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Exploration for Porphyry Copper Deposits through Multivariate Analysis of Computer-Registered Landsat and Geophysical Data Sets

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ABSTRACT

Airborne magnetic, radiometric, and Landsat reflectance data collected over an area in southern Arizona were computer-registered and subjected to multivariate analysis techniques as a means of exploring for porphyry copper deposits. Initial results show that these techniques are quite useful for producing quick and intelligible multiparameter anomaly maps based on a knowledge of the geophysical characteristics of these deposits. New analysis techniques under development promise to further advance the viability of the multivariate approach to geologic exploration.

INTRODUCTION

The advent of sophisticated satellite systems for remote sensing of earth resources means that many new and different types of digital data will soon become available for use in regional geologic exploration. Add to this information bank the voluminous data being collected by ongoing regional airborne geophysical surveys, and the problems of data management, display, and interpretation in reconnaissance investigations become apparent. There is a need to develop straightforward analysis techniques which would operate on a number of different data sets simultaneously and produce anomaly maps which are neither unwieldy nor difficult to interpret. An obvious approach to this problem is to generate computer-registered data sets and apply multivariate analysis techniques to educe information of geologic importance (Anuta, 1977). This is the approach that is followed in the present study, which is concerned with the development of an automatic process for porphyry copper exploration utilizing Landsat reflectance data and airborne radiometric and magnetic data.

REVELANT CHARACTERISTICS OF PORPHYRY COPPER DEPOSITS

Porphyry copper deposits possess certain characteristics which make them amenable to detection by remote sensing. The extensive hydrothermal alteration that accompanies the formation of the deposit introduces considerable amounts of elemental potassium into the country rocks (Lowell and Guilbert, 1970). This increase in potassium content should be detectable by radiometric scanners tuned to the energy peak of the radioactive isotope, potassium 40. Large values of the radioelement ratio, potassium 40/Thorium (K/Th) should also be observed over a deposit as elemental thorium is not preferentially localized through hydrothermal alteration (Davis and Guilbert, 1973).

Weathering of the copper minerals produces gossans that are rich in red- and yellow-colored iron oxides. Vincent (1973) has demonstrated that such gossans are detectable on images produced by ratioing Landsat bands 5 and 4 (MSS 5/MSS 4), and channels 6 and 7 (MSS 6/MSS 7). Iron oxides should appear brighter than most other materials on such images due to the combined effect of their high reflectivity in bands 5 and 6--the yellow and red coloration--and very low reflectivity in bands 4 and 7--due to the presence of iron absorption bands.

Vein-type uranium mineralization is also commonly associated with porphyry copper deposits (Davis and Guilbert, 1973). If uranium-series disequilibrium is not severe, such mineralization should be detectable by radiometric scanners. The radioelement ratio, U/Th, would be of special interest as high values of this ratio would indicate anomalous concentrations of uranium relative to background (thorium).

Finally, Gay and Mardirosian (1970) have shown that a majority of the known porphyry copper deposits have magnetic "lows" associated with them. This feature is due to the relatively low magnetite content of these deposits, presumably the result of destruction by hydrothermal fluids. Less frequently, highly magnetic skarn zones are found peripheral to the main deposit. Such magnetic "lows" and "highs" should be detectable by an airborne magnetometer.

Based on these characteristics, porphyry copper deposits should be detectable if the appropriate remote sensing parameters are manipulated in such a way so as to enhance common anomalies over background. In this study, computer-registered aeromagnetic, aeroradiometric, and Landsat ratio data collected over an area in southern Arizona are analyzed with this approach in mind.

THE STUDY AREA

The area of study is located within the Basin and Range province of southern Arizona (Figure 1). It is bounded to the south by the U.S.-Mexican border, to the north by the Coyote Mountains, and to the east and west by the Baboquvari Mountains and the Santa Rita Mountains, respectively. This area was chosen as the initial study site for three basic reasons. First, the economic potential of the area is very high. It lies within the porphyry copper belt of Arizona where the majority of the U.S.'s copper reserves are located. Indeed, three open-pit copper mines, Pima Mission, Twin Buttes and Esperanza, lie just within the study area to the northeast. Also, the study site contains extensive pediment cover, presently the major focus of porphyry copper exploration.

Second, the geophysical data collected over this area is of good quality. There are no major gaps in the data stream as would be found in data collected over a more mountainous terrain. Also, available Landsat coverage of this site is cloud-free.

Finally, the vegetation cover is sparse here. This is important from the standpoint of utilizing Landsat reflectance ratios in the investigative procedure.

