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**DEVELOPMENT OF DATA ENHANCEMENT
AND DISPLAY TECHNIQUES
FOR STREAM-SEDIMENT DATA
COLLECTED IN THE NATIONAL
URANIUM RESOURCE EVALUATION PROGRAM
OF THE UNITED STATES
DEPARTMENT OF ENERGY**

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August, 1979

GEOLOGY

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
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by

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SECTION 1. INTRODUCTION

1.1 SUMMARY OF THE PROBLEM

In 1973, the United States Department of Energy (DOE) began the National Uranium Resource Evaluation (NURE) Program in all of the United States except Hawaii. The program includes airborne radiometric and hydrogeochemical (stream water, ground water, and stream sediment) surveys, surface geologic investigations, and sub-surface drilling.

In the Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) phase of the NURE program, extensive data are collected. Not only are many sites being sampled, but to the three principal media of stream sediments, ground water, and stream water are added other media yielding geobotanical, soil, and other samples. Moreover, at each sampling site, as many as forty-three chemical elements as well as other variables are determined.

The HSSR and other NURE data are published for individual two-degree National Topographic Map Series (NTMS) quadrangles. In one of these areas, the Winston-Salem quadrangle in North Carolina, Virginia, and Tennessee, there are about 1,400 sample sites and fourteen variables represented in the preliminary raw data release (Baucom and others, 1977). A subsequent data release (Ferguson, 1979) provided analyses for an additional twenty chemical elements. In all, there are 621 two-degree NTMS quadrangles in the United States, which will yield some 650,000 sample sites from which more than one million samples will be collected (Shannon, 1977, p. 4). Thus, considering the number of variables measured for each sample, the total data base will contain several tens of millions of numerical values.

There is a need to extract, evaluate, and display as much information as possible from the HSSR raw data base in a manner readily usable for uranium favorability interpretation. The problems, already evident from the volume of data for one NTMS quadrangle, become severe when the total data base to be accumulated is considered.

Of great importance is the concentration of most of the information content regarding uranium in those few sample sites that yield anomalous values. Therefore, from the vast amount of uranium data we must extract and analyze the small proportion of values which may indicate areas favorable for uranium occurrences.

The HSSR surveys for the two-degree NTMS quadrangles are done by three Department of Energy national laboratories: the Savannah River Laboratory (SRL), the Oak Ridge National Laboratory (ORNL), and the Los Alamos Scientific Laboratory (LASL). Each laboratory has developed its own procedures for field sampling, sample preparation, and chemical analysis. Each has also chosen a set of chemical elements and other variables for analysis and reported the results in its own way. Because all of the resulting reports are generally similar, we may discuss the Winston-Salem report as an example. This report contains two principal forms of data display: first as histograms and cumulative-frequency plots, and second as maps of point-values indicating the concentrations of chemical elements and other variables. While an excellent method of data display for obtaining information about specific sites, the point-value method presents problems where goals concern determining regional patterns, making multi-element correlations, and relating geochemical data to regional geology. Moreover, point-value maps by themselves do not permit an appraisal of the sources of variability in the data nor an error analysis. Both of these factors are essential for determining overall data validity. Serious for any single variable, these deficiencies in point-value displays become all the more pressing for multivariable data representations, and, in particular, for transformations through factor analyses and ratios.

Furthermore, there are two possible goals for the geochemical map: (1) rapid presentation of data emphasizing the local high values and (2) a presentation of the clearest summary of information about the geochemical surface. The first objective is admirably met in the displays by SRL scientists for the Winston-Salem report, as well as in the reports for other areas from the other two laboratories; the second has not yet been approached. And the second is essential, because "the human eye has a particularly difficult task in attempting to integrate symbolic information scattered over a map in point fashion" (Howarth, 1977, p. 7).

Therefore, the purpose of the research explained in this report is the development of data enhancement and display techniques for multi-element geochemical data developed in the HSSR program.

1.2 OBJECTIVE AND SCOPE

Our objective was to combine statistical, mapping and geological techniques in order to evaluate and appropriately display geochemical data for the identification of uranium

associated halos utilizing the NURE HSSR data base. In order to fulfill this objective, we have developed a set of computer-based procedures implemented in a time-sharing interactive mode on a Control Data Corporation Cyber 70 and 174 computer.

We have placed emphasis upon the application and extension of the procedures described in the summary. We provide a combined statistical and geological analysis with the output in graphical and tabular display form in order to facilitate visual interpretation of uranium favorability. Within the time and cost limitations of the project, we have provided a set of computer referenced procedures (methodology), specifically including data smoothing and enhancement, in order to provide statistical analyses for interpretation of HSSR and multivariate data for stream sediments.

We have studied multivariate data from stream-sediment sampling in the three geographic areas identified in figure 1.1. The first area, in the southeastern United States, comprises the Winston-Salem, Charlotte, Spartanburg, and Greenville quadrangles. We selected a block of four quadrangles, rather than the single Winston-Salem quadrangle specifically required by the contract, because the power of our procedures is best demonstrated on a larger than two-degree area. This southeastern area has a sub-tropical humid climate comprising parts of the Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain geologic provinces; the rocks are sedimentary, igneous, and metamorphic and range in age from Precambrian to Recent. The second area is the two-degree Seguin quadrangle in Texas. In this area, the climate is sub-tropical, semi-arid, and the rocks are entirely sedimentary beds ranging in age from Cretaceous to Tertiary. The third area is the Pueblo quadrangle in Colorado. The eastern part of the quadrangle, in the Great Plains geologic province, includes sedimentary rocks ranging in age from Cretaceous to Recent. Westward lie the Southern Rocky Mountains, making up one-half of the quadrangle, and consisting of sedimentary, igneous, and metamorphic rocks of Precambrian to Recent age. Data for the first area were provided by SRL, for the second area by ORNL, and for the third area by LASL. Each laboratory devised its own sampling procedures and analyzed for different chemical elements and other variables.

For these three areas, we have performed these tasks:

- (1) Edited the data sets in order to identify the mistakes and questionable data and to reconcile these data with scientists of the appropriate laboratories.

FIGURE 1.1. - Index map locating the six quadrangles studied.

- (2) Developed, used, and evaluated statistical techniques for identifying outliers in the data.
- (3) Calculated and displayed basic statistics for the variables including frequency distributions of original and transformed variables, means, variances, coefficients of variation, regionalized variances, and confidence intervals.
- (4) Selected and evaluated statistical techniques for application to the multivariate geochemical data. Among the techniques that we have investigated are those related to truncated or censored distributions, simple linear regression, multiple linear regression, factor analysis, discriminant analysis, and trend surface analysis.
- (5) Determined the applicability of various analytical mapping techniques including low-pass filters using effective radii of one or more cells, picture-frame filters using various apertures and standard deviation designations, double low-pass difference filter using different effective radii, and high-pass difference filters.
- (6) Related the statistical display of thematic maps developed in tests of the previous paragraph to geology. Determined geochemical signatures, possible uranium associated halo discrimination, and applicability to identification of "near miss" sample sites.
- (7) Organized the applicable procedures into a standardized analysis and output format.
- (8) Provided computer program and documentation for the statistical cartography mapping program.

Because the data from the Southeastern area were available at the beginning of the project in August, 1978, we have spent most of our effort in analysis of this area. A substantial amount of lead time was required to read each data tape and reconcile the data with scientists of the laboratories concerned before our analysis could begin.

1.3 ORGANIZATION OF THIS REPORT

In the rest of this introductory section, we explain the development and nature of the data base used for statistical analysis and make acknowledgements. In Section 2, we develop techniques of data analysis. These techniques are statistical and geological in nature and are implemented through computer procedures. For implementation of most of the procedures, computers are essential because of the nature of the calculations and the large data sets handled.

In Section 3, we present the results of our data analysis for the Southeastern area, Seguin quadrangle, and Pueblo quadrangle. Finally, in Section 4, we draw conclusions and state recommendations. In Appendix A, we discuss some technical problems that we met in working with the data tapes received from the three laboratories.

Appendix B is a computer program for the boxplot procedure; Appendix C explains and lists rock codes; and Appendix D lists geochemical anomalies developed through a mineralogical model for the Southeastern area.

1.4 DATA BASE

The data base consists of stream-sediment data obtained from the three laboratories. SRL supplied data on punched cards, and the other two laboratories on magnetic tapes. We verified all of the data by comparing the means and standard deviations for uranium with those in the published quadrangle reports.

Table 1.1 gives the boundaries, number of sample sites, number of variables, and number of chemical elements for the six quadrangles. Because the three laboratories worked independently, and because the number of small streams suitable for the collection of stream-sediment samples differed according to climate and topography, the number of sample sites per quadrangle and the number of variables are different. Moreover, table 1.2 shows that titanium, uranium, and vanadium are the only three chemical elements for which all three laboratories analyzed. Furthermore, this table shows that, for several elements, only a few values are above the detection limit.

In addition to the numerical data on chemical elements and other variables for each sample site, we consider it essential to consider the geologic age and lithology of the rock units. For the Seguin quadrangle, this information had been coded by the project geologist. For the other quadrangles, one of us (Susan F. Carpenter) devised a coding scheme (Appendix C) and applied it to each sample point. She based these coding schemes on the geologic maps accompanying the laboratories' quadrangle reports. She coded each site according to the drainage supplying the bulk of the stream sediment at each site. The distribution of sample sites according to lithology and age of rocks is tabulated in Section 3 of this report.

TABLE 1.1.- Sources of data

Quadrangle	<u>Boundaries</u>				Number of stream sediment samples	Number of variables	Number of chemical elements
	North	South	East	West			
Winston-Salem	37°	36°	80°	82°	1346	15	12
Charlotte	36°	35°	80°	82°	1249	19	16
Spartanburg	35°	34°	80°	82°	1201	19	16
Greenville	35°	34°	82°	84°	1401	19	16
Total, Southeastern quadrangles					5197		
<hr/>							
Seguin	30°	29°	96°	98°	472	18	17
<hr/>							
Pueblo	39°	38°	104°	106°	1058	43	43

We spent a substantial amount of time in assembling the data base for this report. These data bases are large in comparison to those most common in scientific computing, and we needed to rearrange the data in an efficient form in order to make our calculations at reasonable costs.

1.5 ACKNOWLEDGEMENTS

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TABLE 1.2. Means of elements in parts per million (ppm) by areas.Values below detection limits are set to one-half the detection limit.

Element	Area		
	Southeast	Seguin	Pueblo
Ag			2.96
Al	50900		65500
As		3.35	
Au			.053
B		31.0	
Ba		334	770
Be			1.53
Bi			2.75
Ca			31720
Cd			2.61
Ce	237		151
Cl			92.7
Co		3.57	12.4
Cr		22.8	48.4
Cs			3.12
Cu		5.38	28.8
Dy	13.5		9.18
Eu	1.31		1.86
Fe	26600		28320
Hf	80.9		23.4
K			20640
La	175		79.1
Li		9.38	26.5
Lu	4.16		1.06
Mg			14830

TABLE 1.2. (Continued)

Element	Area		
	Southeast	Seguin	Pueblo
Mn	1216	254	825
Na			13590
Nb			22.7
Ni		6.40	15.9
Pb		10.01	23.3
Rb			52.1
Sb			1.61
Sc	9.82	5.73	10.9
Se		1.55	
Sm	30.0		11.7
Sn			5.73
Sr			308
Ta			1.60
Tb			1.19
Th	45.3		21.7
Ti	16000	3220	5067
U	11.5		7.07
U-F		1.27	
U-NT		2.57	
V	118	28.5	101
W			8.56
Yb	14.4	15.0	8.43
Zn			124
Zr		762	

Susan F. Carpenter devised and applied the geological rock codes for the Southeastern area and the Pueblo quadrangle; she also discussed with us the geology, particularly of the Southeastern area.

Two post doctoral students, C. Y. Chork at Imperial College and D. D. Sarma at the University of Georgia, participated in particular phases of the study. We appreciate their help and that of the following graduate and undergraduate students who did a great deal of work in processing the voluminous data: Jonathan Koch, Michael Maccucci, Gary Paulson, Fred Schultz, and D. E. Wraith.

The final report was edited by Ruth Koch and typed by Nancy Blum, Patricia McNeel, and Diane Brackman.

In making these acknowledgements, we wish to stress that we accept all responsibility for errors in judgment and mistakes that we have overlooked.

SECTION 2. TECHNIQUES OF DATA ANALYSIS

In this section, we discuss statistical/cartographic mapping techniques, a study of high uranium values using box plots, methods for basic statistical analyses, and a mineralogical model to calculate residual uranium from original uranium.

2.1 STATISTICAL/CARTOGRAPHIC MAPPING TECHNIQUES

Introduction

The type of geochemical map will vary with the goal of the investigation. We contrast maps in which emphasis is on the value at the original sample site with those in which interest is primarily centered on the broad-scale variation. The investigator is often concerned with very local contrasts in the former situation and may not wish to interpolate values into intervening areas in which the sampling medium differs (for example in extrapolating from a stream-sediment or ground-water sample location into neighboring areas without drainage or other sources of water). At the opposite end of the scale, emphasis may be placed on broad-scale variations, using smoothing of the data values to enhance the regional trends of variation at the expense of some local detail. Obviously, a mapping technique best suited to one of these aims may not necessarily be optimum in all cases, and each type of map has particular cartographic problems associated with it. However, as the complexity of the data increases, the aesthetic aspects of map production play an increasingly important part in aiding the human to extract the maximum from the map, for example the increased information gain achieved by the use of color-encoded classes.

We may broadly classify geochemical maps into four types:

- (1) point-source maps, giving the value at each sample site;
- (2) maps in which some kind of geochemical surface is fitted to the data;
- (3) anomaly maps, placing emphasis on local departures from the regional surface;
- and (4) multi-component maps showing the effects of the simultaneous variation of several different elements.

Point-Source Maps

These will normally consist of a symbolic representation of the data value plotted at the sample location. A wide variety of graduated black and white symbols of increasing size and/or density are in use, and such maps form a standard part of the NURE data releases for two-degree quadrangles. While this type of map is excellent for attracting the eye to particular sample locations, usually corresponding to high absolute concentration values as shown by larger and/or darker symbols, the human eye has a particularly difficult task in attempting to integrate symbolic information scattered over a map in point fashion (e.g. Vetter and Pizer, 1970). In addition, inherent 'noise' in the data (reflecting sources of natural sampling variability together with the generally much smaller laboratory-derived sub-sampling and analytical errors) make the broader-scale background variations difficult to establish reliably (Rhind and others, 1973). This is apparent at the regional scale even when color-encoded maps are used, e.g. distribution of zinc over 130,000 sq km (50,000 square miles) of England and Wales (Webb and others, 1978). Class and symbol selection, particularly in a mineral exploration context, tends to favor recognition of localities of highest concentration rather than placing emphasis on relative changes, which may be equally important in terms of contrast in a low-background area.

Surface Fitting

Methods designed for extraction of regional patterns of variation by fitting some kind of geochemical surface, representing 'background', to the data may be conveniently grouped into: (1) global methods, in which a generalized function is fitted to the entire data set; and (2) local methods, which include contouring in general, with moving average and kriging regarded as different types of interpolating functions.

Global Methods

These are generally fitting of polynomial 'trend surface' (e.g. Agterberg and Chung, 1975) or Fourier series (James, 1966) functions to the entire data set (Koch and Link, 1971, Vol. 2, Chap. 9). Although they have been used extensively in geological applications and are very fast to compute, problems with matrix inversion or computer work-length (Agterberg and Chung, 1975), sensitivity to data point distribution (Doveton and Parsley, 1970), and difficulties of assessing the significance of the fitted surface (Howarth, 1967; Norcliffe, 1969; Chayes, 1970; Agterberg and Chung, 1975) have placed these methods in disfavor. Improved methods of calculation together with methods for automatically plotting half-confidence intervals about the fitted polynomial surface (Agterberg and Chung, 1975) certainly make the 'trend' technique potentially useful for detection of local anomalies in a suitably homogeneous environment. However, many workers believe that the regional scale of variation (with inherent discontinuities in rock type, soils, or even climatic regime) is too broad for this type of global surface to be validly applied.

Local Methods

Exact contouring interpolation techniques aim to be faithful to relatively small-scale variations in the topography of the geochemical surface, in contrast to the global fitting approach. The processes may be generalized into two main steps: first, interpolation from the raw data (usually irregularly spaced owing to geological constraints) onto a regular grid; and second, contour threading through the interpolated values. This is followed by the final contour plotting which may involve a variety of cosmetic operations to improve the visual appearance of the final map.

Although algorithms are available for interpolation by triangulation through the original data points, the methods now generally adopted interpolate onto a square grid, both for computational simplicity and to give the option of subsequently using the interpolated mesh values for stereographic, hidden line, or hill-shaded views of the topography.

A wide variety of interpolation techniques exist (table 2.1), and no single method is necessarily optimum for all requirements (e.g. the contrast between flight-line data and irregular stream sediment or ground-water sampling patterns). The majority of methods are exact interpolators at the data points. The final appearance of the map with attractively drawn smooth contours is not necessarily a reflection of the veracity of the results. General reviews are given by Crain (1970) and Rhind (1975).

TABLE 2.1. - Classes of contouring algorithms

Partitioning into patches
Local quadratic interpolation
Distance weighted means
Finite difference methods
Spline surfaces
Multi-quadratic analysis
Contour-chasing techniques
Hybrid methods

The human may be very subjective in approach to the contouring problem, but in certain circumstances (such as abrupt discontinuities in the data) he may intuitively give a better performance than some algorithms (Dahlberg, 1975). The better contouring programs are capable of: sophisticated annotation, placement of labelling, blanking of areas with inadequate data control points, smoothing of contours using splines, variety of line styles, suppression of contours where they bunch too closely together, etc. However, production costs may increase heavily with improvement in the aesthetic quality of the map. Production of good quality hidden-line views or shaded surfaces can also be computationally expensive, and while these are useful for visualization of topography, they are not well suited for measuring values from the map at a particular point. They should be regarded as complementary to the contour map.

The factors which control the variability of the contoured map are: the number of samples and their spatial distribution; the size of grid used for the interpolation; the method used to select points from which the value at the grid node is to be determined (nearest-neighbor, or quadrant or octant search); the weighting assigned to the data points; the algorithm yielding the value at the mesh point, and the method used to thread contours through the mesh points.

It should also be remembered that while most contour interpolation techniques are exact at the data points, it is quite possible for spurious maxima and minima to be generated as artifacts of the methods used. There are few comparative studies of the results of different contouring algorithms (Walden, 1972; Wren, 1975), and no general guidelines have yet emerged about techniques best suited for geochemical data. Harbaugh and others (1977) discuss the results of a series of empirical investigations on contouring a set of subsurface elevation data from approximately 3000 wells in Kansas. They evaluated the success of the gridding method by predicting the elevations in known wells, not included in the current 'training' data, using one of the relatively sophisticated contouring procedures incorporated in the Kansas Geological Survey SURFACE II contouring package. It was found on the basis of different trials in which both the search pattern type and form of the inverse distance weighting function were varied that "the different objectives of the contouring procedures considered are not mutually obtainable. An algorithm which faithfully honors the original control points should utilize a weighting function that drops off extremely rapidly with distance and which uses only a few nearest neighbors. However, such an algorithm will produce poor predictions or estimates at locations where no control is available. The best estimating procedure might be one that uses 16 or 24 control points in each calculation of a grid node and which weights distant points relatively heavily. This, of course, would provide a poor reproduction of the original control points. Since apparently it is not possible to specify a combination of features that will lead to a map that is 'best' in both a representational and predictive sense, the selection of features should be based on the specific purpose for which an individual map is made" (Harbaugh and others, 1977, p. 114-115). A third constraint, namely that of the computer resources required to produce an acceptable result, is also mentioned and may be the greatest practical (time/cost) limitation.

Matheron's Theory of Regionalized Variables has been used for some years in the context of ore reserve analysis (e.g. Guarascio and others, 1976; David, 1977), and there is current interest in its possible application for regional

geochemical mapping problems. Universal kriging offers an optimum interpolation technique in the sense of minimum estimation error, together with a measure of the probable estimation variance (which other interpolation algorithms cannot provide) associated with the interpolated value. However, the technique requires reliable estimation of the spatial auto-correlation structure of the data on the basis of the empirically derived semi-variogram, and of the regional trend or 'drift' component. It also appears to be as difficult to allow for intrinsic error (sampling plus analytical variance) in the data with these methods as with the other interpolation techniques. Further, the spatial auto-correlation structure must be assumed to apply globally to the whole of the data set, which may be very difficult to justify with regional geochemical data (quite apart from the lack of knowledge about the sampling variance of the semi-variogram). In the absence of detailed comparative case histories at the present time, it is difficult to judge the practical advantages of these methods for geochemistry.

Methods of moving average interpolators have long been applied to geochemical data in an attempt to recover broad regional patterns from the inherently noisy data. A window is passed across the mapped area, and the average value of all data points falling within it is assigned to the grid node. Variables include window size, overlap, and the weighting function used. The resulting map may be contoured in a similar fashion to the maps resulting from the use of the exact interpolation techniques.

Map Cell Processing

Introduction

The Applied Geochemistry Research Group (AGRG) at Imperial College, London, England began in 1969 a series of large-scale regional multi-element studies of parts of the United Kingdom (Webb and others, 1973, 1978) based on stream sediment sampling at a nominal sampling density of one sample per 2.6 sq. km (1 sq. mile), following earlier studies in Africa and elsewhere. At that time it was apparent that for rapid production of geochemical maps at a variety of scales from 'point source' at 1:253,440 to synoptic regional coverage at 1:2,000,000 based on data sets varying in size from 5,000 to 50,000 samples, existing computer contouring packages such as SYMAP would not be suitable for handling such large data sets in the ways required. Accordingly, a mapping program was written (Howarth, 1971) to cope with data sets of moderate size using the computer lineprinter as

a basis, partly on the grounds of ease of turnaround and low cost of the output medium in a large multi-user university environment. This program has since gone through several evolutions to incorporate moving average and anomaly mapping techniques (Howarth and Lowenstein, 1974; Howarth, 1974) and is still undergoing further development (this work has been supported in part by the U. K. Natural Environment Research Council).

For lineprinter mapping to scale, the data have to be scaled to the 'map cell' corresponding to rectangular lineprinter character sizes (1/8 by 1/10 inches), preferably using 8 lines/inch printing, and final output is achieved by the usual technique of overprinting characters to give a tonal gray-scale. Alternatively, one can scale to square cells, accepting temporary distortion in intermediate lineprinter output maps, if final map plotting is to be via a device capable of dimensionally exact tonal output such as a Dresser laser plotter (Webb and others, 1973, 1978) or ink-jet plotter (Hertz and Orhaug, 1976). The AGRG mapping program has currently been adapted by C. Y. Chork and S. J. Mancey for a Calcomp microfilm plotter, using a pseudo half-tone technique to build up the tonal levels. This is more effective for visual recognition of patterns in the data than the relatively crude gray-levels achievable with line-printer overprinting, although the 35mm microfilm has to undergo photographic enlargement, etc. for hardcopy production. Several examples of this type of output follow in this section (plates 1-8). Extremely subtle tonal variations can be produced with raster dot patterns on microfilm when carefully used (e.g. Knowlton and Harmon, 1972; Gard, 1976).

Cell-Averaging and Gap-Filling

If we consider the map area to be divided into a number of (square) map cells, equivalent to positioning a mesh over the irregularly spaced data prior to contour interpolation, then we may represent the local element concentration in any one occupied cell as the average of any data points falling within that cell (fig. 2.1). Obviously, the number of data points falling into any one cell will depend on the cell size. Previous AGRG work on a variety of data sets comprising both stream sediment and soil surveys suggests that a suitable cell size is such that the average number of points per cell is in the order 1 to 3, depending on the application.

For this study a cell size of approximately 4.8 by 4.8 km (3 by 3 miles) has been found satisfactory, yielding an average of c. 1.5 points/cell in the Southeastern area.

Plate 1 (p. 163) shows the unsmoothed cell-average values for uranium for this region. It is apparent that the relatively 'noisy' appearance of the map even when tonal (rather than symbolic) representation is used, must be attributable to natural and/or sampling variability inherent in the data in view of the high precision of the analyses. A second factor is undoubtedly the visual effect of the presence of gaps in the sampling pattern. It would seem desirable to smooth the pattern to some extent in order to enhance local variations. Experimentation over the last seven years at AGRG has shown that effective results can be achieved using a localized moving average which fills in small holes but leaves large ones intact, thus preserving the general outline of gaps caused by lakes, coastal boundaries, towns, or areas without stream-sediment drainage.

Median = 2pts/cell

FIGURE 2.1 - Cell mean

Consider a block of 3 by 3 cells, forming the moving window, to be passed across the map from top to bottom row by row, and from left to right within the current row. Let the initial value of the central cell be x_0 , and assume that four of its eight neighboring cells are occupied, i.e. the previous within-cell averaging found data points in cells x_0 to x_4 (fig. 2.2). If x_0 is also occupied, then its current value will be replaced in the final map by $x^* = \sum x/n$. However, if x_0 is not occupied it will be replaced by the average value only if at least four immediately adjacent neighboring cells are occupied (fig. 2.2). In the case of

a larger than 3 by 3 window, this process can be imagined as: (a) scan all the map cells to see if they are occupied or not; (b) if they are not, test to see whether they meet the 'at least 4 occupied neighbors' criterion and flag them as either blank or non-blank in consequence; (c) carry out the moving average with the current window size assigning $x^* = \sum x/n$ to the central cell (ignoring blank cells in the original map); and (d) if the central cell of a current window has been flagged blank, replace x^* by 0 (blank) prior to printing out the final map. In this way the local fill-in of the final map can be achieved as desired, preserving larger sampling gaps even when a larger window size is used. Plate 2 shows the beneficial result achieved for the same uranium data as before. Equivalent gap-filling logic is applied to all the filtering operations described later.

	x_3	x_2
x_4	x_0	
		x_1

If $x_0 \neq 0$ then $x^* = \sum x/n$

If $x_0 = 0$ then

$x^* = \sum x/n$ if $n \geq 4$

else

$x^* = 0$

FIGURE 2.2 - Moving average with gapfill

At the synoptic regional level, AGRG experience has shown that incorporation of distance-weighted averaging makes no significant difference to the visual appearance of the map when the data density is scaled in terms of points/cell as indicated above, while incurring a penalty of additional processing time. Although the appearance of these cell-averaged maps may be somewhat unfamiliar to those used to traditional smooth contours, the essential spatial patterns are preserved by the map cells without the computational overhead of contour threading procedures. It should also be borne in mind that however convincing smooth curves look, they can be no better than the original data

allow in terms of accuracy and spatial density. An experimental color plotted version of plate 2 made for us by Richard J. Zinkl on the Applicon ink-jet plotter at Bendix Field Engineering Corp., Grand Junction, Colorado, is extremely effective.

Anomaly Filtering

There is an extensive literature on digital image-processing applied to photographs derived from aerial photography, satellite imagery, and biomedicine such as x-ray films and photomicrography. Many of these applications use sophisticated scanning densitometers and photographic film plotters for input and output of the images, with intermediate computer processing. A number of the image-enhancement problems are specific to video systems (e.g. specialized filters for scan-line and periodic noise removal, high-frequency image restoration, band-width reduction, transmission encoding, image registration, and so on) and are not appropriate in this context.

Imagery of photographic quality is commonly digitized to 64 or 256 gray-levels, and since the data with which we are concerned are not normally of a quality sufficient to justify this number of classes, the results obtained from processing geochemical maps must be expected to be less sophisticated. Nevertheless, the concepts of image-processing can be usefully applied even to material with a relatively low dynamic range.

We will be concerned with two types of map-cell windows (fig. 2.3): the square window, in which a central cell (A_{ij} in fig. 2.3) is related to its immediately adjacent neighbors; and the annulus, in which a central cell (or block of, say, 3 by 3 cells) is contrasted with those cells in a square annulus at a distance removed from it. In fig. 2.3, the effective radius of the windows (r) is 1 cell in each case, giving a total of 9 and 16 for the cells in the square window and annulus.

The low-pass filter (LPF) is the familiar moving average (fig. 2.4). As the effective radius of the window is increased, lower frequency (longer wavelength) spatial patterns are enhanced. As mentioned earlier, an equally weighted filter has been found to be adequate in most problems so far. The LPF (1) uranium map, i.e. effective radius 1 cell (plate 2), shows particularly well the regional patterns of enhancement over the Inner Piedmont province and the Coastal Plain sediments in the southeast. (Figure 3.1.1 locates these areas.)

Effective radius = r

FIGURE 2.3 - Filter window types

It has been shown in studies with artificial data that repeated low-pass filtering (LPFR) with a constant radius window, i.e. refiltering the result of the previous operation:

$$\begin{aligned}
 x_1^* &= \text{LPF}(1) \times x_0 \\
 x_2^* &= \text{LPF}(1) \times x_1^* \\
 x_3^* &= \text{LPF}(1) \times x_2^* \quad \text{equivalent to LPFR}(3) \\
 &\text{etc.}
 \end{aligned}$$

can achieve a better recovery, in the sense of finding the original trend in noisy data, on some occasions than a single application of an equivalent radius low-pass filter (i.e. LPF(3) in the above example), but with natural data it may be difficult to judge the appropriate number of repetitions for best effect.

Of more use may be the subtraction of a broadly smoothed surface from a locally smoothed one to obtain relative differences (e.g. LPF(1) - LPF(5)); this type of LPF difference filter has proved useful in some situations but tends to be very dependent on the size chosen for the larger radius LPF.

FIGURE 2.4 - Low-pass filter

A high-pass filter (HPF) is effectively the difference between the original surface and the LPF (fig. 2.5). For example, in the square window of fig. 2.3, HPF(1) would be the central cell differenced against the average for the whole window. Plate 3 shows the HPF(1) map for uranium, and it is clear that high frequency spikes occur as positive anomalies within the areas of generally elevated concentrations shown by the LPF(1) results in plate 2.

FIGURE 2.5 - High-pass filter

Instead of taking the difference between the original and LPF surfaces, one could also flag a cell if the original exceeded the mean of the window plus, say, two standard deviations. However, the picture-frame filter (below) is preferred for this type of contrasting operation.

