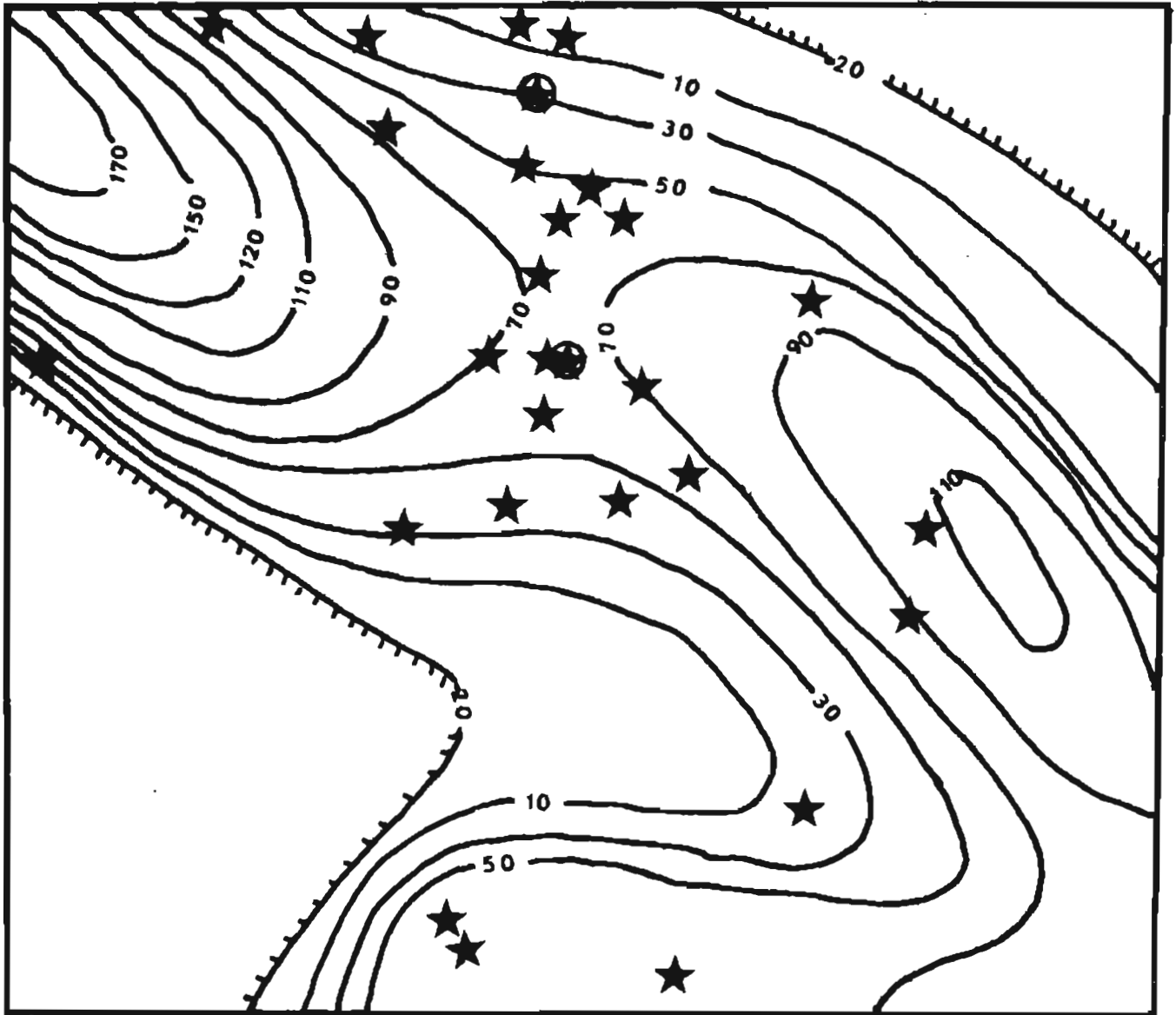


Figure 6 - Strike of Veins, Chichagof District, S.E. Alaska -
Fourth Degree Trend Surface

Contour Interval = 20°

★ = Mine or Prospect Ⓢ = Major Producer
Azimuths in degrees clockwise from west.

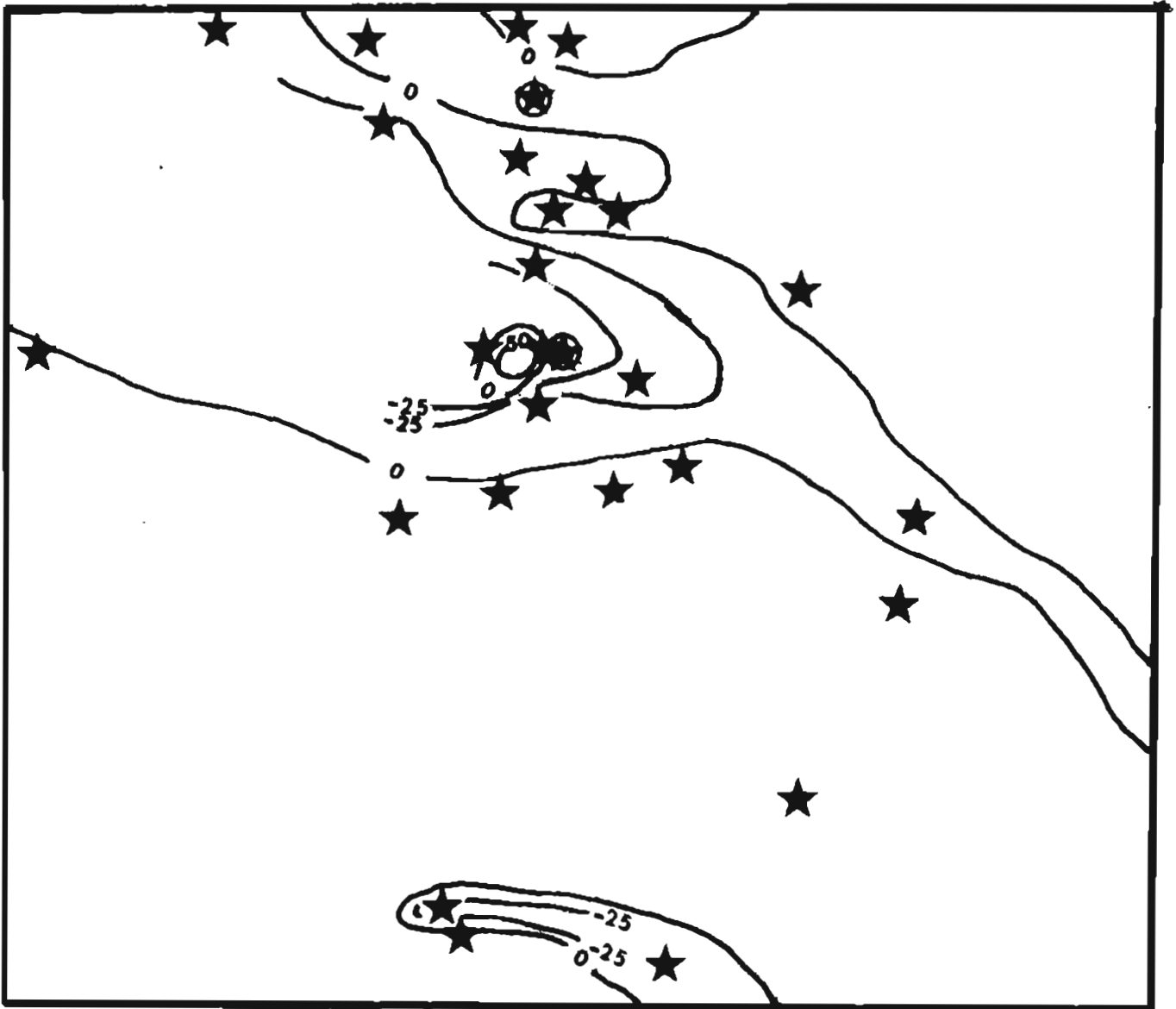


Figure 7 - Strike of Veins, Chichagof District, S.E. Alaska -
Fourth Degree Residuals

Contour Interval = 25°

★ = Mine or Prospect ★⊙ = Major Producer

Contours:

+ = East

- = West

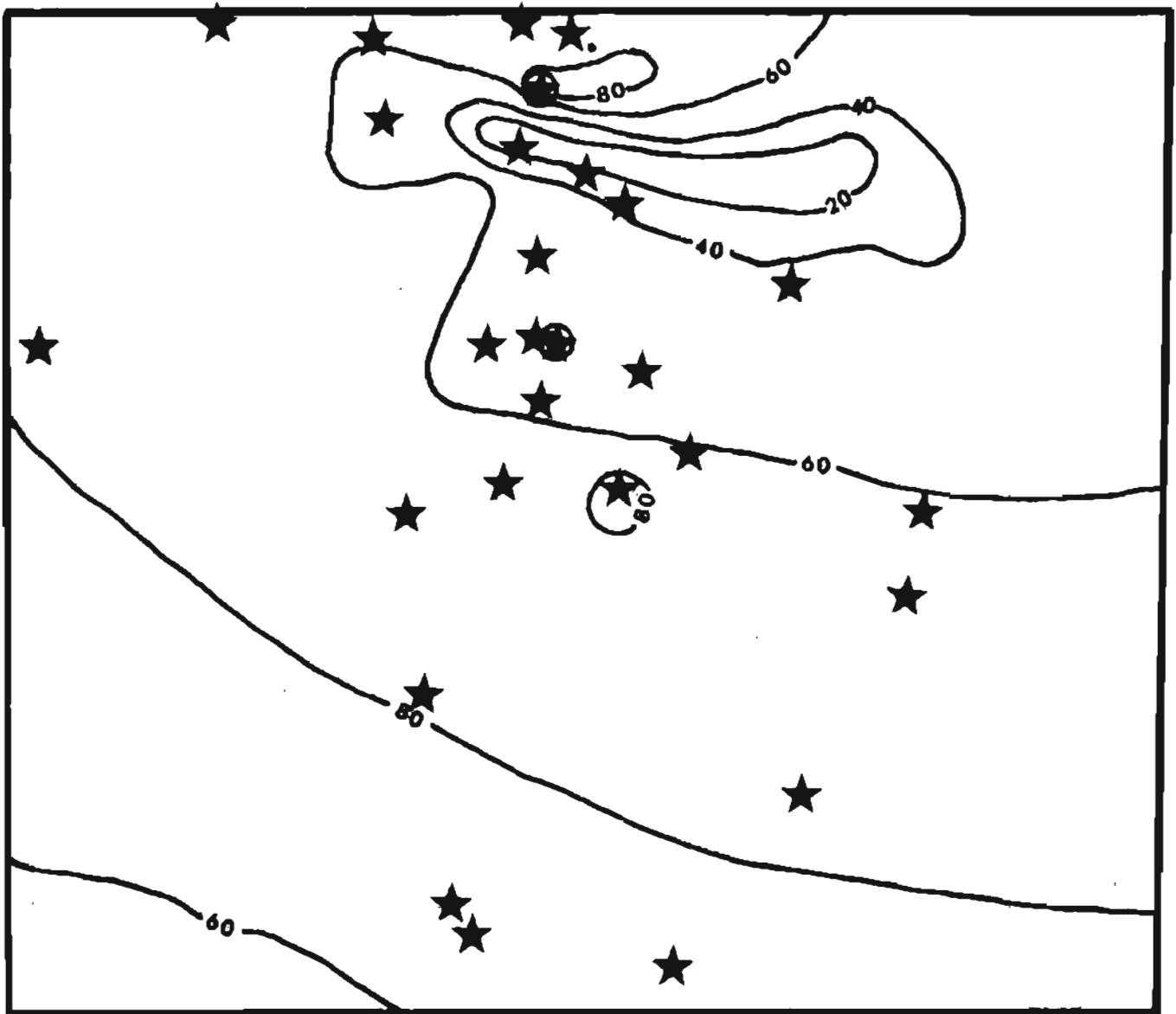


Figure 8 - Dip of Veins, Chichagof District, S.E. Alaska - Original Data

★ = Mine or Prospect ● = Major Producer
 Contour Interval = 20°

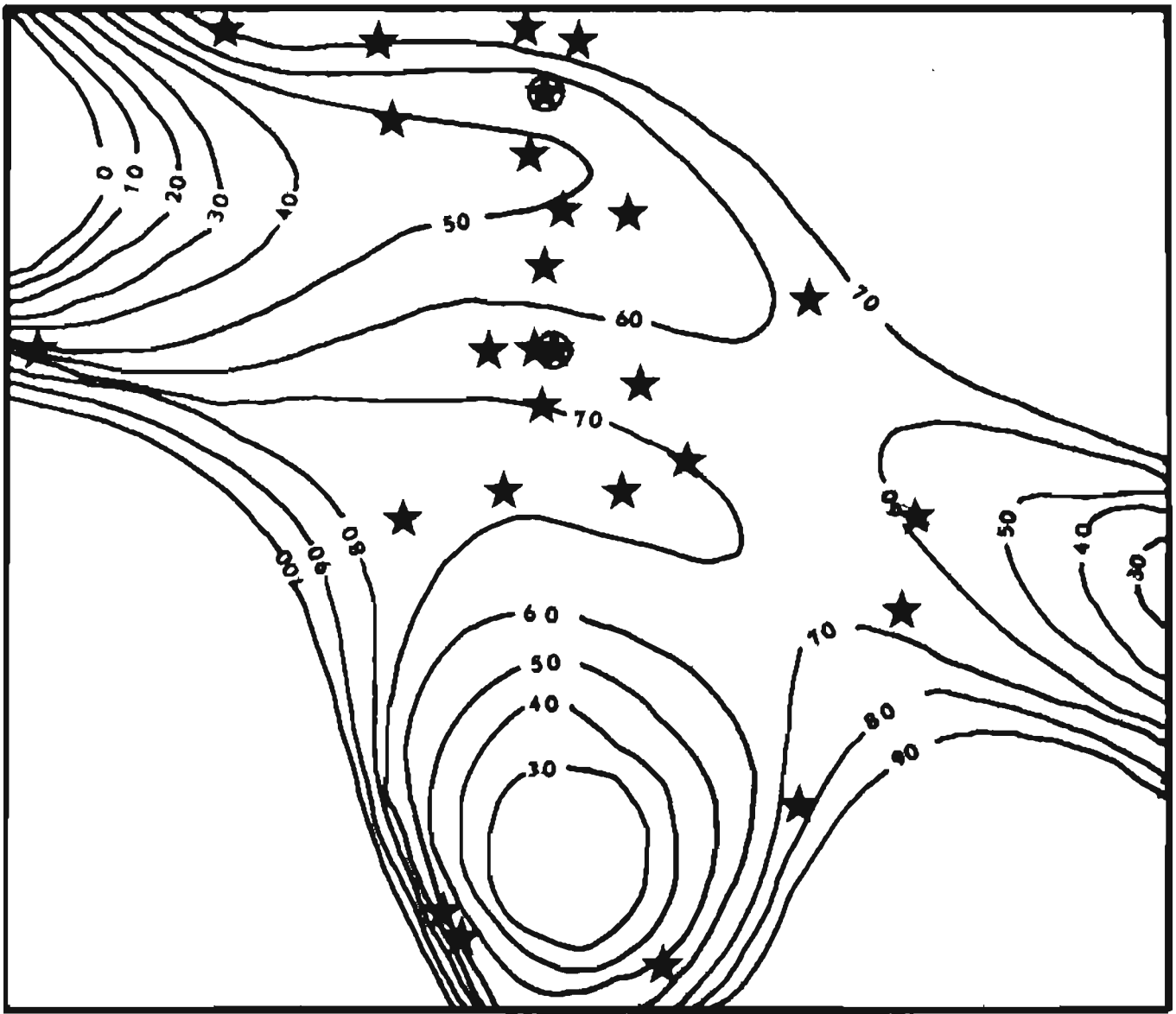


Figure 9 - Dip of Veins, Chichagof District, S.E. Alaska -
Fourth Degree Trend Surface

Contour Interval 10°

★ = Mine or Prospect ⬤ = Major Producer

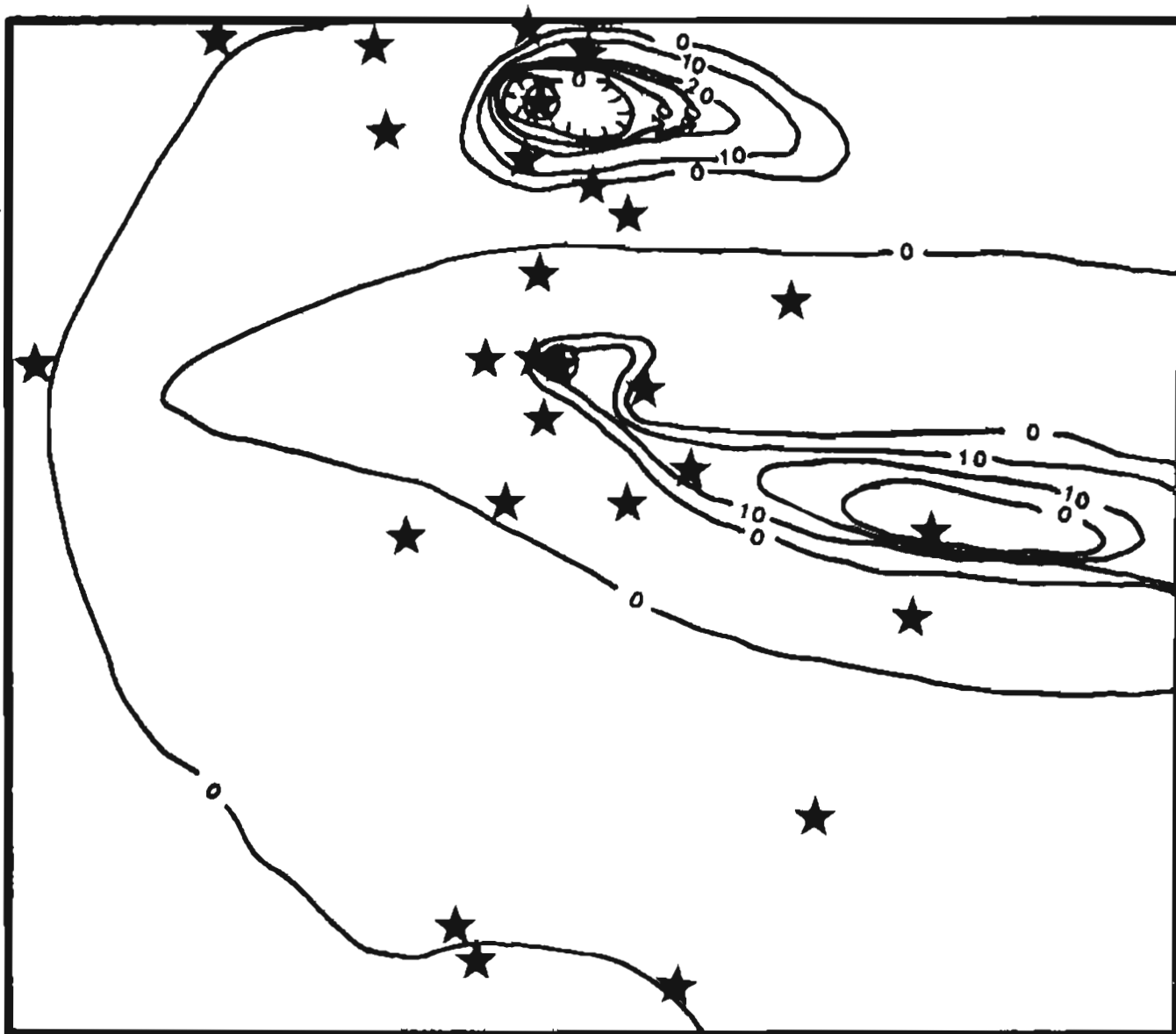


Figure 10 - Dip of Veins, Chichagof District, S.E. Alaska -
Fourth Degree Residuals

★ = Mine or Prospect ⊛ = Major Producer
 Contours:
 + = East
 - = West

Strike of Linears

Figure 11 shows some of the principal linears of the district as interpreted from aerial photographs in U.S.G.S. Bulletin 929. Figure 12, the sixth degree trend surface, indicates that the mineralized veins all lie in areas where the regional trend of faults varies from N 40° W to N 50° W. The residual map, Figure 13, indicates that only three prospects occur in areas where the linears vary more than 10° from the regional trend, and that a 16° deviation is the maximum. In any area, those faults which conform to the regional trend are those mineralized. Standard deviation = 10.43°, correlation coefficient = 0.65.