THE DATA SET

Track-type airborne magnetic and radiometric (U, Th, K, U/Th, U/K, Th/K) data covering the study area were obtained from the Texas Instruments Geophysical Service Corporation. The data were collected at a nominal elevation of 400 feet at flight spacings of 3 miles. Based on a 500 foot square resolution cell, these data were registered to four-channel Landsat data using a procedure described by Anuta (1977). Landsat ratios MSS 5/MSS 4 and MSS 6/MSS 7 were also produced and added to the data base. The entire data set was stored on magnetic tape for subsequent computer-oriented multivariate analysis.

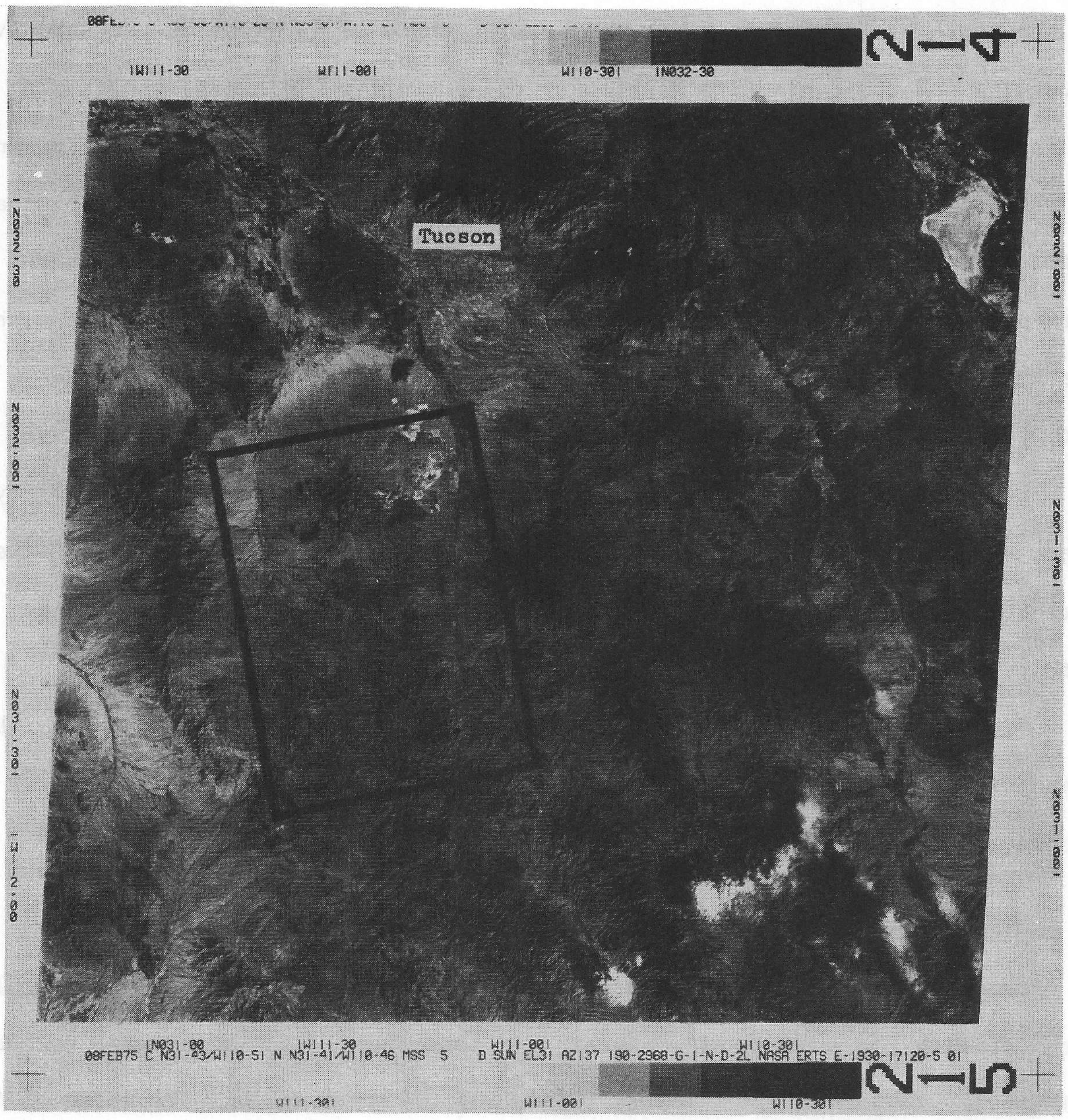

Figure 1. Landsat image showing the location of the study area in southern Arizona.