The picture-frame filter is so-called because a central cell, or block of cells, is contrasted with values in a square annulus at an effective radius r away from it (fig. 2.6). If the mean and standard deviation for the annulus ($\bar{x}_a, s_a$) are determined, the map is made in terms of the number of standard deviations the central cell (or mean for a central block) lies above the mean of the annulus. Blank cells are ignored. This type of filter was originally successfully used for detection of aircraft in aerial photographs (Holmes, 1966). If we compare the area of influence of a one-cell-radius picture frame with the equivalent HPF for a simple anomaly (fig. 2.7), it is apparent that since the HPF makes use of its immediately adjacent neighbors, whereas the equivalent PF(1) does not, it is probable that for the central part of the anomaly the contrast with background will be higher for the picture frame. If a current 3 by 3 cell block is anomalous, only its central cell is flagged for mapping purposes.

$$\text{PF } x^* := 2 \text{ if } x_0 > \bar{x}_a + 2s_a \\ \text{etc.}$$

FIGURE 2.6 - Picture-frame

FIGURE 2.7 - Comparison of PF and HPF contrast

The Kolmogorov-Smirnov filter (KS) also makes use of an annulus contrasted against a central cell, or group of cells (fig. 2.8). However, the nature of the test criterion differs from that of the picture-frame filter; in this case a comparison is made of the frequency distribution of the concentration values in the inner cell(s) with the annulus based on the nonparametric Kolmogorov-Smirnov statistic (Siegel, 1956). This test makes no assumptions about the nature of the frequency distribution from which the samples are drawn and is sensitive to differences in distribution shape as well as central tendency. In this case we use a one-tailed test to decide whether or not the values of one sampled population (inner cell(s), I) are stochastically larger than the values of the other sampled population (annulus, A). If $CP(I)$ and $CP(A)$ are the cumulative distributions corresponding to the cells in I and A respectively, then the test criterion D is the maximum observed difference between the two cumulative probability distributions in the direction of interest, i.e. $D = CP(I) - CP(A)$, $0.0 \leq D \leq 1.0$, in order to determine whether the concentration values from which the inner population is drawn are stochastically larger than the values of the population from which the annulus samples are drawn. In this case we map the level of significance for the test statistic for the current central cell. A similar technique has recently been applied to the processing of Landsat imagery data (Eghbali, 1979).

FIGURE 2.8 - Kolmogorov-Smirnov filter

It has been found that KS testing of a single central cell against an annulus generally yields a rather noisy anomaly map with geochemical data and that a 3 by 3 central cell group is preferable. Plates 7 and 8 show the KS (1:3) and KS (1:4) results for uranium.

Other types of spatial filters are still being developed in the context of picture processing and general pattern recognition work and may ultimately prove useful for study of geochemical maps. However, in many cases picture-processing operations have the advantage of relatively noise-free data (compared with geochemical results) with a wide dynamic range, and perhaps most important of all is the very high spatial resolution in terms of pixels per image which is achieved. In comparison, irregularly spaced geochemical data are extremely sparse, and for the application of some techniques (such as two dimensional Fourier transform filtering) gaps in the data are not permitted. We do not yet know the best way to fill sampling gaps. Interpolation may cause trouble, particularly when the geology differs from cell to cell. As geologists, we are concerned about major changes in geology but may be able to accept small ones. As data analysts we are concerned about the computing expense in coping with changes in geology. Similar concerns are expressed by Harbaugh and others (1977) about computer contouring as cited earlier. Whether sampling gap-filling techniques should be employed will depend, in part at least,

on the scale of the study; perhaps it would be easier in a local context where larger areas of the map will be occupied by the same geologic unit than at a regional level. Similar considerations would, of course, apply to multivariate regression and correlation studies.

Multi-Component Maps

Obviously, map effectiveness in multi-element studies can be optimized by combining element variation patterns. In addition to increasing the map information content, this assists the human to comprehend spatial interactions that would otherwise have to be derived by inspection of different maps --a task for which the eye-brain system is not designed. Ratios, multi-arm 'wind rose' symbols (Plant and Rhind, 1974), and color-mixing techniques (Lowenstein and Howarth, 1973; Howarth and Lowenstein, 1976; Webb and others, 1978; Mancey and Howarth, 1978) have been used successfully as relatively simple cartographic devices.

Color-combination of computer plotted micro-film maps using a multichannel video image-processing system proved very helpful for this project in relating different element maps, and a similar use could be made of an Applicon or other type of ink-jet plotter.

In many cases a particular element is regarded as a function (in part at least) of other element patterns of variation. Statistical devices may be used to obtain multivariate functions which are then mapped by one of the standard procedures. Multivariate regression has been particularly successful. R-mode principal components or factor analysis has also been utilized for a similar purpose but may be more difficult to interpret. In a regional context there are inherent problems with both these techniques. The first is whether it is desirable to lump the data from all geological units together for the purpose of deriving a global regression equation or element associations; the second concerns the sampling properties of the covariance matrix (Howarth, 1973).

Class Selection for Maps

A practical problem underlying all the mapping techniques discussed is that one has to represent an invisible (geochemical) surface in a finite number of slices so that

its topography is shown in an optimum fashion. Unless one is using line contours alone, for good visual distinction gray-scale patterns are usually limited to a maximum of about eight classes. A greater dynamic range is obviously possible with color. The user must also be able to distinguish each pattern on the map and relate it unambiguously to the concentration scale. This problem has proved equally troublesome to geographers. Alternative methods of class-boundary selection include: equal, or geometric intervals (which are often approximated by convenient round-number intervals); percentiles; standard deviations about the mean; and 'natural' breaks in the frequency distribution. Evans (1977) gives a useful review of methods in current use.

Recent experimentation in connection with regional geochemical atlases in the United Kingdom (Webb and others, 1973, 1978) and elsewhere strongly suggests that very great perceptual differences can occur between maps of different elements simply because empirical choice of classes can easily lead to a different number of classes (chosen on a different basis in many cases) on each map. The use of a standardized method of class selection for all elements (e.g. equal quintiles, octiles, or deciles or non-linear division into, say, 10, 20, 40, 60, 80, 90, 95, and 99th percentiles) has proved very effective in both standardizing the appearance of the maps and emphasizing spatial correlation between maps for individual elements. We believe that standardization of the method of multielement class selection for all elements may be more important than the choice of method used. Class selection should also be related to the nature of the data being mapped, full advantage being made of the continuous measurement scales available on modern instrumentation. In a smoothed map, the precision of the mapped surface will be a factor of at least $\sqrt{n}$ (where n is the number of points averaged) better than that of the original data, and this will generally be improved still further by the contiguity properties of the data. We have adopted octile (i.e. 12.5 percentiles) classes where appropriate (e.g. LPF maps).

2.2 A STUDY OF HIGH URANIUM VALUES USING BOX PLOTS

In this part of the report, we report on a study made by one of us (JHS) of high uranium values using box plots.

In the four Southeastern quadrangles there are 5197 uranium stream samples. The upper 5 percent of the uranium values are the 261 values greater than or equal to 40 ppm.

High uranium values (≥ 40 ppm) in the sediments from two selected rock units from the Inner Piedmont, the biotite schist (05BS----) and the biotite gneiss (05BG----), are studied. Basic summary statistics for these units are presented in table 2.2.

TABLE 2.2. Summary statistics in parts per million (ppm) for uranium in the biotite schist and biotite gneiss units.

Rock unit	Biotite schist	Biotite gneiss
All samples	712	282
$\bar{w}$	25.809	14.625
s	27.999	13.756
≥ 40 ppm U	116	17
$\bar{w}$	73.870	56.888
s	40.386	13.462
< 40 ppm U	596	265
$\bar{w}$	16.522	11.914
s	9.431	8.249

A plot of the biotite schist uranium sample locations is given in figure 2.9 while those for biotite gneiss are in figure 2.10. Values ≥ 40 ppm are plotted as asterisks. Variables with the largest Pearson product moment correlations for the biotite schist unit are shown in table 2.3. Another way to view the association between random variables and to gain insight into their separability is to partition the data according to high and low values of uranium (above and below 40 ppm) and compare the respective distributions of each random variable.

A compact way to display empirical distributions is with a box plot (see McGill, Tukey, and Larsen, 1978). A box plot is a schematic diagram of a distribution which displays the maximum and minimum values, upper and lower quartiles, and the median. In figure 2.11 box plots of the log transformed (base e) data for the biotite schist unit are given. The numbers $5.816 = \log(\max U)$ and $-0.223 = \log(\min U)$. The box plot on the left is of values ≥ 40 ppm

FIGURE 2.9 - Biotite schist uranium stream-sediment locations

FIGURE 2.10 - Biotite gneiss uranium stream-sediment locations

VARIABLE 17	VARIABLE 15	VARIABLE 6	VARIABLE 19	VARIABLE 5	VARIABLE 10
U	Th	Dy	Yb	Ce	La
5.816	7.230	6.645	5.707	8.907	8.458
0	02	0	0	0	0
0	02	X	02	03	03
0	1	1	1	1	1
X	1	1	1	1	1
1	-+-	-+-	-+-	02	0
-+-	1 1	1 1	1*1	03	-+-
1 1	1*1	1 1	1 1	X	1 1
1*1	1 1	1*1	1 1	1	1*1
-+-	-+-	1 1	-+-	1	-+-
X	1	1 1	1	1	1
1	1	-+-	1	1	1
1	X	1	X	-+-	X
-+-	0	1 1	0	1 1	0
1 1	1 1	X	1 1	1*1	1 1
1*1	1*1	1 1	-+-	1 1	@
1 1	1 1	0	1	1 1	-+-
-+-	-+-	-+-	@	-+-	1
1	@	1	1	1	1
1	1	1	X	1	1
1	1	1	09	1	1
1	1	X	09	1	X
X	1	03	03	X	09
03	X	0	@	09	05
04	09		@	02	08
@	08		02	02	02
	@	03	03	06	
	04	02	03	@	
@	06	09	@	02	02
-0.223	0.693	-2.303	-2.303	1.609	0.693

FIGURE 2.11 - Log transformed data for biotite schist

VARIABLE 14 Sm	VARIABLE 11 Lu	VARIABLE 16 Ti%	VARIABLE 7 Eu	VARIABLE 9 Hf
7.038	4.564	3.408	3.653	7.262
02	@	@	@	0
04				@
	0	@		03
X	X	X	02	@2
1	1	1	X	X
1	1	1	0	@2
1	1	1	1	1
1	02	1	X	03
1	X	1	1	06
-+-	-+-	1	1	04
1	1	-+-	1	X
1 1	1 1	1 1	1	1
1*1	1*1	1 1	-+-	-+-
1 1	1 1	1*1	1 1	1 1
1 1	-+-	1 1	1*1	1 1
1 1	1	-+-	1 1	1*1
-+-	1	-+-	1 1	1 1
1	X	1	1 1	-+-
1	1 1	1	1 1	1 1
1	1 1	1	1 1	1 1
1	02	1	-+-	1*1
X	-+-	X	1	1 1
1*1	1	04	1	1 1
02	1	02	1	1
1 1	1	1	X	1
1 1	1	1	1 1	1
1 1	X	1	1 1	1
-+-	X	@	1 1	X
1	@	X	02	0
1	09	05	1	X
1	09	02	@4	0
1	03	02	1	08
1		@2	1	03
1		@	1	02
X	09	@	@	@2
0.693	-2.303	-2.996	-2.303	1.386

FIGURE 2.11 continued - Log transformed data for biotite schist

VARIABLE 12	VARIABLE 18	VARIABLE 4	VARIABLE 8	VARIABLE 3
Mn	V	Al%	Fe%	Alk
9.261	7.352	2.719	3.563	-0.248
0	@	0	@	@
02	@	02		0
X	@	X	@	
1	02	1	@	
1		1	@	
1		1	02	0
1		1	03	X
1	02	1	04	1
-+-	X	-+-	X	1
1 1	1	1 1	1	X
1 1	1	1*1	1	1
1*1	1	1 1	1	1
1 1	1	1 1	-+-	1
1 1	1	-+-	1 1	1
1 1	-+-	1	1*1	1
-+-	1 1	1	-+-	-+-
1	1 1	1	1	1 1
1	1*1	1	X	1 1
1	1 1	X	1	1 1
1	1 1	03	0	1*1
1	-+-	02	0	1 1
1	1		05	1 1
X	1	@	@3	-+-
0	1	@	@2	1
X	1	@	@	1
06	03	@	@3	1
04				X
@	0	@	@	1
3.689	2.303	-0.223	-2.996	04
				X
				-2.813

FIGURE 2.11 continued - Log transformed data for biotite schist

VARIABLE 13		VARIABLE 1		VARIABLE 2	
Sc		PH		Cond	
3.837		2.116		5.460	
e	e	e	e	e	e
	e		03		
0	04		02		
	09		X	e	e
0	X		1		e2
X	1	X	1		e
1	1	1	1	0	02
1	1	1	1	02	05
1	1	1	1	05	X
1	1	1	-+-	X	1
-+-	-+-	-+-	1 1	1	1
1 1	1 1	1 1	1 1	1	1
1 1	1 1	1*1	1*1	1	-+-
1*1	1*1	1 1	1 1	-+-	1 1
1 1	1 1	1 1	-+-	1 1	1 1
-+-	1 1	1 1	1	1*1	1*1
1	-+-	-+-	1	1 1	1 1
1	1	1	1	-+-	-+-
1	1	1	1	1	1
1	1	1	1	1	1
1	1	X	X	1	1
X	1			X	X
	X		02	02	05
0	02	02	0		0
	02	0	03		
	0				e
	e			e	e
0.262		e		e	e
		1.740		2.197	

FIGURE 2.11 continued - Log transformed data for biotite schist

while that on the right is for values < 40 ppm. For each box plot the top dashed line is the upper quartile, the asterisk is the median, and the lower dashed line is the lower quartile. The X denotes either the maximum value or one interquartile range. Values greater than the top X or less than the bottom X may be considered outliers if the distribution is symmetric. For thorium, the box plot on the left is of thorium values associated with ≥ 40 ppm uranium and the box plot on the right is for thorium values in samples with < 40 ppm uranium. If for thorium no overlap occurred between the box plots, then all samples with high values of uranium would have high values of thorium. The box plots for all of the chemical elements are ordered visually in terms of a decreasing degree of separability associated with samples containing uranium values above and below the cutoff. A listing of the box-plot program is given in Appendix B. A similar display of box plots for the biotite gneiss is given in figure 2.12. Note that in figure 2.12, lower values of scandium, alkalinity, and conductivity tend to be associated with samples containing high uranium. However, each of the left-hand-side box plots is based on just 17 observations.

TABLE 2.3. Correlation matrix for the untransformed data for biotite gneiss.

			1	2	3	4	5	6	7	8
(6)	Dy	1								
(5)	Ce	2	.747							
(10)	La	3	.732	.966						
(11)	Lu	4	.812	.689	.646					
(15)	Th	5	.736	.953	.974	.656				
(18)	Yb	6	.867	.767	.738	.942	.750			
(7)	Eu	7	.529	.561	.607	.618	.583	.605		
(19)	U	8	.797	.845	.855	.718	.882	.812	.475	
(14)	Sm	9	.584	.740	.742	.516	.734	.607	.581	.617

VARIABLE 17 U 4.413	VARIABLE 5 Ce 8.029	VARIABLE 15 Th 6.725	VARIABLE 10 La 7.535	VARIABLE 19 Yb 4.968	VARIABLE 14 Sm 6.621
X	0	@	@2	X	0
1	X			1	
-+-	1			1	
1*1	1	X		1	
1 1	-+- X	1 X	X	-*- X	.0
-+-	1*1 1	1 1	-+- X	1 1 1	0
	1 1 1	-+- 1	1*1 1	1 1 1	
	-+- 1	1*1 1	-+- 1	-+- 1	-+- X
	1	-+- 1	X 1	1 1	1 1 1
	1	1 1	@ 1	1 1	1 1 1
	1	1 1	1 1	X -+-	1*1 1
	1	1 1	1	1 1	1 1 1
	@ -+-	X 1	@ -+-	1 1	-+- 1
-+-	1 1	1	1 1	1*1	1 1
1 1	1 1	-+-	1 1	1 1	1 1
1 1	1 1	1 1	1 1	1 1	1 1
1*1	1 1	1 1	1 1	-+-	-+-
1 1	1*1	1 1	1*1	1	X 1 1
1 1	1 1	1 1	1 1	1	1 1
1 1	1 1	1*1	1 1	1	1 1
1 1	1 1	1 1	1 1	1	1*1
-+-	1 1	1 1	1 1	1	1 1
1	-+-	1 1	-+-	X	1 1
1	1	-+-	1	02	1 1
1	1	1	1		1 1
1	1	1	1	@2	-+-
1	1	1	1	@2	1
X	1	1	1		1
02	1	1	1		1
0	X	X	X	@	X
0.588	2.303	0.693	1.792	-0.511	0.693

FIGURE 2.12 - Log transformed data for biotite gneiss

[illegible]

VARIABLE 4	VARIABLE 8	VARIABLE 12	VARIABLE 1	VARIABLE 18
Al%	Fe%	Mn	PH	V
2.771	2.812	9.506	2.041	7.123
0	0	0	X	0
X		0	1	0
1	0		1	0
1	0		-+-	
1	0		1 1	
1	0		1 1	
1	02	06	1 1	0
1	X	X	1 1	0
X	1	X	1 1	X
1	1	1	1 1	1
-+-	1	1	1*1	1
1*1	1	1	1 1	1
1 1	-+-	1	1 1	1
1 1	1 1	-+-	1 1	X
1 1	1 1	1 1	1 1	1
1 1	1*1	1*1	1 1	-+-
-+-	1 1	1 1	-+-	1
1	-+-	1 1	1	1
1	1	1 1	1	1*1
1	1	-+-	1	1 1
X	X	1	X	1 1
0	1	X		-+-
	X	1		X
	02	1	02	1
	02	1	0	1
X	02	0	0	X
04	02	X	0	
0		03	0	02
03		03		
		0		
0	0	0	0	03
0.392	-1.386	4.094	1.775	2.303

FIGURE 2.12 continued - Log transformed data for biotite gneiss

FIGURE 2.12 continued - Log transformed data for biotite gneiss

2.3 BASIC STATISTICAL ANALYSES

In this sub-section, we (GSK) explain and discuss the distributional forms of the chemical elements, our program for calculating basic statistics, the procedure for the one-way analysis of variance, and geological diversity in the cell-averaging program used to produce data for the maps explained in sub-section 2.1.

The distributional forms of the elements are presented in graphical and tabular forms in the reports by the three national laboratories. The Savannah River Laboratory presents distributions for all elements, the Oak Ridge National Laboratory for selected elements, and the Los Alamos Scientific Laboratory for uranium only. For the trace elements, the distributions are skewed, and some may be lognormal. For the major elements, such as aluminum and iron, most of the distributions are less skewed. Because there is no generally accepted theoretical basis for expecting elemental distributions to follow a particular distributional form, we have not concerned ourselves with whether or not some distributions may in fact be lognormal. We have transformed distributions to lognormal distributions when it seemed appropriate. Most of the distributions contain several, and sometimes many, values below the detection limit. For computation, we have either ignored these values or have arbitrarily set them equal to one-half the detection limit. Neither of these procedures is wholly satisfactory, because either one provides a "spike" in the data, but better methods to handle such data have not been devised. As discussed in sub-section 2.1, we have used the distribution-free Kolmogorov-Smirnov filter for some of our map analyses.

For all elements and other variables, we have calculated basic statistics. We have made these calculations for the original data grouped by quadrangles, for the four Southeastern quadrangles taken as a group, and for the data stratified according to rock type. Figure 2.13 is a typical example of the computer output obtained by use of a previously published program (Koch and others, 1972, p. 8). The table lists a title, the total number of observations, the calculated t-value used to find confidence limits at the user's specified risk level, the mean, variance, standard deviation, coefficient of variation, confidence limits for the mean and variance, minimum value, maximum value, frequency distribution, and histogram (shown by a pattern of stars). While we have calculated and studied these basic statistics, we do not display them except as selected data for various tables throughout this report. Study of this output was essential as a basis for our understanding of the data.

+++VARIABLE 2 UR UR

TOTAL OBSERVATIONS 783
T(10%) = 1.647

MEAN	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
5.49789	178.495	13.3602	2.43000

CONFIDENCE LIMITS	LOWER	UPPER
MEAN	4.71145	6.28434
VARIANCE	177.519	179.785

MINIMUM VALUE -138.920
MAXIMUM VALUE 70.7400

FREQUENCY DISTRIBUTION

782 VALUES FROM 783 OBSERVATIONS		CLASS INTERVAL 5.00000		EACH * IS		OBSERV	
NUM	CLASS INTERVAL	FREQ	RELATIVE FREQ	CUM FREQ	RELATIVE CUM FREQ	%	%
1	-50.0000	-45.0000	2	.26	782	100.00	!
2	-45.0000	-40.0000	0	0.00	780	99.74	!
3	-40.0000	-35.0000	3	.38	780	99.74	!
4	-35.0000	-30.0000	1	.13	777	99.36	!
5	-30.0000	-25.0000	7	.90	770	99.23	!*
6	-25.0000	-20.0000	0	.77	769	98.34	!*
7	-20.0000	-15.0000	10	1.28	763	97.57	!*
8	-15.0000	-10.0000	10	1.28	753	96.29	!*
9	-10.0000	-5.00000	28	3.58	743	95.01	!****
10	-5.00000	0.	88	11.25	715	91.43	!*****
11	0.	5.00000	287	36.70	627	80.18	!*****
12	5.00000	10.0000	163	20.84	340	43.48	!*****
13	10.0000	15.0000	75	9.59	177	22.63	!*****
14	15.0000	20.0000	40	5.12	102	13.04	!*****
15	20.0000	25.0000	18	2.30	62	7.93	!***
16	25.0000	30.0000	14	1.79	44	5.63	!***
17	30.0000	35.0000	9	1.15	30	3.84	!*
18	35.0000	40.0000	5	.64	21	2.69	!
19	40.0000	45.0000	3	.38	16	2.05	!
20	45.0000	50.0000	2	.26	13	1.66	!
21	50.0000	55.0000	0	.77	11	1.41	!*
22	55.0000	60.0000	2	.26	5	.64	!
23	60.0000	65.0000	0	0.00	3	.38	!
24	65.0000	70.0000	2	.26	3	.38	!
25	70.0000	75.0000	1	.13	1	.13	!

FIGURE 2.13 - Example of computer output for basic statistics. Data, described in sub-section 2.4, are observed uranium values from the biotite schist unit of the Inner Piedmont in the Southeastern area.

We have also calculated many one-way analyses of variance, using this standard statistical method to compare the means of elements and other variables among two or more data sets. Figure 2.14 is a typical example. Our notation and display follow Koch and Link (1970, p. 131), and the program is from Koch and others (1972, p. 21). In the analysis of variance, two important assumptions are made. The first is that the observations are random samples and the second is that the observations follow a normal distribution. Random samples would be those for which every point in a quadrangle located at a suitable place with regard to the drainage had an equal chance of being sampled. Clearly, the sample sites are not randomly distributed, because many are located at or near road/stream intersections for sampling efficiency. While these samples may behave like random samples, we cannot be sure. For instance, it is probable that bridges are built where it is easy to cross streams, and these may be places where the rocks are on the average different from those elsewhere. Because of the integrating effect provided by stream-sediment samples, we believe it reasonable to assume that the samples collected behave like random samples, but it is important to remember that they are not in fact true random samples.

The second assumption, that observations follow a normal distribution, is less important than the first because statisticians have repeatedly shown that the analysis of variance, the calculation of confidence limits, and other statistical procedures used in this report are relatively "robust". That is, these procedures are relatively insensitive to data that are not normally distributed. We have done many of our analyses using both raw and also lognormally transformed data. Nearly always, the results of the analyses are the same, and we see no systematic pattern of difference.

Every time a statistical test is made, for example a test of the hypothesis in the one-way analysis of variance that two means are equal, we must accept a risk of being wrong. We have set this risk level at 10 percent, believing this a reasonable level for problems in economic geology. Thus, for any particular comparison of means, there is a 10 percent risk of being wrong; by the time we compare 40 elements, we expect to make four mistakes simply because of statistical fluctuation. This is a necessary consequence of statistical methodology, although statisticians have devised ways to cope with this problem (Miller, 1976).

Finally, in constructing map cells for the mapping programs explained in sub-section 2.1, it is important to study the data within each cell. Ideally, each cell would

ELEMENT IS NO. 1, 0				
ROCK GROUP	SAMPLE TOTAL	SAMPLE SIZE	SAMPLE MEAN	
GROUP 1	525.	85	6.17	
GROUP 2	459.	80	5.34	
TOTALS	984.	171	5.75	
ANALYSIS OF VARIANCE				
	SUM OF SQUARES	D.F.	VARIANCE (MEAN SQUARE)	F F(90%)
AMONG-SAMPLE	29.85860	1	29.85860	4.01 2.74
WITHIN-SAMPLE	1259.626	169	7.453411	
TOTAL	1289.485	170		

FIG. 2.14 - One-way analysis of variance to compare uranium in Quaternary alluvium (Group 1) and windblown sand (Group 2) in the Pueblo quadrangle.

contain an equal number of original sample points from the same rock type. But how closely is this ideal approached by the actual data? We have made this analysis only for the Southeastern area, and table 2.4 gives the results. The table shows that the 3 mile by 3 mile square map cell adopted for the Southeastern area yields for the total rectangular area encompassed by the map 77 columns and 69 rows, or a total of 5,313 cells. Because only four of the six quadrangles in this area were sampled, there are 3,542 cells potentially sampled. Of these 3,542 cells, 675 or 19 percent, contain no sample sites. We do not have the number of sample sites that are absolutely unavailable because their locations coincide with cities and lakes, nor the ones unsampled because there are no suitable streams within them. Most sample sites, 2,349 in number, or 66 percent, are located so that there are either one or two sites per cell, yielding the average of 1.5 sample sites per cell. Only 12 percent of the cells contain three sample sites, and only 2 percent contain four.

The rest of table 2.4 shows the number and percent of cells with multiple rock codes, considering the diversity among and within major units. The major units are the geologic provinces shown in table 3.1.1. Ideally, of course, we would have no diversity. The table shows that 93.6 percent of the cells contain only one major rock unit, and 81.7 percent contain only one minor rock unit within the major rock units. Therefore, we believe that the individual cells portray reasonably well areas of homogeneous geology. Essentially no cells contain more than two major units or two minor units within a major unit. Through consideration of the facts in this table and through analysis of the detailed data summarized in this table, we believe that the cell size is a suitable one and that the loss of information is minimal in this averaging procedure.

2.4 MINERALOGICAL ANALYSES

By calculating residual uranium values from multi-element data and identifying anomalous samples through analysis of the frequency distribution, we can locate residual anomalies. Residual uranium values are those that remain after the uranium present in resistate minerals is accounted for. The resistate minerals include monazite, xenotime, allanite, zircon, and many others.

While one of us (RHC) developed this method for data from the Southeastern area, he has also applied it to data

TABLE 2.4.- Number and percent of sample points and multiple rock codes for cells in Southeastern area.

No. of points per cell	Number and percent of sample sites		Number and percent of multiple rock codes			
	No.	%	Among major units		Within major units	
	No.	%	No.	%	No.	%
0	675	19				
1	} 2349	66 {	2683	93.6	2342	81.7
2			181	6.3	511	17.8
3	427	12	3	.1	14	.5
4	79	2	0		0	
5	10	0.3	0		0	
6	2	0.06	0		0	
Totals	3542	99.36	2867	100.0	2867	100.0

from the Tallahassee Creek area in the Pueblo, Colorado, quadrangle. In this section, we review the principles involved. We further develop the method in Section 3 of the report.

Stream-sediment samples in the Inner Piedmont are extremely variable in uranium content, with concentrations ranging from 0.5 to 335 ppm ("total analysis", neutron activation). This variability exceeds that of any other province in the southern Appalachians; most of it reflects concentrations of certain uranium-bearing accessory minerals (heavy minerals such as monazite, zircon, xenotime, etc.) in the samples. The abundance and proportions of these minerals probably differ from place to place due to such factors as: (1) relative abundance in soils (hence, source rocks); and (2) mechanical concentration factors (stream hydraulics) at sample sites. According to Mertie (1953), the Western Monazite Belt, a belt rich in monazite and xenotime, comprises a significant portion of the Inner Piedmont (figure 3.1.1). In the early 1900's, monazite was produced from several placer occurrences in the area.

Certain geochemical relationships form the basis for the present study. First, uraninite is the principal uranium mineral in uranium deposits throughout the world. Like the uranium in monazite, xenotime, allanite, zircon, and many other uranium-bearing accessory minerals in rocks, the contained uranium has a 4+ valence. However, unlike these minerals which are chemically and mechanically stable, the contained uranium in uraninite is readily oxidized to the 6+ valence. Typically, 6+ uranium is thoroughly leached from soils and enters streams in ground water rather than sediment. However, some 6+ uranium can be scavenged to co-precipitate under certain conditions. In soil formation, some 6+ uranium can be fixed by certain anionic complexes (vanadates, phosphates, arsenates) and by sorption of iron oxides. In streams, 6+ uranium in solution can be scavenged by iron oxide in boulder coatings, aquatic bryophytes, and other forms of organic matter. Based on these considerations, the concentration of 6+ uranium in stream-sediment samples is of much greater importance than that of 4+ uranium in accessory minerals whose occurrence is genetically unrelated to uraninite. In the Inner Piedmont, it is quite clear that most of the variability in uranium concentration in stream-sediment samples is due to 4+ uranium in heavy minerals.

These relationships are fully appreciated by the scientists at SRL involved in the NURE program. Their basic approach has been to determine metal ratios and plot their distributions on maps. Ratios included in their reports include $\log U / \log Hf$, $\log U / \log Th$, $\log U / \log Ce$, $\log U /$

$\log \text{Th} \cdot \text{Hf}$, and $\log \text{U} / \log \text{Hf} \cdot \text{Th} \cdot \text{Ce}$. Because accessory minerals are the principal residence sites for hafnium, thorium, and cerium, samples with higher ratios are much more likely to represent a 6+ uranium source, hence uraninite, than a sample with a lower ratio. Data processed in this manner are more useful in exploration than the raw data. However, there are several drawbacks to this procedure:

(1) A high ratio can result from elevated values of the numerator, or decreased values of the denominator. It is not always clear which accounts for an anomalous value unless one checks back to the raw data.

