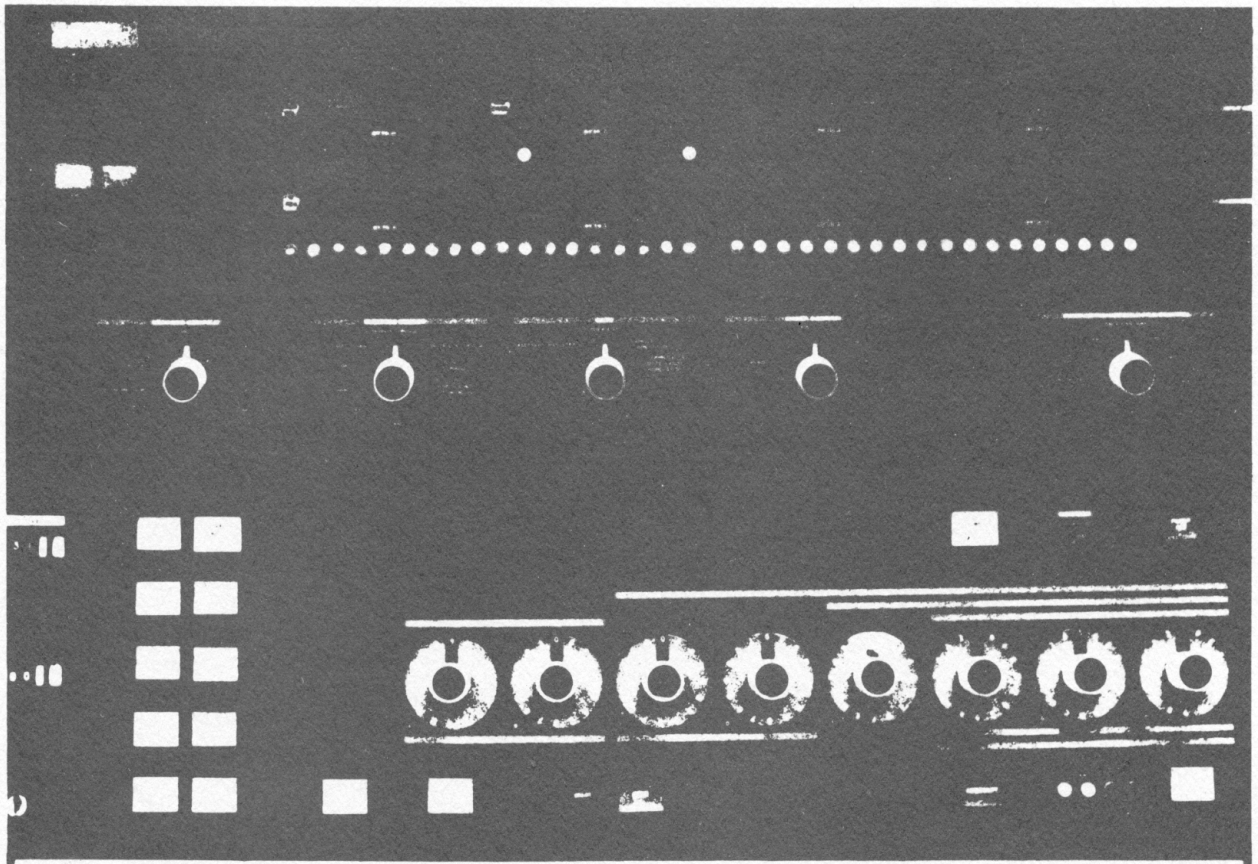

GEOCHEMICAL DATA PROCESSING AT THE IDAHO BUREAU OF MINES AND GEOLOGY

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INTRODUCTION

This is a discussion of the various statistical methods of interpretation of geochemical data currently under study at the Idaho Bureau of Mines and Geology. By their inherent nature, geochemical exploration projects quickly accumulate massive amounts of samples, descriptions and analytical data all of which need integration into one data pile for intrepretation. This usually leads to compiling the field observations and analytical results in tables, plotting them on maps and making correlations. Further exhaustive interpretation of the information entails applying moving averages to the plotted data, calculating means and thresholds for various homogenous units in the study area and locating geochemical anomalies.

Even with this effort the geochemist is not certain that the geochemical anomalies interpreted are real. Also, he has dealt with each element separately and therefore may have missed anomalies (due to special ratios or relationships among elements) that identify a given type of mineralization. A computer can be programed to do all of this and present results which take into account many variables and conditions.

At present, geochemical data are being processed by means of an IBM 360/40* computer installed at the University of Idaho. There are several programs which will calculate the basic statistics of the data wherein the type of distribution of a variable may be tested parametrically. There are several t-tests available to make comparisons between pairs of variables (elements) as well as programs to do analysis of variance and covariance. A number of regression programs such as step-wise discriminant analysis and R-mode factor analysis are in use. For map preparation there is a program which creates grid data sets from random data sets and makes use of an off-line Cal-Comp plotter to contour the results. This program, known as STAMPEDE will be described later.

The following section describes some of the more commonly used programs and gives examples of their application to geochemical studies.

Acknowledgments

I would like to thank the computer center of the University of Idaho for providing unsponsored research computer time.

*As of July 1974 the computer available is an IBM 370/145.

APPLICATIONS

Basic Statistics: REDUCE

This program will list a data matrix with up to 12 elements in columns and 499 samples in rows. The first four moments are calculated for each element both with and without a log transformation and the results are given in the form of a table. Important for future handling of the data is the standardizing subroutine which puts all elements in the same range. This gives them equal weight in any multivariate procedure that may follow. This is also important for map making, so that contours can be given in standardized units (e.g. zero is the mean) and similarities between the various element maps will show up better. Histograms are also given by this program.

The first four moments that are calculated are the mean ($\bar{x}$), the variance (s^2), the skewness (a_3) and the kurtosis (a_4). These are expressed mathematically as follows:

$$\bar{x} = \frac{1}{n} \Sigma x_i \qquad S^2 = \frac{1}{n-1} \Sigma (X_i - \bar{x})^2$$

$$a_3 = \frac{1}{ns^3} \Sigma (X_i - \bar{x})^3 \qquad a_4 = \frac{1}{ns^4} \Sigma (X_i - \bar{x})^4$$

when n is the number of observations for each element, and X_i is the value of an observation. The mean is the center of gravity or central value for the element. The variance is a measure of the spread of the data, and may be given in terms of the original units (e.g. ppm) by finding the square root of the variance (standard deviation). The skewness indicates the symmetry of the data about its mean. For a normal distribution, $a_3 = 0$; for a distribution skewed to the right, a_3 is negative. The kurtosis is a measure of the peakedness of the distribution. For a normal distribution, $a_4 = 3$ (or $a'_4 = a_4 - 3 = 0$). For a distribution which is peaked, a'_4 is positive, and if it is flat, a'_4 is negative.

Geochemical trace-element data is usually positively skewed (Ahrens, 1953, 1954a, 1954b, 1957) and as a consequence a log transformation usually makes the distribution more symmetric. Many times, after a log transformation, the distribution is still positively skewed. This is a good indication of inhomogeneity of the data (the converse is not necessarily true) and the possibility that mineralization gives rise to an interferring population (Lepeltier, 1969). Kurtosis is also a good indicator of the possible presence of mineralization. If, after a log transformation, the kurtosis is positive, there may be two populations present with the same or nearly the same mean, but different standard deviations.

Table 1 is a listing of stream sediment data obtained from streams in the Bighorn Crags area in central Idaho in the Long Tom Mtn. quadrangle, south of the Salmon River (Knowles, 1975). These data include results from examinations of samples reflecting natural conditions and samples which come from an area contaminated by mine workings. As a consequence, these data increased the mean and threshold values significantly above normal for this area. These samples were removed and the data were passed through the REDUCE program. Table 2 shows the revised listing, and table 3 gives the statistics. Table 4 registers the statistics for log transformed data and Figs.1 (a-g), 2 (a-g) show frequency distributions and histograms for raw data and log transformed data. Table 5 lists the standardized values for log data. Any value in table 5 that is 0, 1 or 2 is the mean, the mean plus one standard deviation or the mean plus two standard deviations respectively.

Table 3 shows that every trace element has a positively skewed and positively kurtotic distribution and hence none of these data was derived from a population which is Gaussian normal. Table 4 shows that in every case the skewness and the kurtosis (a'_4) tend to be close to zero. Tables are available for determing whether the skewness and kurtosis are significantly greater or less than zero (Snedecor and Cochran, 1967) but as a rule of thumb if these values are less than unity the distribution of the element may be considered normal. It is known that in the Bighorn Crags area the trace-element distribution is reflected mainly by two lithologic units (quartz monzonite and quartzite) and minorly by copper mineralization. Samples from the quartz monzonite and the copper mineralized units tend to have high values and samples from the quartzite tend to have low trace element values. Inhomogeneity of the study area therefore, affects the trace-element distributions. This, however, can be statistically recognized for geochemical evaluation.