ANALYSIS TO DATE

Analysis of the data set began with the production of histograms for each of the variables. Thresholds for each histogram were chosen to lie at ± 1 standard deviation from the mean--values falling outside these limits were considered to be anomalous. An example of a histogram showing the threshold cutoff is presented in Figure 2. Printouts were then generated showing those picture elements (pixels) which exhibited anomalous characteristics of interest. For example, Figure 3 shows a printout which displays all pixels (in black) exhibiting both anomalously high values of K and anomalously low values of Th/K. The pixels flagged are of interest from an exploration standpoint because they signify places where there are high concentrations of potassium in the soil or bedrock. To determine which of these locations would be prime candidates for field checking, additional constraints were placed on the classification of anomalous pixels.

Figure 4 shows a printout which displays all pixels exhibiting anomalously high values of K, anomalously low values of Th/K, and anomalously high values of U/Th. The number of pixels flagged has decreased substantially. With the added constraint that the pixel must also exhibit anomalously high values of the Landsat ratio, MSS 5/MSS 4, the printout shown in Figure 5 is produced. Only three pixels are now flagged as being anomalous. These are certainly worth field checking in order to determine whether the anomalies are due to cultural or natural causes (in this case, two of the pixels (A and B) lie within an open pit mining complex, the other (C) lies on undisturbed pediment cover and is a potential exploration target).

The problem with the above methodology is the subjectivity involved in picking the threshold cutoffs. It is quite possible that some anomalies might be missed because of extreme thresholding on one key parameter out of the

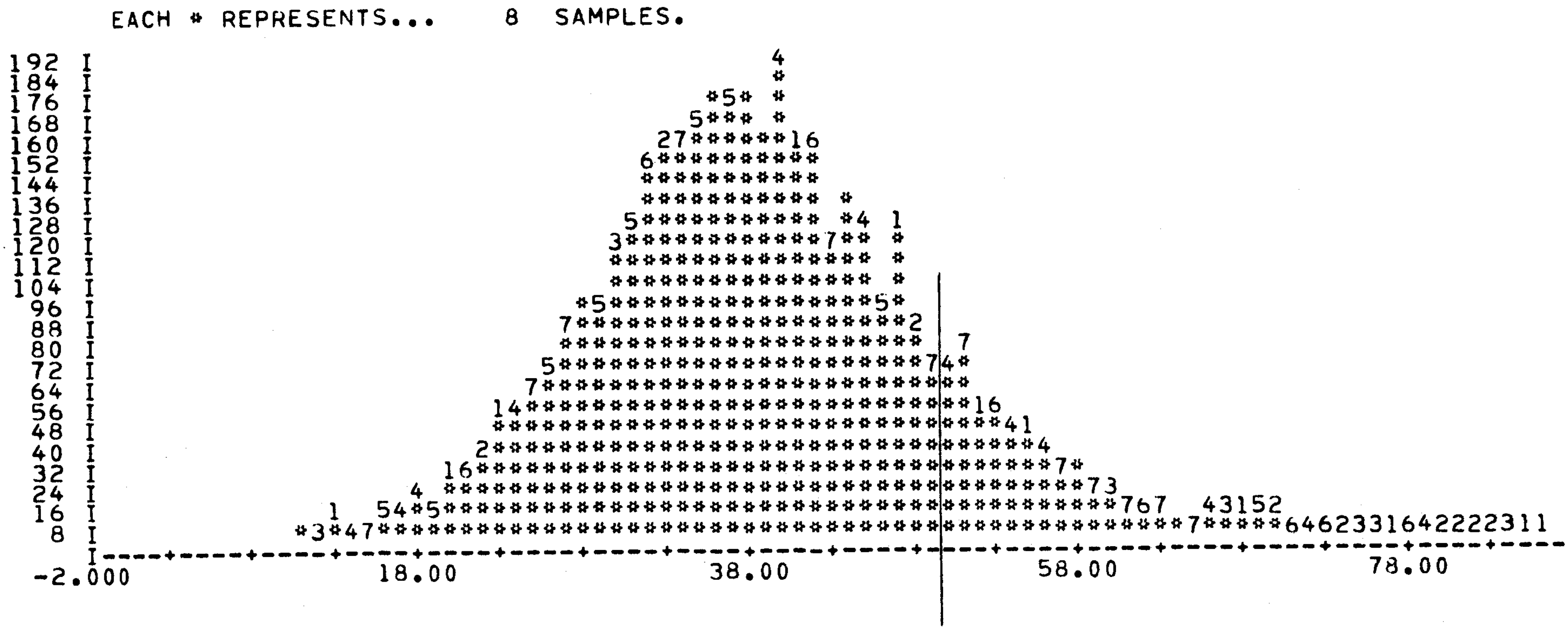

Figure 2. Histogram of Uranium distribution showing the threshold cutoff at +1 standard deviation from from the mean.