(2) If a uraninite deposit occurred in a small stream in the monazite belt but supplied only 10 to 20 percent of the contained uranium in the sample, the calculated ratios might still be low.

(3) The ratios are not precise indicators of the mineralogical residence of uranium. For example, the term $\log \text{U} / \log \text{Th} \cdot \text{Ce} \cdot \text{Hf}$ gives equal weight to thorium, cerium, and hafnium. This term basically reflects the abundance of monazite ($\text{Th} \cdot \text{Ce}$) and/or zircon (hafnium). However, monazite has a significantly higher concentration of uranium.

We have attempted to approach the problem by developing a formula for Residual Uranium (UR). In the formula, 4+ uranium in the minerals monazite, xenotime, and zircon is calculated from thorium, cerium, hafnium, and dysprosium data. The combined uranium concentration calculated for these minerals is subtracted from the observed uranium value (UO) to yield UR. The frequency distribution of UR is the primary method used in this report for selecting uranium anomalies in the Inner Piedmont. This procedure will be discussed in greater detail in a subsequent section.

Analysis of the frequency distribution is a proven technique in geochemical exploration. The applicability of the method is based on the following:

(1) In a terrain of comparable host-rock lithologies and cultural development, metal concentrations in stream sediment derived from background sources are lognormally distributed.

(2) A different lognormal distribution results from mineralization within the same terrain.

(3) Plots of cumulative percent on a probability scale versus metal concentration on a log scale serve to define the separate distributions and anomaly threshold values. Samples

in which the metal concentration exceeds the calculated threshold value normally have a high probability of being associated with mineralization.

The SRL reports routinely show the frequency distribution of uranium and other elements on cumulative frequency plots for the separate NTMS Area Studies.

We have attempted to refine this procedure to improve anomaly discrimination. Experience has shown that when analytical data for a variety of geologic terrains, or a large geographic area, are treated as a unit, most of the individual lognormal distributions, both background and anomalous, will tend to coalesce to form a single lognormal distribution. Since most trace elements in the earth's crust approach a lognormal distribution, there is a tendency to approach the world-wide distribution as the size of the survey area increases. Associated with this is the loss of resolution of anomalies related to mineralization.

In this report, all stream-sediment localities in the Inner Piedmont have been referenced to lithologic units displayed on summary geologic maps accompanying the reports. Each unit has been assigned a numerical code which is stored in the computer with SRL analytical data. For the Inner Piedmont, the principal rock units, code numbers, and number of sample sites are included in table 2.5.

The suite of elements analyzed by SRL in their surveys is of interest in that it enables reasonable assumptions to be made concerning the abundance of certain accessory minerals in the samples. Through published data on the average uranium and thorium concentrations of these minerals, it is possible to develop equations whereby a certain amount of the uranium contained in each of the minerals is subtracted from the total. The remaining uranium, here termed residual uranium (UR), is a measure of the uranium not accounted for by assumptions implicit in the equations.

The following section presents the rationale behind the development of equations for UR and ThR for stream-sediment samples in the Inner Piedmont.

The formula developed for this study is presented in table 2.6. Individual terms are discussed in the next seven numbered headings:

- (1) UR. Residual Uranium in ppm.
- (2) UO. Observed Uranium. Actual analytical determination in ppm.

TABLE 2.5.- A summary of rock units, computer code numbers, and number of sample localities analyzed for observed uranium (UO) in the Inner Piedmont.

Rock Units	Code Numbers	No. of UO values
Biotite schist	05BS---- 05-B----	811
Biotite gneiss	05BG----	326
Metagranites	05-G-R-- 05-G-T--	204
Granites (undivided)	05-G----	75
Amphibolites	05-A----	64
Henderson gneiss	05-D----	36
Cherryville quartz monzonite	05-G-R-- 05-G-RCR	19
Elberton granite	05-G-REL	13
Toluca quartz monzonite	05-G-T-- 05-G-TTU	7
Pacolet Mills granite	05-G-XPM	4

(3) Ce/45. This term expresses the Ce/U ratio assumed for monazite. Naturally occurring monazite generally contains between 20 to 30 percent cerium and .2 to .8 percent uranium. Numerous analyses are cited by Overstreet (1967) for monazite in the Inner Piedmont of North and South Carolina; the analyses are typically in this range, although locally uranium concentrations are reported to exceed 2 percent uranium. Assuming the average monazite contains 25 percent cerium, the average uranium concentration implicit in the ratio is 0.55 percent uranium. The value of 45 was selected from trial evaluations of a suite of samples containing a wide range in cerium concentrations, but with relatively low hafnium and dysprosium. At values below 45, a very large percent of UR values were negative. At values above 45, high positive UR values result, even from samples containing several percent monazite. The term assumes that all of the cerium in the samples is in monazite. Allanite, samarskite, and other cerium-rich minerals are rather widespread in nature. How-

TABLE 2.6.- Mineralogical data for selected accessory minerals which occur in the Inner Piedmont. Values of x are those assumed for the equations for residual uranium.

Mineral	Composition	Selected parameters	References
Monazite	$(\text{Ce}, \text{La}, \text{Nd})\text{PO}_4$ Ce-La rich	Ce 20-30%; x=25% U .2-4%; x=.55% Th 1-15%; x=4.34% Dy x=0.5%	Overstreet (1967)
Xenotime	YPO_4 Y-RE with high atomic number	Dy 2-5%, x=4.0% U .2-4%, x=.57% Th .1-3.3%, x=.44% Ce .05-.1%, x=.08%	Reider (1975) Shaw (1957)
Zircon	$(\text{Zr}, \text{Hf})\text{SiO}_4$	Hf .2-7%, x=1.0% U .02-4.3%, x=.017% Th .02-5.9%, x=.017%	Hess (1962) Ahrens (1965)
Allanite	$(\text{Ca}, \text{Ce}, \text{Th})_2 (\text{Al}, \text{Fe}, \text{Mg})_3 \text{Si}_3 \text{O}_{12} (\text{OH})$		
Samarskite	$(\text{Y}, \text{Er}, \text{Ce}, \text{U}, \text{Fe}, \text{Th}) (\text{Nb}, \text{Ta})_2 \text{O}_6$		
Gadolinite	$\text{Be}_2 \text{Fe} (\text{Y}, \text{U}, \text{Th}, \text{RE})_2 \text{Si}_2 \text{O}_{10}$		
UR = UO - Ce/45 - Hf/60 - (Dy-.02Ce)/7 - .3(ThO - Dy/9 - Ce/5.75 - Hf/60)			

ever, in numerous mineralogical analyses of heavy mineral concentrates in the Inner Piedmont province summarized by Overstreet (1967), they are not reported to be significant.

(4) $\text{Hf}/60$. The geologic occurrence of hafnium is virtually restricted to the mineral zircon. The concentration range varies from 0.2 to 7 percent hafnium. Analyses of zircon from the southeastern U.S. average about 1.0 percent hafnium (Hess, 1962). Although Ahrens (1965) reports average uranium and thorium concentrations of 1330 ppm and 630 ppm respectively, zircons in the Inner Piedmont probably contain much lower amounts of these elements. Samples containing high concentrations of hafnium normally yield negative UR values if the Hf/U ratio is less than 1/60. The same is true for ThR. The low uranium and thorium concentrations assumed for zircon in the southeastern U.S. are somewhat confirmed by analyses of zircon from beach sands along the Atlantic Coast. These zircons contain less than 200 ppm uranium and thorium. Our estimate is 170 ppm uranium and thorium.

(5) $(\text{Dy} - .02\text{Ce})/7$. Unlike monazite, which is enriched in rare earths with low atomic numbers (cerium, lanthanum, neodymium), xenotime contains yttrium and rare-earth elements with high atomic numbers. Thus dysprosium may be a reliable index of xenotime concentration. In mineralogical analyses of heavy minerals in the Western monazite belt, the concentrations of xenotime are typically about 1/10 that of monazite (Overstreet, 1967). Based on published values in the literature (principally those of Reider (1975) and Shaw (1957)) we assume average concentrations of dysprosium, uranium, and thorium to be 4.0 percent, .57 percent, and .44 percent, respectively. The dysprosium estimated to occur in monazite (.02 Cerium) is subtracted from the analyzed dysprosium value. Uranium is estimated to be 1/7th of the residual dysprosium. It is not uncommon for xenotime to locally contain up to 2 percent uranium. In some cases, uranium may equal or exceed dysprosium. Although analyses of uranium-rich xenotime are not reported for the Inner Piedmont, occurrences in pegmatites throughout the world are commonly uranium-rich.

(6) $.3(\text{Th}0 - \text{Dy}/9 - \text{Ce}/5.75 - \text{Hf}/60)$. This term expresses the assumption that if the average thorium concentrations of xenotime, monazite, and zircon are subtracted from observed thorium, any thorium remaining represents one of the following: either another thorium-bearing mineral in the sample, or more thorium in xenotime, monazite, or zircon than assumed. We have assumed that 30 percent of the residual thorium will be supported by uranium.

(7) ThR. This equals the term within the parentheses given above.

Examples of the computer output of frequency distribution of UO and UR for the biotite schist unit in the Inner Piedmont are presented in figures 2.13 and 2.15 to demonstrate the data management techniques currently utilized and to show the differences in frequency distribution of UR as compared to UO. Values are classed in 5 ppm intervals. The number of samples, percentage of samples, cumulative number of samples, and cumulative percentage are given for each class interval. A histogram is plotted for visual inspection of the distribution pattern. Statistical parameters for the frequency distribution are also presented. These include the mean, variance, standard deviation, coefficient of variation, and confidence limits of the mean and variance. Log-probability plots are prepared by plotting cumulative percentage against the upper limit of each class interval on a log scale using log-probability paper.

Differences in the frequency distribution of UO and UR are apparent from the data. The mean value of UR is 5.5 compared to 25.5 for UO. The dispersion about the mean is much less for UR than for UO. Negative values of UR result from lower Ce/U, Hf/U, Dy/U, or Th/U ratios in a given sample than those assumed in the equation. For the biotite schist unit, only 4 percent of the values are below -10 ppm UR.

Figure 2.16 is a portion of the print-out which lists all sample localities in the biotite schist unit. It contains a tabular listing of sample numbers, together with a list of latitude, longitude, UR-ThR, UR, UO, ThR, and ThO. Samples which lack analytical values for elements used in the calculation of UR and ThR are flagged. These are not included in the frequency distribution analysis of UR and ThR. From these lists, sample localities are selected which contain analytical values for UR selected as anomalous from the log-probability plots.

***VARIABLE 3 UR UU

TOTAL OBSERVATIONS 811
T(10%) = 1.641

MEAN	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
25.5295	747.984	27.3493	1.07128

CONFIDENCE LIMITS		LOWER	UPPER
MEAN	23.9477	27.1113	
VARIANCE	743.954	753.285	

MINIMUM VALUE .800000
MAXIMUM VALUE 335.600

FREQUENCY DISTRIBUTION

811 VALUES FROM 811 OBSERVATIONS

CLASS INTERVAL 5.00000

EACH * IS 4 OBSERV

NUM	CLASS INTERVAL	FREQ	RELATIVE FREQ %	CUM FREQ	RELATIVE CUM FREQ %
1	0.	48	5.92	811	100.00 !*****
2	5.00000	156	19.24	763	94.08 !*****
3	10.0000	154	18.99	607	74.85 !*****
4	15.0000	105	12.95	453	55.80 !*****
5	20.0000	70	9.37	348	42.91 !*****
6	25.0000	63	7.77	272	33.54 !*****
7	30.0000	41	5.05	209	25.77 !*****
8	35.0000	36	4.69	168	20.72 !*****
9	40.0000	13	1.60	130	16.03 !***
10	45.0000	26	3.21	117	14.43 !*****
11	50.0000	15	1.85	91	11.22 !***
12	55.0000	11	1.36	76	9.37 !**
13	60.0000	11	1.36	65	8.01 !**
14	65.0000	8	.99	54	6.66 !**
15	70.0000	6	.74	46	5.67 !*
16	75.0000	3	.37	40	4.93 !
17	80.0000	4	.49	37	4.56 !*
18	85.0000	4	.49	33	4.07 !*
19	90.0000	4	.49	29	3.58 !*
20	95.0000	3	.37	25	3.08 !
21	100.000	5	.62	22	2.71 !*
22	105.000	2	.25	17	2.10 !
23	110.000	1	.12	15	1.85 !
24	115.000	0	0.00	14	1.73 !
25	120.000	3	.37	14	1.73 !

FIGURE 2.15 - Basic statistics. Residual uranium values from the biotite schist unit of the Inner Piedmont.

SAMPLE	LAT.	LONG.	UR-THR	UR	UU	THR	THU	UTICD -FLAGS
NCAE001S1	30.0090	81.1895	-1.70	1.18	4.10	1.88	18.00	
NCAE003S1	30.0109	81.1338	-8.76	-1.19	6.90	8.57	39.00	
NCAE004S1	30.0175	81.1177	-11.50	2.90	11.70	14.40	40.00	
NCAE006S1	30.0230	81.0740	-13.19	27.25	62.10	40.44	191.00	
NCAE007S1	30.0305	81.0547	-3.42	.85	5.10	4.26	24.00	
NCAE027S1	30.0035	81.2155	-6.29	1.69	12.40	7.98	56.00	
NCIRO57S1	30.0114	80.7910	-3.61	-.92	8.70	2.69	70.00	
NCIRO58S1	30.0103	80.7797	10.39	5.06	12.60	-5.34	64.00	
NCIRO60S1	30.0430	80.7438	1.85	2.08	4.70	.23	15.00	
NCIRO62S1	30.0242	80.8229	12.30	4.66	10.80	-7.64	58.00	
NCIRO63S1	30.0466	80.8458	-5.88	-.67	5.70	5.21	36.00	
NCIRO64S1	30.0551	80.8691	.87	3.72	9.10	2.85	35.00	
NCIRO65S1	30.0480	80.9431	10.58	8.24	13.30	-2.33	42.00	
NCIRO66S1	30.0411	80.9604	-999.00	-999.00	-999.00	-999.00	-999.00	99999
NCIRO67S1	30.0233	80.9693	-9.41	4.64	15.90	14.05	53.00	
NCIRO68S1	30.0253	80.9945	-6.97	9.16	26.30	16.13	105.00	
NCIRO69S1	30.0026	80.9728	-3.29	.75	4.30	4.04	17.00	
NCIRO70S1	30.0184	80.9407	-29.55	7.82	37.60	37.37	161.00	
NCIRO71S1	30.0163	80.9152	-2.65	1.28	7.90	3.93	40.00	
NCnL030S1	30.0715	80.9533	-8.33	1.87	8.60	10.21	32.00	
NCnL031S1	30.0950	80.9090	-17.95	-.65	15.50	17.30	94.00	
NCnL076S1	30.1422	80.8941	-10.43	.34	4.20	10.77	12.00	
NCnL077S1	30.1398	80.9267	-9.45	-.25	9.80	9.20	64.00	
NCnL079S1	30.1620	80.9919	.05	3.64	7.10	3.59	12.00	
NCnL117S1	30.0329	81.0910	-.92	2.97	7.00	3.89	22.00	
NCnL118S1	30.0339	81.0600	-17.51	2.03	26.10	19.54	159.00	
NCnL119S1	30.0572	81.0783	-10.95	2.70	10.20	13.65	32.00	
NCYD001S1	30.1337	80.8617	-16.73	5.93	25.70	22.65	115.00	
NCYD002S1	30.1233	80.8605	-10.05	-1.59	20.20	8.46	160.00	
NCYD009S1	30.0851	80.6873	-999.00	-999.00	2.60	-999.00	-999.00	.9.9.
NCAE002S1	35.9845	81.1815	-18.74	2.16	14.10	20.90	52.00	
NCAE009S1	35.9734	81.0042	-14.44	.32	13.60	14.76	77.00	
NCAE010S1	35.9507	81.0115	-8.08	18.01	46.80	26.10	166.00	
NCAE011S1	35.9332	81.0196	2.08	6.09	15.10	4.01	61.00	
NCAE012S1	35.9109	81.0307	-21.13	31.34	91.00	52.47	383.00	
NCAE013S1	35.8987	81.0457	-30.32	.24	36.30	30.56	226.00	
NCAE014S1	35.9207	81.0694	-38.28	.53	22.10	38.81	103.00	
NCAE015S1	35.9204	81.0878	-40.09	4.08	45.70	44.17	245.00	
NCAE016S1	35.9369	81.0817	-37.52	1.17	21.00	38.68	84.00	
NCAE018S1	35.9418	81.1186	-59.52	-2.14	34.70	57.38	167.00	
NCAE019S1	35.9346	81.1349	9.25	3.73	6.00	-5.51	20.00	
NCAE020S1	35.9566	81.1261	3.71	1.92	2.60	-1.80	4.00	
NCAE021S1	35.9663	81.1620	-17.28	.69	29.60	17.97	179.00	
NCAE022S1	35.9469	81.1895	-26.45	7.68	32.00	34.13	116.00	

FIGURE 2.16 - Example computer print-out listing sample localities for the biotite schist unit in the Inner Piedmont.

SECTION 3. RESULTS OF DATA ANALYSES

3.1 ANALYSIS OF DATA FROM THE SOUTHEASTERN AREA

Introduction

The Southeastern area (fig. 3.1.1, reproduced as a transparent overlay in plate 17) includes parts of the states of Virginia, North Carolina, South Carolina, Georgia, and a small area of eastern Tennessee. The quadrangles include a cross-section of the southern Appalachian Mountains, extending from the Valley and Ridge province in the northwest through the Blue Ridge, Inner Piedmont, Charlotte belt, and smaller units, through to the Carolina slate belt in the southeast. The rocks in the southern Appalachians range in age from Precambrian to Pennsylvanian. Southeastward from the southern Appalachians is the Coastal Plain, consisting of Cretaceous and younger sedimentary rocks that dip gently southeastward toward the Atlantic Ocean. Within the southern Appalachian Mountains, Triassic sedimentary rocks have been deposited in northeastward trending basins; parts of three of these basins occur in the Southeastern area.

Table 3.1.1 lists the distribution of sample points by geologic units and physiographic provinces. Of the 5,264 sample sites, the largest numbers are in the Blue Ridge belt, the Inner Piedmont, and the Charlotte belt. (This number of sample sites is somewhat larger than the 5,197 sites for which uranium was determined.) SRL collected stream-sediment samples at a nominal density of one per 13 square kilometers in rural areas. Table C-1 details the geologic distribution of stream-sediment-sample sites according to the rock codes assigned by one of us (SFC) to the geologic units. In Appendix C, we (SFC) explain the coding scheme.

Table 3.1.2 gives basic statistics for the 16 elements analyzed in the stream-sediment samples from the Southeastern quadrangles. It also lists analyses for pH, conductivity, and alkalinity. For the elemental analyses, we set values below the detection limit equal to one-half the detection limit. Data for lanthanum, lutetium, samarium, and ytterbium were not available for the Winston-Salem quadrangle. The means are within expected limits for stream-sediment data, and the coefficients of variation are those expected from well-conducted geochemical surveys, indicating that no excessive variability was introduced through the processes of sampling, sample preparation, and chemical analysis.

FIGURE 3.1.1 - Southeastern area, basic geology. Winston-Salem quadrangle (northernmost), Charlotte quadrangle (central), Spartanburg quadrangle (southeast), and Greenville quadrangle (southwest).

TABLE 3.1.1. - Classification of Southeastern data points by geologic type.

Geologic Type	Number of samples
<u>Valley and Ridge Province</u>	259
Chilhowee Group	40
Shady Dolomite, Rome Fm., Conasauga Gp.	118
Knox Group	42
Chickamauga Group	14
Silurian to Mississippian Rocks	45
<u>Blue Ridge Belt</u>	1206
Basement (gneisses > 1 B.Y. old)	234
Gneiss, schist, and amphibolite	293
Amphibolite	60
Schist	44
Gneiss	436
Metasediments	50
Spruce Pine Group	11
Metagranites	23
Crossnore Group	17
Elk Park Group	29
Miscellaneous	9
<u>Smith River Allochthon</u>	95
<u>Brevard Zone - Kiokee Belt</u>	86
<u>Inner Piedmont</u>	1565
Biotite schist	738
Biotite gneiss	330
Hornblende gneiss, amphibolite	64
Henderson gneiss	37
Schist and gneiss	30
Granites, undated	97
Cherryville quartz monzonite, 345 M.Y.	19
Toluca quartz monzonite, 535 M.Y.	7
Metagranites	198

TABLE 3.1.1. (Continued)

Geologic Type	Number of samples
<u>Kings Mountain Belt</u>	157
Metamorphic rocks, undifferentiated	132
Granite	10
High Shoals granitic gneiss	15
<u>Charlotte Belt</u>	1088
Undifferentiated	673
Granites, age unknown	67
Granites, 300 M.Y.	43
Granites, 400 M.Y.	10
Metagranites	14
Gabbro, 413 M.Y.	42
Metagabbro, amphibolite	60
Metavolcanics	17
<u>Carolina Slate Belt</u>	514
Uwharrie, Wildhorse Br., Persimmon Fk. Fms.	100
Tillery, Richtex formations	103
McManus formation	180
Yadkin greywacke	18
Granite, age unknown	3
Granites, 300 M.Y.	34
Undifferentiated	76
<u>Coastal Plain</u>	240
Black Creek Formation (Cretaceous)	7
Middendorf Formation (Cretaceous)	166
Black Mingo Formation (Eocene)	38
Duplin Marl (Miocene)	17
Alluvium	12
<u>Triassic Basins</u>	54
TOTAL	5264

TABLE 3.1.2. Basic statistics for the Southeastern quadrangles. Number of observations, n; mean, $\bar{w}$; standard deviation, s; coefficient of variation, C. Means of chemical elements in ppm. Values below detection limit set to one-half detection limit. Values are in ppm.

Element	n	$\bar{w}$	s	C
Al	5127	50900	24500	.48
Ce	4883	237	489	2.07
Dy	5154	13.5	31.0	2.30
Eu	4931	1.31	2.13	1.62
Fe	4849	26600	21600	.81
Hf	5142	80.9	129.7	1.60
La	3433	175	332	1.90
Lu	3558	4.16	5.86	1.41
Mn	5022	1216	1390	1.14
Sc	5196	9.82	7.02	.71
Sm	3456	30.0	93.5	3.11
Th	4921	45.3	94.3	2.08
Ti	4997	16000	20500	1.28
U	5197	11.5	17.8	1.55
V	4909	118	128	1.09
Yb	3433	14.4	20.1	1.39
<hr/>				
pH	5072	7.26	.64	.09
Conductivity ¹	5071	68.2	80.9	1.19
Alkalinity ²	5176	.36	.41	1.13

¹ Conductivity, measured in $\mu\text{mhos/cm}$.

² Alkalinity as milliequivalents of sulfuric acid required per liter of sample to filtrate to a pH of approximately 4.5.

Basic Statistical Analyses

Having coded the data according to rock type, we can compare concentrations of the elements and other variables from one geologic unit or province to another through the one-way analysis of variance. We present and explain only some of the analyses that we have made. Our purpose is to indicate methodology helpful for data analysis.

Table 3.1.3 lists the means of the stream-sediment analyses from the nine principal geologic provinces. The F-values test the hypothesis that the means are equal. For all elements, there are evidently differences in the means, because the F-values are larger than the tabled value of 1.67 at the 10-percent significance level.

We continue with comparisons to test specific hypotheses. The first of these (table 3.1.4) compares the granites in the Inner Piedmont province with those in the Charlotte belt. If the calculated F-values exceed the tabulated F-value of 3.71, there is evidence that the population means corresponding to these sample means are different. Applying this test, we find that all elements except scandium and titanium are evidently different. However, the difference for aluminum is small, and this fact, coupled with the agreement of the data for scandium and titanium, suggests that the stream sediments were derived from granites that differ strongly in the amount of uranium and some of the rare-earth elements. For instance, the Inner Piedmont granites contain almost twice the amount of uranium as the Charlotte belt granites.

Table 3.1.5 compares granites with metagranites in the Inner Piedmont province. If the F-values are greater than 2.72, we accept the hypothesis that the population means are different for a particular element or other variable. The table shows that the content of uranium, thorium, and several other elements is evidently the same for these two groups of stream-sediment samples derived from these two groups of rocks. However, there are distinct differences in some of the other chemical elements, pH, and alkalinity.

Table 3.1.6 compares, for the Charlotte belt alone, 300 M.Y. old granites with 400 M.Y. old granites. If the F-values exceed 2.81, the granites are evidently different. In comparing the 300 M.Y. old granites of the Charlotte and slate belts, we find (table 3.1.7) distinct differences in the content of uranium, thorium, and several other elements. Values that exceed the tabled F-value of 2.78 suggest differences in population means.

TABLE 3.1.3.- Southeastern area. Means of stream-sediment analyses from the principal geologic provinces in the Southeastern area. The F-values test the hypothesis that the means are equal. Number of observations, n. $F_{10\%} = 1.67$.

	Valley and Ridge	Blue Ridge	Smith River Alloch- thon	Inner Pied- mont	Kings Mtn. Belt	Char- lotte Belt	Carolina Slate Belt	Triassic Basins	Coastal Plain	F
n	259	1206	98	1563	156	1061	466	52	229	
Al	34100	53200	42900	58000	48900	53000	47400	44300	19300	98.51
Ce	59.5	184	98.9	441	61.2	75.3	160	68.1	457	68.90
Dy	3.54	11.8	4.72	25.0	3.04	3.84	7.61	4.73	25.7	58.07
Eu	.756	1.52	1.00	1.64	.551	.974	1.02	.950	1.48	15.48
Fe	16900	29800	32100	22200	26100	37100	25200	22100	6240	78.14
Hf	41.8	71.4	73.4	102	42.9	84.0	45.8	39.5	124	19.99
La	0	272	0	259	39.8	42.0	99.0	49.5	290	45.28
Lu	.400	4.95	0	5.63	1.38	2.44	2.71	1.95	5.99	34.68
Mn	656	1150	1540	1070	953	1860	1360	732	189	58.16
Sc	3.54	7.67	6.09	9.43	10.4	14.1	12.5	8.21	6.28	133.33
Sm	5.36	54.6	0	48.4	0	5.42	10.5	5.62	31.1	21.29
Th	9.25	29.2	14.4	86.7	14.6	15.4	33.5	13.3	95.7	78.35

TABLE 3.1.3.-(Continued)

	Valley and Ridge	Blue Ridge	Smith River Alloch- thon	Inner Pied- mont	Kings Mtn. Belt	Char- lotte Belt	Carolina Slate Belt	Triassic Basins	Coastal Plain	F
Ti	5430	18500	32600	17100	9560	17900	11400	9940	10600	27.18
U	3.78	7.60	6.02	20.6	4.50	5.53	7.34	4.63	24.9	123.23
V	75.3	132	103	102	106	164	104	82.8	49.7	36.06
Yb	0	17.4	0	20.5	4.18	7.26	8.67	5.69	19.5	45.08
pH	8.20	7.33	7.30	7.09	7.54	7.57	7.03	7.27	5.80	477.85
Cond.	161	33.2	36.8	48.5	98.0	113	89.4	70.8	35.3	168.62
Alk.	1.20	.189	.206	.218	.436	.631	.377	.357	.0889	434.22

TABLE 3.1.4.- Southeastern area. Means of stream-sediment analyses from granites in the Inner Piedmont and the Charlotte Belt. The F-values test the hypothesis that the means are equal. Number of observations, n.
 $F_{10\%} = 3.71.$

	Inner Piedmont	Charlotte Belt	F
n	320	289	
Al	53900	58400	4.34
Ce	274	79.4	45.40
Dy	18.2	2.77	53.56
Eu	1.31	.875	10.62
Fe	19200	26400	18.28
Hf	130	82.6	6.85
La	168	46.5	40.96
Lu	5.25	2.30	30.58
Mn	1000	1400	10.41
Sc	9.74	10.3	.74
Sm	24.2	5.03	32.36
Th	57.1	20.3	38.04
Ti	12900	13200	.02
U	15.5	7.98	49.96
V	81.3	120	16.00
Yb	16.8	6.43	53.53
pH	7.12	7.53	216.08
Cond.	61.0	92.0	7.56
Alk.	.230	.490	271.52

TABLE 3.1.5.- Southeastern area, Means of stream-sediment analyses from granites with metagranites in the Inner Piedmont. The F-values test the hypothesis that the means are equal. Number of observations, n.

$$F_{10\%} = 2.72.$$

	Granites	Metagranites	F
n	122	189	

Al	55400	62200	6.96
Ce	256	285	.29
Dy	11.2	23.1	7.80
Eu	1.01	1.50	3.96
Fe	17300	20600	4.94
Hf	65.8	173	9.68
La	160	172	.10
Lu	3.39	6.13	9.45
Mn	762	1180	14.88
Sc	7.36	11.4	23.87
Sm	24.8	24.3	.00
Th	58.8	55.7	.08
Ti	10600	14800	4.99
U	14.3	16.3	1.09
V	68.4	91.9	6.72
Yb	12.3	18.9	5.59

pH	7.32	6.98	92.15
Cond.	64.9	58.7	.09
Alk.	.257	.209	13.28

TABLE 3.1.6.- Southeastern area. Means of stream-sediment analyses from 300 M.Y. with 400 M.Y. granites in the Charlotte Belt. The F-values test the hypothesis that the means are equal. Number of observations, n.
 $F_{10\%} = 2.81.$

	300 M.Y.	400 M.Y.	F
n	42	9	
Al	63600	40900	7.28
Ce	67.6	30.8	3.77
Dy	2.70	3.34	.30
Eu	.741	.410	3.42
Fe	22100	24700	.06
Hf	84.6	37.4	1.53
La	47.8	28.6	2.31
Lu	1.92	2.40	.23
Mn	1480	1800	.16
Sc	7.29	10.3	2.45
Sm	6.27	1.40	3.41
Th	19.6	7.40	3.04
Ti	10500	97100	.03
U	9.63	5.19	2.87
V	92.4	107	.21
Yb	8.00	9.36	.20
pH	7.48	7.61	.74
Cond.	68.0	89.6	7.42
Alk.	.385	.578	14.75

TABLE 3.1.7.- Southeastern area. Means of stream-sediment analyses from 300 M.Y. granites between the Charlotte and Slate Belts. The F-values test the hypothesis that the means are equal. Number of observations, n.
 $F_{10\%} = 2.78.$

	Charlotte Belt	Slate Belt	F
n	42	32	
Al	63600	69700	.76
Ce	67.6	382	7.34
Dy	2.70	19.0	13.21
Eu	.741	1.42	7.41
Fe	22100	34500	1.75
Hf	84.6	226	14.72
La	47.8	238	4.88
Lu	1.92	7.40	17.77
Mn	1480	2850	4.76
Sc	7.29	8.68	1.61
Sm	6.27	24.8	4.29
Th	19.6	83.0	5.95
Ti	10500	19900	7.52
U	9.63	20.7	6.72
V	92.4	114	.43
Yb	8.00	21.9	9.44
pH	7.48	6.82	30.29
Cond.	68.0	64.0	.39
Alk.	.385	.329	1.91

TABLE 3.1.8.- Southeastern area. Means of stream-sediment analyses from gneisses in the Blue Ridge basement, Blue Ridge, Inner Piedmont, and Charlotte Belt. The F-values test the hypothesis that the means are equal. Number of observations, n. $F_{10\%} = 2.09$.