Computer cards containing the log transformed standarized data are punched by the REDUCE program and may be used in other programs.

At this point it is desirable to have geochemical maps of the study area, and these may be obtained by making use of the program STAMPEDE - Surface Techniques, Annotations and Mapping Programs for Exploration, Development and Engineering (Gussow et. al., 1968). This is a set of thirteen programs which make numerical and analytical approximations to a set of three coordinate values defining a surface, for manipulating one or more of these surfaces, and for preparing a display of surface geometry in the form of printed or plotted, annotated contour maps. It is designed to operate on a system 360 model F computer with floating point features, and an on or off-line plotting device. This program is for unrestricted distribution by IBM.

FIG. 1a: FREQUENCY DISTRIBUTION FOR AG IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	0	0.0	100.0	I
3	8	17.0	83.0	I********
4	11	23.4	59.6	I***********
5	12	25.5	34.0	I************
6	8	17.0	17.0	I********
7	2	4.3	12.8	I**
8	1	2.1	10.6	I*
9	2	4.3	6.4	I**
10	1	2.1	4.3	I*

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 1.0000 IS 2

THE CLASS WIDTH IS 0.1000

FIG. 1b: FREQUENCY DISTRIBUTION FOR AU IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	0	0.0	100.0	I
3	5	10.6	89.4	I*****
4	14	29.8	59.6	I**************
5	8	17.0	42.6	I********
6	10	21.3	21.3	I**********
7	3	6.4	14.9	I***
8	4	8.5	6.4	I****
9	0	0.0	6.4	I
10	0	0.0	6.4	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 10.0000 IS 3

THE CLASS WIDTH IS 1.0000

FIG.1c: FREQUENCY DISTRIBUTION FOR CO IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	10	21.3	78.7	I**********
2	20	42.6	36.2	I********************
3	13	27.7	8.5	I*************
4	2	4.3	4.3	I**
5	1	2.1	2.1	I*
6	0	0.0	2.1	I
7	0	0.0	2.1	I
8	1	2.1	0.0	I*
9	0	0.0	0.0	I
10	0	0.0	0.0	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 50.0000 IS 0

THE CLASS WIDTH IS 5.0000

FIG. 1d: FREQUENCY DISTRIBUTION FOR CU IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	8	17.0	93.0	I********
2	11	23.4	59.6	I***********
3	10	21.3	38.3	I**********
4	6	12.8	25.5	I******
5	5	10.6	14.9	I*****
6	4	8.5	6.4	I****
7	2	4.3	2.1	I**
8	0	0.0	2.1	I
9	0	0.0	2.1	I
10	0	0.0	2.1	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 50.0000 IS 1

THE CLASS WIDTH IS 5.0000

FIG. 1e: FREQUENCY DISTRIBUTION FOR MO IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	22	46.8	53.2	I**********
3	10	21.3	31.9	I**********
4	6	12.8	19.1	I******
5	1	2.1	17.0	I*
6	0	0.0	17.0	I
7	2	4.3	12.8	I**
8	1	2.1	10.6	I*
9	1	2.1	8.5	I*
10	0	0.0	8.5	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 10.0000 IS 4

THE CLASS WIDTH IS 1.0000

FIG. 1f: FREQUENCY DISTRIBUTION FOR PB IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	19	40.4	59.6	I********************
3	6	12.8	46.8	I******
4	10	21.3	25.5	I**********
5	5	10.6	14.9	I*****
6	3	6.4	8.5	I***
7	1	2.1	6.4	I*
8	1	2.1	4.3	I*
9	0	0.0	4.3	I
10	1	2.1	2.1	I*

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 50.0000 IS 1

THE CLASS WIDTH IS 5.0000

FIG. 1g: FREQUENCY DISTRIBUTION FOR ZN IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	16	34.0	66.0	I****************
3	13	27.7	38.3	I*************
4	6	12.8	25.5	I******
5	4	8.5	17.0	I****
6	5	10.6	6.4	I*****
7	1	2.1	4.3	I*
8	0	0.0	4.3	I
9	1	2.1	2.1	I*
10	0	0.0	2.1	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 200.0000 IS 1

THE CLASS WIDTH IS 20.0000

FIG. 2a: FREQUENCY DISTRIBUTION FOR AG AFTER A LOG TRANSFORMATION OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	8	17.0	83.0	I********
3	11	23.4	59.6	I***********
4	22	46.8	12.8	I**********************
5	4	8.5	4.3	I****
6	2	4.3	0.0	I**
7	0	0.0	0.0	I
8	0	0.0	0.0	I
9	0	0.0	0.0	I
10	0	0.0	0.0	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO -1.0000 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 1.0000 IS 0

THE CLASS WIDTH IS 0.2000

FIG. 2b: FREQUENCY DISTRIBUTION FOR AU AFTER A LOG TRANSFORMATION OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	0	0.0	100.0	I
3	5	10.6	89.4	I*****
4	14	29.8	59.6	I**************
5	16	34.0	25.5	I****************
6	9	19.1	6.4	I*********
7	1	2.1	4.3	I*
8	1	2.1	2.1	I*
9	1	2.1	0.0	I*
10	0	0.0	0.0	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 1.5000 IS 0

THE CLASS WIDTH IS 0.1500

FIG. 2c: FREQUENCY DISTRIBUTION FOR CO AFTER A LOG TRANSFORMATION OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	0	0.0	100.0	I
3	2	4.3	95.7	I**
4	18	38.3	57.4	I******************
5	12	25.5	31.9	I************
6	12	25.5	6.4	I************
7	2	4.3	2.1	I**
8	1	2.1	0.0	I*
9	0	0.0	0.0	I
10	0	0.0	0.0	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 2.0000 IS 0

THE CLASS WIDTH IS 0.2000

FIG. 2d: FREQUENCY DISTRIBUTION FOR CU AFTER A LOG TRANSFORMATION OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	0	0.0	100.0	I
3	4	8.5	91.5	I****
4	9	17.0	74.5	I*********
5	10	21.3	53.2	I**********
6	8	17.0	36.2	I*********
7	10	21.3	14.9	I**********
8	6	12.8	2.1	I******
9	1	2.1	0.0	I*
10	0	0.0	0.0	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 2.0000 IS 0

THE CLASS WIDTH IS 0.2000

FIG. 2e: FREQUENCY DISTRIBUTION FOR MO AFTER A LOG TRANSFORMATION OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	17	36.2	63.8	I**********
2	3	6.4	57.4	I***
3	2	4.3	53.2	I**
4	9	19.1	34.0	I*********
5	6	12.8	21.3	I******
6	1	2.1	19.1	I*
7	1	2.1	17.0	I*
8	1	2.1	14.9	I*
9	2	4.3	10.6	I**
10	1	2.1	8.5	I*
11	2	4.3	4.3	I**
12	2	4.3	-0.0	I**
13	0	0.0	-0.0	I
14	0	0.0	-0.0	I
15	0	0.0	-0.0	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 1.5000 IS 0

THE CLASS WIDTH IS 0.1000

FIG. 2f: FREQUENCY DISTRIBUTION FOR PB AFTER A LOG TRANSFORMATION OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	0	0.0	100.0	I
3	0	0.0	100.0	I
4	3	6.4	93.6	I***
5	18	38.3	55.3	I**********
6	6	12.8	42.6	I******
7	14	29.8	12.8	I**********
8	4	8.5	4.3	I****
9	2	4.3	0.0	I**
10	0	0.0	0.0	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 2.0000 IS 0

THE CLASS WIDTH IS 0.2000

FIG. 2g: FREQUENCY DISTRIBUTION FOR ZN AFTER A LOG TRANSFORMATION OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

CLASS	F	%F	CUM %F	
1	0	0.0	100.0	I
2	0	0.0	100.0	I
3	0	0.0	100.0	I
4	0	0.0	100.0	I
5	0	0.0	100.0	I
6	0	0.0	100.0	I
7	4	8.5	91.5	I****
8	12	25.5	66.0	I**********
9	14	29.8	36.2	I**********
10	9	19.1	17.0	I*********
11	6	12.8	4.3	I******
12	1	2.1	2.1	I*
13	1	2.1	0.0	I*
14	0	0.0	0.0	I
15	0	0.0	0.0	I
16	0	0.0	0.0	I
17	0	0.0	0.0	I
18	0	0.0	0.0	I
19	0	0.0	0.0	I
20	0	0.0	0.0	I

THE NUMBER OF VALUES LESS THAN OR EQUAL TO 0.0 IS 0

THE NUMBER OF VALUES GREATER THAN OR EQUAL TO 4.0000 IS 0

THE CLASS WIDTH IS 0.2000

Map Preparation: STAMPEDE

Figure 3 is an example of a printer map display of the distribution of cobalt (Co) in the Bighorn Crags study area. This map was produced in lieu of a Cal-Comp plotted map which would take more time, but could be more accurately scaled and which also allows for the stipulation of maximum and minimum contours to be plotted. This was not done here because the plotting routine in STAMPEDE was not set up at the time of this writing.