Strike of Bedrock

Figure 14, showing strike of bedrock, indicates that there is some tendency for prospects to occur in regions where the strike is N 40° to 50° W. The regional trend, Figure 15, indicates a concentration of veins between N 50° W and N 60° W. Figure 16 shows that the deviations from the regional trend are small. Apparently, there is little tendency for mineralized veins to occur along the regional strike of bedrock, although there is a preference, as noted, for a certain range of strikes. Standard deviation = 8.9°, correlation coefficient = 0.63.

Dip of Bedrock

No relationship is apparent between dip of bedrock and veins (Figure 17). The fourth degree trend surface (Figure 18) indicates a slight preference for the steeper dips (60-70°).

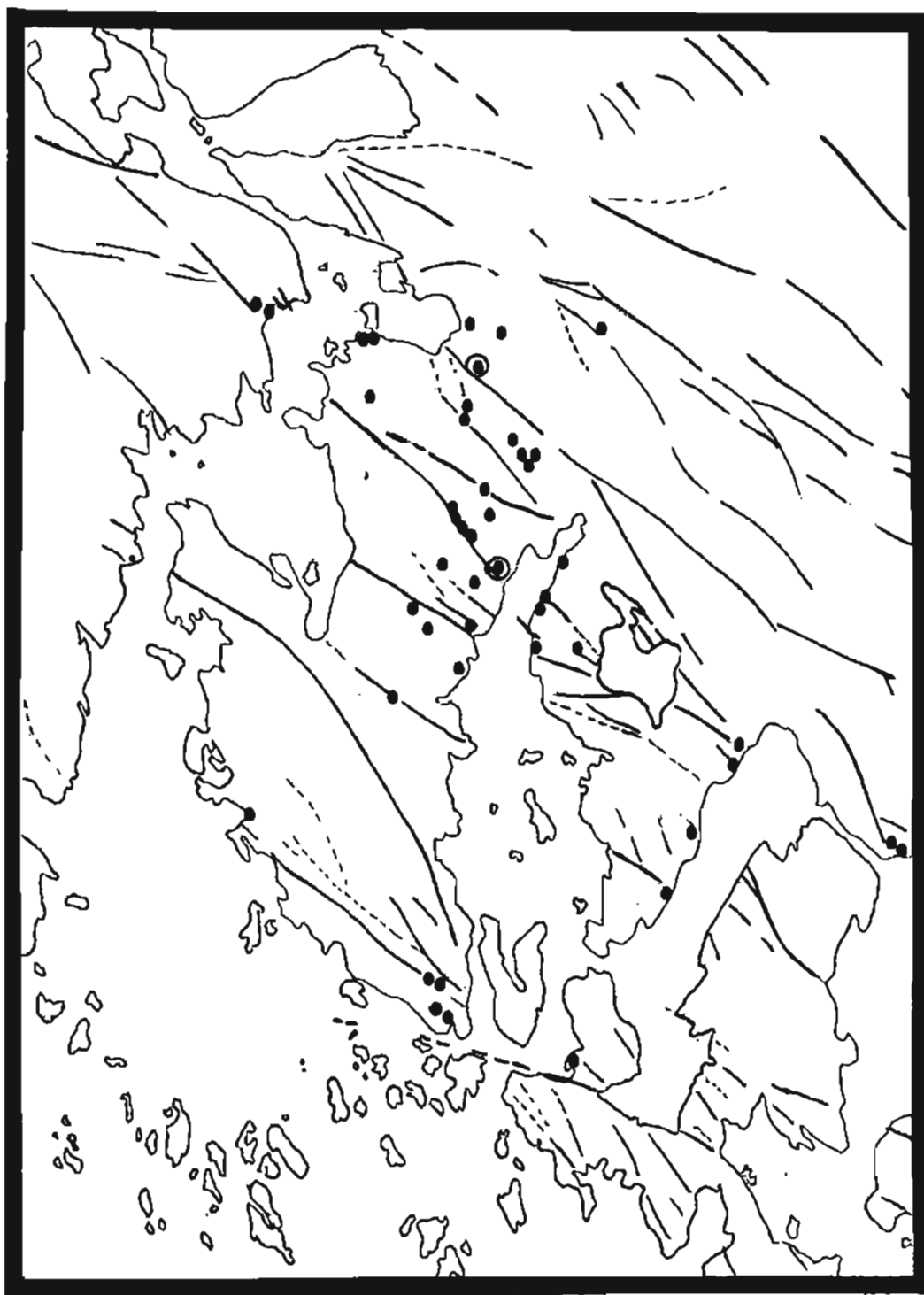


Figure 11 - Linears in Chichagof District, S.E. Alaska

● Mine or Prospect
○ Major Producer
(After U.S.G.S. Bull. 929)

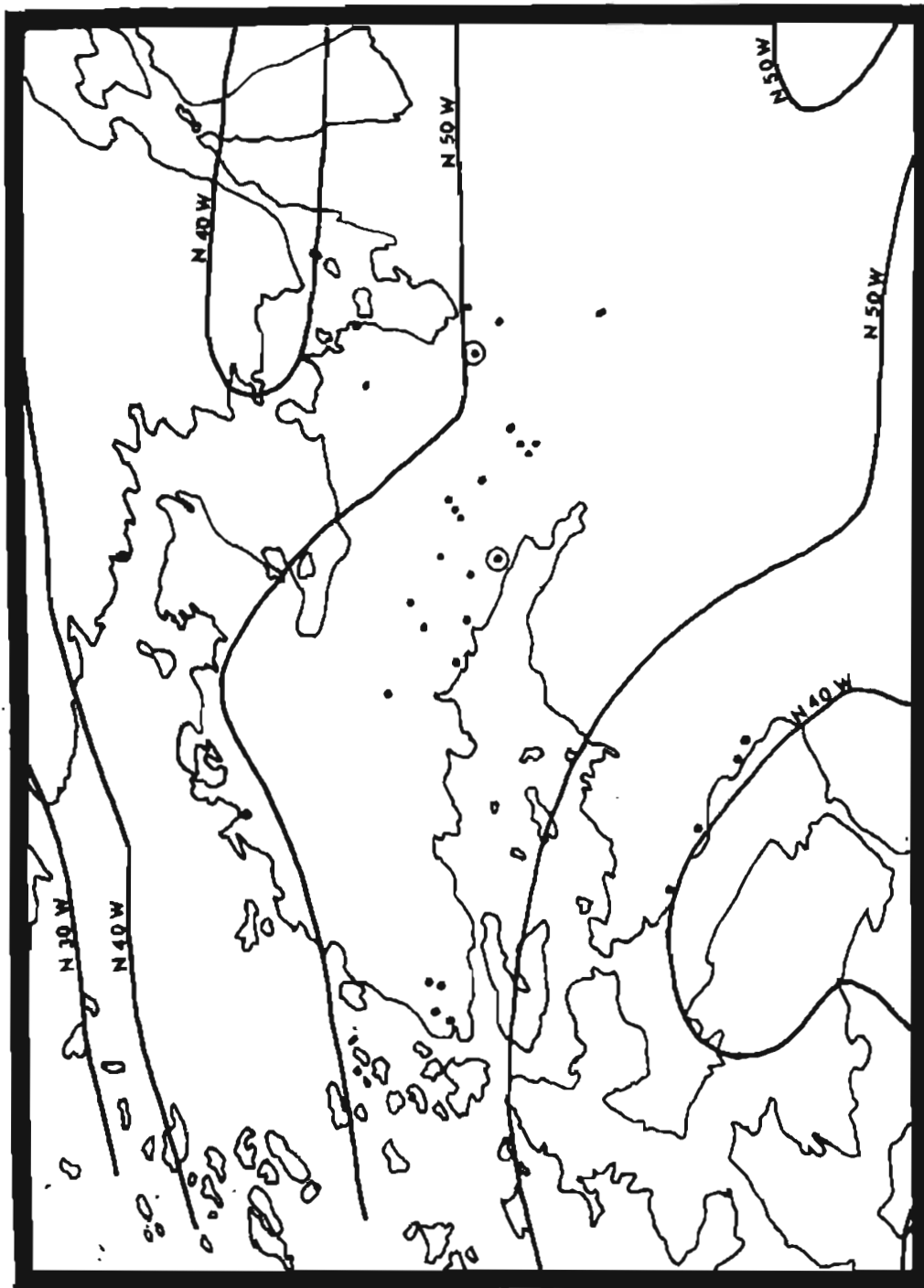


Figure 12 - Strike of Linears, Chichagof District, S.E. Alaska - Sixth Degree Trend Surface.

Contour Interval = 10°

● = Mine or Prospect ⊙ = Major Producer

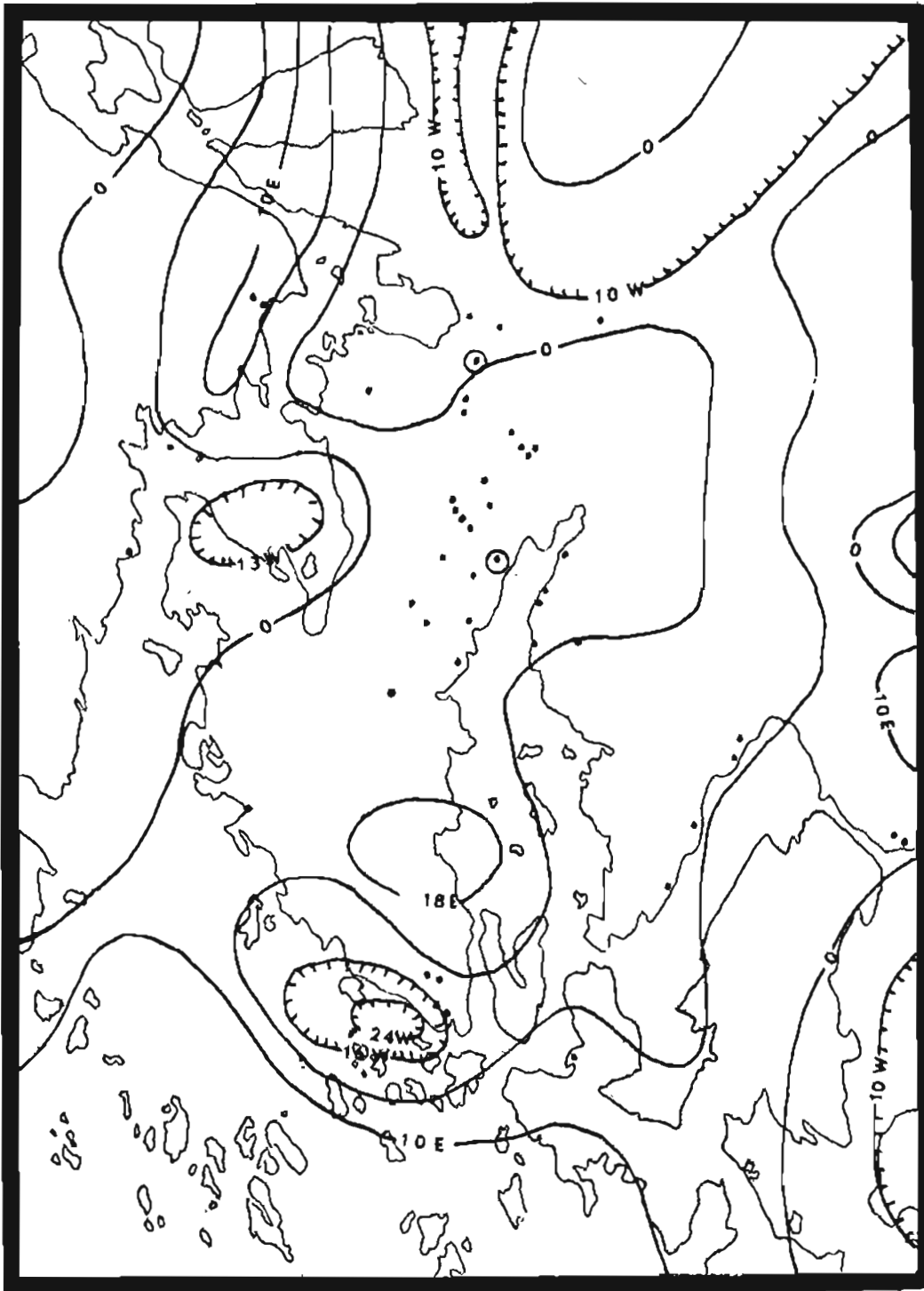


Figure 13 - Strike of Linears, Chichagof District, S.E. Alaska -
 Sixth Degree Residuals
 • = Mine or Prospect ⊙ = Major Producer
 Contours in degrees

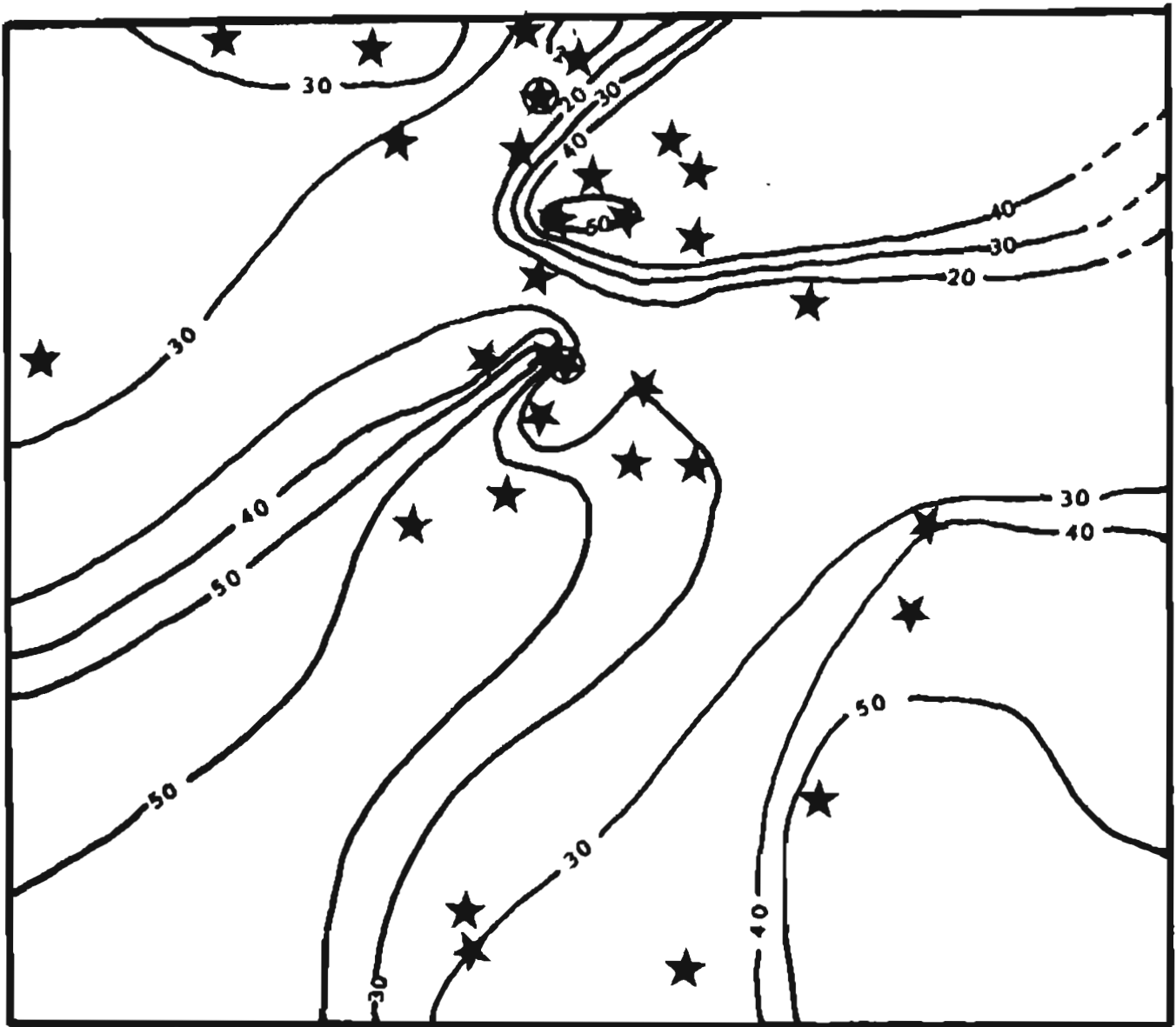


Figure 14 - Strike of Bedrock, Chichagof District, S.E. Alaska - Original Data

★ = Mine or Prospect

⊙★ = Major Producer

Azimuths in degrees clockwise from west.