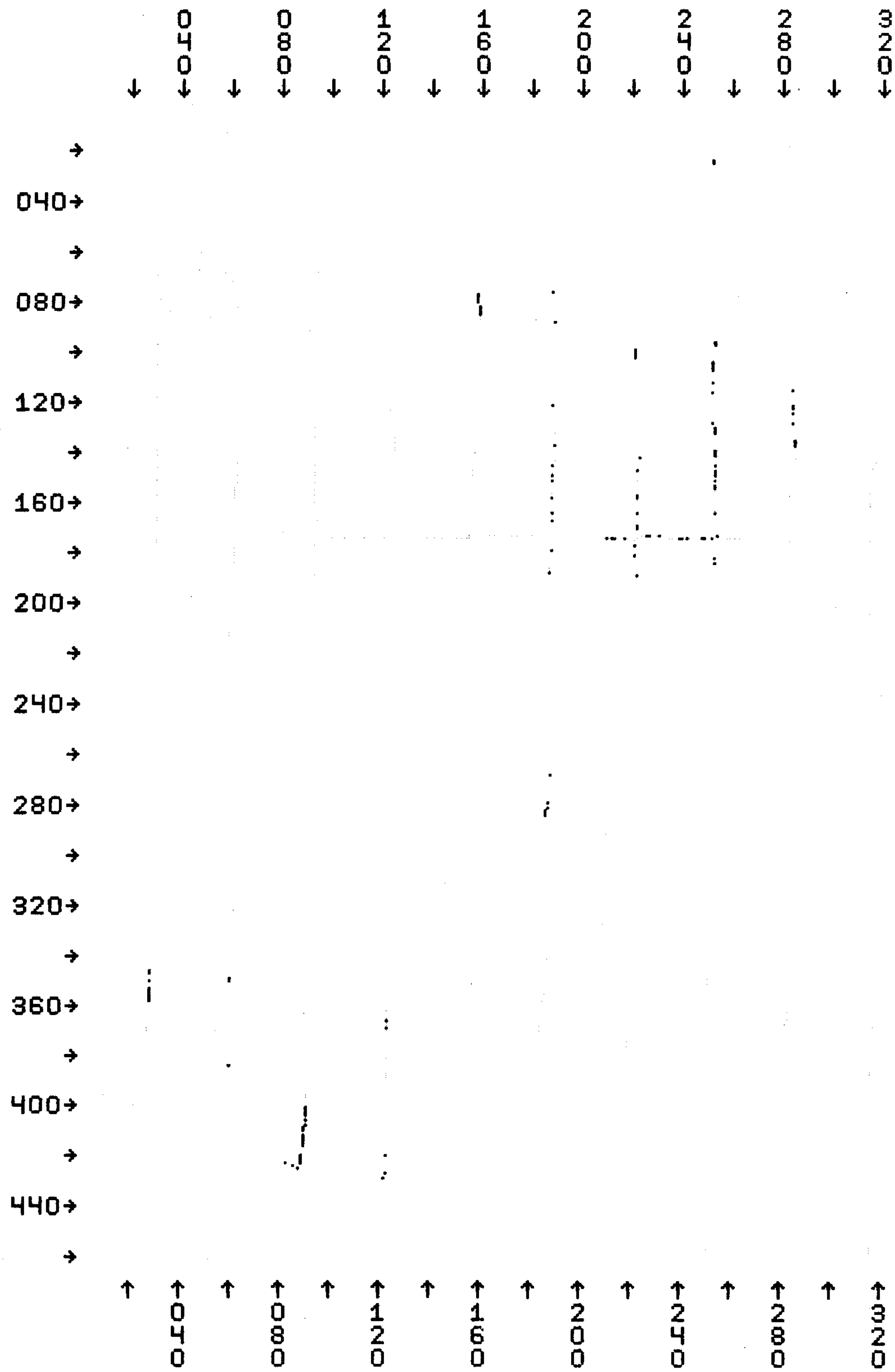

Figure 3. Computer printout showing the locations of pixels (in black) exhibiting both anomalously high values of K and anomalously low values of Th/K. The flight tracks are indicated by the dotted lines.