To prepare this type of map a set of data is entered from samples randomly located within a rectangular area. The computer program considers random data as any data that does not conform to a systematic grid pattern over a retangular area. Therefore, the random data is used by the program to determine the values at the intersections of grid lines, and this requires interpolation between random data points. In this case the grid data set is those values of cobalt that are determined at the intersection of horizontal and vertical lines (mesh points) which are separated by a constant width (grid width). One problem is the choice of grid width to be used. If the grid width is too large than the data will be essentially smoothed and local fluctuations will be lost. If the grid width is too small then computer costs increase substantially. As a rule of thumb, the grid width should be such that at most, one sample lies within a square. To aid in the application of the rule, the following formula is presented to determine the average distance between data points (Gussow et al., 1968, p. 41):

$$d = (Xmax - Xmin) \quad (Ymax - Ymin)/N^{\frac{1}{2}}$$

where N is the number of data points or samples, Xmax and Xmin are the maximum and minimum values of the X coordinate, and Ymax and Ymin are the maximum and minumum values of the Y coordinate. The grid interval G should be such that:

$$\frac{d}{4} \leq G \leq \frac{d}{2}$$

The values at the mesh points are calculated by finding a plane which passes through the centroid of the square and immediately surrounding data points. The surface fit gives high weighting to data points closer to the centroid. The mesh points of each grid are assigned the value corresponding to the intersection of the plane and the mesh points.

For the data presented here, the origin is the southwest corner, the X-axis extends to the east, the Y axis extends to the north, Xmin = Ymin = 0, Xmax = 360, Ymax = 340 and N = 50. Therefore, $d \cong 50$ units and G should be between 12 and 25 units. A grid width of 10 units was used and this gave a maximum of 36 times 34 mesh points within the map area. If no data exist at the sides of the map the mesh points are not calculated. The scale of the map in Figure 3 is one inch equals two miles which is equivalent to 50.8 mapping units per inch. This is because X and Y coordinates were determined from a map with a scale of one inch equals one mile and were given in millimeters. The reference contour ($) is 30 ppm on the side facing A and 35 ppm on the side facing 1. The map shows the general southeast - northwest trend of a zone of high Co which becomes a maximum near the Blackbird mining district in the southeast.

Fig. 3 Printer map display of the distribution of Cobalt in the Bighorn Crags study area.

Smoothing Techniques

Data such as that presented in the previous section may be smoothed by a number of methods. The first is by the application of a smoothing program within the STAMPEDE program. This program adjusts a particular mesh point value to a value determined from a second order surface that is fitted by the least-squares method using nearby mesh points. The degree of smoothing is varied by selection of a radius about each grid point in terms of grid intervals. Grid values within this radius are included in the computation of the second order surface. The disadvantage with this method is that the maximum smoothing order allowed is four, and this is usually found to be too small. A second method, which was alluded to in the previous section, is to increase the grid width in the preparation of isoplethic maps. With a larger width there will be more than one data point within a grid square and these will be averaged during the determination of mesh-point values.

A third method of smoothing data is to apply trend surface analysis which is the least-squares fit of orthogonal polynomials to a set of data. In this case the data may be regular or irregular, that is, grid or random respectively. In general, the more irregular the surface, the higher the degree of the equation that must be used to represent the surface. This third method may be applied by means of a program within STAMPEDE or by means of another computer program called TREND. Figures 4a to d are trend surfaces of order one to four respectively. These surfaces were obtained by means of the TREND program and the isoplethic maps were drawn by means of a plotting program called DBMCI 1. The data are the cobalt concentration in stream sediments collected at Bighorn Crags. However, in this case the data were log transformed before the technique was applied. The plus signs in Figure 4a show the location of the sample stations. Figure 4a shows that the linear regional trend of cobalt increases to the northeast. This is because of the belt of high concentration cobalt which clearly shows up in the representation of the fourth degree surface in Figure 4d. After each fit a total of 28,52,64, and 72 percent of the available data was fitted by the first, second, third, and fourth degree surface respectively.

If desired, residuals could be determined after the application of any one of the three smoothing techniques described. A residual map shows local irregularities after the regional trend has been removed, and could be useful in the location of sites with a high potential for mineralization.

Three-Dimensional Maps

In order to improve the search for mineralization in an area, it is possible to prepare three dimensional views of the geochemistry of the study area. For comparitive purposes the data from Bighorn Crags are again used to show the method and two, three-dimensional views are shown in Figures 5a and b. The program used was BLOCK which was adapted for use on the IBM 360/40 by J. Davis at the University of Idaho and for use on the IBM 360/67 at Washington State University.

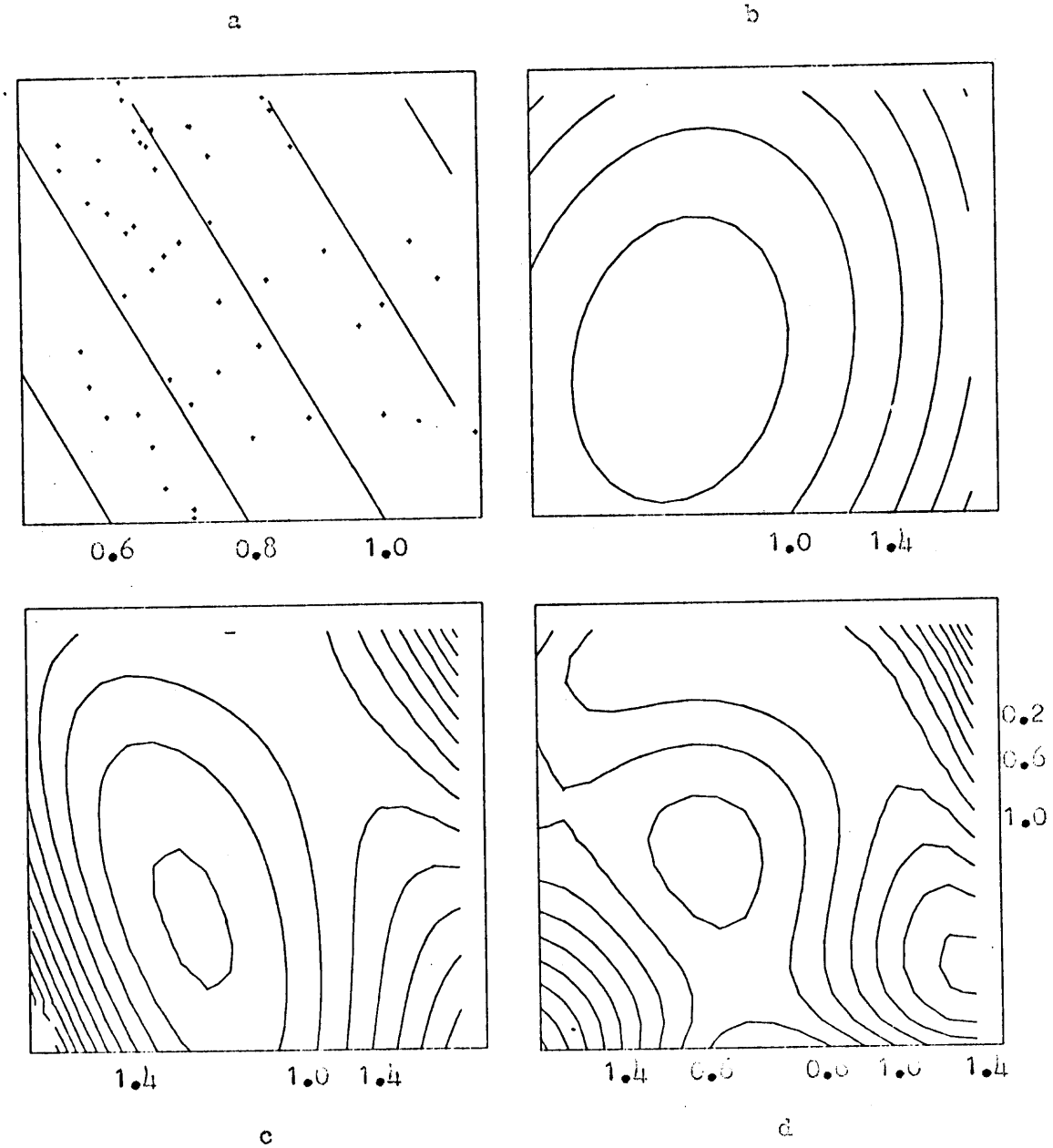

Fig. 4 Trend surfaces for the distribution of Cobalt in the Bighorn Crags study area.

A square grid of points which describe the surface was first produced by STAMPEDE and put on magnetic tape. A program called TFRGRD was used to transfer the grid data to a set of cards in such a way that the parts of the area where no data were available were set near the mean concentration which for cobalt was about 10 ppm.