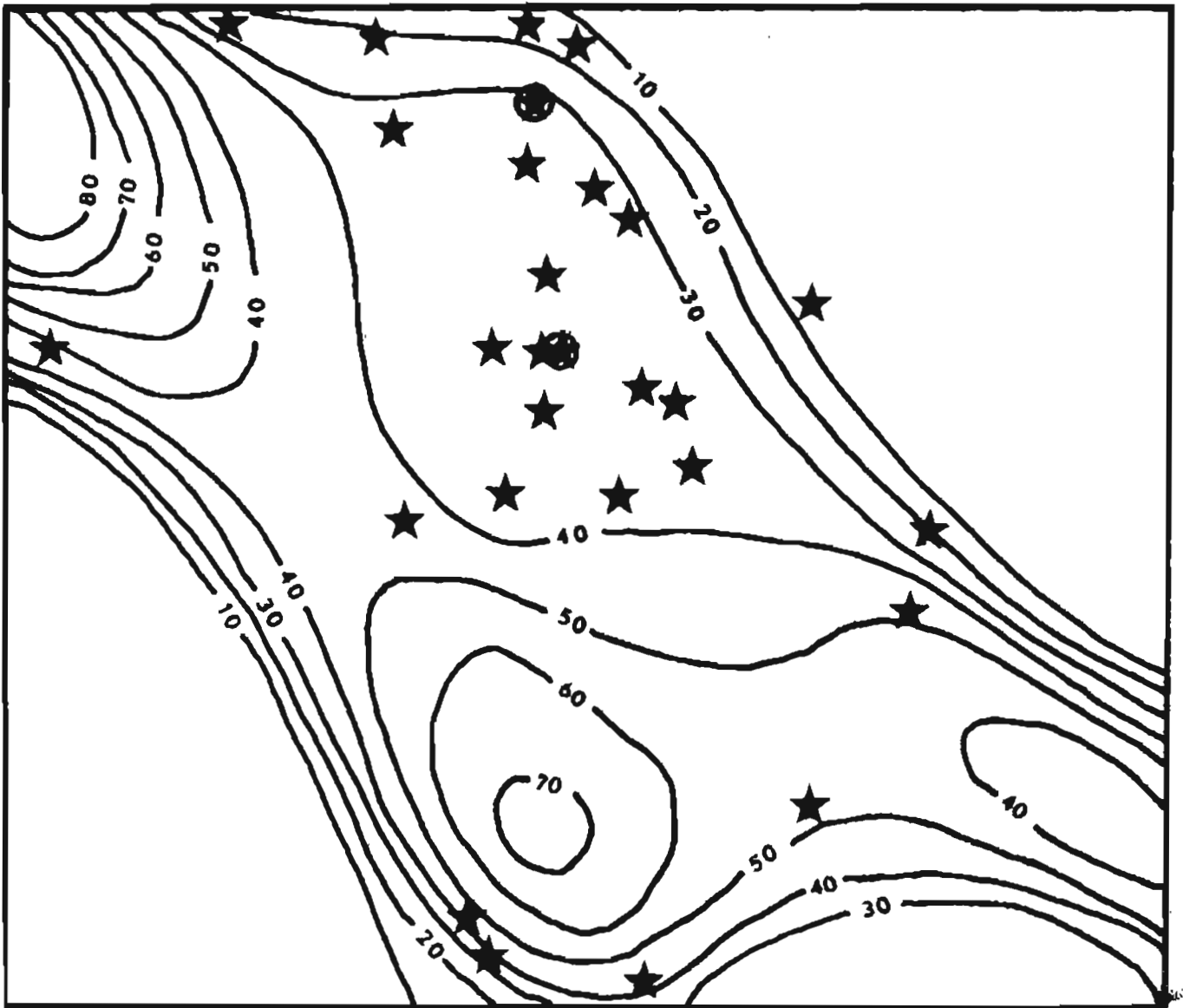


Figure 15 - Strike of Bedrock, Chichagof District, S.E. Alaska - Fourth Degree Trend Surface.

★ = Mine or Prospect ★ = Major Producer
 Contour Interval = 10°
 Azimuths in degrees clockwise from west.

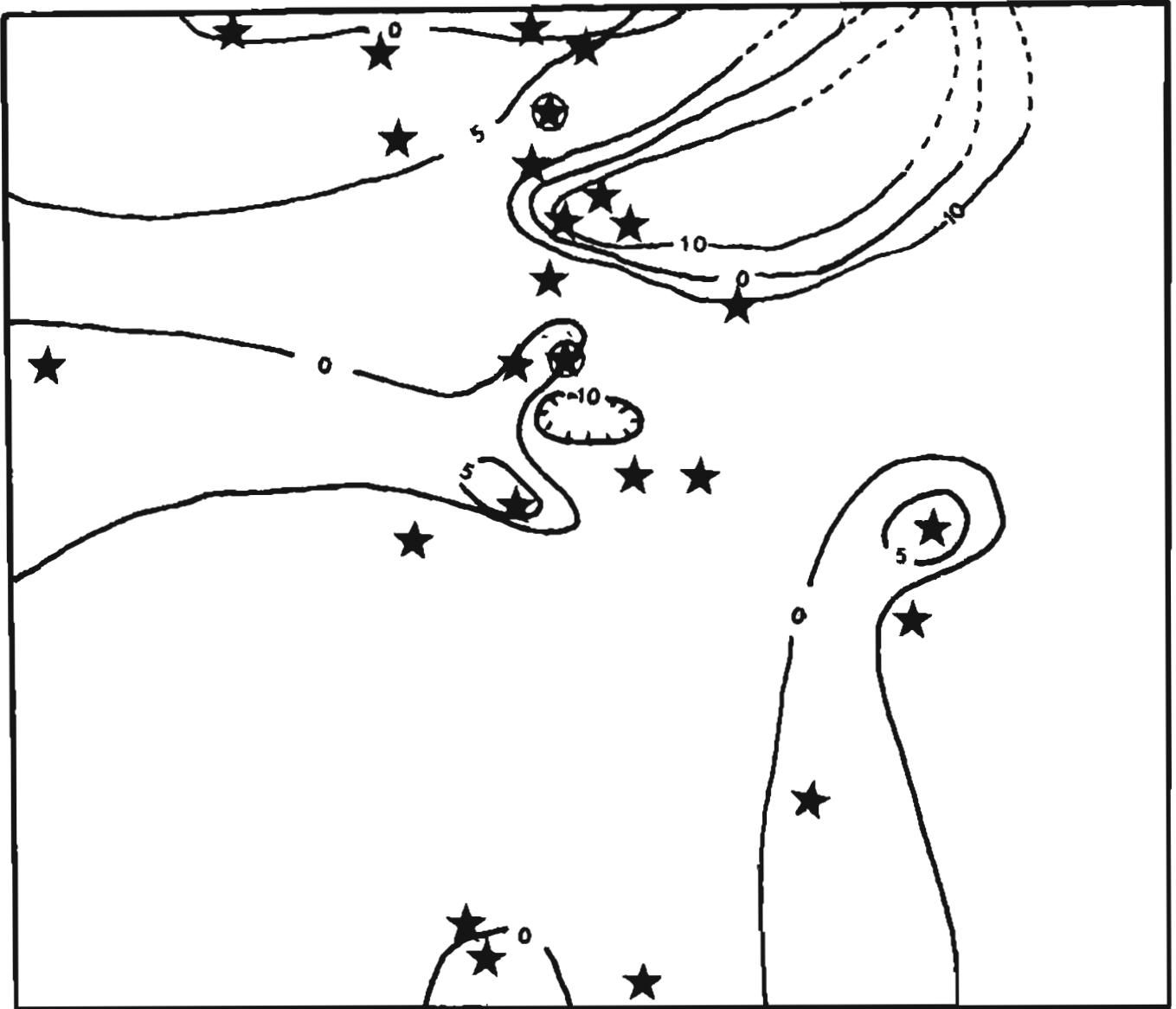


Figure 16 - Strike of Bedrock, Chichagof District, S.E. Alaska - Fourth Degree Residuals.

★ = Mine or Prospect ★ inside circle = Major Producer
 Contours:
 + = East
 - = West

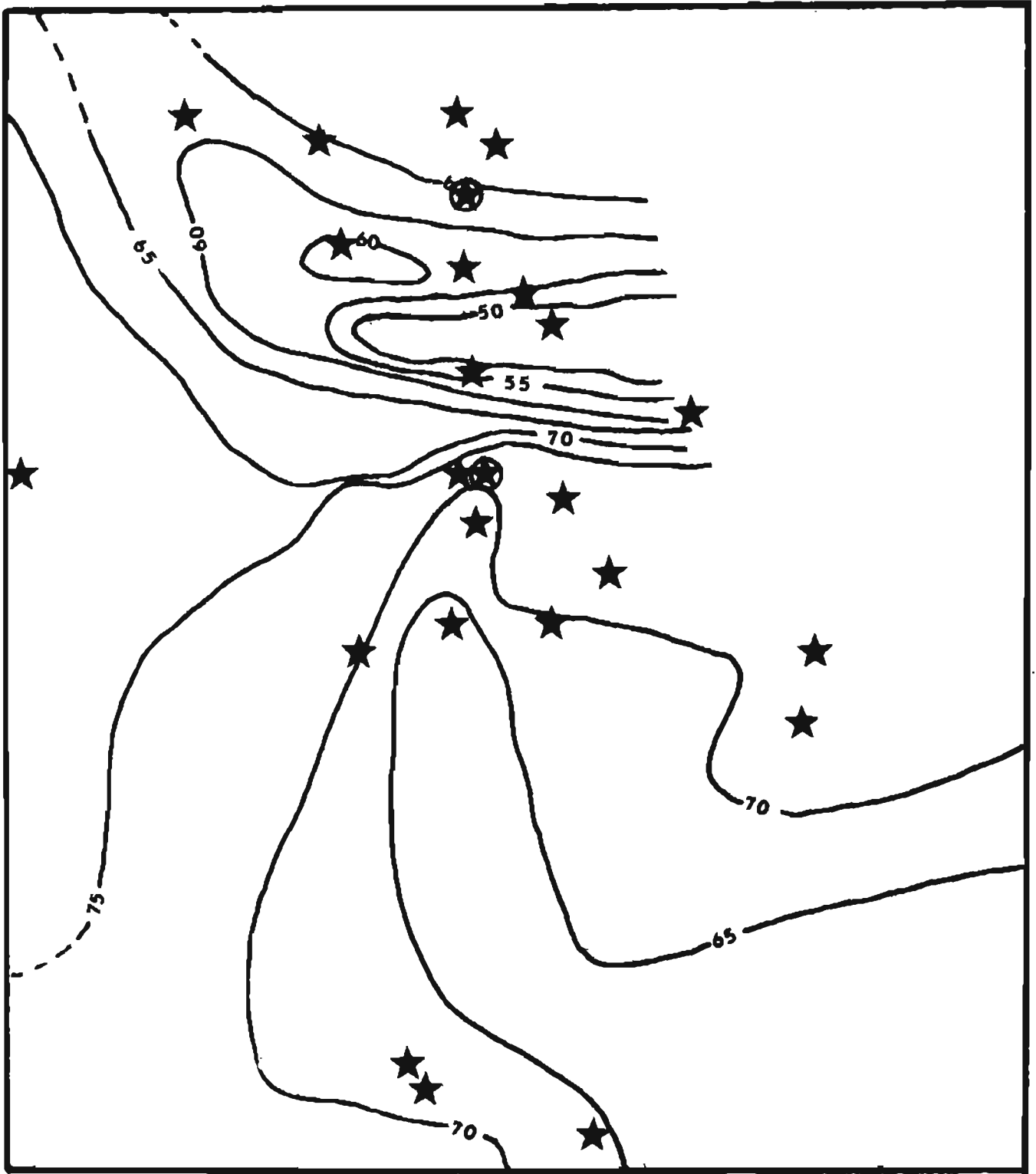


Figure 17 - Dip of Bedrock, Chichagof District, S.E. Alaska - Original Data

Contour Interval = 5°

★ = Mine or Prospect Ⓢ = Major Producer

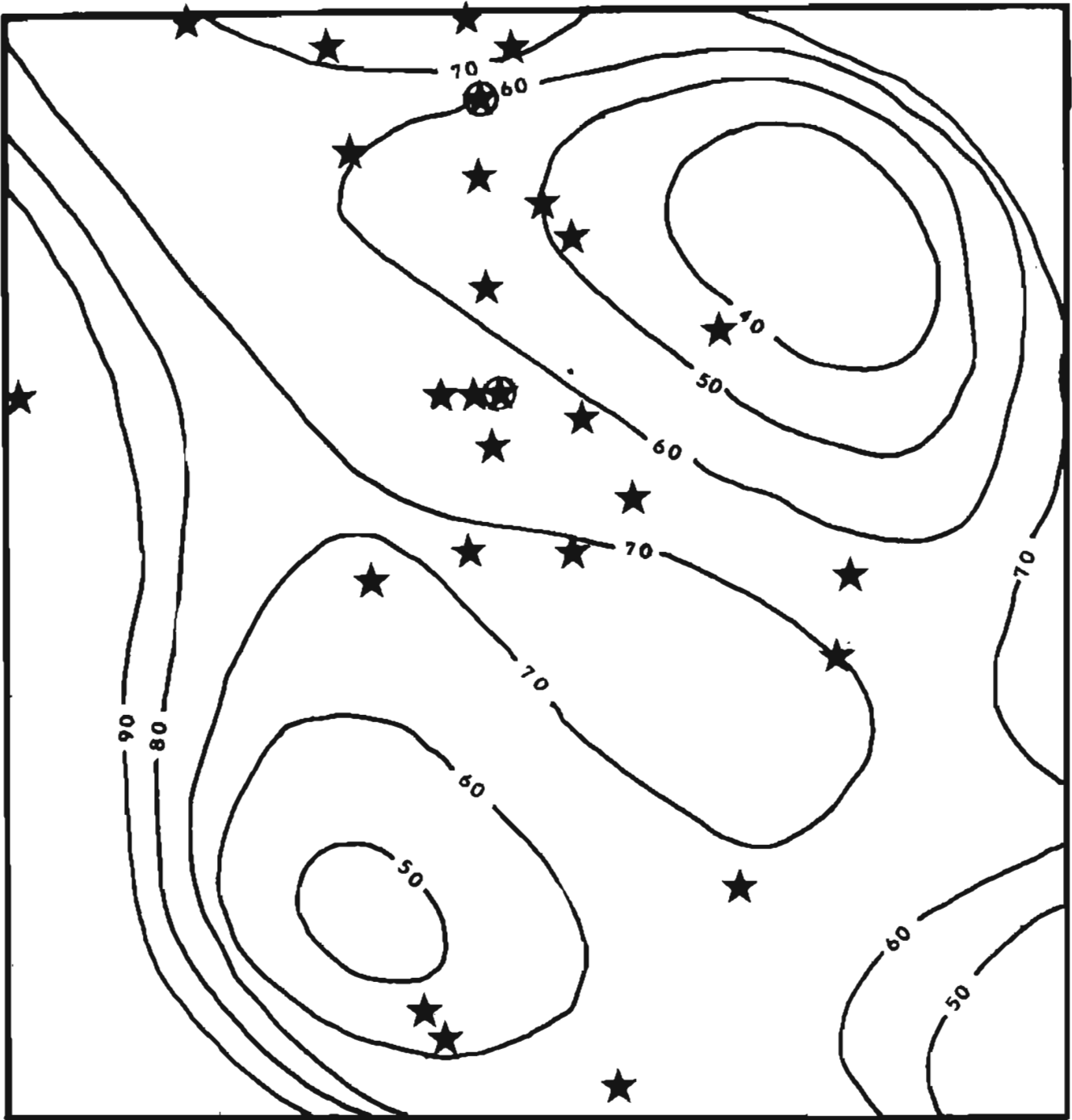


Figure 18 - Dip of Bedrock, Chichagof District, S.E. Alaska -
Fourth Degree Trend Surface.

Contour Interval = 10°

★ = Mine or Prospect ★⊙ = Major Producer

However, the residuals, (Figure 19), indicate that only three deposits occur in areas of anomalous bedrock dip. Standard deviation = 4.96° , correlation coefficient = 0.66.

APPLICATION OF TREND SURFACE ANALYSIS TO A GEOCHEMICAL PROBLEM

Alaska Division of Mines and Minerals Geochemical Report No. 2, by D. H. Richter, on the Slana District, provided a test for trend surface analysis of geochemical data. The map of geochemical data was subdivided into one inch squares, and the coordinates of sample points as well as geochemical content at those points were tabulated and punched. All samples are stream sediments. Trend surfaces for first through sixth degree were obtained for copper, molybdenum, zinc, lead, and citrate soluble heavy metal content. Approximately 130 data points were involved in each run, utilizing ten minutes of IBM 360/40 computer time each.

The sixth degree trend map for zinc (Figure 20) indicates an area of high zinc content encompassing most of the quartz monzonite pluton and border zone south of Long Lake. A regional high of 200 ppm zinc is computed for this area. The 100 ppm trend contour extends westward to include the diorite-quartz diorite intrusives northeast of Grubstake Creek. The zinc residual map (Figure 21) indicates local highs south of Long Lake and southeast of Flat Lake. These range from 100 to 200 ppm higher than the computed trend for the area. Three other areas are indicated; one south of Grubstake Creek, one northeast of Grubstake and one north of Indian Pass Lake. These are 100 ppm above regional trend.