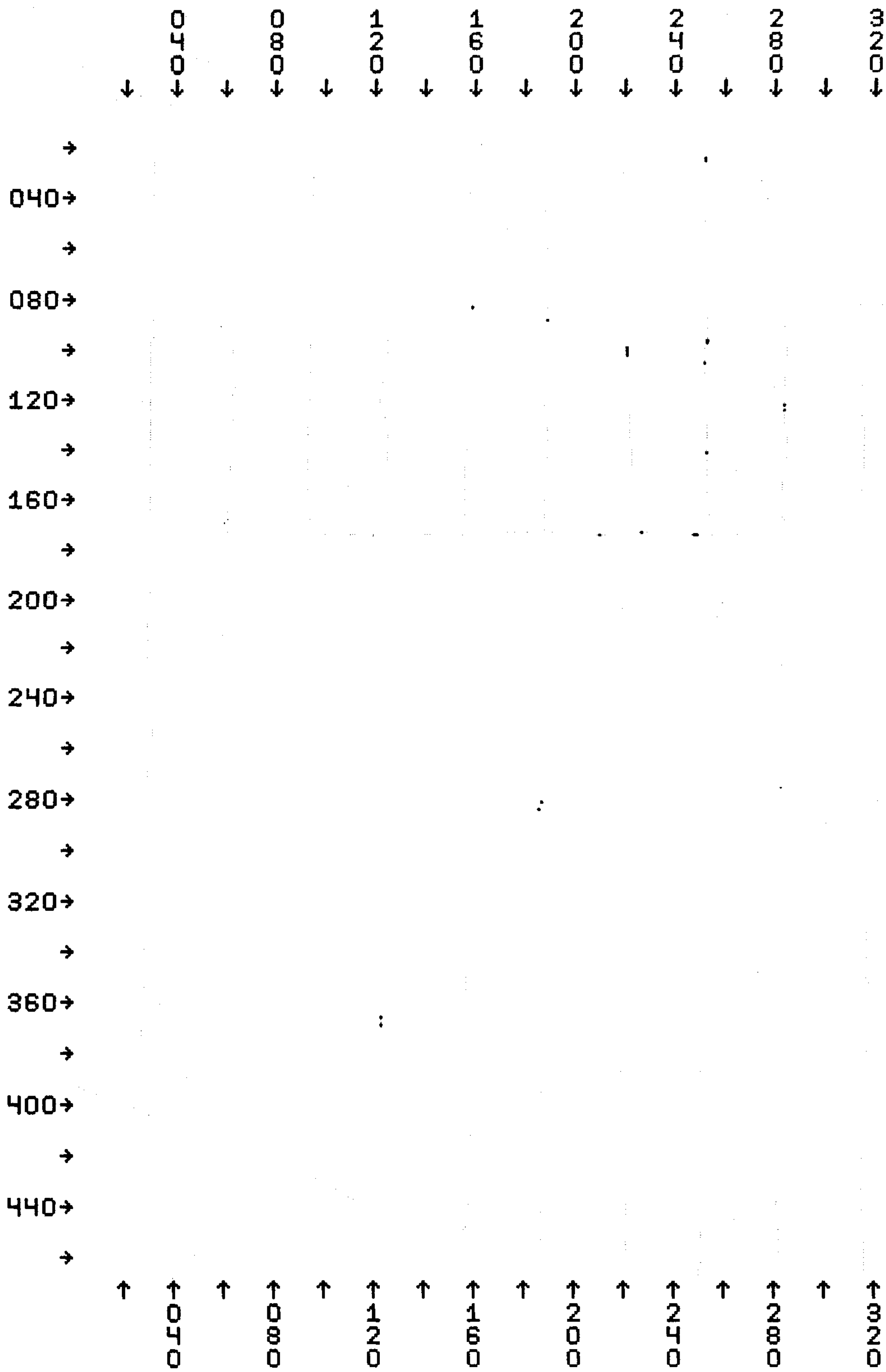

Figure 4. Computer printout showing the locations of pixels exhibiting anomalously low values of Th/K, and anomalously high values of K and U/Th.