With the BLOCK program several options are available and these are: viewing distance; orientation of the line of view; inclination of the line of view, vertical exaggeration; elevation of the bottom of the block; number of views desired; and limits on the width and length of the view. In Figures 5a and b the viewing distance is 1.25, the orientation of the lines of view are such that Figure 5b has been rotated 75^{o} with respect to Figure 5a, the inclination of the views is 20^{o}, the vertical exaggeration is five times, and the elevation (concentration of cobalt) at the bottom of the view is zero.

Figure 5b is oriented such that the viewer is looking directly down the zone of high Co in the quartzites in the Bighorn Crags study area. The small ripples in the southwest reflect the trace-element values in sediments draining quartz monzonites.

R-Mode Factor Analysis

Very briefly, the purpose of R-mode factor analysis is to clarify specific relationships among numerous variables such that the total picture (or most of it) is explained by means of fewer components or characteristics (factors) which may be termed as new and hypothetical variables. This technique has been used by Garrett and Nichol (1969); Nichol, and Webb, (1967) and by Saager, and Essenlaar, (1969), in the interpretation of geochemical data.

In R-mode factor analysis an n x p data matrix (n is the number of samples and p is the number of elements) is converted into a p x p matrix of correlations, similarities, or distances between variables. This matrix is reduced to a p x k factor matrix where k is the number of eigenvectors whose eigenvalues are "sufficiently large." The decision as to the number of factors to extract is to some extent, arbitrary and will not be discussed here. This p x k matrix is rotated either obliquely or orthogonally in such a manner that the resulting factors become more easily interpretable geologically.

The program available for use at the University of Idaho is M03 (Dixon, 1970, p. 169), which was taken from a set of biomed programs distributed by the University of California at Los Angeles. This program finds a p x p correlation matrix, and as a final step carries out an orthogonal rather than an oblique rotation of the factors. This program was applied to a set of eight elements determined in 121 soil samples collected over a malaquite-rich quartz vein in a fault at Fazenda Matino in the state of Bahia, Brazil (Galbraith, 1973). The eight elements determined were total Copper, soluble copper, cobalt, chromium, manganese, nickel lead and zinc. These data were transformed logarithmically before the program was applied.

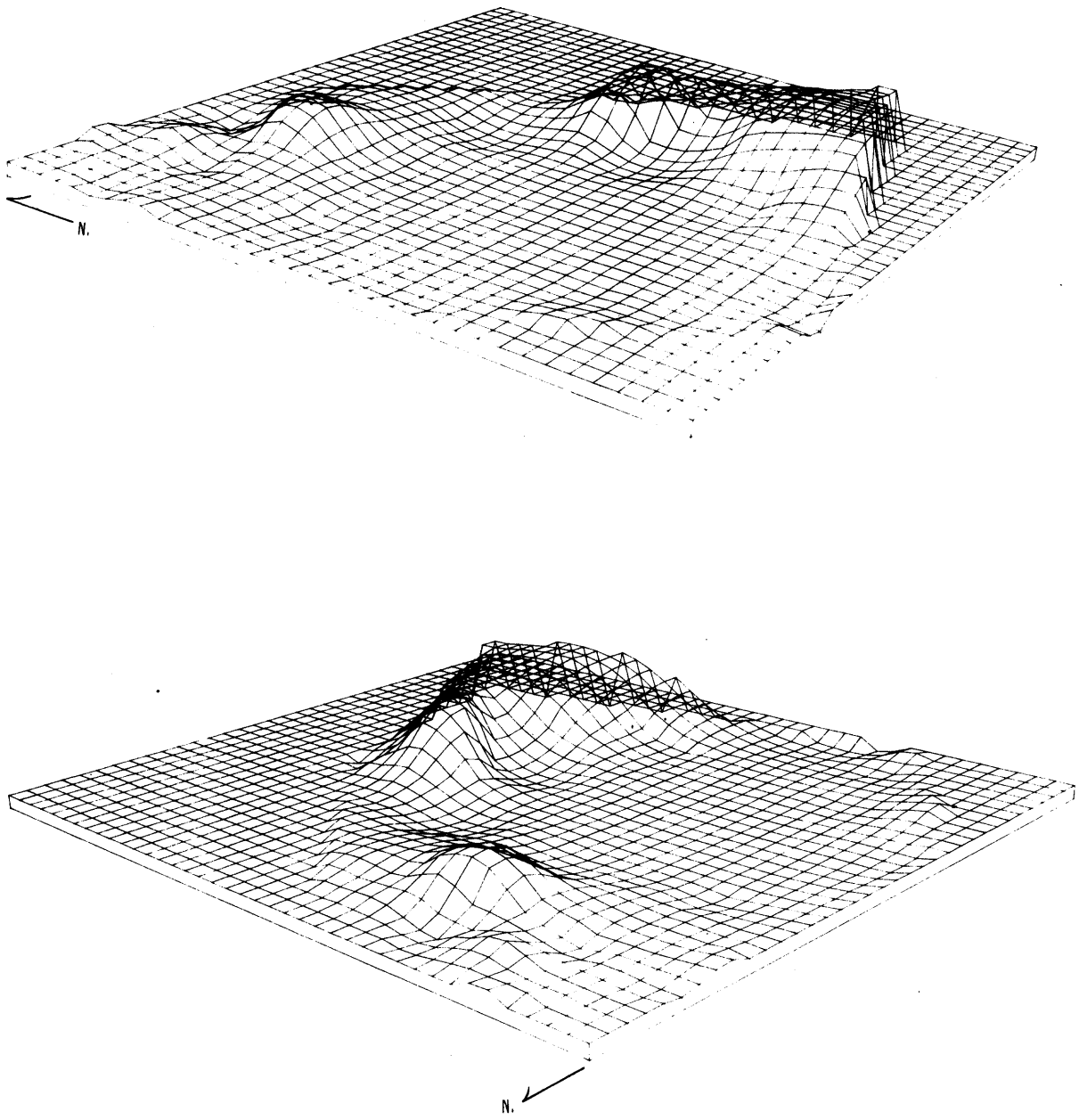

Fig. 5 Three dimensional views of the distribution of Cobalt in the Bighorn Crags study area

Table 6 is the correlation matrix for the eight elements. When the eigenvalues were extracted, a total of 35.4, 44.3, and 50.6 per cent of the available information was explained by the first three factors. Table is the rotated factor matrix and shows the relationships of the elements and Figure 6 shows the distributions of the factor scores. Factor 1 has high loadings (that is, factor 1 consists predominantly of total copper, soluble copper, manganese and cobalt). These four elements are associated with the quartz vein and all show high tenors over the vein and low tenors on either side (see Figure 6a). Factor 2 has high loadings of lead, cobalt, zinc, manganese, soluble copper (negative) and nickel and may reflect the relationship of these elements in the country rock which is a gneiss (Fig.6b). Factor 3 has high loadings of chrome and nickel and this factor reflects the relationships in the mafic portion of the gneissic country rock (Fig. 6c). In fact, the nickel map itself (not shown) shows the offset of the fault as left lateral. This is because the gneissic foliation intersects the fault at about 90^{o} and the bands of high-concentration nickel bend as they get closer to the vein.

Stepwise Discriminant Analysis

Stepwise discriminant analysis is a procedure whereby several groups are classified by means of as few variables (or elements) as possible. For instance, ten characteristics may be measured on three types of material, say lithologic units. It may be that it is only necessary to measure several of the characteristics in order to distinguish them from each other. As an example, three groups will be considered. These are 1) a set of 32 soil samples overlying a copper-rich quartz vein, 2) a set of seven soil samples overlying a copper-rich zone and 3) a set of 11 soil samples overlying a diabase dike. Seven elements were determined in each sample and are shown in Table 8. These data were standardized before the application of stepwise discriminant analysis. The program used was M07 (Dixon, 1970, p. 214a) which was obtained from a set of biomed programs distributed by the University of California at Los Angeles. Table 9a is a list of the means and Table 9b is a list of the standard deviations of each element in each group.