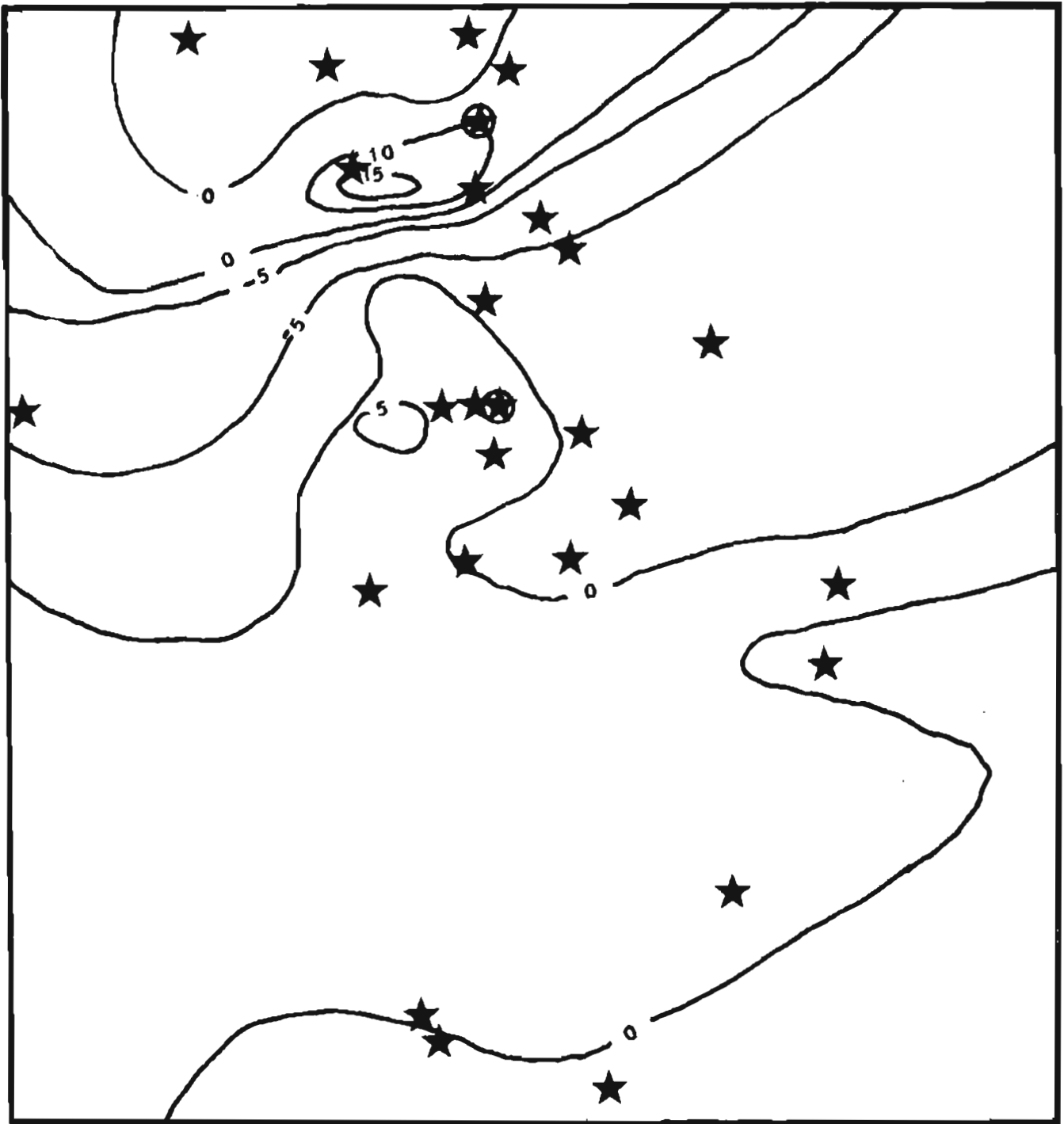
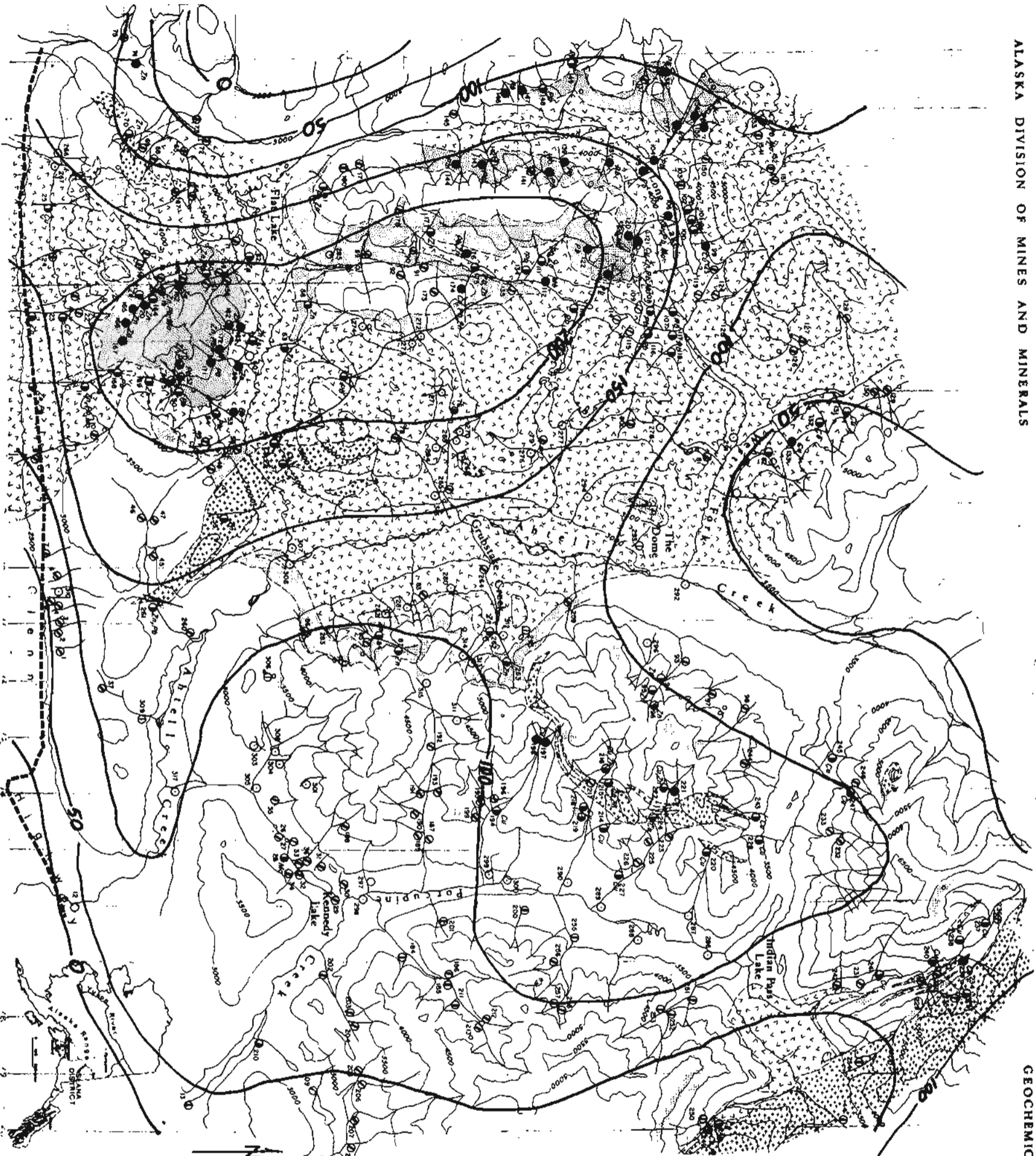


Figure 19 - Dip of Bedrock, Chichagof District, S.E. Alaska -
Fourth Degree Residuals

- ★ = Mine or Prospect
- ⊛ = Major Producer
- Contours:
- + = East
- = West



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 20 - Zinc, Sixth Degree Trend Map

EXPLANATION

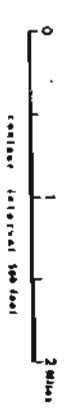
- Diorite and quartz diorite.
- Quartz monzonite, porphyritic quartz monzonite, and other granodiorite.
- Quartz monzonite, hypocrystalline quartz monzonite, K-feldspar quartz monzonite, quartz monzonite rock, and altered country rock.
- Bedded volcanic and sedimentary rocks.
- Oligocene limestone, clay, or siltstone alteration zones.
- Zones with siliceous quartz, carbonate, or barite veins.
- Inferred faults.

Stream sediment sample and number. Circles 1-10 represent stream sediment samples. Circles 11-20 represent stream sediment samples collected by field methods only (samples 18-20).

Concentration of copper, silver, lead, and antimony in laboratory analyzed samples. Threshold values (upper background level): Cu, 150 ppm; Ag, 150 ppm; Pb, 50 ppm; Sb, 5 ppm.

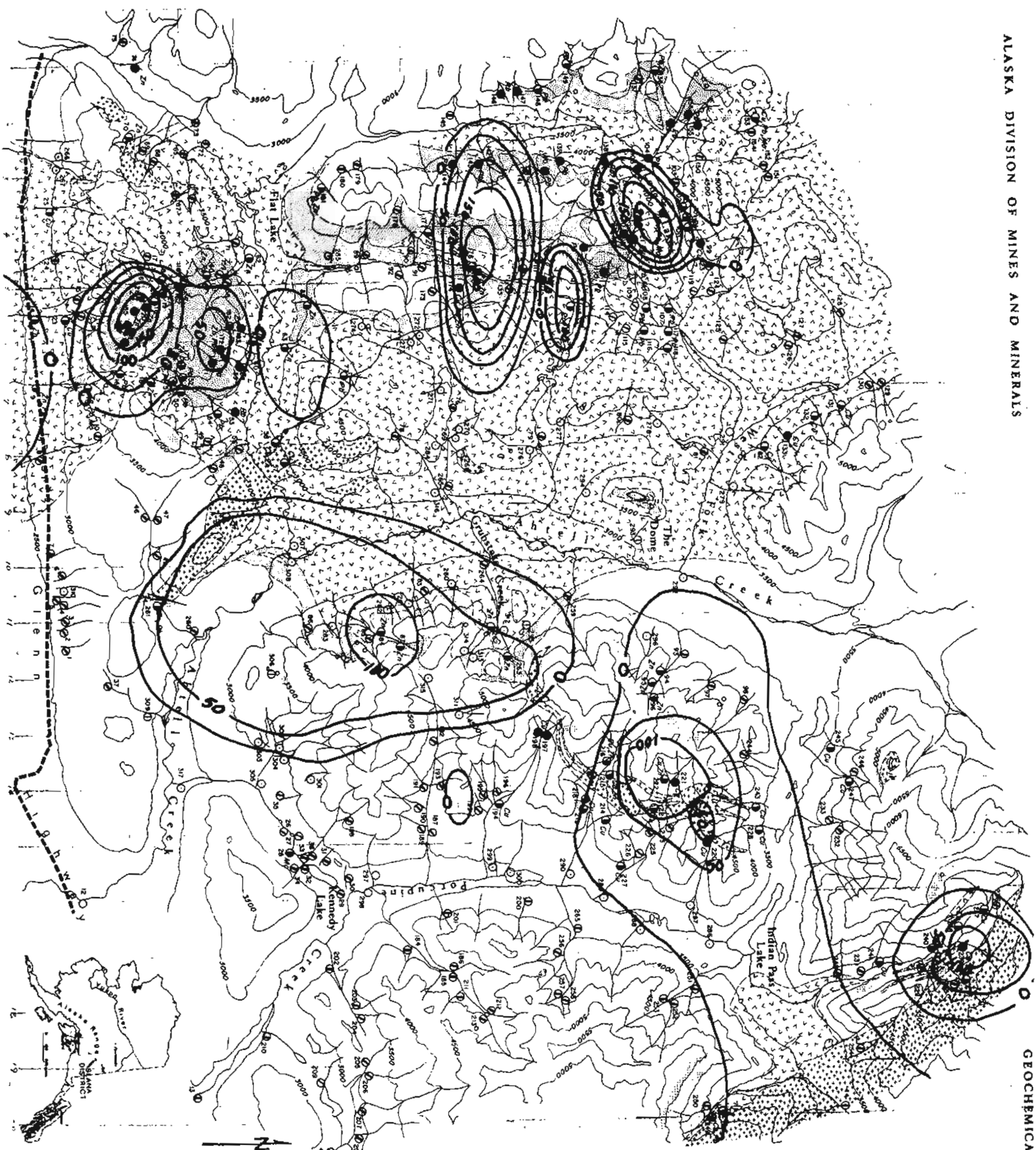
- Less than threshold.
- Between threshold and 2 times threshold for one or more metals.
- Greater than 2 times threshold for one or more metals.
- Principal enriched metals shown in red.

Concentration of heavy metals greater than background level (of samples analyzed by field methods only).



Geology and geochemical sampling by R. Richter 1962 and 1964, assisted by K. Phillips, Jr., 1962 and D. Schwab, S. Strickland, and E. Richter 1964.

Topography modified from U.S. Geological Survey, 1:50,000 scale, 1964 (see also Slana District, Alaska, 1:50,000 scale, 1964).



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 21 - Zinc, First Degree Residual Map

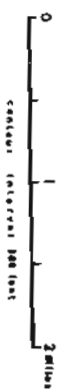
EXPLANATION

- Diorite and quartz diorite.
- Quartz monzonite, porphyritic quartz monzonite, and micro granodiorite.
- Quartz monzonite border zone (fine-grained quartz monzonite, porphyritic quartz monzonite, and quartz monzonite).
- Seamed volcanic and sedimentary rocks.
- Conglomerate, limestone, clay, or siltstone.
- Young siliceous-bearing quartz, carbonates, or barite veins.
- Inferred fault.

Stream sediment sample and number. Circles in stream or stream at sample site. Dot in circle indicates sample tested by field methods only (samples 266-315).

Concentration of copper, zinc, lead, and cadmium in stream sediment (ppm) (method: Lickorish; 100 ppm Zn, 150 ppm Pb, 50 ppm Cu, 5 ppm Cd).

- Less than threshold.
- Between threshold and 1 ppm.
- Greater than 1 ppm.
- Principal enriched metals above 1 ppm.
- Concentration of heavy metals greater than background (same for samples tested by field method only).



Geology and geochemical mapping by G. Sticker 1962 and D. W. Anderson, Jr., 1963. Topography modified from U.S. Geological Survey (Alaska Col and Div. and Alaska Col and Div. quadrangles).

The sixth degree surface for copper (Figure 22) indicates that the pluton and most of the upper part of the map area has a copper content of greater than 50 ppm. The residual map (Figure 23) localizes several anomalies, one near Long Lake, northeast of Indian Pass Lake, and northeast of Grubstake Creek. Other positive areas are indicated within the boundaries of the zero contours. A sample having 1000 ppm copper near Long Lake was removed and new surfaces generated. This resulted in a northward shift of the sixth degree trend (Figure 24) and the inclusion of a trend high north of Flat Lake. The residual map (Figure 25) becomes more distinct, and shows more regions of interest because the trend surface is lowered. Anomalous regions along the border zone of the pluton are delineated.

The sixth degree surface (Figure 26) shows a regional high for lead west of Long Lake, including portions of the pluton and the border zone, and a high lead concentration west of Flat Lake. The residual map (Figure 27) again localizes high lead areas.

Maps of regional (Figure 28) and local (Figure 29) distributions of molybdenum in the study area were generated and drawn. Distribution here is similar to that of lead.

A regional area of high heavy metal content, indicated by the sixth degree surface (Figure 30), exists between Long and Pass Lakes, and one southeast of Pass Lake. These areas are further south than total metal highs; possibly indicating downstream transport of soluble ions. The residual map (Figure 31)



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 23 - Copper, Sixth Degree Residual Map (All Data)

EXPLANATION

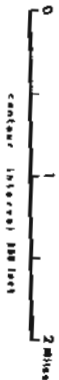
- Olivine and quartz quartzite.
- Quartz monzonite, porphyritic quartz monzonite, and minor gneissiferous.
- Quartz monzonite border zone (disaggregated quartz monzonite, K-feldspar rock, quartz can be seen, quartz-concretionary rock, and altered country rock).
- Bedded volcanic and sedimentary rocks.
- Gneissic limestone, clay, or sericite alteration zones.
- Known sulfide-bearing quartz, arsenopyrite, or barite veins.
- Inferred fault.

○ Stream sediment sample and number. Circle is tangent to stream at sample site. Dot in circle indicates sample located by field notebook only (Sample 246-249).

○ Concentration of copper, silver, lead, and molybdenum in laboratory analysis. Threshold values (upper background limit): Cu, 150 ppm; Ag, 150 ppm; Pb, 20 ppm; Mo, 5 ppm.

- Less than threshold.
- Between threshold and 2 times threshold for one or more metals.
- Greater than 2 times threshold for one or more metals.
- Principal enriched metals shown in red.

○ Concentration of heavy metals greater than background (shown for samples tested by field notebook only).



Contours and geochemical sampling by R. Slobber 1943 and 1945, mapped by R. Phillips, Jr., 1943 and D. Schuch, E. Brockelmann, and L. Sicker 1964.

Topography modified from U.S. Geological Survey Contour 1:50,000 and 1:250,000 and Alaska C-4 and C-4a quadrangles.



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 24 - Copper, Sixth Degree Trend Map (1000 ppm. Data Point Removed)

EXPLANATION

- Diorite and quartz diorite.
- Quartz monzonite, porphyritic quartz monzonite, and silver granodiorite.
- Quartz monzonite border zone: fine-grained quartz monzonite, K-spar rock, quartz cap-board rock, quartz-tremolite rock, and altered country rock.
- Bedded volcanic and sedimentary rocks.
- Conglomerate lamellae, clay, or siltstone alteration zones.
- Some sulfidation quartz, carbonates, or barite veins.
- Inferred fault.

Stream sediment sample and number. Circles in legend to stream at sample site. Dot in circle indicates sample tested by field methods only (Samples 246-315).