	Blue Ridge basement	Blue Ridge	Inner Piedmont	Charlotte Belt	F
n	202	432	330	214	
Al	53500	48400	61300	55400	26.37
Ge	107	49.4	302	49.1	80.06
Dy	3.87	3.22	18.2	2.69	69.37
Eu	.934	.817	1.51	.908	21.93
Fe	23900	32000	25500	43600	52.22
Hf	76.6	54.9	97.5	59.5	19.22
La	56.6	108	159	23.5	21.21
Lu	3.09	3.21	5.62	1.53	23.47
Mn	798	1400	1250	1840	29.57
Sc	6.23	6.96	12.0	18.1	196.42
Sm	8.86	14.8	36.8	3.78	14.46
Th	18.6	8.68	57.7	10.3	76.13
Ti	8950	2290	1620	1530	27.88
U	6.34	3.97	16.3	3.93	100.85
V	104	125	125	216	33.13
Yb	15.9	11.5	20.0	5.64	20.47
pH	7.60	7.45	7.11	7.67	86.10
Cond.	41.6	34.3	44.6	126	227.45
Alk.	.263	.193	.238	.705	601.88

Table 3.1.8 compares gneisses in four major units, the Blue Ridge basement, the remainder of the Blue Ridge province, the Inner Piedmont province, and the Charlotte belt. For all variables, there are distinct differences in elemental composition from one unit to another. For example, the content of uranium is more than twice as great in the Inner Piedmont province as in any of the other three units. Finally, table 3.1.9 compares data from the three Triassic basins. For this test, the tabled F-value is 2.45, and only values are listed for which the population means are evidently different. The table shows that uranium, thorium, and the rare-earth elements except dysprosium are not evidently different in these three formations. However, since there are only a few observations for Basins A and B, the evidence is not compelling.

TABLE 3.1.9. - Southeastern area. Means of stream-sediment analyses from the three Triassic basins. The F-values test the hypothesis that the means are equal. Number of observations, n. $F_{10\%} = 2.45$.

	Basin A	Basin B	Basin C	F
n	3	5	33	
Al	24900	33700	54100	14.42
Dy	2.73	2.16	5.98	4.62
Fe	18600	10800	25100	6.60
Mn	341	535	922	9.71
Sc	3.32	5.12	10.7	28.21
V	40.0	52.0	103	11.00
pH	7.83	7.72	7.15	8.38
Alk.	.483	.404	.296	5.01

Map Analyses

In Section 2.1, we (RJH) explain techniques of map analyses using data from the Southeastern area. Therefore, this sub-section is brief and simply emphasizes some specific points noted in the maps.

In plate 3, a feature of particular note is the pattern of low amplitude anomalies associated with the position of the Western monazite belt located in the Blue Ridge province (fig. 3.1.1) west of the Brevard fault zone in the southwestern part of the area. No striking anomalies occur in the northeastern region of the Blue Ridge in the Winston-Salem quadrangle. In the Inner Piedmont, almost all the anomalies are associated with schists, rather than gneisses, generally within the Western Piedmont monazite belt. Some anomalies are associated with certain metagranites (8(05-G-T08) and 9(05-GT09)). In the Charlotte belt, anomalies are associated with granites near Winston-Salem, near the south end of Lowry's pluton, and over the Winnsboro complex. However, the Eastern Piedmont monazite belt is not particularly evident. A low amplitude anomaly in the Carolina slate belt occurs over the Liberty Hill pluton. The Coastal Plain is broadly anomalous, particularly southeast of the Liberty Hill and Pageland plutons.

Plates 4 to 6 show the effect of changing the picture-frame size parameters for the uranium data, in terms of the number of cells flagged that exceed three standard deviations above the annulus. Individual results for a central cell versus an annulus of radius one, PF(0:1); and two, PF(0:2); and a central three-by-three block of cells versus an annulus of radius three, PF(1:3), are shown in these plates. Intuitively we might expect a large number of single point anomalies to occur with the PF(0:1) or PF(0:2) contrasts. However, using the central block in the PF(0:3) contrast limits the number of anomalies to a smaller number of spatially discrete groups. The PF(1:3) anomaly (plate 6) shows a number of features not brought out by the high-pass filter maps (plate 3); this is particularly evident in the Blue Ridge area of the Winston-Salem quadrangle, in the vicinity of the Crossnore granitic rocks. Scattered anomalies also occur along the Western monazite belt in the southwest near Metagranite 15 (02-G-T15) and the Whiteside rocks (03-G-SWS). Anomalies in the Inner Piedmont are associated with the schists in the Mountain Piedmont monazite belt and some of the granites, for example the one to the southwest of Winston-Salem. In the Charlotte belt, anomalies are associated with Bald Rock pluton, Lowry's pluton, and the granitic bodies south of Mecklenburg pluton and immediately north of the Churchland granite.

We may also compare the results from the picture-frame filter (plate 6) with those from the Kolmogorov-Smirnov filter (plate 7). The numbers of anomalous cells detected are 160 with the picture-frame filter (1:3) alone, 84 with the Kolmogorov-Smirnov filter (1:3) alone, and 123 with both filters. Although individual cells do not coincide perfectly, the broad areas picked out by the two filters are similar. Most anomalies that are picked out by the picture-frame filter, but not the Kolmogorov-Smirnov filter, are either in the more southernly parts of the Inner Piedmont schists or in the Coastal Plain. Joint anomalies of interest in the Blue Ridge include those in the Winston-Salem quadrangle related to the southern part of the Mountain monazite belt and associated with the Crossnore granitic rocks, as well as an unexplained anomaly in the gneiss and amphibolites near the northern edge of this quadrangle. Most joint anomalies in the Inner Piedmont are in schists within the Western Piedmont monazite belt. In the Charlotte belt, anomalies are mainly in three groups of granitic rocks: near Churchland and Landis; the Lowry's, Bald Rock, and Newbury plutons; and the Winnsboro complex. The Pageland pluton is picked out in the Carolina slate belt.

Areas of joint picture-frame and Kolmogorov-Smirnov anomalies in the Inner Piedmont are also delineated by high-pass filter highs, but some of the larger areas of anomalous cells in the Blue Ridge and Charlotte belt are not. The general agreement of the three different techniques is encouraging and enhances features which are not immediately apparent from the raw data or the low-pass filter maps.

Mineralogical Analyses

In this sub-section, we (RHC, GSK) apply to the Southeastern area the model for mineralogical analysis explained in Section 2.3. We give the results for the Inner Piedmont in detail and then outline the results for the other geologic provinces.

Table 3.1.10 summarizes analytical data for the entire Inner Piedmont and for specific rock units within the province. As before, we want to learn whether we can identify anomalies better by using data from individual rather than from all rock units. Table 3.1.10 shows that uranium and thorium are unevenly distributed in stream sediment from various units. The biotite schist, Toluca quartz monzonite, and Pacolet Mills granite are thorium-rich (ThO) relative to other units whereas the Elberton granite, Cherryville quartz monzonite, and Henderson gneiss are thorium-poor. For original uranium (UO), the biotite schists and the Toluca quartz monzonite are uranium-rich. For residual uranium (UR),

TABLE 3.1.10 - Summary of mean uranium and thorium concentrations in minus 100-mesh alluvium in the Inner Piedmont Province.

Unit	$\bar{w}UR$ ppm	$\bar{w}UO$ ppm	$\bar{w}ThR$ ppm	$\bar{w}ThO$ ppm	$\bar{w}(\bar{w}UR-\bar{w}ThR)$ ppm	No. of UO values	No. of anom. samples	UR- thresh- old
Entire Inner Piedmont	4.8	20.6	5.6	86.7	-0.7	1552	25	35
Biotite Schist	5.5	25.5	7.3	114.0	-1.8	811	13	47
Biotite Gneiss	5.1	16.3	1.3	57.7	3.8	326	9	25
Metagranites	4.0	16.5	2.9	60.0	1.2	204	3	28
Granites (Undivided)	2.8	14.6	9.2	62.1	-6.4	75	1	22
Amphibolites	.1	11.2	8.3	56.9	-8.2	64	1	12
Elberton granite	4.5	12.7	11.3	27.5	-6.8	13	0	-
Pacolet Mills gran.	-6.4	12.6	35.7	93.8	-42.1	4	0	-
Toluca Quartz Monzonite	-4.0	26.9	44.0	167.5	-48.1	7	0	-
Cherryville Quartz Monzonite	5.4	9.9	4.6	18.3	0.8	19	1	10
Henderson Gneiss	4.2	11.0	2.9	33.2	1.3	36	0	-

Explanation: $\bar{w}UR$ = mean residual uranium concentration (ppm)
 $\bar{w}UO$ = mean observed uranium concentration (ppm)
 $\bar{w}ThR$ = mean residual thorium concentration (ppm)
 $\bar{w}ThO$ = mean observed thorium concentration (ppm)

the Toluca quartz monzonite, Pacolet Mills granite, and amphibolites are uranium-poor.

Figure 3.1.2 is a log-probability plot for original and residual uranium for all samples from the Inner Piedmont. For both original and residual uranium, breaks in the curves occur at the ten percent cumulative percentile at 45 and 20 ppm, respectively. Clearly, this break reflects anomalous values of uranium in the Western monazite belt. For residual uranium, point t_2 represents an arbitrary threshold at 97.5 cumulative percent and 35 ppm. Within the entire Inner Piedmont province, 25 samples exceed this value. Because there is no break in slope, the validity of t_2 is questionable. In this curve, breaks in slope are not distinctive because too many rock groups are lumped together. Therefore, we analyzed the different units separately.

FIGURE 3.1.2 - Lognormal plot of observed and residual uranium for the Inner Piedmont, all units.

Figure 3.1.3 is a log-probability plot for data from biotite schist rocks in the Inner Piedmont. A clear-cut break-in-slope is indicated for residual uranium, and we select t_1 midway between the two straight line segments at 47 ppm and 2 cumulative percent. This break is consistent with a "mineralized" distribution. We will see later that most of the 13 samples exceeding 47 ppm are clustered geo-

FIGURE 3.1.3 - Lognormal plot of observed and residual uranium for the Inner Piedmont, biotite schist only.

graphically, a fact supporting the conclusion that a separate population of residual uranium values exists in biotite schists in the Inner Piedmont province. For observed uranium, the break at 40 ppm and 20 cumulative percent probably represents the Western monazite belt. An anomalous distribution at a lower cumulative percent corresponding with the curve for residual uranium is not indicated.

For the biotite gneiss, log-probability plots (fig. 3.1.4) indicate threshold values at 25 ppm for residual uranium and 50 ppm for original uranium. The break-in-slope for residual uranium is better defined. Because of this better definition and the fact that only nine samples are anomalous, we believe that valid anomalies may be indicated. For original uranium, the break at 50 ppm probably reflects the Western monazite belt.

For the metagranites, figure 3.1.5 indicates a single break-in-slope for residual uranium at 28 ppm and 2.5 cumulative percent. Three samples exceed this value. For original uranium, breaks occur at 25 ppm (t_1) and 63 ppm (t_2). We have not evaluated the possible significance of these breaks, but it seems unlikely that 28 percent of the samples which exceed t_1 could be related to uranium mineralization.

FIGURE 3.1.4 - Lognormal plot of observed and residual uranium for the Inner Piedmont, biotite gneiss only.

FIGURE 3.1.5 - Lognormal plot of observed and residual uranium for the Inner Piedmont, metagranite only.

Log-probability plots for undivided granites (fig. 3.1.6) show no break-in-slope in residual uranium and a negative break-in-slope in original uranium ($t = 52$ ppm). We see no evidence for separate anomalous distributions of original or residual uranium. We select an arbitrary threshold in residual uranium at 2.5 cumulative percent and 22 ppm, yielding one anomalous sample.

FIGURE 3.1.6 - Lognormal plot of observed and residual uranium for the Inner Piedmont, granite (undivided) only.

For the remaining rock types, there are too few samples to evaluate statistically the frequency distribution using our procedure. We arbitrarily chose two additional samples from the residual uranium values as anomalous; one of these is from amphibolites, and the other is from the Cherryville quartz monzonite.

Table 3.1.11 summarizes the 27 samples in the Inner Piedmont that we have selected as anomalous based on analysis of residual uranium values. We use two more parameters to assign priority values. The ratio of residual uranium to mean residual uranium ($UR/\bar{X}_{UR}$) expresses the value of residual uranium for an anomalous sample relative to the average residual uranium value for all samples in the same rock type. The ratio of original uranium to original thorium (UO/ThO) is the observed uranium/thorium ratio for an anomalous sample. The product of these two ratios is the priority value. Based on this value, the most attractive single sample site in the entire Inner Piedmont province is number SCGV079S1, (priority

TABLE 3.1.11- Listing of anomalous samples according to rock-type in the Inner Piedmont.

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
Biotite Schist ($\bar{w}UR = 5.5$ ppm; $t = 47$ ppm, selected from break in slope; 13 anomalous localities)										
NCBK060S1	35.7612	81.5492	7	51	124	44	387	9.1	.32	3
NCCL048S1	35.8482	81.4482	80	69	88	-11	126	12.6	.70	9
NCCL049S1	35.7905	81.5056	75	49	83	-26	253	8.9	.33	3
NCRU038S1	35.3677	81.7107	45	57	230	12	1316	10.4	.17	2
GAFR033S1	34.3450	83.1492	48	49	103	1	283	8.8	.36	3
GAMD029S1	34.0812	83.2871	46	53	131	7	449	9.7	.29	3
SCAN002S1	34.2575	82.7129	32	53	103	20	372	9.6	.28	3
SCAN016S1	34.3507	82.7868	363	60	135	-304	833	10.8	.16	2
SCGV079S1	34.9032	82.2511	76	66	68	-11	24	11.9	2.82	33
SCGV085S1	34.8293	82.2620	51	54	88	3	227	9.8	.38	4
SCGV104S1	34.6927	82.3097	-27	50	141	77	476	9.1	.30	3
SCSP053S1	34.9244	82.1819	43	55	87	11	208	10.0	.42	4
SCSP076S1	34.8748	82.1663	56	71	98	15	172	12.9	.57	7

TABLE 3.1.11 (Continued)

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
Granite Gneiss ($\bar{w}UR = 5.05$ ppm; $t = 25$ ppm, selected from break in slope; 9 anomalous localities)										
NCBK067S1	35.7280	81.4798	9	29	59	20	188	5.7	.31	2
NCCL033S1	35.8930	81.3743	84	45	59	-40	179	8.9	.33	3
NCCL037S1	35.7894	81.3562	141	94	135	-47	386	18.7	.35	7
NCCL039S1	35.8114	81.4273	45	46	78	1	245	9.0	.32	3
NCCL043S1	35.8364	81.5195	53	27	43	-26	146	5.3	.29	2
NCCL044S1	35.8202	81.5569	45	31	65	-13	238	6.1	.27	2
NCCT055S1	35.6087	81.1475	49	43	64	-6	128	10.5	.50	5
NCRV017S1	35.3702	81.9990	10	38	55	28	80	7.5	.69	5
SCGV072S1	34.9450	82.3522	76	31	83	-45	430	6.1	.19	1
Metagranites ($\bar{w}UR = 4.02$ ppm; $t = 28$ ppm, selected from break in slope; 3 anomalous localities)										
SCGV132S1	34.9181	82.3417	18	31	51	13	108	7.8	.47	4
SCLU005S1	34.6870	82.1526	-8	39	75	47	187	9.7	.40	4
SCLU006S1	34.6715	82.1472	25	31	51	7	116	12.8	.44	

TABLE 3.1.11. (Continued)

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
Granites, Undivided ($\bar{w}UR = 2.8$ ppm; $t = 23$ ppm, at upper 2.5%; 1 anomalous locality)										
NCRU029S1	35.2763	81.8575	-5	25	50	30	136	8.9	.37	4
Amphibolites ($\bar{w}UR = .12$ ppm; $t = 12$ ppm, selected arbitrarily; 1 anomalous locality)										
SCSP011S1	35.1623	81.9411	6	13	38	7	123	110	.30	33
Elberton Granite (no anomalies)										
Pacolet Mills Granite (no anomalies)										
Toluca Quartz Monzonite (no anomalies)										
Cherryville Quartz Monzonite ($\bar{w}UR = 5.4$ ppm; $t = 10$ ppm, selected arbitrarily; 1 anomalous locality)										
NCGA006S1	35.3437	81.3835	1	11	19	10	23	2.0	.82	1

value = 33) which is located near Greenville, South Carolina. For this sample, little of the observed 68 ppm uranium can be accounted for by accessory heavy minerals because residual uranium equals 66 ppm. The priority value provides a basis for rating anomalies for further study. Its overall applicability for uranium exploration is not established because none of the anomalies cited have been evaluated for uranium mineralization.

From these results, it is clear that anomaly resolution in the Inner Piedmont province is enhanced by subdividing the area into the constituent rock units and evaluating each one separately. Secondly, anomaly resolution is further enhanced by calculating residual uranium values and analyzing the frequency distribution of this parameter. Anomalous original uranium values mainly reflect the extensive monazite belt rather than specific anomalous areas.

Geographic Distribution of Anomalous Samples

Up to this point, we have presented evidence from an analysis of the frequency distribution that anomalous distributions for residual uranium occur within the Inner Piedmont province. The extent to which the anomalous values are clustered rather than being randomly distributed is an important consideration in evaluating their significance. Because mineral deposits in the earth's crust are typically clustered in districts each of which is only a few square kilometers in area, anomalous stream-sediment samples in a mineralized province should also be clustered, provided that the sample density is adequate to define clusters. Therefore, randomly distributed anomalous values are less likely to be related to mineralization than clusters of anomalous values. Figure 3.1.7 shows the distribution of anomalous samples in the Inner Piedmont. Although some anomalous samples are isolated, the figure shows at least three distinct clusters labeled A, B, and C. In each of these clusters, at least two adjacent sample sites are anomalous. Cluster A is in the northwestern part of the Charlotte quadrangle, 15 miles northeast of Morganton, North Carolina. The cluster is composed of nine anomalous samples located in both biotite schist and granite gneiss. Most of the anomalous samples are in the Oak Hill pegmatite district, and some are in the Conover district. Cluster B is about ten miles northeast of Greenville, South Carolina. Five anomalous samples are derived from biotite schist, granite gneiss, and metagranites. This area coincides closely with the outline of the northern Greenville pegmatite district. Finally, Cluster C is located

FIGURE 3.1.7 - Anomaly locations for the Inner Piedmont province.

22 miles southeast of Greenville, South Carolina. Two adjacent samples in biotite schist are anomalous. The anomalous samples are not related to known mineral occurrences.

Other Geologic Provinces in the Southeastern Area

For the other geologic provinces in the Southeastern area, we (RHC) performed an analysis identical to that for the Inner Piedmont province. There are residual anomalous localities in addition to the 27 anomalous sites of the Inner Piedmont (table 3.1.12 and fig. 3.1.8). The other provinces contain three additional clusters: Cluster D, along the Brevard zone-Blue Ridge boundary in the Greenville quadrangle; Cluster E, in the Blue Ridge province in the Greenville quadrangle; and Cluster F in the Charlotte Belt in the Spartanburg quadrangle (fig. 3.1.8). These three areas and the three in the Inner Piedmont deserve high priority in future evaluation of uranium potential. In addition, several isolated sites anomalous for original and residual uranium also warrant additional investigation.

TABLE 3.1.12. - Distribution of residual uranium anomalies in the Southeastern areas.

Province	Number of anomalies
Valley and Ridge	0
Blue Ridge	11
Brevard Zone	3
Sauratown Mtns., Smith River Allochthon	0
Inner Piedmont	27
Triassic Basins	1
Kings Mtn. Belt	0
Charlotte Belt	10
Slate Belt	4
Coastal Plain	6
<hr/>	
Total	63

FIGURE 3.1.8. - Map showing locations of 63 sites anomalous for residual uranium (UR). Clusters of anomalous sites are identified as A, B, C, D, E, and F.

Appendix D contains tables giving detailed information for the individual provinces in the same format as tables 3.1.10 and 3.1.11.

Multivariate Statistical Analyses

In this sub-section, we (JHS) explain a multiple regression approach to the Southeastern area and also perform a principal component analysis.

A Multiple Regression Approach

In our mineralogical model, we used the chemical elements cerium, dysprosium, hafnium, and thorium in order to calculate residual uranium. In this section, we use the same chemical elements as carriers in multiple regression to predict uranium in the Inner Piedmont province. Table 3.1.13 presents the regression equations for the three major rock units. We obtained the form of the model displayed in the table by combining coefficients of similar chemical

TABLE 3.1.13.- Inner Piedmont Province, Regression model, Numbers in parenthesis are 90 percent confidence intervals. Model: $U = \beta_0 + \beta_1 Ce + \beta_2 Dy + \beta_3 Hf + \beta_4 Th + E$.

Parameter		Estimated Coefficients		
	Mineralogical model	Schist	Gneiss	Metagranite
$\hat{\beta}_0$	0	6.3501 (5.438, 7.262)	3.4342 (2.07, 4.80)	4.7080 (3.628, 5.789)
$\hat{\beta}_1$	0.0328	-0.008374 (-0.0117, -0.00501)	0.031636 (.0229, .0403)	-.026348 (-.0362, -.0165)
$\hat{\beta}_2$	-0.1095	0.16449 (0.145, 0.184)	0.13926 (.0841, .1944)	0.12896 (0.0942, 0.1637)
$\hat{\beta}_3$	-0.01167	0.00077716 (-0.00427, 0.00582)	0.0054180 (-.0033, .0142)	0.015398 (0.0128, 0.0179)
$\hat{\beta}_4$	-0.3	0.16239 (0.145, 0.1797)	-0.0090112 (-.0506, .0326)	0.24197 (0.1962, 0.287)
$R^2(\%)$		82.4	78.6	84.2

elements. Agreement is poor between the coefficients of the mineralogical model and the output of the multiple regression. Figures 3.1.9 to 3.1.11 give normal probability plots for the residuals. These plots are not normal and the distributions of residuals are not skewed enough to be lognormal. It appears that a change in slope occurs at the 99th percentile for each of the three rock units in the residual plots. However, for this analysis we have used the upper 2.5 percentage point to define anomalous points. Table 3.1.14 lists these anomalous points. The same general clusters appear that are defined by the mineralogical model.

In this example, the mineralogical and the multiple regression models applied to the same chemical elements define similar sets of anomalous points. For example, in the Inner Piedmont schist all but two of the points defined by the mineralogical model are also defined by the multiple regression model; the multiple regression model defines eight points not defined by the mineralogical model. The general agreement of the two models occurs even though the multiple regression model extracts different proportions of uranium than the mineralogical model.

An advantage of the multiple regression approach is that its initial formulation requires only a knowledge of the chemical elements to be included. Estimates of the coefficients are then obtained from a standard regression algorithm. Although more effort may be required to find the coefficients in the mineralogical model, this model has the advantage of allowing the geochemist to use geological judgment.

A Principal Component Analysis of Major Rock Units in the Inner Piedmont

We performed a principal component analysis on three major rock units in the Inner Piedmont province. These rock types are the biotite schist (05BS----) and (05-B----), the biotite gneiss (05BG----), and the metagranites (05-G----). We did the component analysis using routine OFPRIN from the IMSL Library (1979), an extensive set of Fortran programs for mathematics and statistics. Tables 3.1.15 to 3.1.17 list correlation matrices and summary statistics including means, standard deviations, and coefficients of variation for the three rock units. Tables 3.1.18 to 3.1.20 give the largest five eigenvalues and their corresponding eigenvectors. Figure 3.1.12 is a plot of the sorted eigenvectors. The chemical elements are listed in tables 3.1.21 by highest correlation for the given eigenvalue.

FIGURE 3.1.9. - Normal probability plot, biotite schist.

FIGURE 3.1.10. - Normal probability plot, biotite gneiss.

FIGURE 3.1.11. - Normal probability plot, metagranites.

TABLE 3.1.14.- Anomalous points defined by multiple regression. The
 * samples are those defined as anomalous by the mineralogical model.

Sample number	Latitude	Longitude	U	$\hat{U}$	$U - \hat{U}$
Schist					
NCAE012S1	35.9109	81.0307	91.000	56.242	33.758
* NCBK060S1	35.7612	81.5492	123.700	77.658	46.042
NCCL041S1	35.8482	81.4482	88.300	29.914	58.386
* NCCL048S1	35.7905	81.5056	82.500	47.386	35.114
* NCRU038S1	35.3677	81.7107	229.800	185.746	44.054
* GAFR033S1	34.3450	83.1492	103.000	67.457	35.543
* GAMD029S1	34.0812	83.2871	131.300	91.976	39.324
SCAB001S1	34.4554	82.3156	102.200	66.722	35.478
* SCAN002S1	34.2575	82.7129	102.700	53.470	49.230
SCAN022S1	34.3802	82.5546	108.500	77.574	30.926
SCAN025S1	34.3962	82.4822	84.400	46.159	38.241
SCAN099S1	34.6951	82.5399	60.900	29.797	31.103
* SCGV079S1	34.9032	82.2511	67.800	10.751	57.049
* SCGV085S1	34.8293	82.2620	87.600	41.530	46.070
SCGV099S1	34.7231	82.3063	72.300	40.792	31.508
* SCGV104S1	34.6927	82.3097	140.600	90.028	50.572
* SCSP053S1	34.9244	82.1819	86.500	37.477	49.023
* SCSP076S1	34.8748	82.1663	98.100	32.551	65.549
SCSP110S1	34.6827	82.0155	78.800	44.376	34.424
Gneiss					
* NCBK067S1	35.7280	81.4798	59.300	36.766	22.534
* NCCL037S1	35.7894	81.3562	134.900	86.085	48.815
NCCL038S1	35.8067	81.3948	29.000	11.565	17.435
* NCCL039S1	35.8114	81.4273	78.200	49.903	28.297
NCCT051S1	35.5863	81.1900	51.700	34.124	17.576
* NCCT055S1	35.6087	81.1475	64.300	33.913	30.387
NCRU017S1	35.3702	81.9990	55.000	14.330	40.670
Metagranite					
SCAB029S1	34.3103	82.5682	130.800	102.926	27.874
SCAN040S1	34.4260	82.4949	37.000	17.758	19.242
SCAN047S1	34.5008	82.3575	47.500	28.028	19.472
SCGV132S1	34.9181	82.3417	51.200	22.132	29.068
* SCLU005S1	34.6870	82.1526	75.100	34.589	40.511
* SCLU006S1	34.6715	82.1472	51.400	22.451	28.949

TABLE 3.1.15.- Correlation matrix and summary statistics for the Inner Piedmont schist. Logarithms.

	pH	Cond	Alk	Al	Ce	Dy	Eu	Fe	Hf	La	Lu	Mn	Sc	Sm	Th	Ti	U	V
pH	1.000																	
Cond	0.276	1.000																
Alk	0.344	0.693	1.000															
Al	-0.142	-0.058	-0.146	1.000														
Ce	-0.107	-0.170	-0.194	0.029	1.000													
Dy	-0.178	-0.149	-0.169	0.105	0.690	1.000												
Eu	-0.027	0.007	0.023	0.036	0.482	0.445	1.000											
Fe	0.024	0.159	0.240	0.156	0.240	0.195	0.283	1.000										
Hf	0.024	0.167	0.252	-0.102	0.394	0.360	0.332	0.346	1.000									
La	-0.102	-0.192	-0.221	0.020	0.891	0.715	0.403	0.240	0.389	1.000								
Lu	-0.156	-0.111	-0.040	0.019	0.561	0.665	0.446	0.299	0.504	0.540	1.000							
Mn	-0.032	0.220	0.345	0.300	0.259	0.441	0.336	0.597	0.497	0.239	0.446	1.000						
Sc	0.064	0.244	0.370	0.095	0.032	0.085	0.204	0.704	0.460	0.024	0.276	0.583	1.000					
Sm	-0.055	-0.177	-0.162	0.014	0.854	0.673	0.497	0.212	0.378	0.823	0.558	0.285	0.046	1.000				
Th	-0.075	-0.182	-0.195	0.005	0.896	0.684	0.482	0.239	0.422	0.945	0.527	0.222	0.029	0.822	1.000			
Ti	-0.128	0.070	0.064	0.354	0.489	0.602	0.403	0.547	0.464	0.492	0.468	0.840	0.403	0.488	0.469	1.000		
U	-0.179	-0.187	-0.219	0.112	0.803	0.734	0.459	0.184	0.445	0.850	0.665	0.262	0.035	0.748	0.866	0.478	1.000	
V	-0.091	0.105	0.109	0.507	0.231	0.355	0.277	0.663	0.277	0.222	0.268	0.720	0.582	0.242	0.202	0.775	0.188	1.000
Yb	-0.169	-0.135	-0.081	0.055	0.592	0.716	0.425	0.303	0.438	0.614	0.751	0.399	0.217	0.598	0.600	0.478	0.711	0.288

Element	Mean	Standard Deviation	Coefficient of Variation
pH	1.950	0.055	0.028
Cond	3.732	0.397	0.106
Alk	-1.742	0.457	-0.263
Al%	1.673	0.449	0.268
Ce	3.756	1.233	0.214
Dy	2.819	1.338	0.475
Eu	0.024	1.201	49.832
Fe	0.600	0.681	1.136
Hf	4.038	0.957	0.237
La	5.267	1.164	0.221
Lu	1.225	1.213	0.990
Mn	6.591	0.931	0.141
Sc	2.001	0.544	0.272
Sm	3.264	1.350	0.414
Th	4.176	1.128	0.270
Ti	0.249	0.959	3.854
U	2.881	0.843	0.292
V	4.402	0.710	0.161
Yb	2.612	1.134	0.434