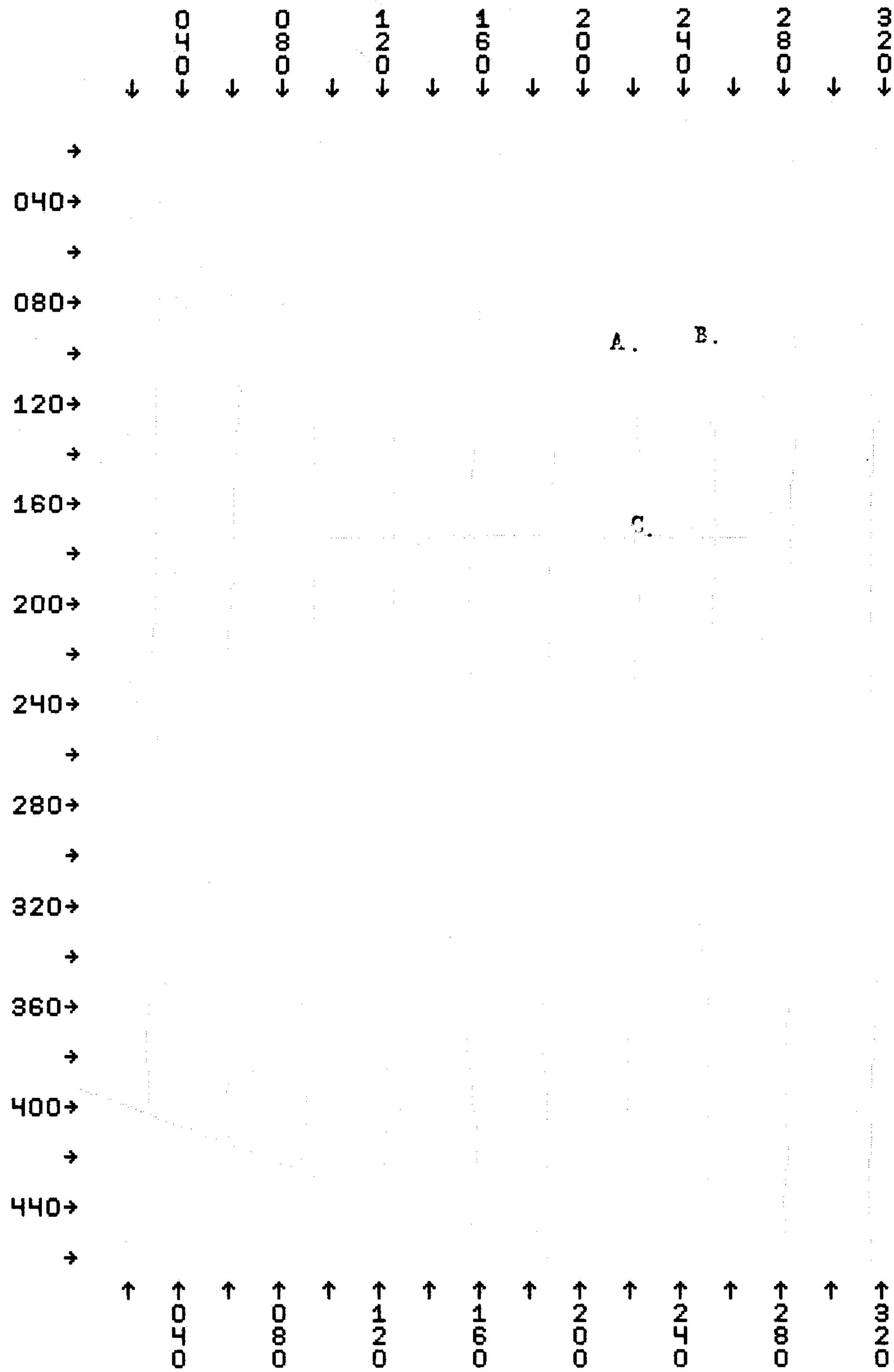

Figure 5. Computer printout showing the locations of pixels exhibiting anomalously low values of Th/K, and anomalously high values of K, U/Th, and MSS 5/MSS 4.

total. One way to avoid this problem is to "stack" the data as schematially shown in Figure 6. With this technique no information is lost to the analyst. Figure 7 shows the result of stacking ("adding") the following parameters: K, K/Th, U/Th, MSS 5/MSS 4. Anomalies of interest are areas that exhibit high values of each of the four parameters. (For purposes of display, only those pixels with values greater than 1.5 standard deviations from the mean are shown in the figure). Such a product gives the analyst a freer hand in making firm decisions concerning the data. This is especially true where the analyst is seeking to establish anomalous trends throughout an area of study.

FUTURE ANALYSIS

Research during the coming contract period will continue to focus on ways of maximizing the information content as well as the reliability of anomaly maps for use in prophyry copper exploration. Specific plans call for the investigation of color composites as a means of displaying three key variables produced by complex ratioing. For example, high values of the three ratios, K^2/Th $(K/\frac{Th}{K})$, UK/Th^2 $(\frac{U}{Th}/\frac{Th}{K})$, and MSS 5/MSS 4, are indicative of an anomalous pixel. By assigning an additive primary color to each of these ratios, a single color composite can be produced which not only shows the locations of anomalous pixels (they would appear whitish) but also the relative contribution of each variable to a pixel's feature vector (based on the hue of the pixel displayed). This technique thus provides the analyst with a visual perception of the data variability. It also simplifies the analysis process by compressing the information of six variables into three variables, thus providing a long-term savings in both time and money.