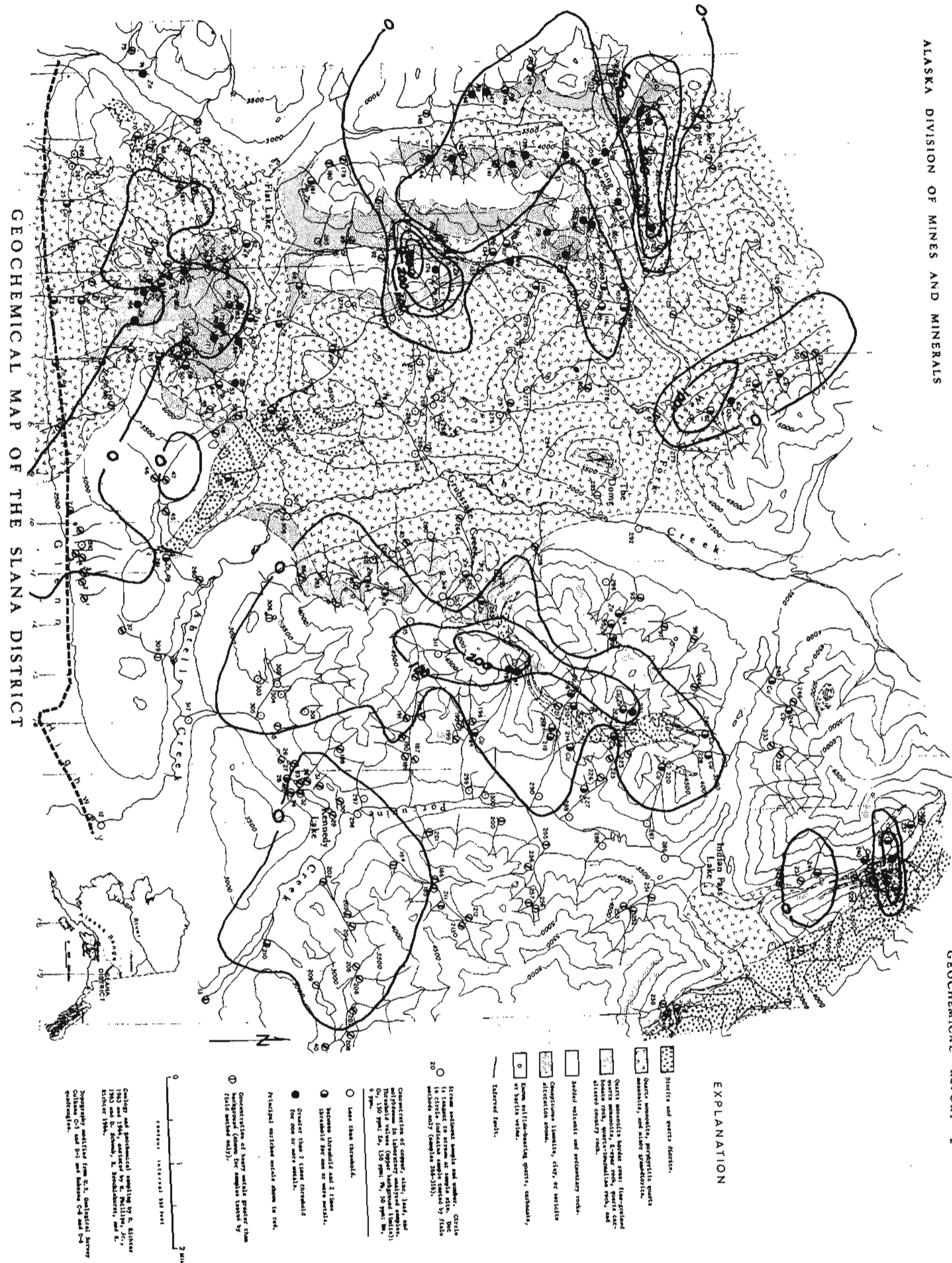
Concentration of copper, silver, lead, and molybdenum in laboratory analyzed samples. Threshold values (upper background limit): Cu, 150 ppm; Ag, 150 ppm; Pb, 50 ppm; Mo, 5 ppm.

- Less than threshold.
- Between threshold and 2 times threshold for one or more metals.
- Greater than 2 times threshold for one or more metals.
- Principal metallic minerals shown in red.
- Concentration of heavy metals greater than background (shown for samples tested by field method only).



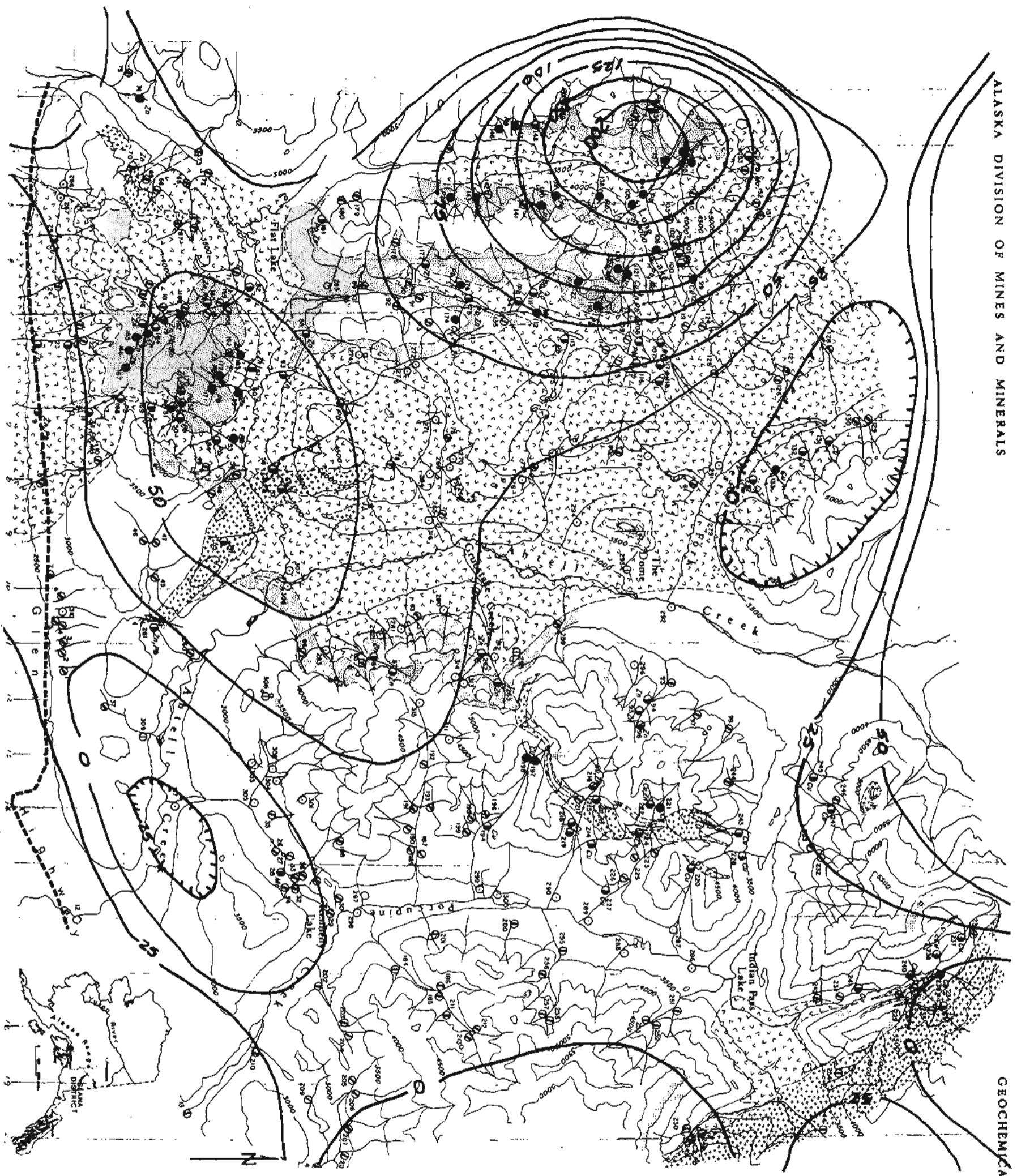
Geology and geochemical sampling by D. Ralston 1963 and 1964, assisted by R. Pulliam, Jr., 1963 and D. Schandy, L. Reinholdson, and E. Richter 1964.

Geography modified from U.S. Geological Survey Geologic C-1 and D-1 and Slana C-4 and D-4 quadrangles.



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 25 - Copper, Sixth Degree Residual Map (1000 ppm. Data Point Removed)



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 26 - Lead, Sixth Degree Trend Map

EXPLANATION

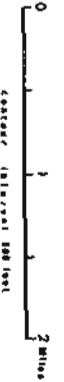
- Biotite and quartz chlorite.
- Quartz monzonite, porphyritic quartz monzonite, and minor granodiorite.
- Quartz monzonite border zone: fine-grained quartz monzonite, feldspar rock, quartz-carbonate rock, quartz-conspicuous rock, and altered country rock.
- Bedded volcanic and sedimentary rocks.
- Omphacite lamellae, clay, or scudite alteration zones.
- Zones with fibrous quartz, carbonate, or barite nodules.
- Inferred fault.

○ Stream sediment sample and number. Circle is largest to stream at sample site. Dot in circle indicates sample tested by field methods only (samples 208-215).

○ Concentration of copper, iron, lead, and molybdenum in laboratory analyzed samples. Threshold values (upper background limit): Cu, 150 ppm; Fe, 150 ppm; Pb, 50 ppm; Mo, 5 ppm.

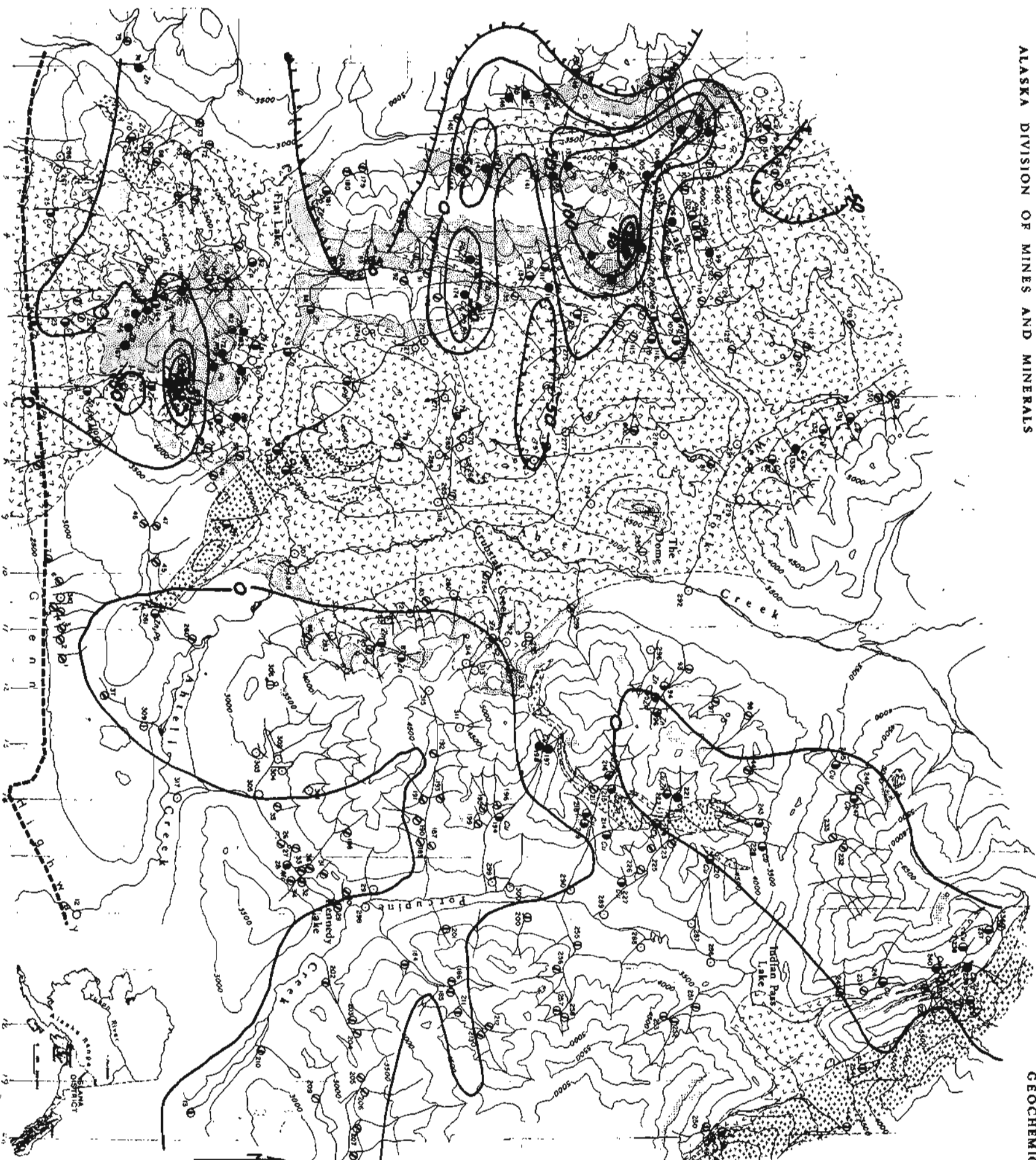
○ Less than threshold.
 ○ between threshold and 1 times threshold for one or more metals.
 ● Greater than 1 times threshold for one or more metals.
 ○ Principal enriched metals shown in col.

○ Concentration of heavy metals greater than background (shown for samples tested by field method only).



Geology and geochemical sampling by D. Kistner 1963 and 1964, assisted by R. Phillips, Jr., 1965 and D. Schmalz, L. Brecht-Werner, and E. Kistner 1964.

Topography modified from U.S. Geological Survey Colours C-1 and D-1 and various Col and D-4 quadrangles.



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 27 - Lead, Third Degree Residual Map

EXPLANATION

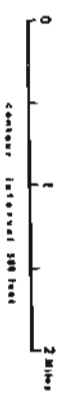
- Placita and quartz dikes.
- Quartz monzonite, porphyritic quartz monzonite, and rhyolite granodiorite.
- Quartz monzonite border zone: fine-grained quartz monzonite, coarse-grained quartz monzonite, quartz-dioritic rock, and altered country rock.
- Welded volcanic and sedimentary rocks.
- Omniporous lamotte, clay, or amictite alteration zone.
- Some sulfide-bearing quartz, carbonates, or barite veins.
- Inferred fault.

Stream sediment sample and number. Circle is tangent to stream at sample site. Dot is circle latitude sample located by field notebook only (samples 284-310).

Concentration of copper, silver, lead, and antimony in laboratory analyzed samples. Threshold values (upper background limit): Cu, 150 ppm; Ag, 150 ppm; Pb, 50 ppm; Sb, 6 ppm.

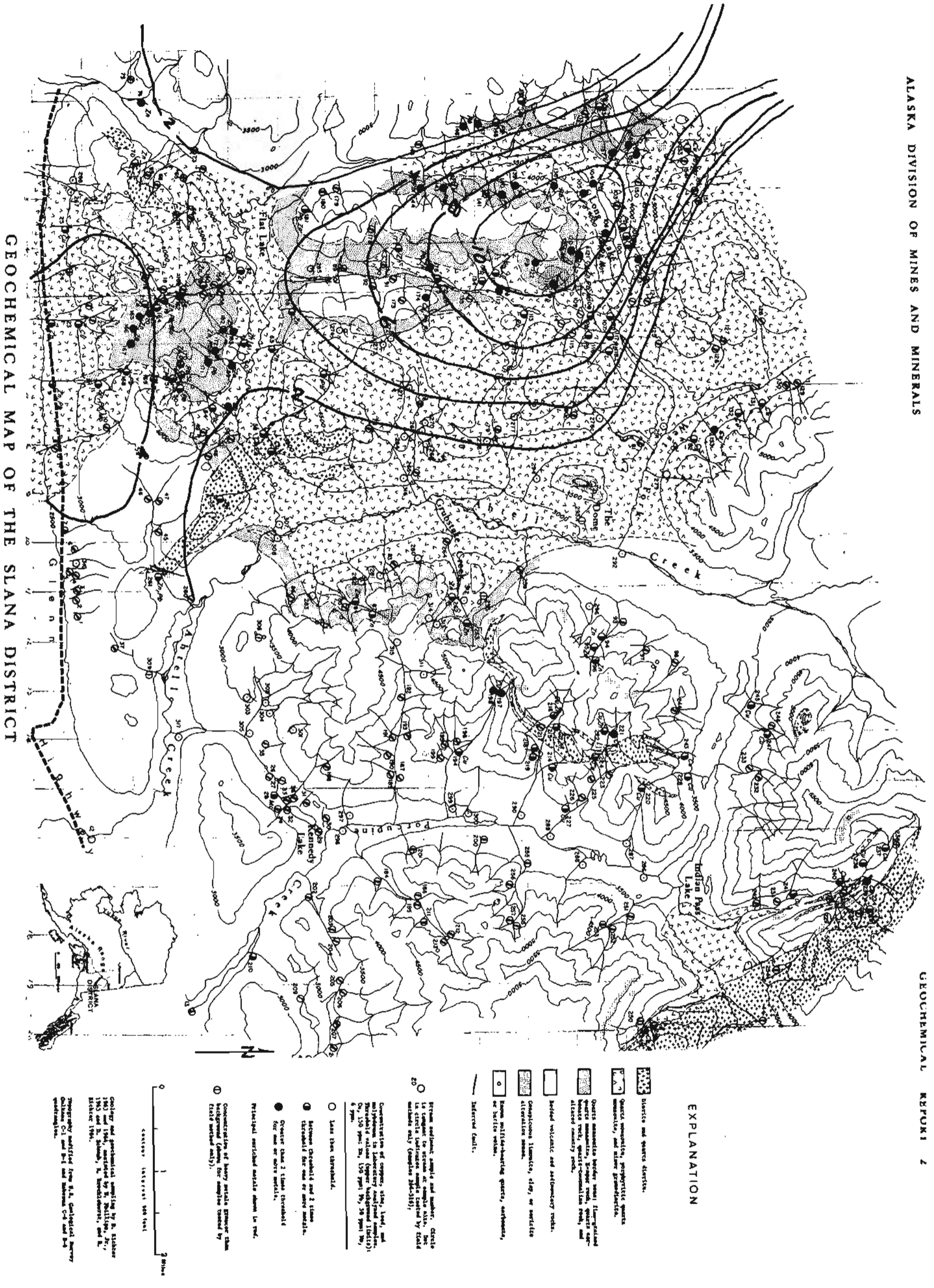
- Less than threshold.
- Between threshold and 2 times threshold for one or more metals.
- Greater than 2 times threshold for one or more metals.
- Principal enriched metals shown in text.