TABLE 3.1.16 · Correlation matrix and summary statistics for the Inner Piedmont gneiss.

	pH	Cond	Alk	Al	Ce	Dy	Eu	Fe	Hf	La	Lu	Mn	Sc	Sm	Th	Ti	U	V
pH	1.000																	
Cond	0.007	1.000																
Alk	0.207	0.539	1.000															
Al	-0.207	0.159	-0.051	1.000														
Ce	0.140	-0.212	-0.226	-0.133	1.000													
Dy	-0.080	-0.049	-0.151	0.108	0.472	1.000												
Eu	0.124	-0.136	-0.090	-0.091	0.500	0.352	1.000											
Fe	0.011	0.086	0.171	0.190	0.120	0.370	0.148	1.000										
Hf	0.200	-0.024	0.082	-0.162	0.310	0.170	0.186	0.207	1.000									
La	0.076	-0.198	-0.247	-0.102	0.965	0.459	0.472	0.097	0.296	1.000								
Lu	-0.035	-0.076	-0.070	-0.050	0.396	0.732	0.323	0.382	0.243	0.312	1.000							
Mn	-0.068	0.170	0.145	0.372	-0.053	0.344	0.018	0.640	0.075	-0.045	0.243	1.000						
Sc	0.027	0.167	0.247	0.236	-0.189	0.122	0.053	0.470	0.149	-0.161	0.137	0.398	1.000					
Sm	0.161	-0.117	-0.055	-0.140	0.834	0.203	0.290	0.101	0.310	0.765	0.313	-0.016	-0.178	1.000				
Th	0.133	-0.199	-0.216	-0.128	0.967	0.393	0.395	0.108	0.327	0.947	0.315	-0.045	-0.187	0.889	1.000			
Ti	0.005	0.073	0.071	0.113	0.232	0.480	0.098	0.806	0.307	0.234	0.417	0.653	0.290	0.254	0.249	1.000		
U	0.056	-0.226	-0.310	-0.066	0.850	0.555	0.399	0.095	0.346	0.825	0.372	-0.017	-0.130	0.679	0.826	0.237	1.000	
V	-0.053	0.150	0.184	0.334	-0.050	0.386	0.038	0.827	0.098	-0.053	0.312	0.692	0.526	-0.025	-0.062	0.811	-0.028	1.000
Yb	0.010	-0.120	-0.096	-0.089	0.578	0.671	0.381	0.266	0.201	0.487	0.882	0.132	-0.011	0.529	0.514	0.324	0.700	0.162

Element	Mean	Standard Deviation	Coefficient of Variation
pH	7.104	0.310	0.044
Cond	43.844	21.093	0.481
Alk	0.231	0.090	0.388
Al%	6.249	2.498	0.400
Ce	285.550	391.979	1.373
Dy	17.951	18.361	1.023
Eu	1.463	1.751	1.197
Fe	2.572	1.659	0.645
Hf	96.496	103.963	1.077
La	159.082	225.552	1.418
Lu	5.700	5.473	0.960
Mn	1290.248	1364.630	1.058
Sc	12.310	7.203	0.585
Sm	32.571	63.456	1.948
Th	54.376	81.320	1.496
Ti	1.608	2.011	1.251
U	14.625	13.756	0.941
V	126.915	123.870	0.976
Yb	19.851	19.982	1.007

TABLE 3.1.17- Correlation matrix and summary statistics for the lower Piedmont metagranite

	pH	Cond	Alk	Al	Ce	Dy	Eu	Fe	Hf	La	Lu	Mn	Sc	Sm	Th	Ti	U	V
pH	1.000																	
Cond	-0.085	1.000																
Alk	0.151	-0.039	1.000															
Al	-0.043	-0.014	0.088	1.000														
Ce	0.055	-0.014	-0.114	-0.057	1.000													
Dy	0.175	-0.029	-0.094	0.010	0.774	1.000												
Eu	0.124	-0.030	-0.053	-0.004	0.594	0.530	1.000											
Fe	0.122	-0.004	0.054	0.273	0.271	0.412	0.345	1.000										
Hf	0.050	-0.033	-0.057	-0.077	0.229	0.300	0.345	0.422	1.000									
La	0.051	-0.010	-0.103	-0.058	0.986	0.740	0.593	0.230	0.223	1.000								
Lu	0.115	-0.039	-0.087	-0.100	0.594	0.741	0.662	0.547	0.684	0.555	1.000							
Mn	0.111	-0.054	0.066	0.250	0.348	0.514	0.364	0.790	0.496	0.331	0.508	1.000						
Sc	0.173	-0.064	0.107	0.219	0.020	0.145	0.202	0.610	0.369	0.003	0.380	0.533	1.000					
Sm	0.142	-0.016	-0.075	-0.091	0.812	0.721	0.670	0.230	0.374	0.779	0.663	0.273	0.101	1.000				
Th	0.042	-0.015	-0.109	-0.066	0.976	0.709	0.532	0.203	0.106	0.902	0.524	0.302	-0.042	0.747	1.000			
Ti	0.026	-0.013	-0.078	0.113	0.569	0.711	0.416	0.732	0.392	0.525	0.636	0.039	0.283	0.468	0.507	1.000		
U	0.175	-0.028	0.118	0.379	0.104	0.323	0.236	0.021	0.222	0.076	0.347	0.732	0.619	0.135	0.048	0.618	1.000	
V	0.153	-0.039	-0.078	-0.089	0.751	0.857	0.635	0.514	0.545	0.714	0.926	0.565	0.283	0.712	0.693	0.690	0.324	1.000
Yb	0.062	-0.021	-0.139	-0.075	0.828	0.740	0.590	0.286	0.466	0.828	0.760	0.383	0.054	0.713	0.841	0.533	0.108	0.843

Element	Mean	Standard Deviation	Coefficient of Variation
pH	7.004	0.313	0.045
Cond	60.275	200.275	3.323
Alk	0.215	0.103	0.479
Al%	6.206	2.773	0.447
Ce	297.747	509.239	1.710
Dy	23.838	44.879	1.883
Eu	1.527	2.326	1.523
Fe	2.026	1.362	0.672
Hf	176.670	371.461	2.103
La	179.396	306.919	1.711
Lu	6.204	7.591	1.223
Mn	1201.494	1091.293	0.908
Sc	11.182	7.187	0.643
Sm	25.445	56.421	2.217
Th	58.813	90.566	1.676
Ti	1.466	1.801	1.229
U	16.829	18.952	1.126
V	90.769	86.978	0.958
Yb	19.271	23.334	1.211

TABLE 3.1.18. - Eigenvalues and eigenvectors for the Inner Piedmont biotite schist.

Items	Eigenvalues				
	7.923	3.227	1.792	1.003	0.935
Eigenvectors					
pH	0.074	-0.141	0.605	-0.112	0.401
Cond	-0.061	-0.424	0.676	-0.326	-0.201
Alk	-0.012	-0.571	0.640	-0.225	0.001
Al%	-0.008	-0.024	-0.428	-0.757	-0.310
Ce	-0.895	0.305	0.063	-0.055	0.149
Dy	-0.862	0.144	0.054	-0.080	-0.182
Eu	-0.716	0.038	0.051	0.009	0.185
Fe	-0.467	-0.698	-0.255	0.032	0.235
Hf	-0.463	-0.358	0.194	0.423	-0.408
La	-0.872	0.337	0.071	-0.051	0.151
Lu	-0.846	0.068	0.087	0.112	-0.306
Mn	-0.618	-0.590	-0.177	-0.022	-0.007
Sc	-0.320	-0.712	-0.028	0.186	-0.081
Sm	-0.732	0.267	0.040	-0.044	0.266
Th	-0.871	0.343	0.089	-0.052	0.139
Ti	-0.686	-0.440	-0.263	-0.049	0.109
U	-0.471	-0.673	-0.364	-0.085	0.183
V	-0.885	0.170	0.079	0.044	-0.231
Yb	-0.832	0.366	0.057	-0.074	-0.121

TABLE 3.1.19.- Eigenvalues and eigenvectors for the Inner Piedmont biotite gneiss.

Items	Eigenvalues				
	6.293	3.972	1.680	1.257	1.125
Items	Eigenvectors				
pH	-0.097	0.094	-0.632	0.098	0.320
Cond	0.202	-0.333	-0.439	0.080	-0.684
Alk	0.203	-0.342	-0.689	0.218	-0.342
Al%	0.075	-0.409	0.341	-0.436	-0.367
Ce	-0.900	0.320	-0.099	-0.192	-0.080
Dy	-0.702	-0.301	0.299	0.273	-0.127
Eu	-0.529	0.081	-0.043	0.164	0.103
Fe	-0.377	-0.793	-0.065	-0.117	0.182
Hf	-0.415	-0.069	-0.433	0.043	0.337
La	-0.858	0.314	-0.071	-0.274	-0.088
Lu	-0.685	-0.269	0.223	0.573	-0.053
Mn	-0.195	-0.787	0.068	-0.200	-0.016
Sc	0.007	-0.647	-0.138	0.032	0.149
Sm	-0.776	0.266	-0.257	-0.228	-0.138
Th	-0.867	0.328	-0.145	-0.293	-0.082
Ti	-0.505	-0.703	-0.055	-0.169	0.164
U	-0.882	0.243	0.084	0.004	-0.077
V	-0.234	-0.890	0.030	-0.138	0.104
Yb	-0.784	-0.059	0.165	0.468	-0.144

TABLE 3.1.20.- Eigenvalues and eigenvectors for the Inner Piedmont metagranites.

Items	Eigenvalues				
	8.403	3.143	1.303	1.206	0.967
Eigenvectors					
pH	-0.148	-0.131	0.231	0.708	-0.212
Cond	0.041	0.047	-0.132	-0.396	-0.900
Alk	0.084	-0.228	-0.055	0.624	-0.295
Al%	-0.014	-0.444	-0.618	0.026	0.118
Ce	-0.854	0.413	-0.235	0.067	0.003
Dy	-0.869	0.111	-0.107	0.060	-0.009
Eu	-0.713	0.114	0.176	0.084	-0.045
Fe	-0.609	-0.685	-0.079	-0.079	-0.026
Hf	-0.539	-0.232	0.580	-0.233	0.022
La	-0.827	0.437	-0.242	0.079	0.007
Lu	-0.872	-0.080	0.353	-0.099	-0.009
Mn	-0.681	-0.598	-0.083	-0.083	0.038
Sc	-0.331	-0.687	0.183	0.078	-0.015
Sm	-0.798	0.327	0.037	0.121	-0.057
Th	-0.799	0.465	-0.268	0.072	0.012
Ti	-0.794	-0.313	-0.192	-0.172	0.043
V	-0.443	-0.775	-0.207	0.049	-0.026
Yb	-0.930	0.048	0.165	-0.016	-0.015
U	-0.857	0.324	0.038	-0.042	0.020

TABLE 3.1.21.- Eigenvector interpretation in the Inner Piedmont.

Eigenvalues in descending order	Rock Unit	Chemical elements by largest correlation with eigenvalues
1	Schist	Ce,Dy,Eu,Hf,La,Lu,Mn,Sm,Th,Ti,U,Yb
	Gneiss	Ce,Dy,Eu,La,Lu,Sm,Th,U,Yb
	Metagranite	Ce,Dy,Eu,La,Lu,Mn,Sm,Th,Ti,U,Yb
2	Schist	Fe,Sc,V
	Gneiss	Fe,Mn,Sc,Ti,V
	Metagranite	Fe,Sc,V
3	Schist	PH,Cond,Alk
	Gneiss	PH,Alk,Hf
	Metagranite	Al%,Hf
4	Schist	Al%
	Gneiss	Al%
	Metagranite	pH,Alk
5	Schist	-
	Gneiss	Cond
	Metagranite	Cond

FIGURE 3.1.12. - Eigenvalue plot for the Inner Piedmont schist and gneiss.

While there is considerable similarity among the eigenvalues, there is some dissimilarity, particularly among the two largest principal components. Also, for the metagranite, the third and fourth eigenvalues differ from those for the other two rock groups. Scores for the first principal component were computed for each rock unit. We also computed the principal component analyses using the natural logarithmic transformation for each chemical element; however, the results are similar to the analysis of the untransformed data.

Table 3.1.22 lists the locations of the anomalous upper 2.5 percentage points for the first factor score for each of the three rock units.

In conclusion, in the Inner Piedmont area, the mineralogical model agrees closely with the multiple regression model but disagrees with the principal components model. Further comparisons are needed in other areas to gain added insight into the behavior of these models.

Summary and Conclusions

The means of stream-sediment analyses for all chemical elements and pH, conductivity, and alkalinity are different for the nine principal geologic provinces (table 3.1.3). This fact, demonstrated by a one-way analysis of variance, indicates that stratifying the sample sites by rock type is essential in order to define local backgrounds. Additional one-way analyses of variance, done to test other hypotheses about the stratified data, provide conclusions interpretable in terms of regional geology. For instance, the Inner Piedmont granites contain almost twice the amount of uranium as the Charlotte belt granites. These facts show that stratifying the data geologically (provided enough sample sites are available in each stratified group to obtain meaningful results considering statistical fluctuation) significantly strengthens their statistical analysis. Moreover, we can also conclude that the homogeneity of data within rock types validates the procedures of field sampling, sample preparation, chemical analysis, and file preparation.

Statistical/cartographic map analyses develop coherent patterns that are interpretable in terms of geology. For instance, plate 3 shows a pattern of low amplitude anomalies in the Blue Ridge province that are associated with the Western monazite belt. The various filtering results generally agree with one another and enhance features not

TABLE 3.1.22. - List of anomalous points in Inner Piedmont
defined by the first principal component. The starred
samples are those defined as anomalous by the mineralogical
model. Principal component analysis, PCA.

Sample Number	Latitude	Longitude	U	First PCA Score
----- Schist -----				
*NCBK060S1	35.7612	81.5492	123.700	118.337
NCBK078S1	35.6745	81.5413	138.300	131.132
*NCRU038S1	35.3677	81.7107	229.800	222.366
GAEL023S1	34.2502	82.8314	122.700	133.888
GAFRO10S1	34.3483	83.1949	82.200	105.348
GAHA044S1	34.5320	83.5163	100.100	107.525
GAHA048S1	34.5072	83.5612	127.600	130.296
*GAMD029S1	34.0812	83.2871	131.300	122.628
SCAN010S1	34.3043	82.6825	124.400	143.133
*SCAN016S1	34.3507	82.7868	135.400	172.062
SCAN043S1	34.4553	82.4496	335.600	329.492
SCAN046S1	34.4792	82.3140	109.900	113.893
SCAN079S1	34.5320	82.5397	91.800	106.939
SCGV098S1	34.7214	82.3504	128.700	133.940
*SCGV104S1	34.6927	82.3097	140.600	129.884
SCGV128S1	34.4994	82.3268	136.400	137.186
SCLU016S1	34.6451	82.1912	188.300	194.468
SCOC009S1	34.5763	82.9934	96.200	108.311
----- Gneiss -----				
NCAE032S1	35.9405	81.3111	60.500	65.499
NCAE033S1	35.9281	81.3084	52.200	61.140
*NCCL039S1	35.8114	81.4273	78.200	86.218
*NCCL044S1	35.8202	81.5569	65.400	77.716
NCCT027S1	35.7507	81.2171	80.900	109.177
*NCCT055S1	35.6087	81.1475	64.300	66.736
*SCGV072S1	34.9450	82.3522	82.500	98.775
----- Metagranite -----				
SCAB029S1	34.3103	82.5682	130.800	137.356
SCAN004S1	34.2744	82.6889	80.100	85.159
SCAN012S1	34.3351	82.6433	90.400	120.812
SCAN013S1	34.3482	82.6157	97.600	126.077

apparent from the raw data or low-pass filter maps. The regional approach for four quadrangles makes trends clearer than in the single quadrangles of Pueblo and Seguin. Therefore we believe that the filtering techniques are effective especially as applied to the regional data and that the regional analysis is beneficial.

Applying a mineralogical model to the Inner Piedmont data demonstrates that the model is meaningful, and anomaly resolution is enhanced by subdividing the province into smaller geologic divisions and evaluating each one separately. Anomaly resolution is further enhanced by calculating priority values. Therefore, we think that the mineralogical model is valid. In the Inner Piedmont, the model defines 27 samples anomalous for residual uranium (table 3.1.11). We obtained similar results by applying the model to other geologic provinces in the Southeastern area.

We applied two mathematical models to the Inner Piedmont data. A multiple regression model defines anomalous points similar to those found by the mineralogical model (table 3.1.14). A principal components model defines anomalous points different from those found by the mineralogical model (table 3.1.22). We do not have enough experience with either model applied to data from other regions in the study areas to know whether or not the agreement of the first mathematical model and disagreement of the second with the mineralogical model are fortuitous. Therefore, we conclude that these statistical models are suggestive of methodology but need further development.

3.2 ANALYSIS OF DATA FROM THE SEGUIN QUADRANGLE, TEXAS

Introduction

Arendt and others (1978, p. 13) write that:

The Seguin Quadrangle is a region of gently rolling hills and prairies. Cretaceous carbonates of the Edwards Plateau crop out in the extreme northwest corner of the survey area. The region is characterized by ridges and mesas of moderate relief. The Balcones Fault Zone separates this section of the Edwards Plateau from the Gulf Coastal Plain Province located to the east and southeast. Tertiary and Quaternary units of the Gulf Coastal Plain Province underlie most of the quadrangle and range in age from Eocene through Pleistocene. They represent a variety of marine shore and coastal plain paleoenvironments and consist of beds of marl, claystone, siltstone, and poorly consolidated sandstone.

Figure 3.2.1 (reproduced as a transparent overlay in plate 18) is a generalized geologic map of the quadrangle. Because the four Cretaceous formations are restricted to the northwest corner of the quadrangle and only 17 stream-sediment samples were taken from these units, we omitted these data. Appendix table C-2 lists the distribution of sample points by geologic units. The sampling density for the quadrangle as a whole is less than half that of the other two geographic areas. Including the Cretaceous area, 489 stream-sediment samples were taken in the quadrangle of approximately 21,469 square kilometer area, for a sampling density of one sample per 44 square kilometers. Geologists working for the Oak Ridge National Laboratory assigned the rock codes. After discarding the 17 Cretaceous samples, we had 472 samples.

Uranium occurs in the Whitsett and Catahoula Formations, and the Goliad Formation is a possible host rock. Figure 3.2.1 locates three operating mines (Butz, 1979). Tuffaceous ash beds, which occur intermittently throughout the late Eocene to Miocene interval, are possible source rocks for uranium south of the quadrangle (Arendt and others, 1978).

Table 3.2.1 gives basic statistics for the 17 analyzed elements in the stream-sediment samples. Uranium was determined as both total uranium (U_{NT}) by neutron activation and as acid extractable uranium (U_F) by fluorimetry. The total uranium includes that present in resistate minerals, which probably contain most of the uranium in the stream-sediment samples, therefore reflecting rock forming rather than mineralizing processes. On the other hand, the acid extractable uranium reflects uranium present as uranium oxides, as secondary uranium minerals, and that fixed with secondary iron oxides during weathering processes. Therefore, acid extractable uranium probably better indicates potential mineralization. For most elements the majority of determinations are above the detection limit. However, for cobalt and selenium only about half of the determinations are above this limit.

Table 3.2.2 lists the means of stream-sediment analyses for all Tertiary and Quaternary formations except the Quaternary Alluvium and Fluvial Terrace Deposits. It also lists F-values to test the hypothesis that the mean value of an element is equal in all formations. If the tabulated F-values exceed the test F-value of 1.61, we conclude that the means may be different. The table shows some distinct differences. For example, both manganese and selenium are more abundant in the younger formations than in the older. There are also differences in concentrations of both total and acid extractable uranium, as well as several other elements.

Map Analyses

The spatial distributions of total uranium and acid extractable uranium show relatively little correlation in their regional patterns established by the low-pass filter (plates 9 and 10). The maxima (87.5th percentile) for total uranium occur mainly over the interval including the Carrizo Sand and the Weches Formation or the Caddell, Wellborn, and Manning Formations; both of these intervals are Eocene. On the other hand, the maxima for acid extractable uranium are either near the Recent deposits in the northwestern part of the quadrangle or are associated with the Jackson Group and Catahoula Formation. The high-pass-filter maps for acid extractable uranium (fig. 3.2.2) and total uranium (plate 11) show virtually no correlation for the anomalous cells. The majority of the anomalies for total uranium occur in the Lower Eocene fluvial-marine sequence, and those for acid extractable uranium occur mainly with the Jackson Group sequence.

LEGEND

COUNTY LINE ———
 GEOLOGIC CONTACT (DEFINITE) ———
 GEOLOGIC CONTACT (APPROXIMATE) ———
 GEOLOGIC FAULT (DEFINITE) ———

ERA	SYSTEM	SERIES	GEOLOGIC CODE GROUP	CODE GROUP MEMBERS	MAXIMUM THICKNESS	
					METERS	FEET
CENOZOIC	QUATERNARY	RECENT	QD	ALLUVIUM FLUVIATILE TERRACE DEPOSITS		
		PLEISTOCENE	QPB	BEAUMONT FORMATION	30	100
			QPLI	LISSIE FORMATION	61	200
	TERTIARY	PLIOCENE	TQGW	WILLIS FORMATION GOLIAD FORMATION	61	200
		MIOCENE	TMF	FLEMING FORMATION OAKVILLE FORMATION	518	1700
		OLIGOCENE?	TOC	CATAHOULA FORMATION WHITSETT FORMATION	152	500
		EOCENE	TEJ	MANNING FORMATION WELLBORN FORMATION CADELL FORMATION	183	600
			TECY	YEGUA FORMATION	305	1000
			TECL	COOK MOUNTAIN FORMATION SPARTA SAND FORMATION	115	380
			TEMS	WECHES FORMATION QUEEN CITY SAND REKLAW FORMATION	115	380
			TECC	CARRIZO SAND	43	140
			TPWM	WILCOX GROUP MIDWAY GROUP	440	1450
	CRETACEOUS	UPPER CRETACEOUS	UKNM ¹⁴	NAVARRO GROUP MARLBROOK MARL	183	600
			UKAP	PECAN GAP CHALK AUSTIN CHALK	183	600
			UKED	EAGLE FORD GROUP BUDA LIMESTONE DEL RIO CLAY GEORGETOWN FORMATION	61	200
		LOWER CRETACEOUS	LKE	EDWARDS LIMESTONE	122	400

SOURCE OF GEOLOGY FOR GEOLOGIC MAP

1. BARNES, V. E.; GEOLOGIC ATLAS OF TEXAS, SEGUIN SHEET (1974).

FIGURE 3.2.1. - Legend

FIGURE 3.2.1. - Generalized geologic map of the Seguin quadrangle (after Arendt and others, 1978, p. 17)

TABLE 3.2.1.- Basic statistics for the Seguin quadrangle.

Number of observations, n; mean, $\bar{w}$; standard deviation, s; coefficient of variation, C. Means in ppm.

Element	Data above detection limit				All data			
	n	$\bar{w}$	s	C	n	$\bar{w}$	s	C
As	471	3.35	2.71	.81	471	3.35	2.71	.81
B	440	32.5	16.17	.50	472	31.0	16.6	.54
Ba	471	334.3	373.6	1.12	472	334	374	1.12
Co	239	5.10	2.54	.50	472	3.57	2.38	.67
Cr	447	23.81	15.71	.66	472	22.8	15.9	.70
Cu	437	5.73	3.02	.53	472	5.38	3.16	.59
Li	337	12.31	10.68	.87	471	9.38	10.16	1.08
Mn	471	254.8	273.2	1.07	472	254	273	1.07
Ni	399	7.21	4.15	.58	472	6.40	4.25	.66
Pb	463	10.17	6.62	.65	472	10.01	6.65	.66
Sc	397	6.43	3.22	.50	472	5.73	3.37	.59
Se	175	3.31	3.19	.96	471	1.55	2.37	1.53
Ti	469	3223	2563	.80	470	3220	2560	.80
U-F	467	1.29	.56	.43	472	1.27	.57	.44
U-NT	454	2.57	.94	.37	454	2.57	.94	.37
V	465	28.85	15.94	.55	472	28.5	16.1	.56
Yb	400	16.77	11.04	.66	472	15.0	11.0	.74
Zr	469	765.0	1408	1.84	471	762	1406	1.85

TABLE 3.2.2.- Seguin quadrangle. Means of stream-sediment analyses for all Tertiary and Quaternary formations except the Quaternary alluvium and fluvial terrace deposits. The F-values test the hypothesis that the means are equal. Number of observation, n.

F-test value = 1.61.

	QPB	QPLI	TQGW	TMF	TOC	TEJ	TECY	TECL	TEMS	TECC	TPWM	F
n	32	35	70	105	20	34	29	24	46	9	43	
As	2.98	3.75	3.95	3.18	2.50	2.26	2.52	5.47	3.08	1.71	2.13	4.74
B	33.1	27.1	25.4	25.7	35.8	32.4	29.7	31.5	36.7	26.1	44.0	6.05
Ba	207	287	547	287	418	448	334	197	242	293	364	4.0
Co	3.81	3.86	4.53	3.61	2.70	3.12	3.76	3.29	2.74	2.00	3.28	2.70
Cr	23.8	21.1	20.1	18.2	21.1	14.3	20.0	30.4	30.1	57.8	30.2	10.67
Cu	3.21	5.94	6.56	5.22	3.50	3.21	3.24	5.04	4.41	3.00	6.14	8.31
Li	13.4	6.97	10.6	12.8	8.10	12.4	6.55	3.92	4.84	3.11	6.12	5.63
Mn	239	316	465	272	184	166	119	115	151	138	260	7.80
Ni	7.78	5.29	5.89	6.75	3.60	3.76	4.86	6.58	6.37	4.67	9.14	6.12
Pb	8.44	9.17	10.9	9.57	11.4	11.4	9.69	10.2	12.0	6.67	9.28	1.28
Sc	6.44	5.20	6.50	5.83	5.25	4.06	4.97	4.96	5.26	3.78	6.88	2.69
Se	1.92	2.87	2.23	1.13	1.18	.735	.897	1.67	1.10	.50	.721	5.65
Ti	2460	3140	3180	2600	2920	2330	2530	2350	4510	6390	5540	8.99
U-F	1.17	.874	.967	1.40	1.90	1.74	1.12	1.31	1.09	1.13	1.28	12.74
U-NT	2.36	2.08	2.25	2.45	3.13	3.00	2.34	2.68	3.31	3.99	2.40	9.56
V	22.5	24.6	26.5	32.3	21.0	18.7	22.6	26.5	26.6	29.4	46.4	10.55
Yb	15.2	16.2	14.1	11.8	15.8	12.9	12.7	11.9	19.5	24.4	20.9	4.24
Zr	376	934	875	324	946	586	478	410	1530	2630	1360	5.78

FIGURE 3.2.2 - Seguin quadrangle. Anomalous cells for acid extractable uranium (U_F) and thorium. High-pass filter

The picture-frame filter shows broadly similar relationships for acid extractable uranium (plate 12) and total uranium (fig. 3.2.3), although the picture-frame filter shows some anomalous cells over the Post-Oligocene sediments and at two locations in the Recent sediments along the Colorado River. The acid extractable uranium results from the Kolmogorov-Smirnov filter (fig. 3.2.4) pick out only a small number of cells over the Eocene and Pleistocene sediments.

Comparing these results with those for other elements determined for the Seguin quadrangle suggests that at the level of regional low-pass-filter patterns there is some correlation between highs for acid extractable uranium and local enhancement of boron, barium, lead, lithium, and titanium throughout the Upper Eocene to Oligocene Formations in the interval including the Yegua to Catahoula Formations. Assuming that zirconium is a reasonable index for distribution of resistate minerals, we think that the general distribution of the larger groups of anomalous cells identified by applying the various filters for total uranium correlates with the distribution of zirconium (fig. 3.2.5). Although these uranium occurrences are known in the Oligocene sediments (fig. 3.2.5), the relatively low drainage sediment cover does not permit complete correlation with the anomalous cells. Three groups of cells lie on, or close to, the Whitsett and Catahoula Formations. Two (A and C in fig. 3.2.5) are anomalous for both acid extractable uranium and total uranium. Anomaly B is anomalous only for acid extractable uranium and has associated picture-frame filter anomalies for boron, barium, lithium, lead, scandium, and titanium. All three of these anomalies are related to drainage from the Whitsett and Catahoula Formations, and anomaly B is also associated with high stream-water uranium (Arendt and others, 1978).

A brief examination of the low-pass and other filtered maps for the other elements suggests that while at the local scale patterns may appear to be irregular, there are strong regional patterns aligned parallel with the strike for most elements. General patterns of element enhancement in the formations are indicated in table 3.2.3. The table suggests strongly that patterns in the Recent sediments of the Colorado River followed transport toward the Southeast.

FIGURE 3.2.3 - Seguin quadrangle. Anomalous cells for acid extractable uranium (U_F) and thorium. Picture-frame filter

FIGURE 3.2.4 - Seguin quadrangle. Anomalous cells for acid extractable uranium (U_F) and thorium. Kolmogorov-Smirnov filter

FIGURE 3.2.5 - Seguin quadrangle. Anomalies defined by groups of anomalous cells for total uranium (U_{NT}), acid extractable uranium (U_F), and zirconium. Three mines and the outline of the Catahoula and Whitsett Formations are also shown.