An F test was applied to each element to determine if there was a significant difference between the means of the elements in the different groups. The element with the highest F value was used first to test to see if it alone would discriminate among the three groups. The element with the greatest variance was zinc and by itself only one of the 32 samples from group FM was classified as DD. One sample from PM was classified as DD and two samples from group DD were classified as PM and one as FM. With the inclusion of cobalt only one sample from FM was classified as DD and only one sample from DD was classified as FM. This means that with the determination of only zinc and cobalt it is possible to distinguish the PM group, but there is a small chance that a sample from the DD group could be classified erroneously as FM and visa versa. With the inclusion of lead all groups are correctly classified so that it appears that if only three elements are

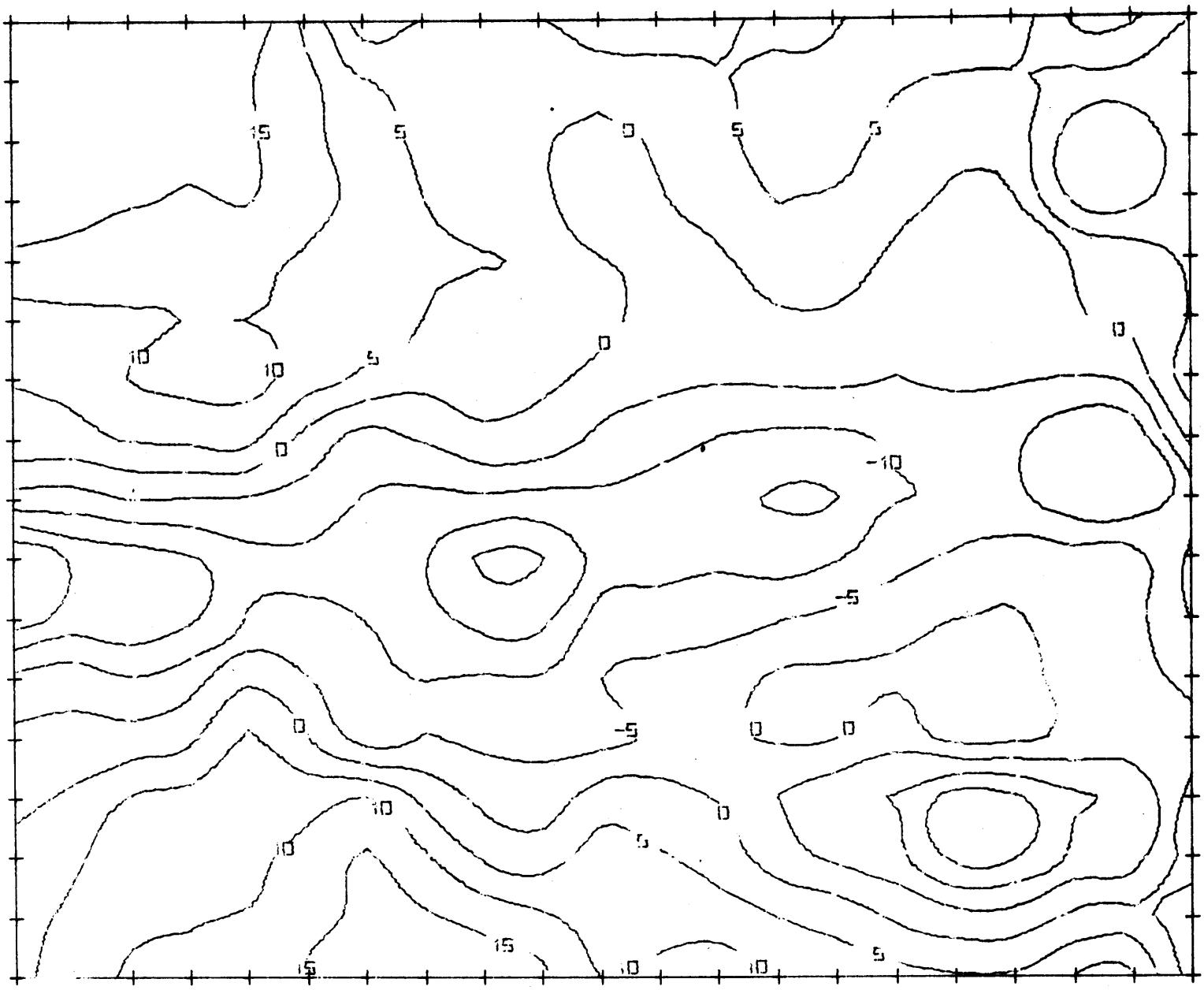

Fig. 6a Isoplethic map of factor scores for factor 1 determined after R-mode factor analysis on eight elements and 121 samples

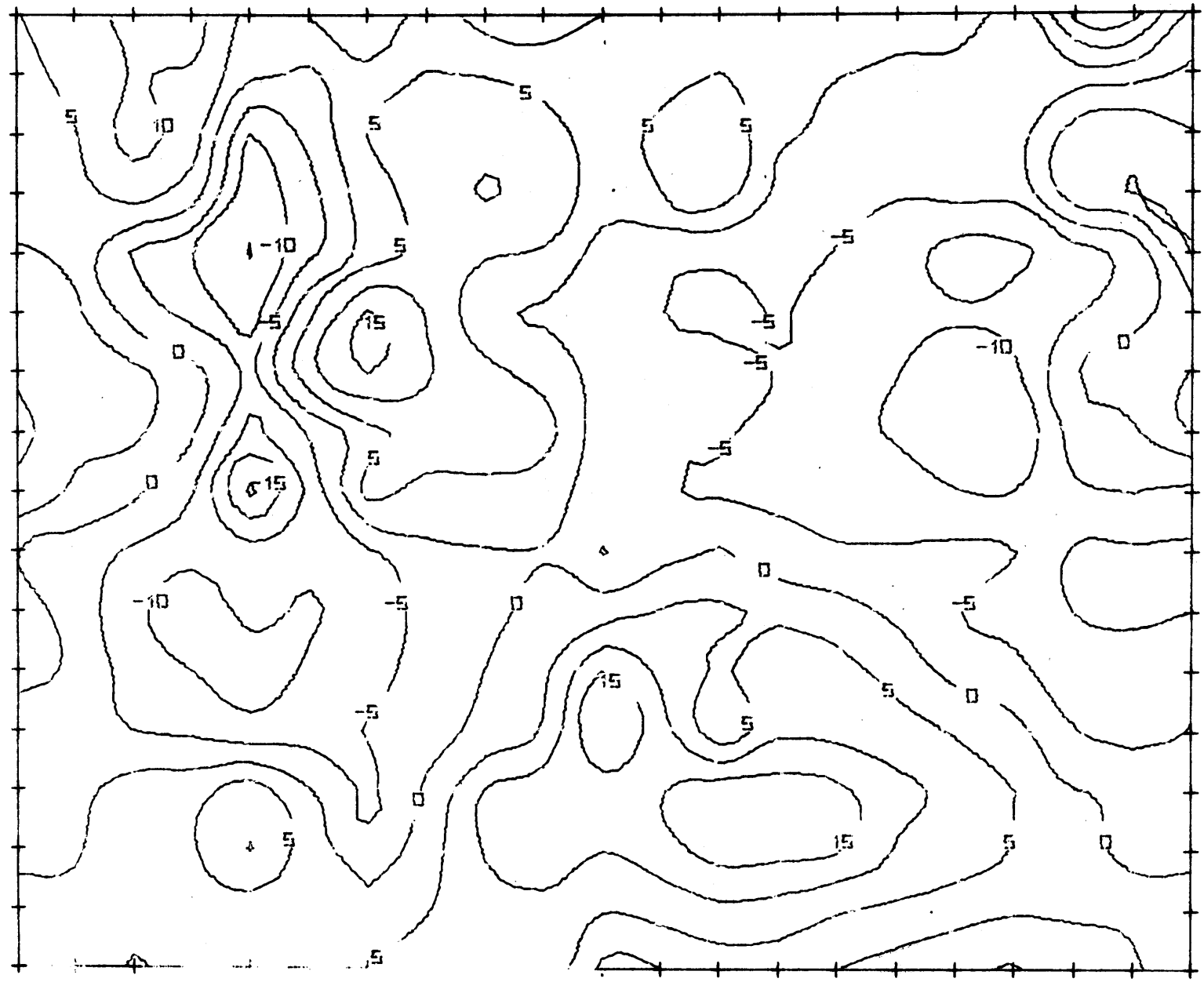

Fig. 6b Isoplethic map of factor scores for factor 2 determined after R-mode factor analysis on eight elements and 121 samples