Research will also be conducted on the advantages of having an ancillary geology channel as part of the data base. With such a channel available,

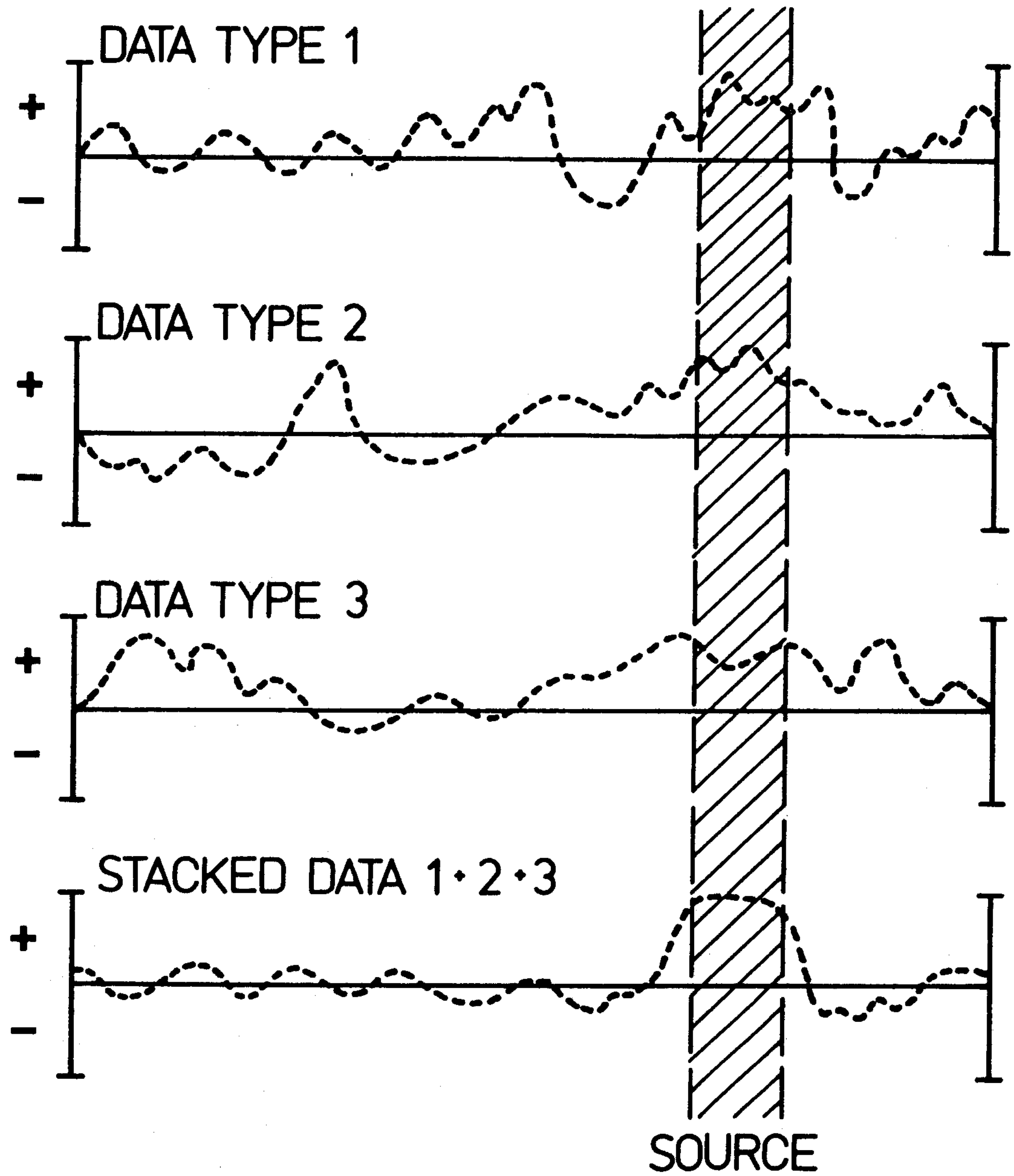

Figure 6. Schematic illustration of multi-data type correlation leading to increase in signal-to-noise ratio.