Concentration of heavy metals greater than background (shown for samples covered by field notebook only).



Geology and geochemical sampling by R. Stohrer 1963 and 1964, summarized by R. Phillips, Jr., 1963 and D. Schmitt, R. Brockmeyer, and R. Stohrer 1964.

Topography modified from U.S. Geological Survey Contour Chart No. 971 and Robinson C-4 and D-4 quadrangles.



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 28 - Moly, Fifth Degree Trend Map

EXPLANATION

- Diabase and quartz diorite.
- Quartz monzonite, porphyritic quartz monzonite, and minor gneiss/diorite.
- Quartz monzonite border zone; ilmenite-quartz monzonite, biotite zone, quartz monzonite, quartz-gneiss, and quartz monzonite rock.
- Bedded volcanic and sedimentary rocks.
- Conglomerate, limestone, clay, or siltstone alteration zone.
- Some molybdenum-bearing quartz, calcite, or barite veins.
- Inferred fault.

From radiometric analysis and analysis of samples for strontium and barium. Circles in legend are shown as background by field analysis only (samples 100-110).

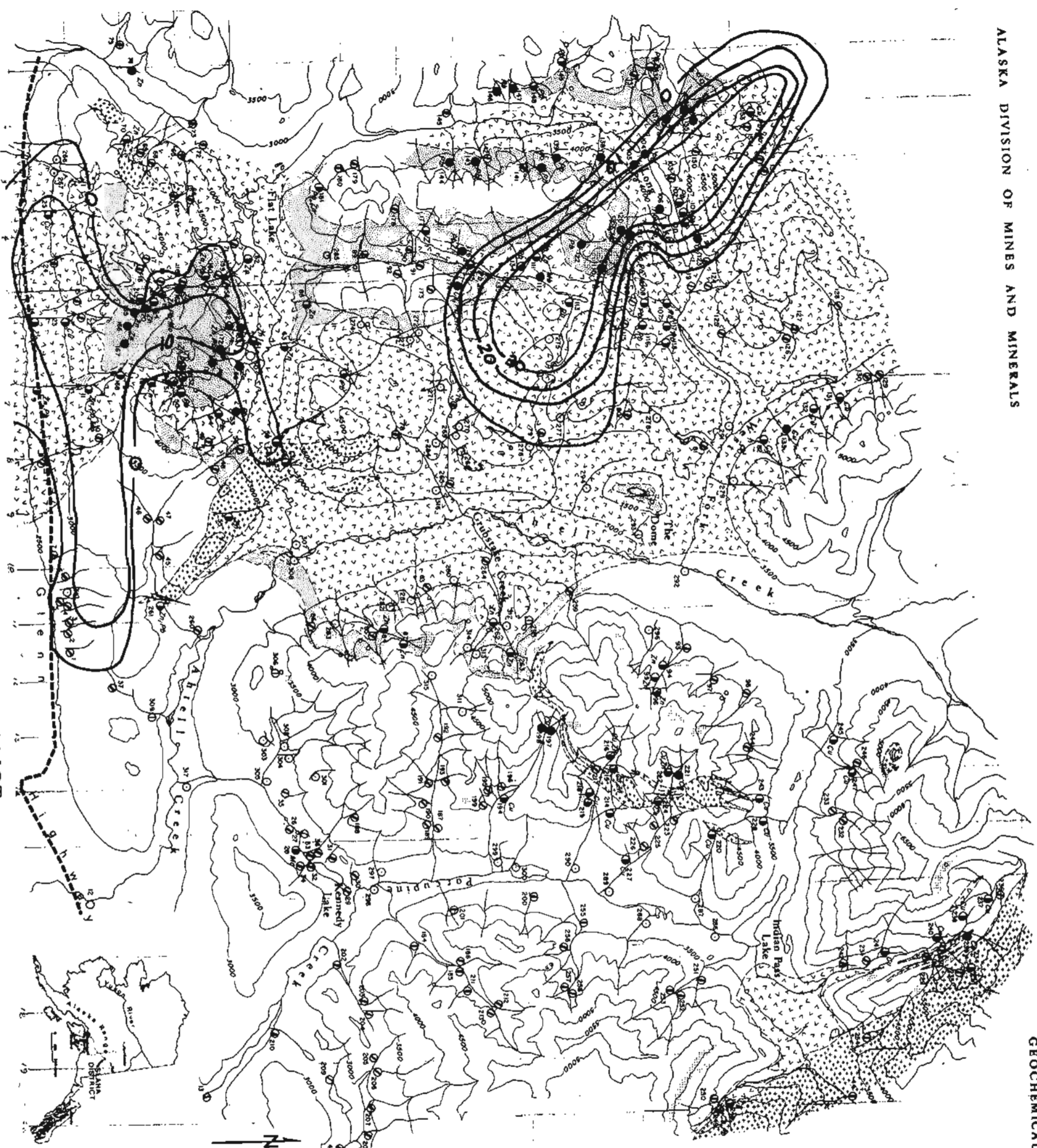
Concentration of copper, zinc, lead, and molybdenum in laboratory analysis. Molybdenum values (ppm) are shown by field analysis only (samples 100-110).

- Less than threshold.
- Between threshold and 1 time threshold for one or more metals.
- Greater than 1 time threshold for one or more metals.
- Principal enriched metals shown in red.
- Concentration of heavy metals greater than background (shown for samples tested by field methods only).



Geology and geochemical sampling by R. Stuber 1963 and 1964, analyzed by R. Phillips, Jr., 1965 and R. Stuber, R. Woodsworth, and R. Kibler 1966.

Topography modified from U.S. Geological Survey District C-1 and B-1 and Subarea C-4 and B-4 quadrangles.



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 29 - Moly, First Degree Residual Map

EXPLANATION

- ▨ Quartz and quartz dykes.
- ▨ Quartz monzonite, gabbroic quartz monzonite, and minor gneissosity.
- ▨ Quartz monzonite border zone (fine-grained quartz monzonite, biotite rock, quartz-carbonate rock, quartz-chlorite rock, and altered country rock).
- ▨ Bedded volcanic and sedimentary rocks.
- ▨ Omphacitic lamellae, clay, or sericite alteration zones.
- Known outcrop-bearing quartz, carbonates, or barite veins.
- Inferred fault.

○ Stream sediment sample and number. Circles 1-6 refer to stream at sample site. Dot in circle indicates sample tested by IAD methods only (samples 164-170).

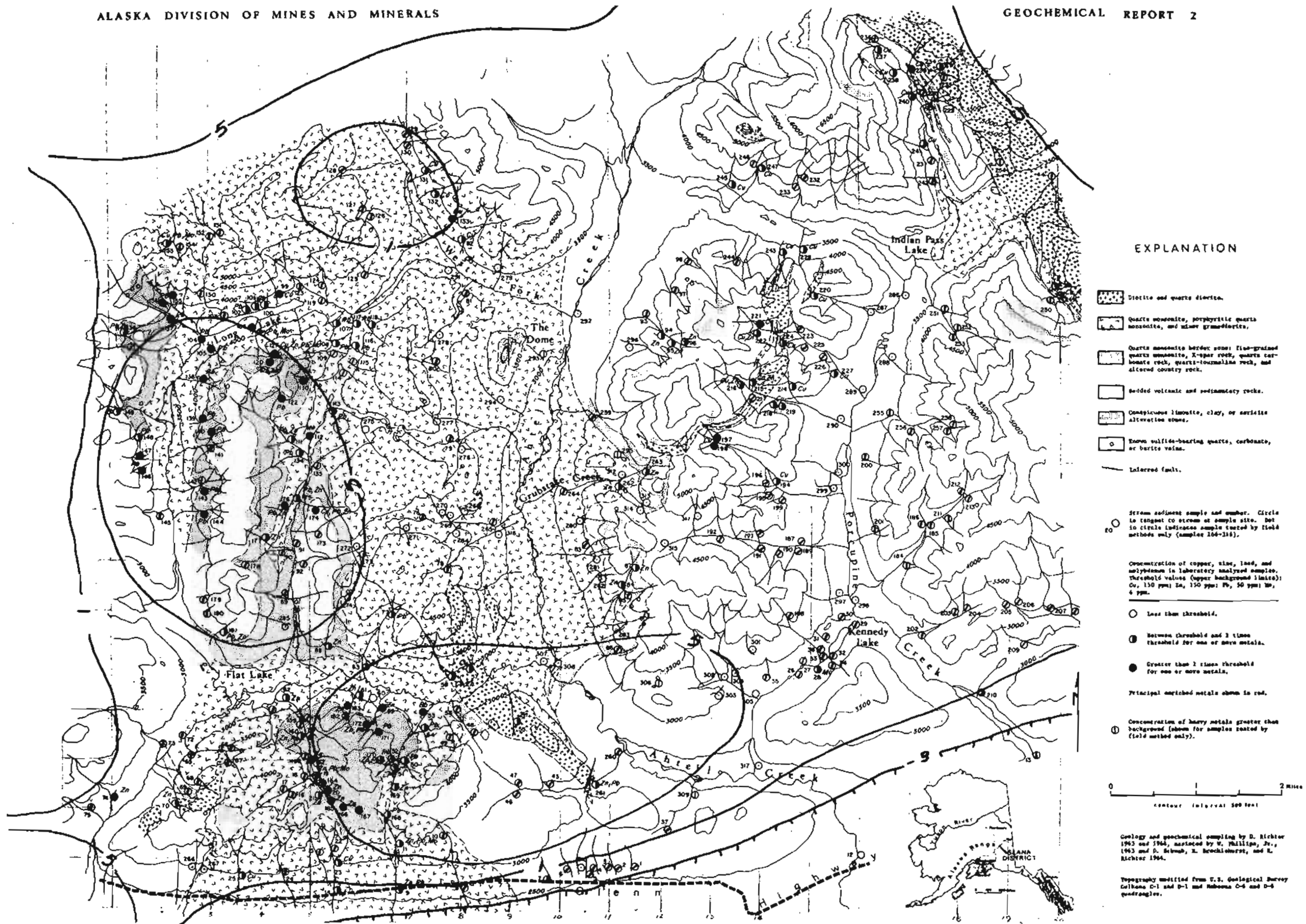
○ Concentration of copper, silver, lead, and molybdenum in laboratory analyzed sample (ppm) values (upper background level) is 150 ppm; Cu, 150 ppm; Pb, 50 ppm; Mo, 5 ppm.

- Less than threshold.
- Barren chlorite and 2 claus threshold for one or more metals.
- Greater than 2 claus threshold for one or more metals.
- Relative enriched metals shown in red.
- Concentration of heavy metals greater than background (shown for samples tested by IAD methods only).



Geology and geochemical sampling by D. Richter and J. H. S. Smith, by K. M. Miller, Jr., and B. Schaub, W. Besselbacher, and L. Richter 1964.

Topography modified from U.S. Geological Survey outline C-1 and B-1 and American C-4 and B-4 quadrangles.



EXPLANATION

- Dotted and quartz diorite.
- Quartz monzonite, porphyritic quartz monzonite, and minor granodiorite.
- Quartz monzonite border zone: fine-grained quartz monzonite, K-spar rock, quartz carbonate rock, quartz-tourmaline rock, and altered country rock.
- Bedded volcanic and sedimentary rocks.
- Conspicuous limonite, clay, or sericite alteration zones.
- Known sulfide-bearing quartz, carbonate, or barite veins.
- Inferred fault.

Stream sediment sample and number. Circle is tangent to stream at sample site. Dot in circle indicates sample tested by field methods only (samples 166-214).

Concentration of copper, zinc, lead, and antimony in laboratory analyzed samples. Threshold values (upper background limits): Cu, 150 ppm; Zn, 150 ppm; Pb, 50 ppm; Ni, 4 ppm.

- Less than threshold.
- Between threshold and 1 times threshold for one or more metals.
- Greater than 1 times threshold for one or more metals.

Principal enriched metals shown in red.

Concentration of heavy metals greater than background (shown for samples tested by field method only).

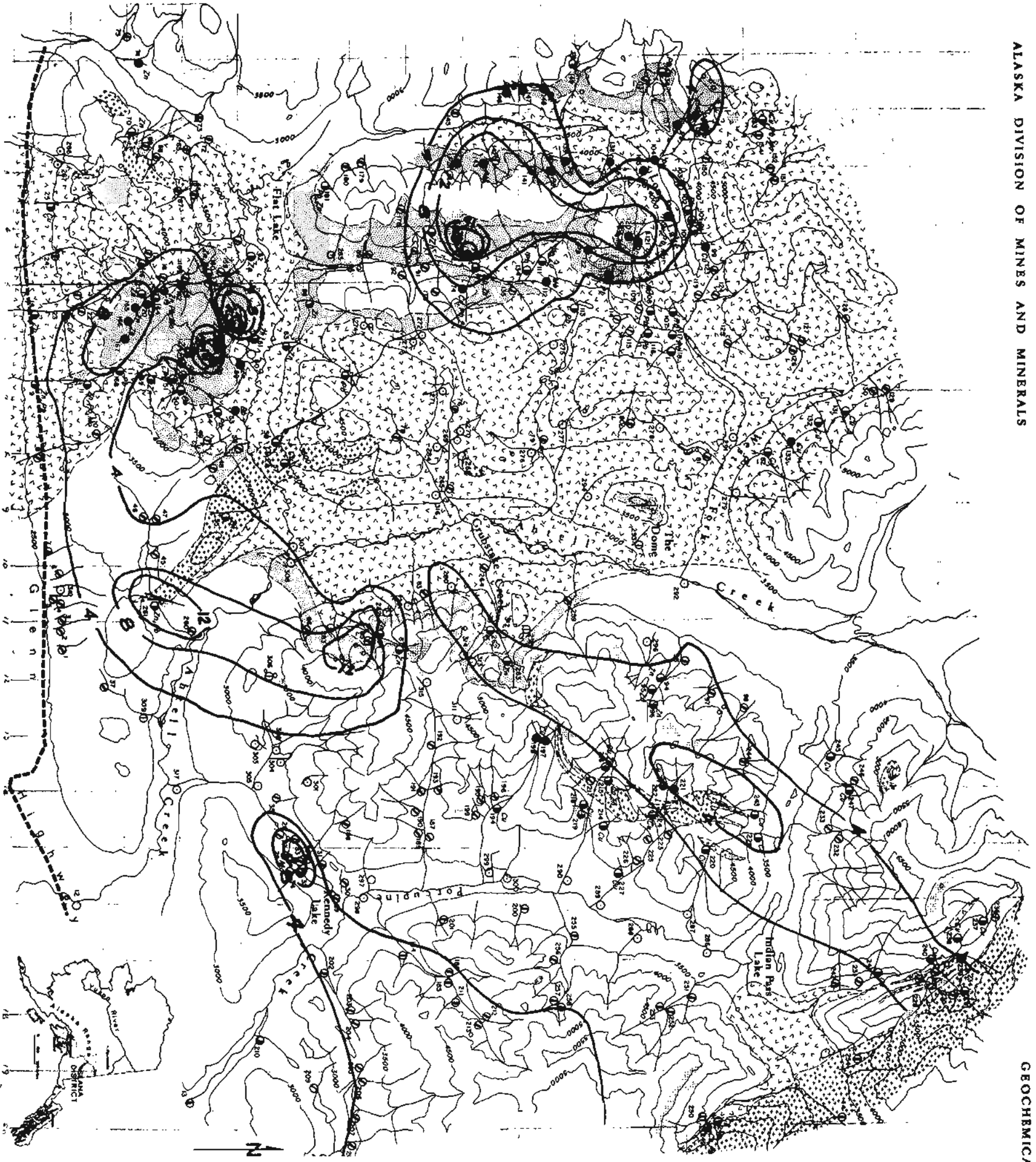
0 1 2 Miles
Contour Interval 500 feet

Geology and geochemical mapping by D. Richter 1963 and 1964, assisted by W. Phillips, Jr., 1963 and D. Sebman, K. Hochleberst, and K. Richter 1964.

Topography modified from U.S. Geological Survey Colono C-1 and D-1 and Nabesna C-6 and D-6 quadrangles.

GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 30 - Heavy Metal, Sixth Degree Trend Map



GEOCHEMICAL MAP OF THE SLANA DISTRICT

Figure 31 - Heavy Metal, Sixth Degree Residual Map

EXPLANATION

- Diorite and quartz diorite.
- Quartz monzonite, porphyritic quartz monzonite, and alkali granodiorite.
- Quartz monzonite bordering small fine-grained quartz monzonite, K-feldspar, quartz car-bonate rock, quartz-concretion rock, and altered country rock.
- Banded volcanic and sedimentary rocks.
- Oolitic limestone, clay, or siltstone alteration zones.
- Epithermal sulfidation: quartz, calcaneite, or barite veins.
- Inferred fault.

Stream sediment sample and number. Circles in legend or stream at sample site. The 1x circle indicates sample control by field analysis only (sample 284-310).

Concentration of copper, silver, lead, and molybdenum in laboratory analyzed samples. Threshold values (upper background limit): Cu, 150 ppm; Ag, 150 ppm; Pb, 50 ppm; Mo, 5 ppm.

- Less than threshold.
- Narrow threshold and 2 class threshold for one or more metals.
- Greater than 2 class threshold for one or more metals.
- Principal enriched metals shown in red.

Concentration of heavy metals greater than background (same for samples treated by field method only).



Geology and geochemical sampling by D. Stokker 1963 and 1964, assisted by G. Phillips, Jr., 1963 and D. Schreyer, R. Bruchmann, and R. Albrecht 1964.

Topography modified from U.S. Geological Survey Outline C-1 and C-11 and Shalman C-4 and C-4a quadrangles.

points to local anomalies, the highest being 20 ml above regional trend.