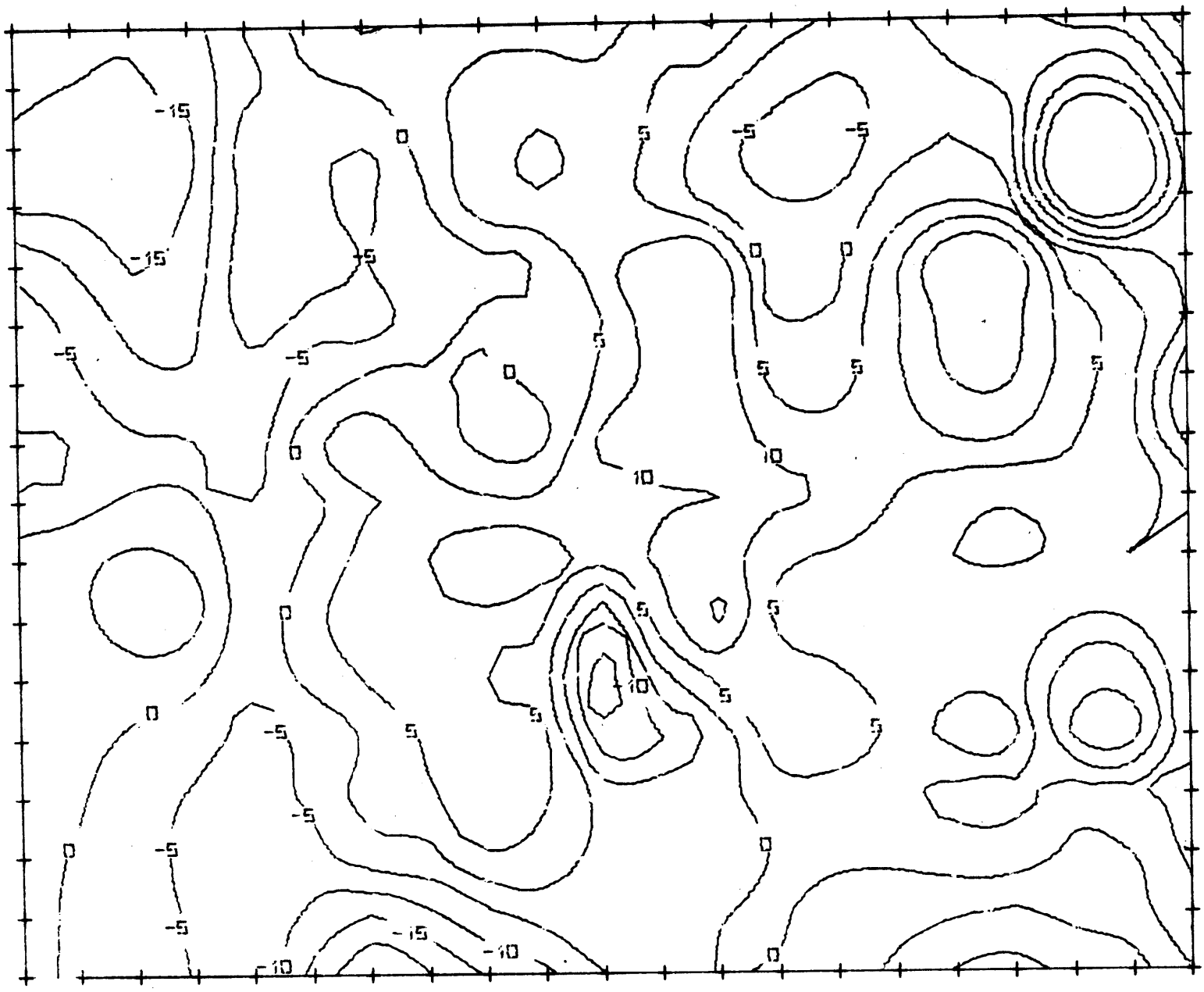

Fig. 6c Isoplethic map of factor scores for factor 3 determined after R-mode factor analysis on eight elements and 121 samples

measured rather than seven it would be possible to distinguish the three groups. The next most important elements are copper, nickel, chromium, and manganese, which means that manganese is the least important element for distinguishing these three groups. From these results, it appears that the copper in group 2 has a genesis different from that in group 1. Also, it is readily possible to distinguish between copper anomalies due to barren mafic units such as diabase dikes and copper anomalies due to mineralization.

Q-Mode Cluster Analysis

The purpose of a cluster analysis is to place similar objects into a number of distinct categories, with the objects in each category more similar to each other than to the objects in all other categories. Thus, a sample-by-sample comparison on some measurements by similarity must be made. Parks (1970) makes use of the simple distance function which permits the use of continuous as well as presence-absence data. Before this sample-by-sample comparison is carried out the variables are made orthogonal by the application of R-mode factor analysis (see p. 12) which also reduces the number of variables which must be utilized. Following this, distances between samples are determined and the results are output in the form of a dendogram.

Q-mode cluster analysis is a procedure which is opposite to that of discriminant analysis. In discriminant analysis, samples are already known to belong to given groups, whereas in Q-mode cluster analysis the samples must be classified into various groups.

CONCLUSIONS

In summary, with judicious application of the various programs described it is possible to physically handle many thousands of samples efficiently. In this respect, the computer makes an excellent secretary. Also, geochemical maps may be produced quickly and manipulated in such a way that anomalous sites may be rapidly and easily spotted, especially when the map is presented as a three-dimensional view. Finally, it is possible to distinguish between true and false anomalies, and with sufficient background information, distinguish between various types of deposit.

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APPENDIX

TABLE 1: COORDINATES AND TENORS OF TRACE ELEMENTS IN SEDIMENTS BIGHORN CRAGS.

NUMBER	COORDINATE X	COORDINATE Y	AG	AU	CO	CU	MO	PB	ZN
BD-01	134	3	0.2	3.0	3.0	5.0	1.0	22.0	59.0
BD-03	134	9	0.3	3.0	4.0	4.0	3.0	16.0	62.0
BD-04	119	12	0.7	7.4	11.1	9.2	11.1	33.2	129.0
BD-06	112	25	0.3	4.0	5.0	4.0	13.0	25.0	92.0
BD-10	102	57	0.6	3.0	6.1	12.2	13.7	35.1	178.0
BD-13	133	89	0.3	3.2	4.9	14.6	1.6	19.4	64.7
BD-16	154	113	0.3	3.0	4.0	3.0	2.0	17.0	49.0
BD-20	180	63	0.4	3.0	6.0	16.0	3.0	18.0	119.0
BD-23	186	132	0.5	2.0	5.0	6.0	1.0	8.0	22.0
BD-25	224	77	0.3	4.0	8.0	10.0	1.0	17.0	77.0
BD-35	282	79	0.6	4.4	710.0	12680.0	2.9	19.2	108.0
BD-37	282	162	0.5	7.0	186.0	390.0	1.0	12.0	42.0
CC-02	67	80	1.3	12.8	12.8	51.2	6.4	51.2	310.0
CC-05	91	82	0.4	5.4	5.4	9.4	2.7	21.4	93.7
CC-07	116	108	1.5	4.0	4.0	4.0	2.0	21.0	78.0
CC-09	53	103	0.8	17.0	8.5	25.4	8.5	17.0	118.0
CC-10	47	130	0.4	4.0	6.0	8.2	6.1	21.5	111.0
CC-15	82	172	0.2	3.0	4.0	3.0	1.0	11.0	56.0
CC-18	104	191	0.2	3.0	4.0	3.0	4.0	13.0	51.0
CC-23	113	201	0.2	3.0	4.0	4.0	2.0	11.0	49.0
CC-27	125	211	0.4	2.0	5.0	11.0	1.0	10.0	33.0
CC-30	155	166	0.3	6.9	3.5	3.5	3.4	6.9	31.1
CC-32	149	226	0.3	3.0	7.0	11.0	1.0	7.0	31.0
CC-35	192	182	0.5	2.6	5.2	15.6	1.3	23.4	65.0
CC-39	238	203	0.2	3.0	5.0	5.0	1.0	5.0	20.0
CC-41	213	282	0.2	4.0	20.0	24.0	1.0	5.0	21.0
CC-46	264	146	0.3	5.0	8.0	7.0	1.0	9.0	35.0
GT-01	84	219	0.2	2.3	4.6	5.8	2.3	10.4	74.2
GT-02	90	224	0.6	5.7	7.6	22.9	7.6	28.6	116.0
GT-03	70	234	0.8	5.1	9.1	30.3	12.1	28.3	107.0
GT-07	54	242	0.9	4.7	9.4	29.8	3.1	15.7	42.3
GT-09	63	274	0.3	5.0	10.0	16.0	1.0	8.0	39.0
GT-12	31	286	0.5	4.0	9.0	22.0	2.0	9.0	38.0
LC-01	91	296	0.4	5.0	10.0	12.0	1.0	9.0	38.0
LC-02	96	287	0.2	3.0	6.0	8.0	1.0	5.0	33.0
LC-03	100	284	0.4	3.0	8.0	10.0	1.0	9.0	54.0
LC-04	107	267	0.3	3.0	14.0	10.0	2.0	9.0	22.0
LC-05	133	299	0.5	2.3	6.9	8.0	1.1	49.4	40.2
LC-06	135	299	0.4	7.0	13.0	30.0	3.0	9.0	37.0
LC-09	105	297	0.4	5.8	14.6	18.9	1.5	8.7	36.4
LC-14	98	304	0.3	6.0	18.0	29.0	1.0	8.0	37.0
GC-01	148	275	0.4	5.0	39.0	29.0	2.0	8.0	40.0
GC-06	191	320	0.4	6.0	11.0	8.0	3.0	9.0	92.0
GC-07	197	310	0.5	10.0	13.0	11.0	2.0	9.0	81.0
LD-02	353	65	0.4	7.0	163.0	370.0	1.0	9.0	19.0
S-01	82	320	0.4	4.0	12.0	21.0	1.0	10.0	48.0
S-02	80	333	0.4	5.0	15.0	24.0	2.0	9.0	42.0
A-01	325	181	0.5	5.0	13.4	16.8	1.7	16.8	47.0
B-01	32	267	0.5	7.6	13.9	16.4	1.3	15.1	47.9
G-01	304	209	0.5	7.0	12.8	12.8	1.2	16.3	33.9

TABLE 2: COORDINATES AND TENORS OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS, (CONTAMINATED SAMPLES REMOVED).