TABLE 3.2.3.- Generalized patterns of element enhancement in the stream sediments of the Seguin Quadrangle based on low pass filter maps (12.5 percentiles)

Series	Geologic code group	As	B	Ba	Co	Cr	Cu	Li	Mn	Ni	Pb	Sc	Se	Ti	U _F	U _{NT}	V	Y	Zr
Recent	QD*	X			X	X	X		X		X				X		X	X	
Pleistocene	QPB		X					X				X	X				X	X	
	QPLI					X							X				X	X	
Pliocene	TQGW			X	X	X			X				X	X			X	X	
Miocene	TMF	X	X				X	X	X			X					X		
Oligocene?	TOC														X	X			
Eocene	TEJ		X	X											X	X			
	TECY		X	X	X						X				X	X			
	TECL	X	X		X						X	X			X	X			
	TEMS		X			X					X			X		X			X
	TECC		X			X								X		X	X	X	X
	TPWM		X	X		X			X			X		X		X	X	X	X
U. Cretaceous	UKNM																		

* Colorado River

Summary and Conclusions

We were unable to do a complete analysis for the Sequin quadrangle because only 472 data points are available. Means for all chemical elements except lead are different in the various geologic formations. This result (table 3.2.2), established by a one-way analysis of variance, leads us to the conclusion that stratifying the sample sites by rock types is helpful in order to define local backgrounds.

Statistical/cartographic map analyses show little correlation for regional patterns of total and acid extractable uranium (plates 9 and 10). However, the picture-frame filter shows broadly similar relationships for these two variables (plate 12 and fig. 3.2.3). Known uranium occurrences (fig. 3.2.5) show some relationship to the filtered map patterns, but the agreement is not striking. We conclude that further study of the statistical/cartographic and other data enhancement techniques is required in this area, which would need to be extended to include one or two more quadrangles.

3.3 ANALYSIS OF DATA FROM THE PUEBLO QUADRANGLE, COLORADO

Introduction

The geology of the Pueblo quadrangle (fig. 3.3.1, reproduced as a transparent overlay in plate 19) is diverse, comprising rock units of many different lithologies, ranging in age from Precambrian to Recent and forming a nearly complete record of events throughout geologic time. Figure 3.3.1 shows the principal physiographic divisions of the quadrangle, and figure 3.3.2 is a geological sketch. The eastern half of the quadrangle, including most of El Paso and Pueblo counties, is in the High Plains part of the Great Plains geologic province. In this province, the rocks are horizontal or gently dipping sedimentary rocks; those exposed at the surface range in age from Cretaceous to Recent. The western half of the quadrangle is in the southern Rocky Mountains physiographic province. The mountain ranges are of various types composed of rocks ranging in age from Precambrian to Recent; the intermountain valleys have rocks at the surface mainly of Tertiary to Quaternary age. There are three principal divisions of the mountainous area: the Front range, the Wet Mountains, and the Sangre de Cristo Range. The three intermountain valleys are South Park, Wet Mountain Valley, and the San Luis Valley.

Table 3.3.1 lists the distribution of sample points by geologic units and physiographic provinces. For the entire quadrangle, the largest number of stream-sediment samples are from Quaternary formations and the second largest number from Precambrian formations. However, within the southern Rocky Mountains, about 43 percent of the points are Precambrian. And in the Great Plains, about 50 percent of the points are Quaternary.

Appendix table C-3 details the geologic distribution of stream-sediment sample sites according to the rock codes assigned by one of us (SFC) to the geologic units defined by Scott and others (1978). Because the geology is complex in many parts of the Pueblo quadrangle, it was sometimes hard to determine the predominant lithology yielding a particular stream sediment. However, because we find marked distinctions in elemental compositions for the various units, the assignment of codes must be generally valid.

FIGURE 3.3.1 - Pueblo quadrangle physiographic divisions
(from Shannon, 1978, p. 13)

FIGURE 3.3.2. Geological sketch, Pueblo Quadrangle. Geological symbols:
 (Xgn) Migmatitic gneiss; (Xgd) Granodiorite; (Ysi) San Isabel granite;
 (Yqm) Quartz Monzonite; (Ypp) Pikes Peak granite; (P) Paleozoic Sedi-
 mentary rocks; (M) Mesozoic Sedimentary rocks; (TQvs) Tertiary volcanics
 and sediments, Quaternary sediments; (T) Tertiary intrusive rocks; (Q)
 Quaternary alluvium. The eastern part of the map area, in the Great
 Plains province, is underlain by Cretaceous and Cenozoic sedimentary rocks.

TABLE 3.3.1.- Pueblo quadrangle. Distribution of sample points by geologic units and physiographic provinces.

Geologic unit(s)	<u>Pueblo quadrangle</u>		<u>Southern Rocky Mtns.</u>		<u>Great Plains</u>	
	No.	%	No.	%	No.	%
Quaternary	328	31	118	18	210	50
Tertiary	157	15	143	23	14	3
Cretaceous	216	20	17	3	199	47
Cambrian to Jurassic	85	8	85	13		
Precambrian	272	26	272	43		
<hr/>						
Total	1058	100	635	100	423	100

For the Pueblo quadrangle, LASL collected 1,060 stream-sediment samples at a density of one per 18.58 square kilometers. After discarding one sample lacking latitude and longitude and another with an extraordinarily high manganese content (which upset the other elemental analyses), we had 1,058 samples.

In addition to this reconnaissance sampling, LASL did more detailed sampling in four areas of the quadrangle. Of these areas, we have analyzed the data from the Tallahassee Creek area (fig. 3.3.3), because most uranium production in the quadrangle has been from mines there, and exploration is active. Shannon (1979, p. 2) writes that:

The Tallahassee Creek area was selected by the DOE for detailed HSSR investigation because of (1) new major discoveries of uranium orebodies in Eocene and Oligocene paleochannels, (2) geologic similarity to major world districts, (3) the likelihood for substantial increases in uranium reserves there, and (4) the chance for discovery of intermediate grade--200 parts per million (ppm)--uranium resources. Past production of the Tallahassee Creek area has been more than 200,000 kg of uranium (Nelson-Moore and others, 1978). Guarnera (1978)

reports, "Cyprus Mines announced a 13.6 million-kg (30 million-lb) discovery in sediments below the Tallahassee Creek volcanics."

Appendix table C-4 gives the geologic distribution of sample sites in the Tallahassee Creek area. Of the 311 sites, 118 (38 percent) are in Precambrian basement rocks. The rest are in Tertiary Formations, most of which are volcanic rocks or sedimentary rocks derived directly from volcanic material.

Table 3.3.2 gives basic statistics for the 43 elements analyzed in the stream-sediment samples from the Pueblo quadrangle. The table shows two sets of information:

- (1) only those analyses above the detection limit and
- (2) all data with arbitrary values assigned to those below the detection limit. For many elements, all values are above the detection limit. For most elements at least two-thirds of the values are above this limit. Although several elements have ten percent or fewer values above the detection limit, nonetheless these values may provide valuable information depending on their geologic localization and geographic location.

Table 3.3.3 provides basic statistics for the Tallahassee Creek area of the Pueblo quadrangle. The remarks for the quadrangle as a whole apply to this area.

Basic Statistical Analyses

With the data coded according to rock type, we can compare chemical concentration from one geologic unit or physiographic province to another through the one-way analysis of variance. In this report, we present and explain only a few of these analyses. As before, our purpose is not to present a complete analysis, but rather to indicate some methodology for data analysis.

One interesting comparison is of the compositions of the Precambrian granitic rocks classified by age. There are three groups of granites: one billion years (B.Y.), 1.5 B.Y., and 1.7 B.Y. Table 3.3.4 lists means and F-values for one-way analyses of variance to test the hypothesis that, considering statistical fluctuation, the means are essentially the same. If the tabulated F-values are greater than the tabled F-value of 2.34 at the ten percent risk level, we conclude that the means are evidently different.

The table contains eight of the elements commonly reported in whole rock analyses: aluminum, calcium, iron,

DESCRIPTION OF MAP UNITS

	ALLUVIUM (HOLOCENE AND PLEISTOCENE)
	LANDSLIDE DEPOSIT (HOLOCENE AND PLEISTOCENE) Earthflows and debris slides on steep slopes
	ANDESITE OF WAUGH MOUNTAIN (MIOCENE) Andesitic and basaltic flows, flow breccias, lahars and tuffs
	CONGLOMERATE OF FEAR CREEK (MIOCENE) Conglomerate, air-fall tuff, ash-flow tuff and water-laid tuff
	LATITE OF WAUGH MOUNTAIN (MIOCENE) Autobrecciated flows
	GRIBBLES PARK, THORN RANCH, AND EAST GULCH TUFFS (OLIGOCENE) Rhyolite ash-flow tuff
	BADGER CREEK TUFF (OLIGOCENE) Latite ash-flow tuff
	ANTERO FORMATION (OLIGOCENE) Water-laid andesitic ash interlayered with air-fall and ash-flow tuff and lahar
	THIRTYNINE MILE ANDESITE (OLIGOCENE) Lower member Laharic breccia from local vents
	BIOTITE ANDESITE (OLIGOCENE) Flow-layered domes and domal lavas
	TALLAHASSEE CREEK CONGLOMERATE (OLIGOCENE) Poorly sorted, bouldery, volcanic conglomerate more than 105 m thick in paleovalleys
	WALL MOUNTAIN TUFF (OLIGOCENE) Rhyolite ash-flow tuff
	ECHO PARK ALLUVIUM (EOCENE) Poorly sorted arkosic gravel and conglomerate more than 300 m thick in paleovalleys and grabens
	LATITE PORPHYRY (EOCENE?)
	SOUTH PARK FORMATION (PALEOCENE) Andesitic conglomerate, sandstone, siltstone, and claystone
	WHITEHORN GRANODIORITE (UPPER CRETACEOUS)
	MINTURN AND BELDEN FORMATIONS (PENNSYLVANIAN) Shale, siltstone, and sandstone
	MISSISSIPPIAN, DEVONIAN, ORDOVICIAN, AND CAMBRIAN ROCKS Leadville limestone, Chaffee group, Fremont dolomite, Harding sandstone, Manitou limestone, and Sawatch sandstone
	QUARTZ MONZONITE (PRECAMBRIAN Y)
	GRANODIORITE (PRECAMBRIAN X) Quartz diorite forms borders of granodiorite plutons
	METAMORPHIC ROCKS (PRECAMBRIAN X) Metagabbro, migmatitic gneiss, biotite gneiss, and metavolcanic and metasedimentary rocks

TALLAHASSEE CREEK

FIGURE 3.3.3 - Tallahassee Creek area of the Pueblo quadrangle (after Shannon, 1979, plate I)

TABLE 3.3.2.- Basic statistics for the Pueblo quadrangle.

Number of observations, n; mean, $\bar{w}$; standard deviation, s; coefficient of variation, C. Means in ppm.

Element	<u>Data above detection limit</u>				<u>All data</u>			
	n	$\bar{w}$	s	C	n	$\bar{w}$	s	C
Ag	87	8.05	9.69	1.20	1058	2.96	3.16	1.07
Al	1058	65500	10200	.16	1058	65500	10200	.16
Au	30	.36	.29	.79	1058	.05	.07	1.36
Ba	1037	782	309	.40	1058	769.5	318.8	.41
Be	762	1.93	2.04	1.06	1058	1.53	1.85	1.21
Bi	111	4.92	3.00	.61	1058	2.75	1.22	.44
Ca	1052	31900	34600	1.08	1058	31700	34500	1.09
Cd	63	4.32	4.05	.94	1058	2.61	1.07	.41
Ce	1058	150.8	164.8	1.09	1058	150.8	164.8	1.09
Cl	260	224.7	241.8	1.08	1058	92.7	142.1	1.53
Co	1058	12.4	5.06	.41	1058	12.4	5.06	.41
Cr	1028	49.6	30.8	.62	1058	48.4	31.1	.64
Cs	928	3.43	1.66	.48	1058	3.12	1.75	.56
Cu	984	30.6	35.4	1.15	1058	28.8	34.7	1.20
Dy	1057	9.19	9.90	1.08	1058	9.18	9.90	1.08
Eu	1058	1.86	.75	.41	1058	1.86	.75	.41
Fe	1058	28300	18200	.64	1058	28300	18200	.64
Hf	1058	23.4	38.1	1.63	1058	23.4	38.1	1.63
K	1048	20790	7009	.34	1058	20640	7142	.35
La	1057	79.1	84.9	1.07	1058	79.1	84.9	1.07
Li	1056	26.6	16.0	.60	1058	26.5	16.0	.60
Lu	1055	1.06	1.38	1.30	1058	1.06	1.38	1.30
Mg	947	16300	7860	.48	1058	14800	8543	.58

TABLE 3.3.2. (Continued)

Element	Data above detection limit				All data			
	n	$\bar{w}$	s	C	n	$\bar{w}$	s	C
Mn	1058	825.2	656.6	.80	1058	825.2	656.6	.80
Na	1058	13600	4850	.36	1058	13600	4854	.36
Nb	295	55.6	75.4	1.36	1058	22.7	44.7	1.97
Ni	467	26.5	19.3	.73	1058	15.9	15.9	1.00
Pb	1007	24.4	52.6	2.16	1058	23.3	51.6	2.21
Rb	834	62.0	24.0	.39	1058	52.1	28.7	.55
Sb	49	6.65	9.33	1.40	1058	1.61	2.32	1.47
Sc	1058	10.9	4.34	.40	1058	10.9	4.34	.40
Sm	1058	11.7	17.3	1.48	1058	11.7	17.3	1.48
Sn	99	12.8	12.1	.95	1058	5.73	4.34	.76
Sr	278	627.5	301.2	.48	1058	308.3	250.6	.81
Ta	415	3.12	4.02	1.29	1058	1.60	2.85	1.78
Tb	401	2.27	2.03	.90	1058	1.19	1.51	1.27
Th	1058	21.7	26.9	1.24	1058	21.7	26.9	1.24
Ti	1054	5080	2240	.442	1058	5067	2252	.44
U	1058	7.07	9.56	1.35	1058	7.07	9.56	1.35
V	1044	102.0	62.8	.62	1058	100.8	63.3	.63
W	99	18.8	14.6	.77	1058	8.56	5.53	.65
Yb	1030	8.62	11.1	1.29	1058	8.43	11.1	1.31
Zn	875	132.5	137.6	1.04	1058	123.7	129.2	1.04

TABLE 3.3.3.- Basic statistics for the Tallahassee Creek area of the Pueblo quadrangle. Number of observations, n; mean, $\bar{w}$; standard deviation, s; coefficient of variation, C. Means in ppm.

Element	<u>Data above detection limit</u>				<u>All data</u>			
	n	$\bar{w}$	s	C	n	$\bar{w}$	s	C
Ag	20	12.6	16.7	1.33	311	3.15	4.81	1.53
Al	311	70800	7008	.10	311	70800	7008	.10
Au	2	.42	.22	.53	311	.05	.03	.68
Ba	309	847.1	230.7	.27	311	843.4	234.5	.28
Be	205	1.81	5.87	3.24	311	1.37	4.81	3.52
Bi	21	7.38	6.87	.93	311	2.83	2.13	.75
Ca	311	20900	15322.2	.733	311	20900	15320	.73
Cd	29	5.38	1.40	.26	311	2.77	.94	.34
Ce	310	127.3	56.2	.44	311	126.9	56.6	.45
Cl	31	318.1	810.7	2.55	311	83.1	264.2	3.18
Co	311	12.5	3.89	.31	311	12.5	3.89	.31
Cr	305	39.6	19.3	.49	311	39.0	19.7	.50
Cs	252	2.81	.92	.33	311	2.45	1.11	.45
Cu	311	33.1	9.16	.28	311	33.1	9.16	.28
Dy	311	10.9	33.7	3.10	311	10.9	33.7	3.10
Eu	310	1.71	.70	.41	311	1.71	.70	.41
Fe	311	31950	16760	.525	311	31950	16760	.53
Hf	310	16.5	19.9	1.21	311	16.4	19.9	1.21
K	307	19730	3054	.16	311	19530	3507	.18
La	310	65.3	28.0	.43	311	65.1	28.2	.43
Li	308	21.1	12.2	.58	311	20.9	12.3	.59
Lu	311	.85	.61	.72	311	.85	.61	.72
Mg	295	14607	5296	.36	311	14007	5770	.41

TABLE 3.3.3. (Continued)

Element	Data above detection limit				All data			
	n	$\bar{w}$	s	C	n	$\bar{w}$	s	C
Mn	311	1061	355.1	.34	311	1061	355.1	.34
Na	311	15160	2899	.19	311	15160	2899	.19
Nb	68	31.0	13.1	.42	311	14.6	10.6	.73
Ni	103	24.4	12.6	.51	311	13.1	10.7	.82
Pb	275	20.7	12.2	.59	311	18.6	12.9	.69
Rb	246	57.1	13.7	.24	311	48.5	20.8	.43
Sb		no observations			311	1.50	.40	.27
Sc	311	12.5	5.20	.42	311	12.5	5.20	.42
Sm	310	9.52	5.39	.57	311	9.50	5.39	.57
Sn	14	13.6	6.71	.49	311	5.39	2.25	.42
Sr	74	700.3	471.7	.67	311	331.7	309.7	.93
Ta	80	1.64	.70	.43	311	.85	.76	.89
Tb	115	1.97	.92	.47	311	1.06	.90	.84
Th	310	18	11.1	.62	311	17.9	11.1	.62
Ti	309	6786	3349	.49	311	6748	3373	.50
U	311	5.65	3.86	.68	311	5.65	3.86	.68
V	310	112.5	58.3	.52	311	112.1	58.6	.52
W	11	20.7	8.20	.40	311	7.97	2.86	.36
Yb	295	7.12	4.63	.65	311	6.81	4.70	.69
Zn	251	100.8	39.7	.39	311	95.4	46.9	.49

TABLE 3.3.4.- Pueblo quadrangle. Means of stream-sediment analyses from sites in granitic rocks and F-values. There are 65 sites in rocks of age 1.7 B.Y., 30 in rocks of age 1.45 B.Y., and 60 in rocks of age 1 B.Y. $F_{10\%} = 2.34$.

Element	<u>Age of granitic rocks, billion years</u>			F
	1.7	1.45	1	
Ag	3.12	2.77	6.03	4.98
Al	66500	67200	66700	.10
Au	.0752	.0658	.0987	.94
Ba	628	962	599	11.65
Be	2.15	1.35	5.68	36.00
Bi	2.46	2.63	2.79	1.32
Ca	25700	24200	11100	16.98
Cd	2.46	2.72	2.50	1.61
Ce	196	195	515	24.16
Cl	122	93	104	1.18
Co	14.6	15.2	9.24	33.70
Cr	49.3	51.4	39.2	4.56
Cs	4.29	2.81	3.72	9.44
Cu	29.2	26.4	13.4	19.74
Dy	12.9	10.6	33.3	32.80
Eu	2.30	2.67	2.89	6.21
Fe	34500	33900	29100	3.49
Hf	26.1	21.8	88.7	16.88
K	20100	19000	23600	5.71
La	103	107	265	23.7
Li	33.0	21.9	38.6	8.16
Lu	1.42	1.06	4.28	28.48

TABLE 3.3.4. (Continued)

Element	<u>Age of granitic rocks, billion years</u>			F
	1.7	1.45	1	
Mg	16100	13900	58000	48.74
Mn	1150	1280	1630	2.53
Na	15400	15300	16700	1.86
Nb	22.6	13.2	116.0	20.94
Ni	17.8	15.7	10.4	5.60
Pb	27.4	22.3	35.6	3.95
Rb	62.2	49.6	96.0	33.91
Sb	1.61	1.80	1.68	.64
Sc	14.5	14.8	13.1	2.62
Sm	15.5	14.4	47.4	15.88
Sn	6.94	4.83	9.88	4.86
Sr	241	310	254	4.75
Ta	1.65	1.15	7.80	27.37
Tb	1.78	1.43	4.68	27.11
Th	30.2	19.9	73.8	21.38
Ti	6040	6080	5590	.78
U	11.2	8.98	21.2	5.24
V	89.0	100.0	37.3	54.70
W	9.13	8.50	10.7	1.36
Yb	11.4	8.51	34.5	28.78
Zn	134	156	170	3.49

potassium, magnesium, manganese, sodium, and titanium. Of these, the compositions of aluminum, sodium, and titanium are essentially the same in all three groups of rocks. Iron and manganese are slightly lower in the two older units than in the youngest. Calcium is much lower in the one B.Y. rocks than in the other two groups, magnesium is much higher, and potassium is slightly higher. Considering these facts, we may conclude that the stream-sediment samples were derived from granites of relatively uniform compositions; the sampling, sample preparation, and chemical analyses were carefully done; and we correctly classified the data. The youngest granite clearly differs in composition from the other two, but the similar composition in several elements substantiates the validity of these conclusions.

Consider next the uranium and some of the other metallic elements. The youngest granite contains about twice as much uranium and more than twice as much thorium as the older granites, and more of the rare earths. It contains slightly more lead and zinc than the older granites. For copper there is a strong difference; the youngest granite contains about half the amount contained in the older two granites.

For the Tallahassee Creek Conglomerate and seven other similar Tertiary formations, we calculated means and tested the hypothesis that the means for the eight groups are equal. Our purpose was to determine whether the favorably mineralized Tallahassee Creek Conglomerate differs consistently from the other seven formations. For calcium, potassium, magnesium, manganese, sodium, and rubidium, there are substantial differences in the means for the eight formations. For another 27 elements, there are statistically significant but relatively small differences in the means. However, we find nothing distinctive about the elemental composition of the Tallahassee Creek Conglomerate. For some elements, means for the Tallahassee Creek Conglomerate are larger, for some they are smaller, and for some they are about in the middle of the group of data. Therefore, we performed another analysis of variance (table 3.3.5), comparing the seven sites in the Tallahassee Creek Conglomerate with the 44 sites in the seven other similar formations. For manganese, sodium, scandium, and titanium, the means of the Tallahassee Creek Conglomerate are evidently higher than those of the other seven formations; for all other elements there is no evidence of a difference.

For the Tallahassee Creek area, table 3.3.6 compares elemental analyses for 28 stream-sediment sites from the Tallahassee Creek Conglomerate (Oligocene) with 58 sites from the Echo Park alluvium (Eocene). If the tabulated F-values exceed the tabled F-value of 2.77 at the ten percent

risk level, we conclude that the elemental compositions of the two formations are different. Of the base metal and associated elements, the Tallahassee Creek Conglomerate is evidently somewhat richer in lead, gold, cobalt, manganese, and zinc. Although the uranium contents are indistinguishable, it is deficient in thorium, dysprosium, and some of the other rare earths.

TABLE 3.3.5.- Pueblo quadrangle. Means of stream-sediment analyses from 7 sites in Tallahassee Creek Conglomerate and 44 sites in the Dawson Divide, Dry Union, Echo Park, Santa Fe, South Park, and Wagonfire Formations. The F-values test the hypothesis that the means are equal.
 $F_{10\%} = 2.82$.

Element	Tallahassee Creek Conglomerate	Seven other Tertiary formations	F
Mn	1210	802	5.32
Na	17000	12400	3.95
Sc	13.4	10.1	2.84
Tl	6590	5000	4.44

Since the granitic rocks have been postulated as source rocks for the mineralization in the Tallahassee Creek Conglomerate and perhaps also as host rocks, we compared the stream sediments from granites of 1.7 B.Y. with those of 1.45 B.Y. Table 3.3.7 gives the results. If the tabulated F-values exceed 2.76, we conclude that the means for a particular element are evidently different. For the two formations, there are no evident differences in the means for uranium and thorium. However, the content of all of the rare earths except dysprosium is substantially higher in the 1.7 B.Y. old granite than in the younger granitic rocks. This fact suggests that the older granitic rocks have a higher content of monazite and other resistate minerals. Also, hafnium is substantially higher in the 1.7 B.Y. rock.

Finally, table 3.3.8 compares the original sampling of the Tallahassee Creek Conglomerate at seven sites in the Pueblo quadrangle with the detailed follow-up sampling at

TABLE 3.3.6.- Tallahassee Creek area of the Pueblo quadrangle. Means of stream-sediment analyses from 28 sites in the Tallahassee Creek Conglomerate and 58 sites in the Echo Park Alluvium. The F-values test the hypothesis that the means are equal. Ppm. $F_{10\%} = 2.77$.

Element	Tallahassee Creek Conglomerate	Echo Park Alluvium	F
Ag	2.50	2.50	-
Al	72200	71100	.30
Au	.0493	.0402	15.08
Ba	946	798	11.87
Be	.964	2.88	.84
Bi	2.68	3.43	.76
Ca	19800	16800	.50
Cd	2.68	2.59	.57
Ce	110	129	2.83
Cl	64.2	149	.54
Co	12.0	9.84	16.34
Cr	37.1	38.4	.12
Cs	2.61	2.09	7.05
Cu	29.6	31.4	.95
Dy	6.93	10.2	8.64
Eu	1.54	1.42	2.95
Fe	28400	27200	.23
Hf	12.5	12.5	.00
K	19300	21900	10.17
La	58.9	66.8	1.81
Li	18.4	19.7	.12
Lu	.657	1.00	9.12

TABLE 3.3.6. (Continued)

Element	Tallahassee Creek Conglomerate	Echo Park Alluvium	F
Mg	12900	13400	.17
Mn	1040	843	16.51
Na	15500	16300	.65
Nb	12.6	13.1	.07
Ni	12.8	13.6	.11
Pb	25.5	19.0	3.51
Rb	53.1	50.5	.41
Sb	1.57	1.27	12.80
Sc	11.0	9.69	4.37
Sm	7.71	9.98	5.19
Sn	5.09	5.00	.48
Sr	285	313	.07
Ta	.696	.664	.08
Tb	.786	1.13	3.90
Th	14.5	21.1	6.92
Ti	5880	5280	2.69
U	5.35	5.78	.25
V	106	82.7	8.33
W	7.50	7.50	-
Yb	5.45	8.04	8.17
Zn	98.8	77.2	4.96

TABLE 3.3.7.- Tallahassee Creek area of the Pueblo quadrangle. Means of stream-sediment analyses from 76 sites in granitic rocks of 1.7 B.Y. and 21 sites in granitic rocks of 1.45 B.Y. The F-values test the hypothesis that the means are equal. Ppm. $F_{10\%} = 2.76$.

Element	<u>Age of granitic rocks, billion years</u>		F
	1.45	1.7	
Ag	2.50	5.14	1.62
Al	70500	68300	2.02
Au	.0414	.0596	9.77
Ba	869	647	33.70
Be	1.50	.934	14.86
Bi	2.50	2.68	.49
Ca	18400	26400	2.76
Cd	2.50	2.93	2.22
Ce	130	164	6.67
Cl	62.9	72.2	.85
Co	10.3	13.4	25.99
Cr	34.3	51.7	8.45
Cs	2.71	3.09	2.19
Cu	33.2	36.1	1.27
Dy	8.10	21.9	.89
Eu	1.46	2.43	18.96
Fe	23900	40300	9.40
Hf	10.8	36.1	12.70
K	21200	18600	13.52
La	69.2	79.8	2.91
Li	20.9	29.1	13.00
Lu	.676	1.36	18.90

TABLE 3.3.7. (Continued)

Element	<u>Age of granitic rocks, billion years</u>		F
	1.45	1.7	
Mg	13800	18400	14.25
Mn	875	1160	19.72
Na	14600	13900	1.63
Nb	25.0	18.0	3.63
Ni	10.7	18.6	5.58
Pb	19.4	22.5	1.07
Rb	60.4	52.3	2.77
Sb	1.21	1.78	35.31
Sc	9.90	18.5	43.23
Sm	9.40	12.9	10.05
Sn	5.29	5.97	.84
Sr	245	240	.04
Ta	1.05	1.18	.41
Tb	.786	1.78	20.46
Th	21.7	22.5	.15
Ti	5390	9030	22.17
U	7.34	7.41	.01
V	82.3	119	8.16
W	10.5	7.97	5.69
Yb	6.10	10.6	16.46
Zn	94.2	113	2.03

28 points in the Tallahassee Creek area. The table lists means for only the 14 elements for which the calculated F-value is larger than the tabled F-value of 2.86 at the ten percent risk level. For these 14 elements, the sample means are evidently different. For thorium and several of the rare-earth elements, the detailed sampling yields somewhat lower analyses than the original sampling. However, on the whole, the two sets of data are in excellent agreement.

TABLE 3.3.8. - Pueblo quadrangle. Means of stream-sediment analyses from 7 sites in the original sampling of the Tallahassee Creek Conglomerate and 28 sites in the detailed follow-up sampling. The F-values test the hypothesis that the means are equal. $F_{10\%} = 2.86$.

Element	Original sampling	Detailed sampling	F
Cd	2.14	2.68	3.13
Ce	165	110	6.96
Co	15.7	12.0	8.27
Cu	19.1	31.4	10.99
Eu	2.23	1.54	15.96
Hf	22.6	12.5	4.51
La	84.4	58.9	5.09
Mn	1210	1040	3.65
Sc	13.4	11.0	3.00
Sm	12.3	7.71	5.98
Ta	1.71	.696	10.58
Tb	1.36	.786	3.43
Th	22.9	14.5	3.98
W	6.43	7.50	4.40

Map Analyses

The uranium occurrences in this area (Nelson-Moore and others, 1978) fall into a variety of associations. Most are in Precambrian rocks of the Southern Rocky Mountains, the Front Range, Wet Mountains, and the western edge of the Sangre de Cristo Range; others are in Paleozoic or younger

rocks, the most important occurring in the Jurassic Morrison Formation on the western margin of the Denver Basin (fig. 3.3.4).

At the density of the original stream-sediment sampling, some of the areas underlain by Precambrian granodiorites or quartz monzonites (for example, Bare Hills, Blue Ridge, Burned Timber Mountain) were sampled only in a few places and may not be well represented in the broad regional analysis which follows. Some important uranium areas (for example, Tallahassee Creek) are not accompanied by enhanced uranium in the stream sediments, or even in the original point-source data, although surface-water uranium is higher in this area (Shannon, 1978).

The maximum uranium values (total uranium data only available for this area) occur over the Pikes Peak batholith (low-pass filter 95th percentile, 13.8 ppm) and the northern end of the Cripple Creek quartz monzonite. The equal 12.5 percentile low-pass filter map (plate 13) shows that minor regional enhancement is also associated with the Precambrian granodiorites and with the Quaternary alluvium east of Pikes Peak. It is only moderately enhanced over the Isabel batholith. The map cells anomalous with high-pass filter (plate 14) correspond to the Pikes Peak batholith; to the granodiorites south of Pikes Peak, at Castle Rock Gulch, Fernleaf Gulch and near Curley Peak; and possibly also to the Morrison Formation in the Red Creek area. Similar areas of the Precambrian are shown up by the picture-frame filter (plate 15), and the Fernleaf Gulch granodiorite also appears with the Kolmogorov-Smirnov filter (plate 16). Both the Fernleaf Gulch and Castle Rock Gulch anomalies are in areas of high concentrations of uranium in water (Shannon, 1978).