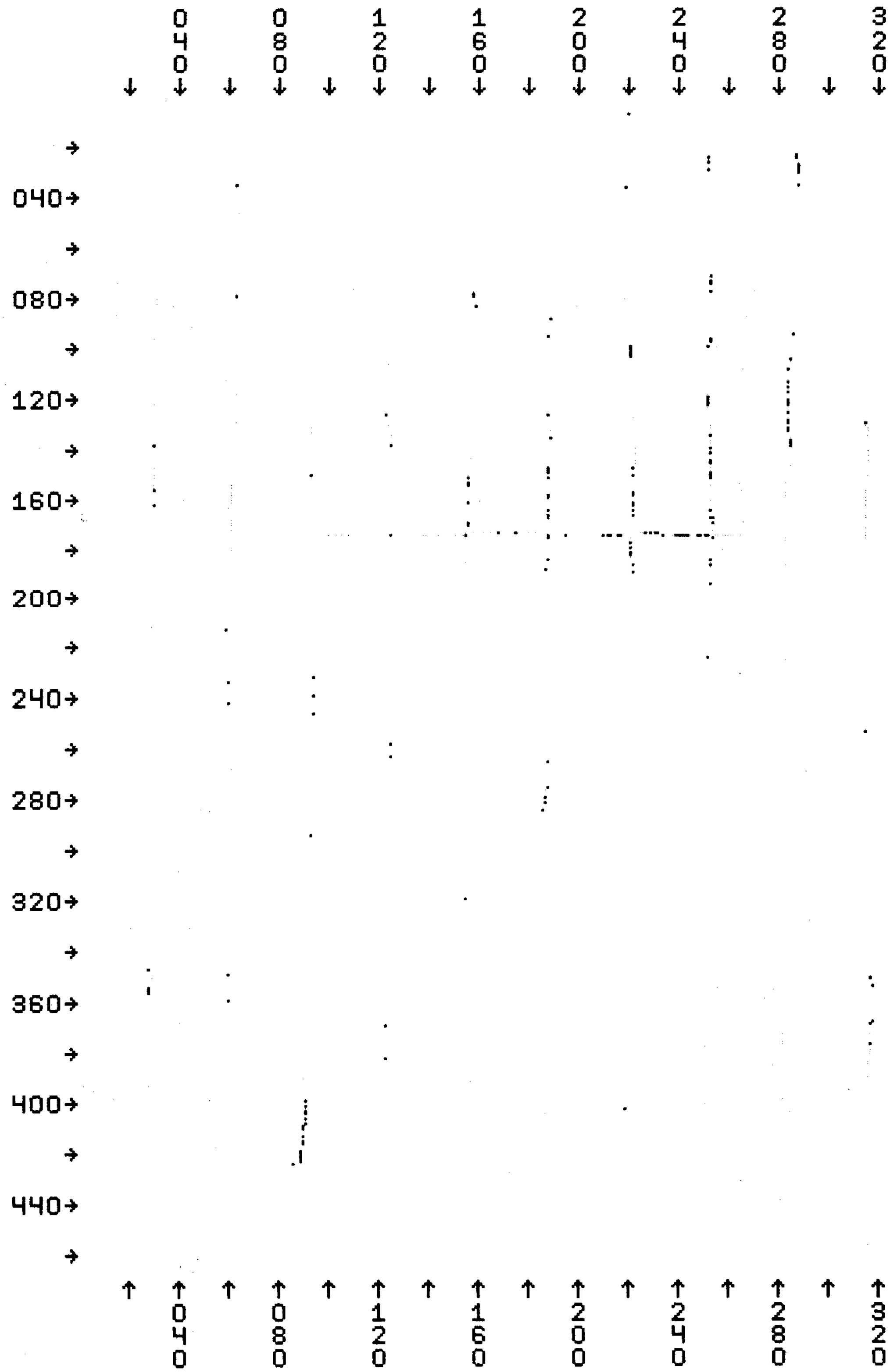

Figure 7. Computer printout showing the locations of pixels whose values of the function, K + K/Th + U/Th + MSS 5/MSS 4, are greater than 1.5 standard deviations from the mean of the population.

histogramming of the variables can be performed on a "per rock type" basis. Given enough data, anomalous values of each variable for each rock type could be determined and used to produce one or more anomaly maps. Areas where anomalous pixels are shown cutting across contiguous rock types would be prime locations for field checking.

Cluster analysis will also be examined during the current grant. It is hoped that recent advances in dynamic scaling of dissimilar data types (Chu and Anuta, 1979) will go a long ways towards allowing cluster analysis to become a viable technique in geologic exploration.

Techniques perfected with this particular data set will be used on other study areas in southern Arizona for which Landsat and geophysical data are available. All strongly anomalous areas resulting from these investigations will be checked using aerial photographs, geologic maps, and mineral commodity maps in order to determine whether on-site examination is warranted.

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