NUMBER	COORDINATE X	COORDINATE Y	AG	AU	CO	CU	MO	PB	ZN
BD-01	134	3	0.2	3.0	3.0	5.0	1.0	22.0	59.0
BD-03	134	9	0.3	3.0	4.0	4.0	3.0	16.0	62.0
BD-04	119	12	0.7	7.4	11.1	9.2	11.1	33.2	129.0
BD-06	112	25	0.3	4.0	5.0	4.0	13.0	25.0	92.0
BD-10	102	57	0.6	3.0	6.1	12.2	13.7	35.1	178.0
BD-13	133	89	0.3	3.2	4.9	14.6	1.6	19.4	64.7
BD-16	154	113	0.3	3.0	4.0	3.0	2.0	17.0	49.0
BD-20	160	63	0.4	3.0	6.0	16.0	3.0	18.0	119.0
BD-23	186	132	0.5	2.0	5.0	6.0	1.0	8.0	22.0
BD-25	224	77	0.3	4.0	8.0	10.0	1.0	17.0	77.0
CC-02	67	80	1.3	12.8	12.8	51.2	6.4	51.2	310.0
CC-05	91	82	0.4	5.4	5.4	9.4	2.7	21.4	93.7
CC-07	116	108	1.5	4.0	4.0	4.0	2.0	21.0	78.0
CC-09	53	103	0.8	17.0	8.5	25.4	8.5	17.0	118.0
CC-10	47	130	0.4	4.0	6.0	8.2	6.1	21.5	111.0
CC-15	82	172	0.2	3.0	4.0	3.0	1.0	11.0	56.0
CC-18	104	191	0.2	3.0	4.0	3.0	4.0	13.0	51.0
CC-23	113	201	0.2	3.0	4.0	4.0	2.0	11.0	49.0
CC-27	125	211	0.4	2.0	5.0	11.0	1.0	10.0	33.0
CC-30	155	166	0.3	6.9	3.5	3.5	3.4	6.9	31.1
CC-32	149	226	0.3	3.0	7.0	11.0	1.0	7.0	31.0
CC-35	192	182	0.5	2.6	5.2	15.6	1.3	23.4	65.0
CC-39	238	203	0.2	3.0	5.0	5.0	1.0	5.0	20.0
CC-41	213	282	0.2	4.0	20.0	24.0	1.0	5.0	21.0
CC-46	264	146	0.3	5.0	8.0	7.0	1.0	9.0	35.0
GT-01	84	219	0.2	2.3	4.6	5.8	2.3	10.4	74.2
GT-02	90	224	0.6	5.7	7.6	22.9	7.6	28.6	116.0
GT-03	70	234	0.8	5.1	9.1	30.3	12.1	28.3	107.0
GT-07	54	242	0.9	4.7	9.4	29.8	3.1	15.7	42.3
GT-09	63	274	0.3	5.0	10.0	16.0	1.0	8.0	39.0
GT-12	31	286	0.5	4.0	9.0	22.0	2.0	9.0	38.0
LC-01	91	296	0.4	5.0	10.0	12.0	1.0	9.0	38.0
LC-02	96	287	0.2	3.0	6.0	8.0	1.0	5.0	33.0
LC-03	100	284	0.4	3.0	8.0	10.0	1.0	9.0	54.0
LC-04	107	267	0.3	3.0	14.0	10.0	2.0	9.0	22.0
LC-05	133	299	0.5	2.3	6.9	8.0	1.1	49.4	40.2
LC-06	135	299	0.4	7.0	13.0	30.0	3.0	9.0	37.0
LC-09	105	297	0.4	5.8	14.6	18.9	1.5	8.7	36.4
LC-14	98	304	0.3	6.0	18.0	29.0	1.0	8.0	37.0
GC-01	148	276	0.4	5.0	39.0	29.0	2.0	8.0	40.0
GC-06	191	320	0.4	6.0	11.0	8.0	3.0	9.0	92.0
GC-07	197	310	0.5	10.0	13.0	11.0	2.0	9.0	81.0
S-01	82	320	0.4	4.0	12.0	21.0	1.0	10.0	48.0
S-02	80	333	0.4	5.0	15.0	24.0	2.0	9.0	42.0
A-01	325	181	0.5	5.0	13.4	16.8	1.7	16.8	47.0
B-01	32	267	0.5	7.6	13.9	16.4	1.3	15.1	47.9
G-01	304	209	0.5	7.0	12.8	12.8	1.2	16.3	33.9

TABLE 3: STATISTICS FOR TENORS OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

OF SAMPLES = 47

VARIABLE	MEAN	STANDARD DEV.	VARIANCE	SKEWNESS	KURTOSIS
AG	0.4447	0.2628	0.0690	2.18	5.43
AU	4.8043	2.7825	7.7421	2.34	6.76
CO	9.1447	6.0971	37.1751	2.59	9.75
CU	14.0638	10.0657	101.3192	1.28	1.93
MO	3.1213	3.3721	11.3713	1.94	2.66
PB	15.8383	10.4672	109.5627	1.65	2.71
ZN	65.9659	49.8981	2489.8169	2.74	9.97

TABLE 4: STATISTICS FOR LOG TENORS OF ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

OF SAMPLES = 47

VARIABLE	MEAN	STANDARD DEV.	VARIANCE	SKEWNESS	KURTOSIS
AG	-0.4059	0.2078	0.0432	0.62	0.32
AU	0.6311	0.1999	0.0399	0.73	0.44
CO	0.8926	0.2373	0.0563	0.44	-0.20
CU	1.0397	0.3198	0.1023	-0.11	-0.97
MO	0.3292	0.3492	0.1219	0.92	-0.27
PB	1.1246	0.2504	0.0627	0.40	-0.57
ZN	1.7381	0.2536	0.0643	0.58	0.14

MEAN	THRESHOLD
0.3928	1.0228
4.2764	10.7346
7.8093	23.2881
10.9562	47.7891
2.1342	10.6555
13.3240	42.2163
54.7191	175.9246

TABLE 5: COORDINATES AND STANDARDIZED VALUES FOR LOG TENORS OF TRACE ELEMENTS IN SEDIMENTS, BIGHORN CRAGS.