These trend surface and residual maps illustrate the versatility and usefulness of the trend surface method. It is particularly useful when large quantities of geochemical data are to be processed. Another desirable feature of the program is that trends and residuals of metal ratios may be easily determined.

MATHEMATICAL MODELS OF A PORTION OF THE CRAIG QUADRANGLE

Regression analysis was used to make a mineral occurrence model of a portion of the Craig quadrangle, Prince of Wales Island, with the view of selecting areas favorable for prospecting. The area was picked because it contains many mines and prospects of varying importance and because it is covered by a report and geologic map (U.S.G.S. Bull. 1108-B, Condon, 1961).

All known mines in the area were plotted, and a value was given to each; 4 - major producer, 3 - minor producer, 2 - major prospect, 1 - minor prospect. Next, cells containing 16 square miles were drawn on a portion of the map (Figure 32). The upper left cell is number one and numbers increase to the right and down, i.e., they are read as one would read a book. Data taken from each cell included:

1. Cell value
2. % cell area occupied by ocean
- *3. % cell occupied by acidic rocks
- *4. % cell area occupied by mafic rocks

- *5. % cell area occupied by metamorphic rocks
 - *6. % cell occupied by sedimentary rocks
 7. % cell occupied by overburden
 8. # NW trending linears
 9. # N trending linears
 10. # NE trending linears
 11. # E trending linears
 12. # Linears longer than 12 miles
 13. Distance to linear longer than 12 miles
 14. Distance from center cell to intrusive
 15. Size of the nearest intrusive (miles²)
 16. Length of metamorphic-igneous contact
 17. Length of igneous-sedimentary contact
 18. Distance from mine to intrusive (average)
 19. Cell #
- *Adjusted for portion of cell occupied by ocean and overburden.

Valid data parameters were chosen by obtaining partial correlation coefficients for each parameter versus cell value. This could be accomplished with either the 360/40 or the 1620 computer, but it was found advantageous to sacrifice the speed of the 360/40 in order to gain the added advantage of the University "open shop" policy for the 1620 computer. It was found economically feasible to utilize the 1620 as a high powered desk calculator. The data were punched, fed into the 1620, and sums, averages, standard deviations and partial correlation coefficients printed on the console typewriter.

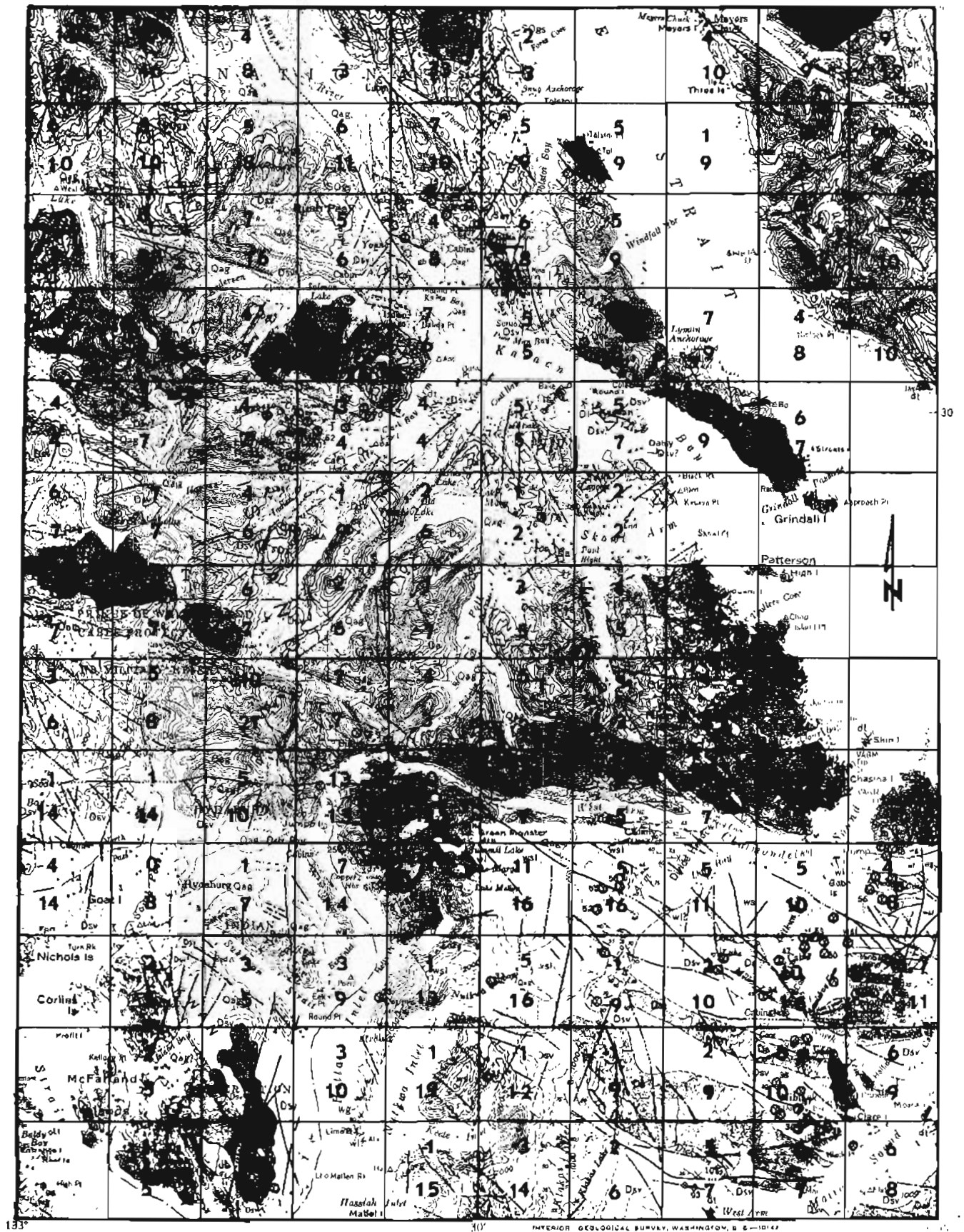


Figure 32, Map of a portion of the Craig Quadrangle, S.E. Alaska, showing computed cell values.

Note: Map adapted from Plate 1, U.S.G.S. Bulletin 1108-B, Scale 1:250,000

It was then possible to select variables having high partial correlation coefficients, insert them via typewriter into the computer, and perform a regression of only these variables. The multiple correlation coefficient, standard deviation, regression coefficients and students T test were printed on the console typewriter and punched on cards, thus enabling visual elimination of nonsignificant variables. The regression equation which best approximates the data was found by this process. These variables were then transformed to their corresponding square, square root and log functions, and a new matrix of partial correlation coefficients produced, to "normalize" the data. The best function of each data variable initially found significant was regressed with value as the dependent variable by the aforementioned "desk calculator" method.

The initial run was composed of all value cells and all of the original variables. The partial correlation matrix was studied and found to contain the following significant relationships:

TABLE 1
Partial Correlation Coefficients
for all Value Cells

<u>Variable 1</u>	<u>Variable 2</u>	<u>Partial Correlation Coefficient</u>
Value	# NW Faults	-0.22
Value	# E Faults	+0.19
Value	# > 12 mile Faults	+0.24

TABLE 1 (Continued)

<u>Variable 1</u>	<u>Variable 2</u>	<u>Partial Correlation Coefficient</u>
Value	Dist. to Major Fault	-0.30
Value	Length Met.-Ig. Contact	+0.33
Value	Dist. Mine to Intrusive	-0.26
Value	Dist. Cell to Intrusive	-0.27
Acid Rx	# E Faults	+0.24
Mafic Rx	# N Faults	+0.22
Mafic Rx	# E Faults	-0.23
Metamorphic Rx	# N E Faults	-0.24
Metamorphic Rx	# E Faults	+0.24
NW Faults	Dist. Mine to Intrusive	+0.28
N Faults	Size Intrusive	+0.30

All significant variables were regressed with value as the dependent variable. Variables were eliminated based upon students T test until a final regression equation was obtained. This equation,

$$\text{Value} = 10.439 - .712(X_1) - .435(X_2) - .044(X_3) + 0.521(X_4) - .424(X_5)$$

Where: X_1 = # NW Faults
 X_2 = Dist. to >12 Mile Fault
 X_3 = Size of the Intrusive
 X_4 = Length Metamorphic Contact
 X_5 = Dist. cell to Intrusive

has a multiple correlation coefficient of .514 and a standard error of 5.00.

At this stage of the analysis it was decided to sort out cells by element, i.e., those cells containing copper, gold, lead and silver, in order to gain a more definitive model.

For these runs, the value cells were not adjusted to eliminate the effects due to other elements. Computer runs for copper and gold cells produced partial correlations illustrated by Tables 2 and 3 respectively.

TABLE 2
Partial Correlation Coefficients
Copper Cells

<u>Variable 1</u>	<u>Variable 2</u>	<u>Partial Correlation Coefficient</u>
Value	Metamorphic Rx	+ .21
Value	# E Faults	+ .25
Value	# >12 Mile Faults	+ .26
Value	Dist. to > 12 Mile Fault	- .33
Value	Size of Intrusive	- .19
Value	Length Met. Contact	+ .35
Value	Dist. Mine to Intrusive	- .18
Value	Dist. Cell to Intrusive	- .21
% Acid Rx	Faults > 12 Miles	+ .24
% Acid Rx	Length Met. Contact	+ .33
% Acid Rx	Length Sed. Contact	+ .21
% Mafic Rx	# N Faults	+ .33
% Met Rx	# NW Faults	+ .24
# NW Faults	Size Intrusive	+ .25
# N Faults	Size Intrusive	+ .28
# 12 Mile Faults	Size Intrusive	- .28

TABLE 3

Partial Correlation Coefficients
Gold Cells

<u>Variable 1</u>	<u>Variable 2</u>	<u>Partial Correlation Coefficient</u>
Value	Faults >12 Miles	+.35
Value	Dist. to 12 Mile Fault	-.32
Value	Length Met. Contact	+.36
Value	Dist. Mine to Intrusive	-.22
Value	Dist. Cell to Intrusive	-.21
% Acid Rx	# NW Faults	-.29
% Acid Rx	# N Faults	+.41
% Acid Rx	# E Faults	+.24
% Acid Rx	Size Intrusive	+.43
% Acid Rx	Dist. Mine to Intrusive	-.49
% Acid Rx	Dist. Cell to Intrusive	-.56
% Mafic Rx	# E Faults	-.25
% Meta Rx	# E Faults	-.22
# NW Faults	Dist. Mine to Intrusive	+.34
# NW Faults	Dist. Cell to Intrusive	+.32
# NW Faults	Size Intrusive	+.32
# NE Faults	Size Intrusive	-.25
# E Faults	Size Intrusive	+.43
# E Faults	Dist. Mine to Intrusive	-.44
# E Faults	Dist. Cell to Intrusive	-.24
# 12 Mile Faults	Size Intrusive	-.38

Best raw variable models for copper and gold are expressed by equations 1 and 2 respectively.

$$\text{Value} = 8.66 + .046(X_1) + .728(X_2) - .379(X_3) - .068(X_4) - .980(X_5) \quad (1)$$

Where: X_1 = % Metamorphic Rocks
 X_2 = # E Faults
 X_3 = Dist. to Major Fault
 X_4 = Size of Intrusive
 X_5 = Dist. Cell to Intrusive

And: Multiple correlation coefficient = 0.56
Standard Error = 4.63

$$\text{Value} = 8.240 + 0.05(X_1) - 0.39(X_2) + 2.59(X_3) - 0.07(X_4) + 0.51(X_5) - 0.86(X_6) \quad (2)$$

Where: X_1 = % Metamorphic Rocks
 X_2 = # NE Faults
 X_3 = # >12 Mile Faults
 X_4 = Size Intrusive
 X_5 = Length Metamorphic Contact
 X_6 = Dist. Mine to Intrusive

And: Multiple correlation coefficient = 0.57
Standard Error = 5.57

Transformations of the variables for both copper and gold cells resulted in the following log models for copper and gold; equations 3 and 4 respectively.

$$\ln(\text{Value}) = 2.445 + .088(X_1) + .442(X_2) - .361(X_3) - .00005(X_4) - .0095(X_5) \quad (3)$$

Where: X_1 = Ln (% Metamorphic Rocks)
 X_2 = Ln (# E Faults)
 X_3 = Ln (Dist. to >12 Mile Fault)
 X_4 = (Size)²
 X_5 = (Dist. Cell to Intrusive)²

And: Multiple correlation coefficient = 0.579
Standard Error = 0.255

$$\ln(\text{Value}) = 2.700 + .0044(X_1) + .1240(X_2) - .0147(X_3) - .00007(X_4) + .0006(X_5) - .0055(X_6) \quad (4)$$

Where: X_1 = % Metamorphic Rocks
 X_2 = # Faults >12 Miles
 X_3 = Ln (# NE Faults)
 X_4 = Size²
 X_5 = (Length Meta Contact)²
 X_6 = (Dist. Cell to Intrusive)²

And: Multiple correlation coefficient = .6206
Standard Error = .2871

Model 5, for gold, was also obtained. It expresses value (not Ln (value)) as the dependent variable against normalized transformations of the significant independent variables. Note that some independent variables are raw form. This model for gold, and the raw model for copper, as well as log models, were used for preliminary predictions of value possible in "no value" cells.

$$\text{Value} = 5.596 + .081(X_1) + 2.530(X_2) - .242(X_3) - .001(X_4) + .007(X_5) - .098(X_6) \quad (5)$$

Where: X_1 = % Metamorphic Rock
 X_2 = # Faults > 12 Miles
 X_3 = Ln (# NE Faults)
 X_4 = (Size Intrusive)²
 X_5 = (Length Metamorphic Contact)²
 X_6 = Ln (Dist. cell to Intrusive)

And: Multiple correlation coefficient = 0.601
Standard Error = 5.414

Table 4 indicates predicted value in each cell of the district. These values are in each case based upon the log models for copper and gold values. Table 5 tabulates those cells used for model building. Analysis of these data indicates that if all cells having a value of four or greater are chosen, then the log model for gold retains 88% of cells with a value of three or more. The same criteria establish 74% retention of copper cells with a value of "3" or greater. These models have multiple correlation coefficients of 0.57 and 0.62 respectively. It is of course understood that estimates based upon these models are "indications" of value,

not a guarantee of mineral wealth. The higher the number, the better the chances are of finding mineralization, assuming that the geologic factors chosen may validly be extended to other areas. Basically, assigning a number to a particular cell merely says that that cell has certain geologic features similar to another cell that has been assigned a value based upon mines contained in it.

TABLE 4
Predicted Cell Value

Cell No.	Gold		Copper	
	Raw Model	Log Model	Raw Model	Log Model
1	31.780	75.63	5.681	13.73
2	26.137	46.26	7.006	6.28
3	6.358	7.99	3.667	4.44
4	-11.800	-3.25	-3.149	-2.68
5	18.708	33.38	.667	-1.50
6	-11.188	-3.45	-2.352	-2.46
8	9.265	10.29	3.959	4.44
9	10.693	9.49	8.598	9.11
10	12.932	11.76	10.015	8.92
11	10.473	10.29	6.758	6.28
12	8.757	10.09	5.224	5.33
13	7.003	7.64	5.393	5.18
14	10.519	11.33	6.722	6.45
18	5.367	9.49	1.509	1.47
19	4.087	5.96	3.082	3.47
21	7.601	7.29	6.797	7.29

TABLE 4 (Continued)

Cell No.	Gold		Copper	
	Raw Model	Log Model	Raw Model	Log Model
22	34.510	88.49	8.692	8.17
23	14.891	16.31	9.310	7.46
27	8.556	8.73	3.675	4.59
29	.457	9.11	-.862	-.79
33	6.423	7.46	3.039	3.87
35	7.264	6.12	7.436	6.95
39	6.872	7.81	3.835	4.01
40	9.929	9.69	6.530	6.28
41	4.337	4.44	3.239	3.74
45	4.615	4.44	3.562	3.87
46	4.433	4.73	4.695	4.73
48	10.326	9.30	7.672	6.61
51	8.129	7.46	7.069	6.12
52	8.045	7.29	9.504	7.29
53	3.590	5.80	4.511	4.30
55	3.783	5.80	1.517	2.31
57	.098	1.94	.735	1.94
64	3.261	6.28	2.537	2.43
65	3.142	7.12	.857	1.02
66	4.715	5.18	3.694	3.46
67	5.324	5.18	3.677	4.15
68	.783	1.71	4.193	3.46
71	2.870	5.96	2.170	2.68
72	6.217	7.64	4.975	5.33
75	3.147	3.46	3.827	3.60

TABLE 4 (Continued)

Cell No.	Gold		Copper	
	Raw Model	Log Model	Raw Model	Log Model
78	3.260	3.60	4.892	3.74
79	.495	1.47	3.407	2.68
81	.437	14.29	-.188	-1.33
82	3.140	11.76	2.064	.91
83	6.260	9.89	4.523	5.18
86	7.899	6.95	7.300	6.61
87	5.755	5.18	7.131	6.28
89	.901	1.71	1.859	2.06
91	-3.656	13.81	-3.214	-3.77
92	.790	8.54	-.357	-.32
93	2.438	6.95	.900	1.25
96	14.987	16.05	11.274	10.70
102	3.922	5.18	1.376	2.18
103	4.931	4.59	3.140	3.20
105	13.291	13.57	9.046	7.12
112	4.995	5.03	1.684	2.06
113	6.122	5.49	3.186	2.68
115	10.390	18.79	2.206	1.25
117	.795	8.92	-.346	-.79
118	5.338	9.49	1.911	1.94
120	10.264	9.30	7.238	6.45
122	4.157	5.18	-1.456	.81
125	5.559	15.28	-1.625	-.88
126	1.548	14.29	-3.907	-3.04
127	3.858	6.12	2.413	2.31
128	7.611	7.29	6.651	5.33