Thorium shows maximum low-pass-filter values (55.7 ppm, 95th percentile) over the Pikes Peak batholith, with moderate enhancement over the granodiorites to the south of it, and elsewhere in the Precambrian basement. Surprisingly, no strong thorium patterns are shown in the thorium-bearing vein area in the Wet Mountains although this area may be the origin of the uranium-thorium anomaly area south of Canon City which is down drainage from it. Thorium is not high over the Isabel batholith, in contrast to the moderate uranium values, but is concentrated in the stream sediments of the Quaternary in the Denver Basin, a similar pattern to uranium. Comparison of high-pass filter uranium and thorium anomalous map cells (fig. 3.3.5) shows a high degree of coherency, except for the uranium anomalies in the northern part of the Cripple Creek quartz monzonite, to the northeast of the Castle Rock Gulch granodiorite, and over the Quaternary southeast of the Curley Peak granodiorite.

FIGURE 3.3.4 - Pueblo quadrangle. Areas of uranium occurrences

FIGURE 3.3.5 - Pueblo quadrangle. Uranium and thorium. High-pass filter anomaly map

The distribution may be broadly correlated with the striking pattern shown by the rare earths (cerium, dysprosium, europium, lanthanum, lutetium, samarium, terbium, and ytterbium), hafnium, tantalum, and niobium. These elements, designated REE, are associated with apatite, zircon, xenotime, monazite, etc. All are enhanced over the southern part of the Pikes Peak batholith and the granodiorite lying to the south of it. A related pattern strongly suggests that heavy minerals have been concentrated in outwash forming part of the Quaternary alluvium of the Denver Basin to the east and southeast of Pikes Peak batholith. Figure 3.3.5 shows the distribution of the REE group elements schematically, based on the coincidence of the 87.5th percentiles for the 11 elements in the low pass filter maps, and clearly their distribution patterns over the Quaternary follow the now dry Chico and Black Squirrel Creek drainage systems, until they meet the Arkansas River east of Pueblo. Tin predictably follows a similar pattern. Other minor enhancements occur over the Precambrian granodiorites, and the Isabel Pluton batholith (not tantalum and niobium). With this in mind, it is clear that most of the anomalous uranium and thorium high-pass filter cells (fig. 3.3.6) are correlated with map cells showing multiple coincidence for REE group high-pass filter anomalies (fig. 3.3.7), particularly in the vicinity of the Pikes Peak batholith and Quaternary of the Denver Basin.

The results of picture-frame filtering of uranium (plate 15) and thorium are compared in figure 3.3.8 and may again be broadly related to coincident REE group picture-frame anomalous cells in figure 3.3.9. Thorium is again correlated closely with the REE group. With a few minor exceptions, the Precambrian igneous rocks at Pikes Peak, Fernleaf Gulch, Castle Rock, and in the Sangre de Cristo Range are again shown up, as well as the Denver Basin Quaternary. Uranium anomalies uncorrelated with thorium and the REE group also occur at the northern end of the Cribbs Creek quartz monzonite and associated with the granodiorites northeast of Castle Rock Gulch; and over the Isabel batholith where the REE group is anomalous, but no thorium anomalies are present. The picture-frame filter brings out, as usual, broader areas than either the high-pass filter or Kolmogorov-Smirnov filters.

Finally, the Kolmogorov-Smirnov filter applied to uranium (plate 16) and thorium (fig. 3.3.10) shows a small number of anomalous cells mainly correlated with REE group anomalies (fig. 3.3.11), with the exception of small uranium anomalies in the Quaternary west of Pueblo and at the west end of the Sangre de Cristo Range. The regional scale

FIGURE 3.3.6 - Pueblo quadrangle. Generalized distribution of REE group based on low-pass filter (1) 87.5th percentiles

FIGURE 3.3.7 - Pueblo quadrangle. REE group. High-pass filter anomalies

FIGURE 3.3.8 - Pueblo quadrangle. Uranium and thorium picture-frame-anomaly map

FIGURE 3.3.9 - Pueblo quadrangle. REE group. Picture-frame anomalies

FIGURE 3.3.10 - Pueblo quadrangle. Uranium and thorium.
Kolmogorov-Smirnov-anomaly map

FIGURE 3.3.11 - Pueblo quadrangle. REE group. Kolmogorov-Smirnov anomalies

anomalies for uranium and thorium are broadly summarized in figure 3.3.12. The uranium-thorium-REE group anomalies over the Quaternary east and southeast of Pikes Peak along the Fountain, Chico, and Black Squirrel Creek drainage systems and their confluence with the Arkansas River are clear. The southernmost of these patterns lie to the north of uranium ground-water anomalies (Shannon, 1978); correlation over the whole area is not possible owing to absence of water samples over much of the northern part of Pueblo county. Uranium-thorium-REE group anomalies elsewhere mainly correlate well with the occurrence of Precambrian granodiorites. Uranium in waters (Shannon, 1978) is generally low over these areas, as well as over the Isabel batholith. The anomaly south of Canon City may be related to the Wet Mountain area of thorium-bearing veins. Of more interest is the granodiorite near Fernleaf Creek which is associated with beryllium and lithium anomalies on the filtered maps and with a uranium water anomaly (Shannon, 1978). Both the Pikes Peak batholith and Fernleaf Creek area are associated with uranium occurrences (fig. 3.3.4). The anomalies for uranium alone are all in areas where the regional uranium/thorium ratio exceeds 0.58 (90th percentile low-pass filter map), and those east of Curley Peak and northeast of the Castle Rock Gulch granodiorites are near reported uranium occurrences (fig. 3.3.4).

Turning briefly to other elements (based on low-pass and other filters), none shows particularly strong correlation with known areas of uranium production. A number of elements show similar enhancement over the Quaternary sediments as discussed above (barium, beryllium, bismuth, cobalt, chromium, cerium, copper, lead, rubidium, vanadium, and zinc). The Pikes Peak batholith is a high area for silver, beryllium, bismuth, cerium, hafnium, potassium, lithium, manganese, lead, rubidium, and tin. The Precambrian schists and gneisses are generally enhanced in cobalt, chromium, copper, iron, nickel and lead. The Thirtynine Mile Volcanic Field is high in barium, cobalt, iron, antimony, titanium, and vanadium. The Kolmogorov-Smirnov filter showed local anomalies for barium in the Tallahassee Creek area and for beryllium at the northern end of the Cripple Creek granodiorite--both areas associated with known uranium enhancement in waters (Shannon, 1978).

Mineralogical Analyses

For the Tallahassee Creek area, we (RHC) have made an analysis similar to that for the southeastern area. We present a formula for residual uranium (UR) which attempts

FIGURE 3.3.12 - Pueblo quadrangle. Generalized anomaly patterns

to identify samples containing significant amounts of uranium that are not associated with resistate heavy minerals or iron oxides. Anomalous values of residual and observed uranium (UO) are determined by analysis of the frequency distribution on log-probability graphs. The distribution of anomalous values relative to the occurrence of various lithologic units and known uranium occurrences are also summarized.

The formula developed for the Tallahassee Creek area is:

$$UR = UO - La/40 - (Dy - .02Ce)/10 - Hf/60 - 0.25 \\ (Th - Ce/6) - (Fe - 20Mn)/40,000.$$

The term $La/40$ is the assumed ratio of La/U in monazite. $(Dy - .02Ce)/10$ is the assumed ratio of Dy/U in xenotime (corrected for a minor amount of Dy associated with Ce -Rare Earths in monazite). $Hf/60$ is the assumed Hf/U ratio in zircon. The term $0.25 (Th - Ce/6)$ attempts to account for thorium-bearing minerals (allanite, thorite, etc.) other than monazite in which the thorium content is about one sixth that of cerium. We assume that 25 percent of any thorium not accounted for by monazite is supported by uranium. The final term $(Fe - 20Mn)/40,000$ attempts to account for uranium associated with sediments rich in iron oxides. Because iron oxides scavenge U^{+6} from solution, a sample rich in iron oxides could conceivably be rich in uranium, but not be associated with mineralization. Normally, iron is 20 times more abundant than manganese. Where iron exceeds this concentration, we assume that .005 percent of it is supported by uranium.

Analytical data for monazite, zircon, xenotime, and other U-Th-REE minerals have been presented previously in the report. This information served as a primary basis for the equation for residual uranium presented here. However, the equation developed for the Inner Piedmont did not prove applicable to the Tallahassee Creek data as it provided many strongly negative values. Consequently, we selected a trial set of analyses from the Tallahassee Creek data set and adjusted the weighting functions to obtain low residual uranium values (particularly for high Ce , La , Dy , and Hf analyses) without producing a significant number of negative residual uranium values. These adjustments are still within the compositional limits of monazite, xenotime, and zircon reported in the literature.

Results

A log-probability plot for observed and residual uranium values in the Tallahassee Creek Project Area is presented in figure 3.3.13. Anomaly-threshold values determined from breaks-in-slope are 9 ppm residual uranium and 12 ppm observed uranium. Of the 311 samples analyzed, seven are anomalous for residual uranium and 13 for observed uranium. A listing of anomalous samples is presented in table 3.3.9.

FIGURE 3.3.13 - Log-probability plot for original and residual uranium values in the Tallahassee Creek area

TABLE 3.3.9. - Listing of anomalous localities for observed and residual in the Tallahassee Creek Project Area. Uranium values are residual for residual anomalies and observed for observed anomalies.

Anomaly type	Sample No.	Uranium, ppm
Residual (+9ppm)	53	15.98
	56	13.22
	57	14.36
	115	11.52
	226	9.47
	243	30.71
	268	23.99
<hr/>		
Observed (+12ppm)	53	17.38
	56	18.48
	57	17.14
	115	14.66
	172	13.68
	173	14.39
	226	18.41
	243	34.80
	244	12.64
	268	31.86
	275	12.17
	277	14.72
	301	28.46

Discussion

Regarding the relationships between uranium geochemistry and geology, Shannon (1979, p. 15) concludes that:

Most samples which contain high uranium values in both water and sediment from the Tallahassee Creek and Castle Rock Gulch areas have a provenance from granodiorite of Precambrian X age.....Other units associated with a number of relatively high uranium concentrations in water or sediments are the Echo Park Alluvium, and the Tallahassee Creek Conglomerate in the Tallahassee Creek area.....

Shannon also indicates that the principal host-rock units for uranium mineralization are the Echo Park Alluvium and the Tallahassee Creek Conglomerate.

Figures 3.3.14 and 3.3.15 show the distribution of anomalous residual and observed uranium localities relative to the known uranium occurrences cited by Shannon. Although both types of anomalies show a close areal association with

known mineralization in some areas, a larger proportion of observed uranium values are not associated with known mineralization.

FIGURE 3.3.14 - Tallahassee Creek area. Distribution of observed uranium localities and known uranium occurrences

Another interesting comparison is the relationship of anomalous values to the Echo Park Alluvium and the Tallahassee Creek Conglomerate. Except for sample 115, all of the residual uranium anomalies are either within these formations or within 0.3 km of a contact of these formations. Sample 115 is in a related unit, the Thirtynine Mile Andesite, and is only 0.7 km east of Cyprus Mines's recent discovery on the Hansen lease. In contrast, a significant number of the observed uranium anomalies are associated with a granodiorite (Precambrian X) previously cited by Shannon as uraniferous, but not as a known host of uranium mineralization.

FIGURE 3.3.15 - Tallahassee Creek area. Distribution of residual uranium localities and known uranium occurrences

Summary and Conclusions

As in the other two study areas, one-way analyses of variance of the data stratified by rock type demonstrate interpretable differences. For instance, for stream-sediment samples from granites of three different ages (table 3.3.4), two agree closely in major-element composition, although the third differs. We may conclude that the stream-sediment samples were derived from granites of relatively uniform compositions; the sampling, sample preparation, and chemical analyses were carefully done; and we correctly classified the sample sites. As another example, table 3.3.8 compares the original sampling of the Tallahassee Creek Conglomerate with the detailed follow-up sampling. For only 14 of 43 elements are sample means evidently different, and only three of these differences are perhaps large. Therefore, we believe that both reconnaissance and detailed follow-up sampling were done effectively.

Statistical/cartographic map analyses develop coherent patterns, although these are more difficult to interpret than for the Southeastern area. Maximum uranium values are in the Pikes Peak batholith (plate 13). Striking enhancement of the rare earths also occurs over the southern part of this batholith and the granodiorite to the south of it (fig. 3.3.5).

Our mineralogical model developed for the Tallahassee Creek area of the Pueblo quadrangle is similar to that for the Southeastern area, although the parameters are different. Our statistical treatment of multielement data appears to define anomalies which are closely related to known uranium mineralization, or favorable host-rock units, better than the raw data. The close correlation of residual uranium anomalies with known uranium occurrences and the Echo Park Alluvium-Tallahassee Creek Conglomerate is remarkable. Original uranium anomalies, in which the effects of residue heavy minerals are probably significant, are apparent in certain Precambrian intrusives (Precambrian X, granodiorite). These anomalies tend to be eliminated in the equation for residual uranium.

A disadvantage of our technique is that the derivation of the equation for residual uranium is based on trial-and-error iterations, and some of the relationships are complex. Consequently, two geologists may not develop the same equation from the same data set. Also, it is difficult to establish that an optimum set of weighting functions has been developed. Thus, as presently used, the technique is somewhat subjective. However, we believe that any similar equation that is logically derived and that takes into account general geochemical-mineralogical relationships between uranium, thorium, and the rare earths can be used to define uranium mineralization better than the raw data.

SECTION 4. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In sub-section 4.1, we discuss our methods for data enhancement and display; in sub-section 4.2, our procedures for data organization and processing; and, in sub-section 4.3, our suggestions for further work.

4.1 METHODOLOGY

With our data enhancement and display techniques, we extract, evaluate, and display more information from the HSSR raw data base than do conventional methods. In the three study areas -- four two-degree quadrangles in the Southeastern United States; the Seguin, Texas quadrangle; and the Pueblo, Colorado quadrangle -- we have developed and refined anomalies in addition to those found by conventional techniques.

There are four essential parts to our approach: geologically stratifying the sample sites, developing statistical/cartographic mapping techniques, devising a mineralogical model, and analyzing the data by regions larger than individual quadrangles.

Geological Stratification

By assigning rock codes to stratify the sample sites geologically, we were able to make one-way analyses of variance in order to compare the amounts of uranium and other elements in the various geological units. In these units, means for uranium and other elements differ consistently in geologically reasonable ways. Therefore, we conclude that stratification is essential in order to remove "noise" introduced if geology is disregarded when defining anomalies. Moreover, detailed sampling of the Tallahassee Creek Conglomerate in the Pueblo quadrangle agrees with the original reconnaissance sampling.

We suggest coding all HSSR sample sites by predominant lithology. For each quadrangle, or group of quadrangles, rock-type codes should be devised (Appendix C). For the entire United States, codes may need to be longer

than our present eight-character code. The same code should be used throughout as many geological provinces as possible, and the geologist making the geological summary should code the sample sites. Using these codes, lithological maps could be compiled. These maps, as well as the usual stratigraphic maps, would be useful for interpreting geochemistry.

Statistical/Cartographic Mapping Techniques

Our statistical/cartographic mapping techniques enhance anomalies for uranium and other elements in all three study areas. The techniques use a cell size of about 3 by 3 miles and several filters. Because choice among them depends on the bedrock geology, the distribution of sample points, and the parameters of anomalous and background mineralization, filter selection depends on the particular situation.

Each filter enhances anomalies, especially for uranium, that agree spatially with the anomalies picked out by another filter. Because the statistical approach identifies anomalous areas on a comparable statistical basis, it is more objective than conventional methods. The anomalous areas differ from their surrounding regions in relative rather than in absolute amplitude. For the Pueblo and Seguin quadrangles, where information on uranium deposits is available, the filters correlate the stream-sediment data with these deposits. Also, stream-sediment anomalies are related to ground- and stream-water anomalies. Spatial filtering of elements besides uranium aids interpretation in all three study areas.

Through the Southeastern regional study, we have identified long-range trends in particular formations, trends not seen on the scale of the individual Seguin and Pueblo quadrangles. Although an individual map cell may contain a number of rock types, we can adapt for this problem by altering window size. "Gaps" in the map are less important at the regional scale, because larger cells containing more map points could be used.

We suggest implementing spatial filtering with an ink-jet color plotter of the Applicon type. An initial trial with a color plotted low-pass filter map was encouraging. Color combined maps based on microfilm are powerful tools. With the ink-jet plotter, colors for three elements could be combined, or results for a single element could be filtered. These color maps are easy for the geochemist without statistical training to interpret, because a cartographic rather than a statistical technique is used.

Mineralogical Models

Our mineralogical models locate anomalies for the residual uranium left after removing the uranium contained in resistate minerals. While the parameters change from area to area, the model applies generally. Some of the residual anomalies correspond to original anomalies. In the Southeastern area, we have identified 63 residual uranium anomalies (table 3.1.12) and have evaluated them by assigning priority values. In the Tallahassee Creek area of the Pueblo quadrangle, 13 of 311 samples are anomalous for observed uranium but only 7 for residual uranium (table 3.3.9). The residual uranium samples are more closely associated with known uranium mineralization than are the observed samples. Therefore, we conclude that the mineralogical model develops new anomalies in the Southeastern area and more closely defines known mineralization in the Tallahassee Creek area.

Using computers, the mineralogical models allow rapid delineation of anomalies for entire quadrangles. Once the rock units are coded and equations are developed for residual uranium and thorium, the only additional procedure is making log-probability plots. (Currently done by us manually, this procedure can also be computerized.)

Regional Studies

We have found it valuable to study the four Southeastern quadrangles regionally (as a block) rather than individually. A regional approach is needed to obtain enough sample sites from individual geologic units for the one-way analyses of variance, for the map analyses of regional trends, and for the optimum use of mineralogical models.

We think it is important to study the HSSR data in regions larger than a single quadrangle. While an excellent way to organize data for preliminary reports, the two-degree quadrangles are unrelated to the geology.

A typical regional area might comprise six quadrangles. Had the data from the Knoxville and Johnson City quadrangles been available to add to those from the four Southeastern quadrangles, we could have made a complete regional study from the Cumberland Plateau to the Coastal Plain. The full block, nearly square, of six quadrangles contains about 9,000 sample sites; this is a number small enough to analyze as a block on a large computer system without spending an excessive amount of time writing special programs for data management.

4.2 DATA ORGANIZATION AND PROCESSING

The data files supplied by the three laboratories are in good order; they contain a few inconsistencies, such as non-numeric data in numeric fields. However, the files are organized for convenience in listing data for publication rather than for data analysis. For example, one file contains control characters (their function is to provide paged lists for printing) which cause unnecessary problems in data analysis.

Reorganizing the data files would make them more useful. All three laboratories should use the same format.

Specifications for a general format would include the following items:

- (1) 80-column long records, so that the files can be made available on either magnetic tape or punched cards.

- (2) Elimination of carriage-control characters.

- (3) Readability by standard FORTRAN programs, avoiding special use of characters, for example the letter "M" for missing data, even though these characters make printed files easy to read.

- (4) Listing the chemical elements in a standard order, probably alphabetical.

Even with these suggested changes, the present data files would be inconvenient for public use, because they contain all data obtained by the laboratories; few, if any, users would ever need all of them.

Therefore, we recommend devising a new set of user-oriented files. Specifications for these files would include the following items:

- (1) Eliminate data of questionable use (for example, the sampler's comment on one record "more angry bulls in field").

- (2) Remove samples with neither latitude nor longitude.

- (3) Remove duplicate samples.

- (4) Segregate the files according to sampling media.

- (5) Provide the data of most use in the first part of

each record. (These data are sample number, sample location, and analytical results.)

(6) Indicate samples below detection limits, un-analyzed samples, and lost analyses by codes readily readable by standard FORTRAN programs.

We consider it undesirable to attempt to devise a "standard" set of procedures universally applicable to the HSSR data. Attractive though the concept may be, in practice all-purpose computer programs seldom provide a panacea for data analysis. We advise the continued development of a suite of programs from which the scientists and engineers working on a given set of data can select those most pertinent for specific applications.

Through statistical calculations and examination of the procedures for data verification and validation used by the national laboratories, we are convinced that the sampling and chemical analyses have been done in a statistically valid and reliable manner. The data files supplied by the laboratories in general match the printed publications, and the means and standard deviations of variables are within reasonable limits. Therefore, we conclude that the NURE program is producing a valid data set. Because the data base that is accumulating will be of tremendous value for both pure and applied geological research for many years, we consider it essential to maintain it carefully.

4.3 SUGGESTIONS FOR FURTHER WORK

Follow-up Field Studies

In the Southeastern area, we have defined anomalous points in several geologic provinces that are related to specific rock units. For several clusters of points (fig. 3.1.8), we recommend follow-up evaluation. Initially, the anomalies should be verified by re-sampling and re-analysis of the original sample sites. Causes of verified anomalies should be identified because economic or sub-economic concentrations of uranium may be present. In the Pueblo quadrangle, where the Tallahassee Creek area has a proven potential for major uranium deposits, further geochemical investigations are warranted.

First, resistate minerals containing uranium, thorium, and rare earth elements introduce "geochemical noise" into the raw HSSR data. Generally, the abundance of these minerals is unrelated to the presence or absence of commer-

cial uranium mineralization. Consequently, samples in which most of these minerals have been removed, either by panning or heavy liquid separations, should provide results amenable to direct interpretation and also to refining the equation for residual uranium.

Second, in flowing streams, iron and manganese oxides form coatings on boulders. These elements are introduced into the streams in a reduced state in ground water and precipitate on boulders due to oxygenation of ferrous and manganous ions in surface water. If enough uranium is present in ground water, this element will be scavenged by the iron oxide components along portions of a stream where anomalous ground water is introduced. Then, anomalous U/Fe ratios may occur in solution extracts of the coated material. The method is essentially a hydrogeochemical procedure as the anomalous metals are hydromorphic in origin. The method reveals certain geochemical relationships in ground water, but sampling is not limited to springs or wells. Shannon (1979) concluded that ground-water surveys were effective in geochemical exploration in the Tallahassee Creek area. Boulder-coating surveys would therefore be a useful follow-up procedure.

Use of the HSSR Data for Uranium Resource Assessment

Our present study demonstrates that the HSSR data contain statistically reliable results with a large information content. From these data, uranium anomalies can be defined by conventional methods and by our techniques for enhancement and display; these anomalies can be related to the other chemical elements, to the geology, and to the uranium assessment.

We suggest investigating the usefulness of the data for uranium resource assessment. It may be possible to make an estimate, within reasonable limits, of the uranium endowment of a quadrangle from the HSSR data. Such a study would include definition of training and test areas in which HSSR and tonnage-grade-production data are available. In the training area, the HSSR data would be related to uranium endowment through one or more mathematical models; in the test area, the model would be applied to predict uranium endowment. The accuracy of the model would be evaluated by comparing the predicted endowment with the known endowment. If successful, the model would be applied to unknown areas.

Other Suggestions

In the three areas studied, we have identified certain anomalies through applying and evaluating statistical, mathematical, and mineralogical models. We recommend that these procedures be used in additional geographic areas to determine whether similar anomalies are present in them. This work will determine the generality, reliability, and range of applicability of our suggested procedures.

While the HSSR data were collected for uranium resource evaluation, they have many other uses. Most closely related is exploration for other natural resources; two examples are exploration for base-metals and barite. Beyond these closely related areas is the use for problems in environmental geochemistry. For example, the Southeastern data provides results similar to those of Shacklette and others (1970) in a study of heart disease.

Using this data base for purposes other than uranium exploration would increase the cost effectiveness of this national sampling program, since the most expensive part of any geochemical survey is sample collection. The variety of sampling media being employed on a regional scale compares favorably with earlier programs of the U.S. Geological Survey, which sampled wide-spaced rock and soil samples and defined background levels. In contrast, the HSSR data base can point up special situations within relatively limited geographic areas. For instance, Shacklette and others (1971) reported for the U.S. Geological Survey concentrations of 20 elements at 863 sites across the conterminous United States. In this area, the present HSSR program will sample about 500 times as many sites.

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PLATE 1 - Southeastern area. Total uranium, unprocessed map.

PLATE 2 - Southeastern area. Total uranium, low-pass filter, effective radius of one cell.

PLATE 3 - Southeastern area. Total uranium, high-pass filter. effective radius of one cell.

PLATE 4 - Southeastern area. Total uranium, picture-frame filter, central cell versus annular window with effective radius of one cell.

PLATE 5 - Southeastern area. Total uranium, picture-frame filter, central cell versus annular window with effective radius of two cells.

PLATE 6 - Southeastern area. Total uranium, picture-frame filter, 3 by 3 central cell block versus annular window with effective radius of three cells.

PLATE 7 - Southeastern area. Total uranium, Kolmogorov-Smirnov filter, 3 by 3 central cell block versus annular window with effective radius of three cells.

PLATE 8 - Southeastern area. Total uranium, Kolmogorov-Smirnov filter, 3 by 3 central cell block versus annular window with effective radius of four cells.

PLATE 9 - Seguin quadrangle. Acid extractable uranium (U_i). Low-pass filter using effective radius of one cell.

PLATE 10 - Seguin quadrangle. Total uranium (U_{NT}). Low-pass filter using effective radius of one cell.

PLATE 11 - Seguin quadrangle. Total uranium (U_{TOT}). High-pass filter using effective radius of one cell.

PLATE 12 - Seguin quadrangle. Acid extractable uranium (U_I). Picture-frame filter, 3 by 3 central cell block versus annulus with effective radius of three cells.

PLATE 13 - Pueblo quadrangle. Total uranium. Low-pass filter using effective radius of one cell.

PLATE 14 - Pueblo quadrangle. Total uranium. High-pass filter using effective radius of one cell.

PLATE 15 - Pueblo quadrangle. Total uranium. Picture-frame filter, 3 by 3 central cell block versus annular window with effective radius of three cells.

PLATE 16 - Pueblo quadrangle. Total uranium. Kolmogorov-Smirnov filter, 3 by 3 central cell block versus annular window with effective radius of three cells.

APPENDIX A--SOME PROBLEMS WITH THE DATA FILES
RECEIVED FROM THE THREE NATIONAL LABORATORIES

We received the data files from the three national laboratories in good order and with suitable documentation. Personnel of the three laboratories were extremely cooperative in supplying us the files as soon as the data were released to the public and in discussing with us problems in reading and manipulating the files. Despite this cooperation, we had problems with the data files.

The largest problem resulted from each of the laboratories using an individual format for the data files. Each of these formats is conceptually different, and therefore we had to write several computer programs merely to restructure the data. All three formats adopted by the three laboratories are orderly, and we found few illegal characters, for example non-numeric values in fields that should contain only numeric data.

We conclude with specific comments on the data formats used by the three national laboratories.

The Savannah River Laboratory format has the advantage of presenting the data in eighty-character card images. These files were supplied on punched card decks, which were in order, complete, and easy to read into our computer. Our principal difficulty in processing these files was the inclusion of two non-numeric characters in numeric fields. One of these, the letter "M" denotes missing data and the other, a period, indicates that the detection limit is uncertain. Because the position

of these characters changes within the numeric fields, according to whether or not integer or floating point values are recorded, we had to test every value through a Fortran program in order to determine whether a non-numeric value is found in that field, and if so, replace it by a numerical code value. Had these values been present at a standard position within each field, we could have changed them through a system editing command. Although the use of these two special characters is excellent for the Savannah River Laboratory's reports, it would be much more convenient in the data tapes supplied for public use to replace these non-numeric values by coded numeric values.

The Oak Ridge National Laboratory supplied us the data files for the Seguin quadrangle in three forms: a magnetic tape, a printed listing in their report GJBX-116(78), and a microfiche record included as part of the printed report. None of these three files agreed for all stream-sediment samples. (We understand that the lack of agreement was a temporary problem that has been rectified in subsequent data releases.) The magnetic tape was that supplied to the public.

As with the data files from SRL, the ORNL files are orderly, and we detected only a few keypunching errors. The greatest difficulty with these files is that each record is 1,700 characters long, and the documentation supplied provides no cumulative count. Therefore, in order to find a variable, we had to count from the beginning of the record to the place where the variable was recorded. In order to do this, we had to make up a cumulative count of the variables and record this on a coding sheet. This task was made more difficult by minor errors in the tape description supplied to us. Another difficulty with the 1,700-character long record is that it is too long for our CDC and other computers to read without special programming. It would be much more

convenient to supply these files to the public in eighty-character long records.

The variable length fields attributable to the different sample types (stream sediment, general water, well water, botanical), together with the sampling phase, necessitate checking of flags within the data sequence (e.g. characters 551-566) in order to locate the further sampling results. However, even for the stream sediments some samples were re-analyzed, and the corresponding multielement analytical results could only be located by checking the laboratory procedure field (character 126), and then reading the appropriate repeat analytical data from characters 583-876. In such a situation, the fields for subsequent data for other methods (e.g. water) are shifted in location, their initial characters now beginning in character position 877 rather than 583. This makes it extremely difficult for the unwary to read, say, the correct water data from the file without undue reference to the preceding stream sediment fields. It would assist to include actual field counts in the documentation.

Further difficulty was caused by the need to edit the Phase 2 data owing to:

- (1) Presence of duplicate samples (20 referred to in Arendt and others, 1978, plus 015846 "which was not originally identified as a duplicate but was deleted") to be deleted from the file.
- (2) Addition of two Phase 1 samples (00342 and 010104) which "actually meet the criteria for Phase 2 so they were included in the data summarized in Appendix B (Arendt and others, 1978)."

- (3) Required deletion of samples which were not re-analyzed (002943, 002947, 009801, 013975, 015644, 013954, 013958, 013959, 015485, 015514, and 015538).