NUMBER	COORDINATE X	COORDINATE Y	AG	AU	CO	CU	MO	PB	ZN
BD-01	134	3	-1.41	-0.77	-1.75	-1.07	-0.94	0.87	0.13
BD-03	134	9	-0.56	-0.77	-1.22	-1.37	0.42	0.32	0.21
BD-04	119	12	1.21	1.19	0.64	-0.24	2.05	1.58	1.47
BD-06	112	25	-0.56	-0.15	-0.82	-1.37	2.25	1.09	0.89
BD-10	102	57	0.89	-0.77	-0.45	0.15	2.31	1.68	2.02
BD-13	133	89	-0.56	-0.63	-0.85	0.39	-0.36	0.65	0.29
BD-16	154	113	-0.56	-0.77	-1.22	-1.76	-0.08	0.42	-0.19
BD-20	180	63	0.04	-0.77	-0.48	0.51	0.42	0.52	1.33
BD-23	186	132	0.50	-1.65	-0.82	-0.82	-0.94	-0.88	-1.56
BD-25	224	77	-0.56	-0.15	0.04	-0.12	-0.94	0.42	0.53
CC-02	67	80	2.50	2.38	0.90	2.09	1.37	2.33	2.97
CC-05	91	82	0.04	0.51	-0.68	-0.21	0.29	0.82	0.92
CC-07	116	108	2.80	-0.15	-1.22	-1.37	-0.08	0.79	0.61
CC-09	53	103	1.49	3.00	0.16	1.14	1.72	0.42	1.32
CC-10	47	130	0.04	-0.15	-0.48	-0.39	1.31	0.83	1.21
CC-15	82	172	-1.41	-0.77	-1.22	-1.76	-0.94	-0.33	0.04
CC-18	104	191	-1.41	-0.77	-1.22	-1.76	0.78	-0.04	-0.12
CC-23	113	201	-1.41	-0.77	-1.22	-1.37	-0.08	-0.33	-0.19
CC-27	125	211	0.04	-1.65	-0.82	0.01	-0.94	-0.50	-0.87
CC-30	155	166	-0.56	1.04	-1.47	-1.55	0.58	-1.14	-0.97
CC-32	149	226	-0.56	-0.77	-0.20	0.01	-0.94	-1.12	-0.97
CC-35	192	182	0.50	-1.08	-0.74	0.48	-0.62	0.98	0.29
CC-39	238	203	-1.41	-0.77	-0.82	-1.07	-0.94	-1.70	-1.72
CC-41	213	282	-1.41	-0.15	1.72	1.06	-0.94	-1.70	-1.64
CC-46	264	146	-0.56	0.34	0.04	-0.61	-0.94	-0.68	-0.77
GT-01	84	219	-1.41	-1.35	-0.97	-0.86	0.09	-0.43	0.52
GT-02	90	224	0.89	0.62	-0.05	1.00	1.58	1.32	1.29
GT-03	70	234	1.49	0.38	0.28	1.38	2.16	1.31	1.15
GT-07	54	242	1.73	0.21	0.34	1.36	0.46	0.28	-0.44
GT-09	63	274	-0.56	0.34	0.45	0.51	-0.94	-0.88	-0.58
GT-12	31	286	0.50	-0.15	0.26	0.95	-0.08	-0.68	-0.62
LC-01	91	296	0.04	0.34	0.45	0.12	-0.94	-0.68	-0.62
LC-02	96	287	-1.41	-0.77	-0.48	-0.43	-0.94	-1.70	-0.87
LC-03	100	284	0.04	-0.77	0.04	-0.12	-0.94	-0.68	-0.02
LC-04	107	267	-0.56	-0.77	1.07	-0.12	-0.08	-0.68	-1.56
LC-05	133	299	0.50	-1.35	-0.23	-0.43	-0.82	2.27	-0.53
LC-06	135	299	0.04	1.07	0.93	1.37	0.42	-0.68	-0.67
LC-09	105	297	0.04	0.66	1.15	0.74	-0.44	-0.74	-0.70
LC-14	98	304	-0.56	0.74	1.53	1.32	-0.94	-0.88	-0.67
GC-01	148	276	0.04	0.34	2.94	1.32	-0.08	-0.88	-0.54
GC-06	191	320	0.04	0.74	0.63	-0.43	0.42	-0.68	0.89
GC-07	197	310	0.50	1.85	0.93	0.01	-0.08	-0.68	0.67
S-01	82	320	0.04	-0.15	0.79	0.88	-0.94	-0.50	-0.22
S-02	80	333	0.04	0.34	1.19	1.06	-0.08	-0.68	-0.45
A-01	325	181	0.50	0.34	0.99	0.58	-0.28	0.40	-0.26
B-01	32	267	0.50	1.25	1.06	0.55	-0.62	0.22	-0.23
G-01	304	209	0.50	1.07	0.90	0.21	-0.72	0.35	-0.82

Table 6: Correlation matrix for eight elements determined in 121 soils collected over a malaquite-rich quartz vein.

Element	T Cu	S Cu	Co	Cr	Mn	Ni	Pb	Zn
T Cu	1.00							
S Cu	0.72	1.00						
Co	0.58	0.44	1.00					
Cr	0.19	0.30	0.33	1.00				
Mn	0.66	0.41	0.61	0.19	1.00			
Ni	0.41	0.29	0.42	0.43	0.35	1.00		
Pb	-0.02	-0.13	0.28	-0.05	0.07	0.15	1.00	
Zn	0.06	-0.02	0.11	0.03	0.19	0.21	0.14	1.00

Table 7: Rotated Factor Matrix

Element	Factor 1	2	3
T Cu	0.86	0.02	0.18
S Cu	0.74	-0.27	0.28
Co	0.59	0.39	0.35
Cr	0.14	-0.05	0.67
Mn	0.72	0.32	0.12
Ni	0.30	0.27	0.54
Pb	-0.03	0.51	0.03
Zn	0.07	0.36	0.02

Table 8: Three groups of data used in stepwise discriminant analysis

Number	Cu	Co	Cr	Mn	Ni	Pb	Zn
FM20-004	165.000	15.000	4.500	675.000	5.000	0.800	26.300
FM20-005	430.000	18.000	5.500	1050.000	5.500	7.000	28.000
FM20-006	115.000	10.000	4.500	260.000	4.000	4.000	13.000
FM20-015	175.000	23.000	5.500	1175.000	9.800	13.000	18.000
FM20-016	265.000	21.300	6.300	815.000	8.000	7.500	24.000
Fm20-017	85.000	12.500	7.500	383.000	5.000	11.000	14.500
Fm20-026	135.000	22.500	4.500	975.000	5.000	9.000	23.000
Fm20-027	165.000	25.000	3.800	900.000	4.500	9.000	21.000
Fm20-028	115.000	22.500	4.500	6125.000	5.000	8.500	25.500
FM20-037	85.000	27.500	7.500	688.000	5.000	7.500	28.500
FM20-038	135.000	17.500	10.000	813.000	6.300	22.500	18.800
FM20-039	115.000	20.000	10.000	563.000	5.000	0.500	27.000
FM20-048	150.000	21.300	7.500	688.000	6.300	3.500	16.000
FM20-049	265.000	27.500	15.000	585.000	8.800	6.000	15.500
FM20-050	135.000	16.300	8.800	323.000	6.300	7.500	12.800
FM20-059	85.000	8.800	2.500	588.000	1.500	5.000	21.500
FM20-060	165.000	18.800	10.000	888.000	6.300	5.500	30.500
FM20-071	115.000	15.000	12.500	825.000	11.300	1.500	25.000
FM20-072	135.000	20.000	10.000	838.000	8.800	14.500	15.300
FM20-073	100.000	20.000	20.000	515.000	7.500	7.000	15.000
FM20-082	125.000	20.000	6.300	623.000	7.500	7.500	19.500
FM20-083	150.000	26.300	8.800	1075.000	8.300	10.000	21.500
FM20-084	100.000	17.500	9.500	723.000	5.800	11.800	24.000
FM20-093	65.000	18.800	6.300	535.000	5.000	11.000	19.000
FM20-094	100.000	18.300	5.800	1625.000	5.800	7.500	33.800
FM20-095	75.000	32.500	13.800	925.000	12.500	13.500	30.100
FM20-104	75.000	18.800	6.300	683.000	5.800	11.800	31.500
FM20-105	150.000	28.800	6.300	1300.00	6.300	2.500	28.000
FM20-106	150.000	20.000	10.000	478.000	5.800	5.500	24.500
FM20-115	125.000	37.000	6.300	745.000	5.800	9.000	28.000
FM20-116	125.000	21.300	4.500	535.000	5.800	7.500	23.500
FM20-117	45.000	7.500	2.000	210.000	3.000	1.500	19.500
PM-0001	107.500	7.000	1.500	329.000	1.000	22.000	58.500
PM-0002	72.500	3.500	1.500	252.000	2.500	23.500	35.000
PM-0012	125.000	5.000	1.500	303.000	2.500	30.000	59.000
PM-0013	247.500	5.000	1.500	340.000	1.500	45.500	62.500
PM-0015	70.000	4.000	1.000	375.000	2.500	32.000	76.000
PM-0016	112.500	4.000	1.500	270.000	2.500	22.000	65.500
PM-0017	750.000	7.000	2.500	238.000	2.500	42.000	80.000
DD-4912	81.500	18.000	1.500	238.000	10.500	40.000	42.500
DD-4913	99.000	32.000	4.500	1150.000	20.500	56.000	65.500
DD-4914	92.500	30.500	1.500	528.000	19.000	44.000	53.500
DD-4915	87.500	30.500	5.500	1000.000	14.500	585.00	54.000
DD-4916	86.500	32.000	4.500	1150.000	20.000	51.500	66.500
DD-4917	87.500	27.500	7.500	1150.000	15.500	40.000	51.500
DD-4918	65.000	30.000	6.000	1075.000	16.000	42.000	47.500
DD-4919	72.500	30.500	5.000	925.000	17.500	42.000	48.000
DD-4920	86.500	29.500	9.000	1100.000	20.000	40.000	48.500
DD-4921	71.500	18.500	1.500	209.000	10.500	30.000	40.500
DD-4922	40.000	18.000	4.000	356.000	7.000	20.000	28.500

Table 9a: Means and grand means of elements in the groups used in stepwise discriminant analysis.

Element	Group FM	Group PM	Group DD	Grand Mean
Cu	0.17	0.46	-0.78	0.00
Co	0.20	-2.04	0.72	0.00
Cr	0.46	-1.61	-0.32	0.00
Mn	0.22	-1.18	0.12	0.00
Ni	-0.08	-1.60	1.24	0.00
Pb	-0.58	0.85	1.13	0.00
Zn	-0.63	1.39	0.95	0.00

Table 9b: Standard deviations of elements in the groups used in stepwise discriminant analysis.

Element	Group FM	Group PM	Group DD
Cu	0.84	1.62	0.49
Co	0.57	0.45	0.40
Cr	0.68	0.36	0.90
Mn	0.92	0.26	1.05
Ni	0.56	0.53	0.49
Pb	0.76	0.27	0.27
Zn	0.54	0.54	0.46


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