TABLE 5

Cells Containing Value

Cell	Original Value	Gold		Copper		Code*
		Raw Model	Normalized Model	Raw Model	Normalized Model	
15	10	10.7	10.3	7.7	6.6	C G
16	3	9.6	8.7	6.4	5.0	C G
17	3	9.5	9.1	6.4	5.0	C G
20	16	8.3	8.2	5.7	6.3	C G
24	2	6.8	6.3	4.6	5.0	C G
25	5	6.7	7.6	4.6	4.4	C G
26	14	8.5	7.5	7.3	6.3	C G
30	2	4.7	10.3	1.3	0.9	C G
31	2	5.0	4.6	4.6	4.3	
32	5	7.4	6.8	6.1	5.0	C G
34	9	5.2	4.7	8.3	7.6	C G
36	4	5.4	5.3	5.3	4.6	C G
37	17	9.5	8.5	6.8	6.3	C G
38	8	10.2	9.3	7.9	7.3	C
42	5	6.8	6.9	3.6	4.0	C G
43	18	6.5	6.9	3.1	3.7	G
44	10	4.6	4.4	2.9	3.3	C G
47	4	7.0	7.1	5.0	5.3	C G
49	3	7.4	6.8	7.1	6.3	C G
54	1	5.0	9.1	0.3	1.1	C G
56	1	-1.2	2.4	-1.1	0.6	C G
61	3	7.7	6.8	6.4	6.4	C G
62	1	8.2	6.9	7.0	6.6	C G

TABLE 5 (Continued)

Cell	Original Value	Gold		Copper		Code*
		Raw Model	Normalized Model	Raw Model	Normalized Model	
63	1	8.4	7.1	7.3	5.8	C G
73	1	6.8	20.6	11.1	10.0	C G
74	4	6.3	6.9	7.3	7.1	C G
76	2	0.8	1.7	6.1	4.9	C G
77	3	0.7	1.7	3.1	3.1	C G
84	18	13.7	12.9	13.3	13.1	C G
85	6	12.5	11.5	10.2	10.1	C
90	2	0.2	1.2	0.9	1.1	C G
94	3	13.5	13.8	7.7	7.1	C G
95	18	13.2	12.9	11.4	10.7	C
97	4	11.8	15.5	5.1	4.9	C G
98	1	9.7	11.3	5.6	5.3	C G
99	3	9.0	10.1	4.9	4.7	
100	5	8.3	8.4	4.7	4.0	C G
104	3	6.6	8.7	2.7	3.2	C G
106	1	11.3	15.5	7.2	5.2	C G
107	2	0.4	13.1	0.2	-1.1	
108	3	4.5	10.5	2.9	2.0	C G
109	11	14.3	16.3	9.8	9.7	C G
110	16	9.0	11.3	7.0	6.6	C G
114	1	8.7	9.7	1.2	2.8	C G
116	1	1.5	12.0	0.0	-0.6	C G
119	15	10.3	9.9	6.6	5.8	C G
123	2	5.4	4.7	1.6	1.8	C G

TABLE 5 (Continued)

Cell	Original Value	Gold		Copper		Code*
		Raw Model	Normalized Model	Raw Model	Normalized Model	
129	5	7.3	7.4	6.7	5.8	C G
130	1	7.4	7.5	6.4	5.5	C G

*C denotes cell used for copper model, G denotes cell used for gold model.

Table 6 indicates selections made by five geologists, independently of each other. Model values for these cells are given in parenthesis as well as the "high priority cells" selected by the operating copper model.

TABLE 6
Cell Number Selected, With Value in Parenthesis

Choice Geologist	1	2	3	4	5	6
* A	94 (7.1)	95 (10.7)	84 (13.1)	85 (10.1)	105 (7.1)	10 (6.6)
B	12 (5.3)	27 (4.6)	53 (4.3)	2 (6.3)	67 (4.1)	47 (5.3)
C	36 (4.6)	53 (4.3)	82 (.91)	103 (3.2)	- -	- -
D	53 (4.3)	24 (5.0)	15 (6.6)	46 (4.7)	96 (10.7)	98 (5.3)
E	12 (5.3)	15 (6.6)	31 (4.3)	42 (4.0)	96 (10.7)	19 (3.5)
Computer High Priority Cells	96 (10.7)	9 (9.1)	10 (8.9)	22 (8.2)	23 (7.5)	52 (7.3)

*Cells already containing known values.

Analysis of this table indicates that all cells selected by the geologists do have merit, if the copper model is used

as a basis. However, each man made his decision upon his personal preference of ore-forming controls, and hence each decision is biased.

The models described in this paper could undoubtedly be improved upon. The authors question further refinement, however, due to the reconnaissance nature of the map used for its compilation. The model presented is thought good enough to be used as a guide to mineral exploration in this area. A study of the partial correlation coefficients indicates the strength of ore control by geologic variables in the area. Analysis of the models indicates the relative significance of each variable.

A description of the IBM 1620 multiple regression program used for the bulk of computations in the regressions is included in the Appendix.

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APPENDIX I

MULTIPLE REGRESSION

This multiple regression program was adapted from a program written by Mr. Philip Johnson, Arctic Environmental Engineering Laboratory of the University of Alaska. The program computes sums, averages, standard deviations, a partial correlation matrix, calculates multiple regressions, including measures of the "goodness of fit" and students T test for each independent variable.

Program Operation

The user is responsible for writing his own Read and Format Statements as well as Fortran Statements to effect any data transformations desired. The source program is then compiled in PDQ Fortran. This compiled program and the PDQ Fortran subroutines must then be loaded. It is now ready to receive data. The data deck has a lead card which contains:

Col 1-3 Number of variables (Not # points)

Col 4-13 Identity (Alphanumeric)

The rest of the data deck is composed of cards for each data point containing the variables for that point. A blank card at the end of the data terminates data reading by the program.

The program will generate and punch out the identity and number of data points as well as:

Sums of the variables

Averages

Standard Deviations

Partial Correlation Matrix

It will also print (on the console typewriter) the partial correlation values of variable 1 versus all other variables. For this reason variable 1 should normally be the dependent variable. The program is now ready to solve regressions and will type: TYPE VARS. The operator must then enter the desired variables on the typewriter.

Selection of Variables

The dependent variable and independent variable(s) are entered on the typewriter, one variable at a time. The dependent variable is the variable entered first. Any variable may be entered as the dependent variable and any one or more variables as the independent variables. Variables are entered in I2 format. Entering 00 as a variable is the clue to the program that all selected variables have been entered. A sample entry to use variables 1, 5, 18, 35, would be:

01RS (the dependent variable)
05RS (the first independent variable)
18RS (the second independent variable)
35RS (the third independent variable)
00RS (end of variable selection--do the regression)

Regression

The program will now form the regression matrix, invert it, and calculate and put out the following regression values:

Printed Output

1. Multiple correlation coefficient, R

2. Standard error
3. For each independent variable:
 - A. The number of the variable
 - B. The coefficient of the variable
 - C. The T-Test (student's t) of significance

Punched Output

1. The number of the dependent variable
2. The equation constant
3. The multiple correlation coefficient, R
4. The standard error
5. For each independent variable:
 - A. The number of the variable
 - B. The coefficient of the variable
 - C. The standard error of the variable
 - D. The T-Test (student's t) of significance

The regression is now complete. The computer will now type TYPE VARS and accept another set of variables.

General procedure to be followed for eliminating non-significant variables is to drop that variable which has the lowest value of students T test. Run the regression, and drop the next low variable. This process is continued until the elimination of any variable from the regression significantly reduces the multiple correlation coefficient or greatly increases the standard error.

To enter a new set of data, branch the program to the beginning by typing 4906600RS.

A fortran listing and sample punched output follow.

```

C   PDO 1620 REGRESSION   ADAPTED FROM PRO SPEC ONE
C   TO FIT A SURFACE
   DIMENSION A(30,31),V(25),S0(25),SUM(25),BSTAR(25),RHS(25)
   DIMENSION BR(25),AV(25),I(25),IX(25),D(25),TT(25)
1  READ 99,NV,A1,A2
   DO 2 I=1,25
     SUM(I) = 0.
   DO 2 J=1,26
     A(I,J) = 0.
C   RAW CROSS PRODUCTS GO IN THE UPPER RIGHT HALF OF THE MATRIX
   N=0
3  READ 98,V(1),V(3),V(4),V(5),V(6),V(19)
   IF(V(1))6,6,55
55  IF(V(19))53,53,54
53  V(19)=0.0001
54  CONTINUE
   DO 51 II=3,6
     IF(V(II))52,52,51
52  V(II)=0.0001
51  CONTINUE
   V(2)=LOG(V(1)+10.)
   V(7)=V(3)*V(3)
   V(8)=(V(3)+10.)**.5
   V(9)=LOG(V(3)+10.)
   V(10)=V(4)*V(4)
   V(11)=(V(4)+10.)**.5
   V(12)=LOG(V(4)+10.)
   V(13)=V(5)*V(5)
   V(14)=(V(5)+10.)**.5
   V(15)=LOG(V(5)+10.)
   V(16)=V(6)*V(6)
   V(17)=(V(6)+10.)**.5
   V(18)=LOG(V(6)+10.)
   V(20)=V(19)*V(19)
   V(21)=(V(19)+10.)**.5
   V(22)=LOG(V(19)+10.)
4  N=N+1
   DO 5 I=1,NV
     SUM(I) = SUM(I) + V(I)
     DO 5 J=I,NV
5    A(I,J) = A(I,J) + V(I)*V(J)
     GO TO 3
6  PRINT 97 ,A1,A2,N
   PUNCH 97 ,A1,A2,N
   PUNCH 96
   DO 7 I=1,NV
7  D(I) = SUM(I)
   PUNCH 95,D(1),D(2),D(3),D(4),D(5),D(6),D(7),D(8),D(9),D(10),
   D(11),D(12),D(13),D(14),D(15),D(16),D(17),D(18),D(19),D(20),D(21),
   D(22)
   XN = N
   PUNCH 94
   DO 8 I=1,NV
     AV(I) = SUM(I)/XN
8  D(I) = AV(I)
   PUNCH 95,D(1),D(2),D(3),D(4),D(5),D(6),D(7),D(8),D(9),D(10),
   D(11),D(12),D(13),D(14),D(15),D(16),D(17),D(18),D(19),D(20),D(21),
   D(22)
C   ADJUSTED CP GO IN THE LOWER LEFT HALF OF THE MATRIX
   DO 10 I=1,NV
   DO 9 J=1,I

```

```

9  A(I,J) = A(J,I) - SUM(I)*AV(J)
   T(I)=SQRT(A(I,1))
   SD(I)=T(I)/SQRT(XN-1.)
10 D(I) = SD(I)
   PUNCH 93
   PUNCH 95,D(1),D(2),D(3),D(4),D(5),D(6),D(7),D(8),D(9),D(10),
   1D(11),D(12),D(13),D(14),D(15),D(16),D(17),D(18),D(19),D(20),D(21),
   2D(22)
   PUNCH 92
C  THE CORRELATION MATRIX GOES IN THE UPPER RIGHT HALF OF THE MATRIX
   DO 11 I=1,NV
11  D(I) = 0
   DO 14 I=1,NV
   DO 50 K=1,NV
50  D(K)=0.
   DO 12 J=1,NV
   A(I,J+1) = A(J,I)/(T(I)*T(J))
12  D(J) = A(I,J+1)
   IF(I-1)13,13,14
   IF(I-2)13,13,14
13  PRINT 91,D(1),D(2),D(3),D(4),D(5),D(6),D(7),D(8),D(9),D(10),
   1D(11),D(12),D(13),D(14),D(15),D(16),D(17),D(18),D(19),D(20),D(21),
   2D(22)
14  PUNCH 95,D(1),D(2),D(3),D(4),D(5),D(6),D(7),D(8),D(9),D(10),
   1D(11),D(12),D(13),D(14),D(15),D(16),D(17),D(18),D(19),D(20),D(21),
   2D(22)
15  PRINT 78
   ACCEPT 90,IY
   DO 16 I=1,20
   ACCEPT 90,IX(I)
   IF (IX(I)) 17,17,16
16  CONTINUE
17  PUNCH 89,IY
18  N = I-1
   NN = 30-N
   NNI = NN+1
   IF (N-1) 22,22,19
19  DO 21 I=2,N
   IF (IX(I)-IX(I-1)) 20,20,21
20  PRINT 88
   GO TO 15
21  CONTINUE
C  FORM CORRELATION MATRIX TO BE INVERTED
22  DO 25 I=1,N
   NNI = NN+I
   IXI = IX(I)
   IF (IY-IX(I))23,20,20
23  RHS(I) = A(IY,(XI+1))
24  DO 25 J=1,I
   NNJ = NN+J
   IXJ = IX(J)
   A(NNI,J) = A(IXJ,IXI+1)
25  A(NNJ,I) = A(NNI,J)
C  MATRIX INVERSION PROGRAM
30  DO 34 I=1,N
   NNI = NN+1
   X = A(NNI,I)
   A(NNI,I) = 1.
   DO 31 J=1,N
31  A(NNI,J) = A(NNI,J)/X
   DO 34 K=1,N

```

```

      NNK = NN+K
      IF(K-1) 32,34,32
32  X = A(NNK,I)
      A(NNK,I) = 0.
      DO 33 J=1,N
33  A(NNK,J) = A(NNK,J)-X*A(NNI,J)
34  CONTINUE
C   CALCULATE REGRESSION COEFFICIENTS (B) AND STANDARD REGRESSION
C   COEFFICIENTS (BSTAR)
37  DO 39 I=1,N
      NNI = NN+1
      BSTAR(I) = 0.
      DO 38 J=1,N
38  BSTAR(J) = BSTAR(J) + A(NNI,J)*RHS(J)
      IXI = IX(I)
39  BR(I) = ESTAR(I) * T(IY) / T(IXI)
      CONST = AV(IY)
      DO 40 I=1,N
      IXI = IX(I)
40  CONST = CONST - BR(I) * AV(IXI)
      PUNCH 87, CONST
      S = 0.
      DO 41 I=1,N
      IXI = IX(I)
41  S=S+BR(I)*A(IY,IXI+1)*T(IY)*T(IXI)
      RR=SQRT(S/T(IY)/T(IXI))
      PUNCH 85, RR
      PRINT 84,RR
      NO = XN
      DEN = NO - N - 1
      STERR=SQRT((T(IY)*T(IXI)-S)/DEN)
      PUNCH 83, STERR
      PRINT 82,STERR
      PUNCH 81
      DO 42 I =1,N
      NNI = NN+I
      IXI = IX(I)
      SR=STERR/T(IXI)*SQRT(A(NNI,I))
      TTT=BR(I)/SR
      PRINT 80,IX(I),BR(I),TTT
42  PUNCH 79, IX(I), BR(I), SR,TTT
      GO TO 15
78  FORMAT(/10HENTER VARS)
79  FORMAT (15,4F15.5)
80  FORMAT(13,F11.4,F8.3)
81  FORMAT( /7HIND VAR,4X,9HREGR COEF,6X,9HSTD ERROR,10X1HT)
82  FORMAT(2HSE,F9.4)
83  FORMAT(2HSE,11XF13.5)
84  FORMAT(1HR,F10.4)
85  FORMAT(1HR,12XF13.5)
87  FORMAT(5HCONST,8XF13.5)
88  FORMAT(/17HPUT VARS IN OKDER)
89  FORMAT(/6HDEPVAR,I7)
90  FORMAT(I2)
91  FORMAT(F6.3/7F6.3/7F6.3/10F6.3/)
92  FORMAT(/4HCORR)
93  FORMAT(/5HSTDDEV)
94  FORMAT(/3HAVG)
95  FORMAT(7F10.5/7F10.5/7F10.5/7F10.5/)
96  FORMAT (/4HSUMS)
97  FORMAT(/2A5,I5)

```

```
98 FORMAT(F4.0,12X,F5.1,14X,F4.0,4X,F5.1,F5.0,14X,F4.0)
99 FORMAT(I3,2A5)
END
```

SAMPLE OUTPUT

CRAIG 048

SUMS

.27300E 03 .69250E 03 .76000E 02 .10479E 04 .24809E 04 .10900E 03 .77000E 02
 .53000E 02 .50000E 02 .19000E 02 .30800E 03 .19320E 03 .90200E 03 .35100E 02
 .14650E 03 .86400E 02 .10470E 03

AVG

.56875E 01 .14427E 02 .15833E 01 .21831E 02 .51685E 02 .22708E 01 .16041E 01
 .11041E 01 .10416E 01 .39583E 00 .64166E 01 .40250E 01 .18791E 02 .73125E 00
 .30520E 01 .18000E 01 .21812E 01

STDEV

.55088E 01 .22687E 02 .52268E 01 .34814E 02 .36541E 02 .14548E 01 .19972E 01
 .15606E 01 .13831E 01 .49420E 00 .30999E 01 .35345E 01 .20401E 02 .23670E 01
 .46565E 01 .19793E 01 .20002E 01

CORR

.10000E 01 .37130E-01 .43929E-01 .45259E-01 .15091E-01-.22017E 00-.14684E 00
 -.43153E-01 .19162E 00 .24178E 00-.95622E-01-.30041E 00-.14182E 00 .33248E 00
 .55805E-01-.26049E 00-.26603E 00
 .00000E-50 .10000E 01-.08890E-01-.23710E 00-.34887E 00-.84736E-01 .17684E 00
 -.92379E-01 .23666E 00-.13893E 00 .11110E 00 .35641E-01 .25124E 00 .36790E 00
 .27005E 00-.48307E 00-.58678E 00
 .00000E-50 .00000E-50 .10000E 01-.17574E 00 .11915E 00-.88089E-01 .22089E 00
 .21865E-01-.23298E 00 .17063E 00 .35235E-01 .85914E-01-.20219E 00-.69260E-01
 -.23566E-01 .21120E-01 .59025E-01
 .00000E-50 .00000E-50 .00000E-50 .10000E 01-.68980E 00 .11969E-01-.23869E-01

DEPVAR

1

CONST

9.96803

R

.52344

SE

5.29024

IND VAR	REGR COEF	STD ERROR	T
6	-.43859	.88819	-.49379
7	.10612	.76644	.13846
9	.49499	.86545	.57193
10	.91286	2.36933	.38528
11	-.20150	.56903	-.35410
12	-.37739	.30704	-1.22911
13	-.04446	.04538	-.97984
14	.42447	.37916	1.11951
16	.07956	.87274	.09116
17	-.52160	.90144	-.57863