It was not apparent from the original report (Arendt and others, 1978) that changes involving: the extra sample referred to in (1), the altered status of the Phase 1 samples to Phase 2 (2), or reanalysis (3) had been undertaken. A special computer program had to be written to cross-check the analytical status of the samples and substitute re-analyzed results for the original in a number of cases (samples 2945, 2950, 2955, 4448, 4744, 5326, 5328, 5330, 5332, 5334, 5338, 5340, 5344, 5346, 5348, 5350, 5354, 6772, 6779, 6782, 6783, 8801, 8803, 8805, 8813, 8819, 8831, 8841, 9789, 9792, 9793, 9798, 9804, 9805, 9813, 9830, 10247, 10248, 10249, 10601, 10623, 10634, 15457, 15459, 15461, 15462, 15463, 15464, 15467, 15468, 15470, 15471, 15473, 15477, 15484, 15486, 15488, 15499, 15508, 15511, 15517, 15524, 15532, 15539, 15643, 15774, 15777, 15781, 15785, 15788, 15793, 15804, and 15805). While the problem caused was only temporary, we would recommend that prior to data release the documentation be rigorously cross-checked against the intended publicly available data tape, and that every effort be made to clean up the file by removal of redundant data items before release.

As with the files from the other laboratories, the files supplied by the Los Alamos Scientific Laboratory are orderly and adequately documented. LASL sent these files direct to us. The record length is 136 characters, a length more convenient than the 1,700-character record length of ORNL but much less convenient than the 80-character length of SRL. Again, we had the problem that the individual field lengths are supplied but not the cumulative counts, so that a decoding format needs to be written out,

particularly since nearly every variable has a different field length. The major difficulty in reading these files is that each one consists of a title record plus 51 record blocks in groups of four, corresponding to the four pages of 51 lines used for the printed LASL reports. Since the last page of each file contains fewer than 51 lines and because the carriage control characters are interspersed throughout the file, it is necessary to write a Fortran program to put the data into a form for processing. The files would be much more convenient to process if they were arranged in eighty-character records with convenient repetitive format statements and without the carriage control characters.

APPENDIX B. -- BOXPLOT PROGRAM FOR DISPLAYING PARTITIONED DATA

```

C*
C*      BOXPLOT PROGRAM FOR DISPLAYING PARTITIONED DATA.
C*
C*      METHOD
C*          USER PARTITIONS THE N TH VARIABLE BY SPECIFYING A PARTITIONING
C*          OR CUTOFF VALUE FOR THAT VARIABLE.  TWO BOXPLOTS ARE
C*          FOR EACH OF THE VARIABLES CORRESPONDING TO VALUES BELOW
C*          AND ABOVE THE CUTOFF VALUE OF THE N TH VARIABLE.
C*
C*      INPUT PARAMETERS/DATA
C*          1- INPUT DATA FILE NAME
C*          2- NUMBER OF VARIABLES
C*          3- READ IN VARIABLES 1 TO N IN ASCENDING ORDER
C*          4- IF ANSWER TO 3 IS NO SPECIFY INDEX NUMBERS OF VARIABLES
C*          5-PARTITIONING VALUE
C*          6- LOG TRANS ON ALL VARIABLES
C*      DATA
C*
C*      SUBPROGRAMS
C*          BOXPLOT SUBROUTINES COMPAR,FILL AND SORT REQUIRED.
C*
C*          DIMENSION VAL(650,38),W(20),SUM(20),SUMSQ(210),WMAX(20),FILIN(2),
1          TVS(20),NW(20),RES(850)
          DATA VAL/24700*0./
90  FORMAT (2A6)
92  FORMAT (A3)
          IN= 10
          KL= 0
          KG= 0
          WRITE(6,94)
94  FORMAT (" FILENAME.")
          READ(5,90) FILIN
          CHANGE(10,TITLE= FILIN)
96  FORMAT (" NUM. VAR.")
          WRITE(6,96)
          READ(5,/) N
          IF (N.LT.1.OR.N.GT.20) STOP
          WRITE(6,98)
98  FORMAT (" USE VAR. 1-N? YES/NO")
          READ(5,92) IANS
          KWT= N
          DO 10 I= 1,N
              NW(I)= I
10  CONTINUE

```


APPENDIX B. (cont'd) -- BOXPLOT PROGRAM FOR DISPLAYING
PARTITIONED DATA

```

      IF (IANS.EQ.3HYES) GO TO 14
100  FORMAT (" TYPE INDEX NUMBERS OF VARIABLES.")
      WRITE(6,100)
      READ(5,/) (NW(I),I=1,N)
      KWT= 0
      DO 12 I= 1,N
        IF (NW(I).GT.KWT) KWT= NW(I)
      12 CONTINUE
      14 WRITE(6,102) NW(N)
102  FORMAT (" PARTITIONING (CUTOFF) VALUE FOR VARIABLE",I4)
      READ(5,/) CUT
      WRITE(6,104)
104  FORMAT (" NATURAL LOG TRANSFORMATION ON ALL VARIABLES? YES/NO")
      ILSW= 1
      READ(5,92) IANS
      IF (IANS.NE.3HYES) ILSW= 0
C*    DATA READ - FORMAT IS FOR SOUTHEAST QUADRANGLES.
C*    NOTE - -9999'S ARE MISSING VALUES . OBSERVATIONS
C*    WITH MISSING VALUE VARIABLES ARE SKIPPED.
C*
      16 READ(10,106,END=32) (TVS(I),I=1,KWT)
106  FORMAT (34X,F5.1,F5.0,2F5.2,F5.0,2F5.1,F5.2,2F5.0,F5.1,
*       F5.0,F5.1,2F5.0,F5.2,F5.1,F5.0,F5.1)
      DO 18 I= 1,N
        L= NW(I)
        IF (TVS(L).LE.0.0) GO TO 16
        W(I)= TVS(L)
      18 CONTINUE
        IF (ILSW.EQ.0) GO TO 22
        TTT= W(N)
        DO 20 I= 1,N
          W(I)= ALOG(W(I))
      20 CONTINUE
      22 IF (TTT.LT.CUT) GO TO 26
        KG= KG+1
        DO 24 JJ= 1,N
          JV= JJ*2-1
          VAL(KG,JV)= W(JJ)
      24 CONTINUE
        GO TO 30
      26 KL= KL+1
        DO 28 JJ= 1,N
          JV= JJ*2
          VAL(KL,JV)= W(JJ)
      28 CONTINUE
      30 GO TO 16
      32 NN= 2*KL
        WRITE(7,108) KG,KL
108  FORMAT (// " BOXPLOTS FOR PARTITIONED DATA - HIGH-LOW."//
*       " VALUES .GE. CUTOFF",I6/" VALUES .LT. CUTOFF",I6/)

```

APPENDIX B. (cont'd) -- BOXPLOT PROGRAM FOR DISPLAYING PARTITIONED DATA

```

      DO 34 I=1,N
      WRITE(7,109)
109  FORMAT(//////////)
      WRITE(7,110) NW(I)
110  FORMAT (//2X,"VARIABLE",I3//)
      II= I*2-1
      CALL COMPAR (VAL(1,II),RES,NN,KL,2,30,0.0,3,1.0E-10)
      WRITE(7,112)
112  FORMAT(//////////)
      34 CONTINUE
      STOP
      END
      SUBROUTINE COMPAR(X,Y,N,NR,NC,IDP,ZM,NGAP,ATOM)
C*
C*      BOXPLOT SUBROUTINE FROM INTERACTIVE DATA ANALYSIS
C*      BY D. MCNEIL, JOHN WILEY, 1977.
      DIMENSION X(650,38),Y(N),IY(99),A(30),ID(999)
      DATA A/"", "1*1", "-+-", "-*-", "-+-", "-*-", "1 1", "=*=", " 1 ",
1      " X ", " "
2      , " 0 ", " 02", " 03", " 04", " 05", " 06", " 07", " 08", " 09", "
3      , " @ ", " @2", " @3", " @4", " @5", " @6", " @7", " @8", " @9"/
      NY= 0
      DO 10 I= 1,NR
        DO 10 J= 1,NC
          IF (X(I,J).EQ.ZM) GO TO 10
          NY= NY+1
          Y(NY)= X(I,J)
10  CONTINUE
      CALL SORT(Y,NY)
      WRITE(7,92) Y(NY)
      XMIN= Y(1)
      AA= (IDP-1.)/(ATOM+Y(NY)-Y(1))
      B= 1.-AA*Y(1)
      DO 16 J= 1,NC
        NZ= 0
        DO 12 I= 1,NR
          IF (X(I,J).EQ.ZM) GO TO 12
          NZ= NZ+1
          Y(NZ)= AA*X(I,J)+B
12  CONTINUE
      CALL SORT(Y,NZ)
      CALL FILL(Y,NZ,IY,IDP)
      DO 14 K= 1,IDP
14      ID(J+NC*(K-1))= IY(IDP+1-K)
      CONTINUE
16  CONTINUE
      DO 18 K= 1,IDP
        WRITE(7,90) (A(1+ID(J+NC*(K-1))),J=1,NC)
18  CONTINUE
90  FORMAT (20(3X,A3))

```

APPENDIX B. (cont'd) -- BOXPLOT PROGRAM FOR DISPLAYING
PARTITIONED DATA

```

      WRITE(7,92) XMIN
92  FORMAT (F12.3)
      RETURN
      END
      SUBROUTINE FILL(X,N,IY,ISIZE)

```

```

C*
C*      BOXPLOT SUBROUTINE FROM INTERACTIVE DATA ANALYSIS
C*      BY D. MCNEIL, JOHN WILEY, 1977.
      DIMENSION X(N),IY(ISIZE)
      ZL= 0.5*(X(INT(0.25*N+0.75))+X(INT(0.25*N+1.)))
      ZM= 0.5*(X(INT(0.5*N+0.75))+X(INT(0.5*N+1.)))
      ZU= 0.5*(X(INT(0.75*N+0.75))+X(INT(0.75*N+1.)))
      D= ZU-ZL
      IL= MAX0(INT(0.5+ZL-1.5*D),1)
      I2= MAX0(INT(0.5+ZL-D),1)
      I3= INT(0.5+ZL)
      I4= INT(0.5+ZM)
      I5= INT(0.5+ZU)
      I6= MIN0(INT(0.5+ZU+D),ISIZE)
      I7= MIN0(INT(0.5+ZU+1.5*D),ISIZE)
      DO 10 K= 1,ISIZE
        IY(K)= 20
10  CONTINUE
      DO 12 K= IL,I7
        IY(K)= 10
12  CONTINUE
      DO 14 K= I2,I5
        IY(K)= 0
14  CONTINUE
      DO 16 J= 1,N
        JJ= J
        IE= INT(0.5+X(J))
        IF (IE.GE.IL) GO TO 18
        IY(IE)= IY(IE)+1
16  CONTINUE
18  DO 20 K= 1,N
        IE= INT(0.5+X(N+1-K))
        IF (IE.LE.I7) GO TO 22
        IY(IE)= IY(IE)+1
20  CONTINUE
22  DO 24 L= JJ,N
        IE= INT(0.5+X(L))
        IF (IE.GE.I2) GO TO 26
        IY(IE)= IY(IE)+1
24  CONTINUE
26  DO 28 M= K,N
        IG= INT(0.5+X(N+1-M))
        IF (IG.LE.I6) GO TO 30
        IY(IG)= IY(IG)+1
28  CONTINUE

```

APPENDIX B. (cont'd) -- BOXPLOT PROGRAM FOR DISPLAYING
PARTITIONED DATA

```

30 DO 32 J= IE,IG
    IY(J)= 9
32 CONTINUE
    IY(IE)= 9
    IY(IG)= 9
    DO 34 J= I3,I5
        IY(J)= 6
34 CONTINUE
    IY(I3)= 0
    IY(I5)= 0
    IY(I4)= 1
    IY(I3)= IY(I3)+2
    IY(I5)= IY(I5)+4
    DO 36 I= IL,I7
        IY(I)= MIN0(IY(I),19)
36 CONTINUE
    DO 38 I= 1,ISIZE
        IY(I)= MIN0(IY(I),29)
38 CONTINUE
    RETURN
    END
    SUBROUTINE SORT(X,N)
    DIMENSION X(N)
    I= 1
10 I= I+1
    IF (I.LE.N) GO TO 10
    M= I-1
12 M= M/2
    IF (M.EQ.0) RETURN
    K= N-M
    DO 16 J= 1,K
        KK= J
14 IF (KK.LT.1) GO TO 16
        IF (X(KK+M).GE.X(KK)) GO TO 16
        W= X(KK+M)
        X(KK+M)= X(KK)
        X(KK)= W
        KK= KK-M
        GO TO 14
16 CONTINUE
    GO TO 12
    END

```

APPENDIX G. -- EXPLANATION AND LISTING OF THE ROCK CODES

For the Southeastern area and the Pueblo quadrangle, one of us (SFC) assigned an eight digit code for each stream sediment sample site which would denote the general rock type for that sample. For the Seguin quadrangle, ORNL assigned codes.

The rock code for the four southeast two degree sheets is based on Robert Butler's classification on the geologic maps in three of the SRL reports. The coding for the Greenville sheet compiled by Robert Hatcher was changed to Butler's classification. The code is broken down into four sub-divisions -- the physiographic region or province, rock type, age and specific location or name.

1. The first two columns reflect the physiographic region or province in which the sample was taken. The number code is the same as that on Butler's geologic map except that numbers were assigned for the Coastal Plain, Triassic basins and the Brevard zone.
2. Columns 3 and 4 denote the underlying rock type or formation(s). The letter code on Butler's geologic maps serves as a base for this classification.
3. Columns 5 and 6 denote the age or grouping of intrusive rock. "-X" or "--" indicates that the age is unknown. Other letters are the same as the geologic maps in the SRL reports.
4. The last two columns pertain to specific names or locations of intrusive rocks. On the Greenville sheet, metagranites which have no formal place name were assigned a number. Triassic basins were assigned a letter designation (A, B, or C).

In addition to the 8-column rock code, each sample was also assigned a number (1, 2, or 3) to denote whether it was taken in one of the three monazite belts in the southeast (Mountain, Western, or Eastern belt). The number 9 indicates that the sample is outside any of the belts.

Pueblo

The rock codes for the Pueblo 2⁰ sheet are based on the published geologic map. Because of the number of rock units on the map, several of the units were lumped together.

1. Members on the geologic map were lumped under the formation name (e.g. the Pierre Shale).
2. Localized volcanic units were listed together.
3. Granites from particular intrusive centers were listed under one code.

The 8-column code is divided into four units.

1. The first two columns represent the age (or ages if lumped) by letters, numbers, and hyphens. For instance, -K = Cretaceous age rocks, JP = Jurassic to Permian rocks.
2. Columns 3 and 4 indicate the general rock type.
3. Columns 5 and 6 represent the region the sample was taken in (thirty mile region, Cripple Creek - Divide region).
4. Columns 7 and 8 indicate the formation name(s) or the intrusive center in the Pikes Peak batholith.

TABLE C-1. - Geologic distribution of sample sites in the four southeastern quadrangles by physiographic province.

Number of sites	Rock code	Geologic unit(s)
40	07-A----	Valley and Ridge Province, Chilhowee Group (Cambrian)
118	07-B----	Valley and Ridge Province, Shady Dolomite, Rome Fm., Conasauga Gp. Cambrian
42	07-C----	Valley and Ridge Province, Knox Gp. (Upper Cambrian and Lower Ordovician)
14	07-D----	Valley and Ridge Province, Chickamauga Gp. and Younger Ordovician
45	07-E----	Valley and Ridge Province, Silurian, Devonian, and Miss. rocks
234	01-----	Blue Ridge Belt, Layered to Massive Gneiss (> 1 B.Y.), (Basement)
60	02-A----	Blue Ridge Belt, Amphibolite
29	03-E----	Blue Ridge Belt, Calcareous Suite (1 B.Y.), Elk Park Plutonic Group

TABLE G-1. - (Continued)

Number of sites	Rock code	Geologic unit(s)
2	02-GCFSP	Blue Ridge Belt, Crossnore Felsic Group, Striped Rock
12	03CF----	Blue Ridge Belt, Felsic Rocks, Crossnore Plutonic-Volcanic Group
436	02-C----	Blue Ridge Belt, Gneiss
293	02-----	Blue Ridge Belt, Gneiss, Schist, Amphibolites
3	03CM----	Blue Ridge Belt, Mafic, Crossnore Plutonic-Volcanic Group
18	02-G-T15	Blue Ridge Belt, Metagranite, Fifteen
5	03-G-SWK	Blue Ridge Belt, Metagranite, Wolk Creek Rocks
50	02-D----	Blue Ridge Belt, Metasedimentary Rocks
1	03-S----	Blue Ridge Belt, Pegmatites, Alaskite, Granodiorite, (Ap. 380 M.Y. Pegmatite)
45	02-B----	Blue Ridge Belt, Schist

TABLE C-1. - (Continued)

Number of sites	Rock code	Geologic unit(s)
2	02-G-SMA	Blue Ridge Belt, Spruce Pine Gp., Mt. Airy
9	02-G-SSO	Blue Ridge Belt, Spruce Pine Gp., Stone Mtn.
8	03UM----	Blue Ridge Belt, Ultramafic and Related Rocks
3	06-A----	Smith River Allochthon, Amphibolite
58	06-C----	Smith River Allochthon, Gneiss
9	06-G----	Smith River Allochthon, Granitic Rocks
3	06-M----	Smith River Allochthon, Mafic Rocks
25	06-B----	Smith River Allochthon, Schist
37	05-D----	Inner Piedmont, Augen Gneiss, Henderson Gneiss
330	05BG----	Inner Piedmont, Gneiss
19	05-G-RCR	Inner Piedmont, Granite (345 M.Y.), Cherryville Quartz Monzonite

TABLE C-1.- (Continued)

Number of sites	Rock code	Geologic unit(s)
16	05-G-REL	Inner Piedmont, Granite Elberton
4	05-G-XPM	Inner Piedmont, Granite, Pacolet Mills Pluton
7	05-G-TTU	Inner Piedmont, Granite (535 M.Y.), Toluca Quartz Monzonite
77	05-G----	Inner Piedmont, Granitic Rocks
64	05-A----	Inner Piedmont, Hornblende Gneiss, Amphibolite
3	05-G-R05	Inner Piedmont, Metagranite, Five
4	05-G-R06	Inner Piedmont, Metagranite, Six
9	05-G-T07	Inner Piedmont, Metagranite, Seven
25	05-G-T08	Inner Piedmont, Metagranite, Eight
22	05-G-T09	Inner Piedmont, Metagranite, Nine
3	05-G-T10	Inner Piedmont, Metagranite, Ten
36	05-G-T11	Inner Piedmont, Metagranite, Eleven
8	05-G-T12	Inner Piedmont, Metagranite, Twelve

TABLE C-1.- (Continued)

Number of sites	Rock code	Geologic unit(s)
41	05-G-T13	Inner Piedmont, Metagranite, Thirteen
47	05-G-T14	Inner Piedmont, Metagranite, Fourteen
783	05BS----	Inner Piedmont, Schist
30	05-B----	Inner Piedmont, Schist and Gneiss
8	08-G----	Kings Mtn. Belt, Granite
2	08-G-T--	Kings Mtn. Belt, Granite (535 M.Y.), Toluca Quartz Monzonite (Ap. 535 M.Y.)
15	08-H----	Kings Mtn. Belt, High Shoals Granitic Gneiss
4	08-T----	Kings Mtn. Belt, Metatonalite
128	08-K----	Kings Mtn. Belt, Schist, Gneiss, Quartzite, Conglomerate, Marble
219	04-A----	Charlotte Belt, Diorite, Tonalite, Gneiss
10	04VF----	Charlotte Belt, Felsic Metavolcanic Rocks

TABLE C-1.- (Continued)

Number of sites	Rock code	Geologic unit(s)
20	04GA-N--	Charlotte Belt, Gabbro (413 M.Y.), Concord Plutonic Group
6	04GA-NDU	Charlotte Belt, Gabbro (413 M.Y.), Dutchmans Pluton
2	04GA-NFA	Charlotte Belt, Gabbro (413 M.Y.), Farmington Pluton
4	04GA-NME	Charlotte Belt, Gabbro (413 M.Y.), Mecklenburg Pluton
8	04GA-NOG	Charlotte Belt, Gabbro (413 M.Y.), Ogden Pluton
2	04GA-NSR	Charlotte Belt, Gabbro (413 M.Y.), South Rock Hill Pluton
5	04-G-L--	Charlotte Belt, Granite (300 M.Y.)
162	04-G----	Charlotte Belt, Granite (Age Unknown)
22	04-G-XBR	Charlotte Belt, Granite, Bald Rock Pluton
18	04-G-LCH	Charlotte Belt, Granite (300 M.Y.), Churchland

TABLE C-1.- (Continued)

Number of sites	Rock code	Geologic unit(s)
1	04-G-LCL	Charlotte Belt, Granite (300 M.Y.), Clover Pluton
4	04-G-XED	Charlotte Belt, Granite, Edgemoor Pluton
10	04-G-T04	Charlotte Belt, Granite, Four
5	04-G-YGD	Charlotte Belt, Granite (400 M.Y.), Gold Hill Pluton
4	04-G-XGF	Charlotte Belt, Granite, Great Falls Pluton
3	04-G-LLN	Charlotte Belt, Granite (300 M.Y.), Landis Pluton
14	04-G-XLO	Charlotte Belt, Granite, Lowry's Pluton
2	04-G-LMC	Charlotte Belt, Granite (300 M.Y.), McConnells Pluton
9	04-G-XNW	Charlotte Belt, Granite, Newberry Pluton
4	04-G-YSA	Charlotte Belt, Granite (400 M.Y.), Salisbury Pluton

TABLE C-1.- (Continued)

Number of sites	Rock code	Geologic unit(s)
4	04-G-XST	Charlotte Belt, Granite, Santuck Pluton
8	04-G-LWN	Charlotte Belt, Granite (300 M.Y.), Winnsboro Complex
1	04-G-YYD	Charlotte Belt, Granite (400 M.Y.), Yadkin Pluton
6	04-G-LYK	Charlotte Belt, Granite (300 M.Y.), York Pluton
7	04VM----	Charlotte Belt, Mafic Metavolcanic Rocks
60	04-M----	Charlotte Belt, Metagabbro, Amphibolite
2	04-G-R01	Charlotte Belt, Metagranite, One
1	04-G-R02	Charlotte Belt, Metagranite, Two
11	04-G-T03	Charlotte Belt, Metagranite, Three
39	04-B----	Charlotte Belt, Schist, Gneiss, Quartzite
415	04-U----	Charlotte Belt, Undivided

TABLE C-1.- (Continued)

Number of sites	Rock code	Geologic unit(s)
5	09CF----	Carolina Slate Belt, Flat Swamp Volcanic Rocks
3	09-G----	Carolina Slate Belt, Granite
23	09-G-LLH	Carolina Slate Belt, Granite (300 M.Y.), Liberty Hill Pluton
2	09-G-LLI	Carolina Slate Belt, Granite (300 M.Y.), Lilesville Pluton
9	09-G-LPA	Carolina Slate Belt, Granite (300 M.Y.), Pageland Pluton
180	09-G----	Carolina Slate Belt, McManus Fm.
103	09-B----	Carolina Slate Belt, Tillery, Richtex Fms.
71	09-U----	Carolina Slate Belt, Undivided
100	09-A----	Carolina Slate Belt, Uwharrie, Wildhorse Branch, Persimmon Fork Fms.
18	09-D----	Carolina Slate Belt, Yadkin Graywacke
35	12-----C	Triassic Basins, Charlotte (SE) and Spartanburg (NE)

TABLE C-1.- (Continued)

Number of sites	Rock code	Geologic unit(s)
14	12-----A	Triassic Basins, Winston-Salem Sheet (ES)
5	12-----B	Triassic Basins, Winston-Salem Sheet and Small Portion of Charlotte Sheet
4	10GN----	Kiokee Belt, Gneiss and/or Granite
12	11-Q----	Coastal Plain, Alluvium
7	11KB----	Coastal Plain, Black Creek Fm., (Cretaceous)
38	11EB----	Coastal Plain, Black Mingo Fm. (Eocene)
17	11MD----	Coastal Plain, Duplin Marl (Miocene)
166	11KM----	Coastal Plain, Middendorf Fm., May include Tertiary Pinehurst Fm. - Cretaceous/Tertiary

TABLE C-2. - Geologic distribution of sample sites studied in the Seguin quadrangle.

Number of sites	Rock code	Geologic unit(s)
25	QD	Alluvium Fluviatile Terrace Deposits
32	QPB	Beaumont Formation
35	QPLI	Lissie Formation
70	TQGW	Willis Formation Goliad Formation
105	TMF	Fleming Formation Oakville Formation
20	TOC	Catahoula Formation Whitsett Formation
34	TEJ	Manning Formation Wellborn Formation Caddell Formation
29	TECY	Yegua Formation
24	TECL	Cook Mountain Formation Sparta Sand Formation
46	TEMS	Weches Formation Queen City Sand Reklaw Formation
9	TECC	Carrizo Sand
43	TPWM	Wilcox Group Midway Group

TABLE C-3. - Geologic distribution of sample sites in the Pueblo quadrangle.

Number of sites	Rock code	Geologic unit(s)
85	-Q-Z----	Quaternary, alluvium, _____,
28	-Q-W----	Quaternary, colluvium, _____,
1	-Q-T----	Quaternary, travertine, _____,
86	-QES----	Quaternary, windblown sand, _____, _____
99	-Q-J----	Quaternary, glacial, _____,
29	-QJZ----	Quaternary, interglacial alluvium, _____, _____
3	-T-XTMDU	Tertiary, fluvial, Thirtynine Mile area, Dry Union Fm.
5	-TCSWDSF	Tertiary, conglomerate and sand, Wet Mtn. and Rosita-Deer Peak Area, Santa Fe Fm.
13	-TSCTMWG	Tertiary, sand and gravel, Thirtynine Mile area, Wagon Tongue Fm.

TABLE C-3. - (Continued)

Number of sites	Rock code	Geologic unit(s)
4	-TSCDDI	Tertiary, sand and gravel, Cripple Ck.-Divide, Divide
10	-TRAWD--	Tertiary, rhyolite to andesite, Wet Mtn. and Rosita-Deer Peak, -----
1	-TRTTMGE	Tertiary, rhyolite ash-flow tuffs, Thirtynine Mile area, Gribbles to East Gulch
12	-TITTMBA	Tertiary, intermediate tuffs, Thirtynine Mile area, Badger- Antero Fm.
73	-T-ATMTM	Tertiary, andesite, Thirtynine Mile area, Thirtynine Mile Andesite
4	-TRATMGU	Tertiary, rhyolite to andesite, Thirtynine Mile area, Guffey
4	-TAVCDFL	Tertiary, andesitic volcanic rocks, Cripple Ck.-Divide, Florissant Lake Beds
7	-TVCTMTC	Tertiary, volcanic conglomerate, Thirtynine Mile area, Tallahassee Ck.

TABLE C-3. -(Continued)

Number of sites	Rock code	Geologic unit(s)
2	-TRT--WM	Tertiary, rhyolite tuff, _____, Wall Mtn. Tuff
2	-TCZ--EP	Tertiary, conglomerate alluvium, _____, Echo Park
1	-TAKTMSP	Tertiary, andesitic sediments, Thirtynine Mile area, South Park Fm.
14	TKAKCSDF	Tertiary-Cretaceous, andesitic sediments, Colorado Springs, Dawson Fm.
13	-K-SCATV	Cretaceous, sandstone, Canon City area, Trinidad and Vermejo Fms.
3	-K-SCSLF	Cretaceous, sandstone, Colorado Springs Area, Laramie and Fox Hills Fms.
64	-K-H--PS	Cretaceous, shale, _____, Pierre shale
9	-KGD TMWH	Cretaceous, granodiorite, Thirty- nine Mile area, Whitehorn Granodiorite

TABLE C-3.- (Continued)

Number of sites	Rock code	Geologic unit(s)
53	-K-L--NI	Cretaceous, limestone, _____, Niobrara Fm.
42	-KLH--CG	Cretaceous, limestone and shale, _____, Carlile to Graneros Fms.
32	-K-S--DS	Cretaceous, sandstone, _____, Dakota Sandstone
6	JP-S--ML	Jurassic to Permian, sandstone, _____, Morrison to Lyons Fms.
16	PPCS--SC	Permian and Pennsylvanian, conglomerate and sandstone, _____, Sangre de Cristo Fm.
28	PN-K--MB	Pennsylvanian, sediments, _____, Minturn and Belden Fms.
17	PPCS--FN	Permian and Pennsylvanian, conglomerate and sandstone, _____, Fountain Fm.
9	MO-L----	Mississippian to Ordovician, limestones, _____, _____
4	OCLS----	Ordovician to Cambrian, limestone and sandstone, _____

TABLE C-3. - (Continued)

Number of sites	Rock code	Geologic unit(s)
5	-C-Y----	Cambrian, syenite, _____
61	-Y-GPPPP	Precambrian Y, granite, Pikes Peak (1 B.Y.), Pikes Peak granite
9	-YQMSPCC	Precambrian Y, quartz monzonite, Silver Plume (1.45 B.Y.), Cripple Creek
1	-YQMSP--	Precambrian Y, quartz monzonite, Silver Plume (1.45 B.Y.), _____
14	-Y-GSPSI	Precambrian Y, granite, Silver Plume (1.45 B.Y.), San Isabel Granite
6	-YQMSPEM	Precambrian Y, quartz monzonite, Silver Plume (1.45 B.Y.), Eleven- mile Canyon
6	-XQMBC--	Precambrian X, quartz monzonite, Boulder Creek (1.7 B.Y.), _____
56	-XGDBC--	Precambrian X, granodiorite, Boulder Creek (1.7 B.Y.), _____
3	-XQDBC--	Precambrian X, quartz diorite, Boulder Creek (1.7 B.Y.), _____

TABLE G-3. - (Continued)

Number of sites	Rock code	Geologic unit(s)
1	-XBU----	Precambrian X, gabbro and ultramafic rocks, _____, _____
98	-X-N----	Precambrian X, gneiss, _____, _____
14	-XON----	Precambrian X, biotite gneiss, _____, _____
4	-X-P----	Precambrian X, metavolcanics and metasedimentary, _____, _____

TABLE C-4. - Geologic distribution of sample sites in the Tallahassee Creek area of the Pueblo quadrangle.

Number of sites	Rock code	Geologic unit(s)
4	-TAFTM--	Andesite of Waugh Mountain (Miocene) Andesite and basaltic flows, flow breccias, lahars, and tuffs
4	-TRTTMGE	Gribbles Park, Thorn Ranch, and East Gulch Tuffs (Oligocene) Rhyolite ash-flow tuff
92	-T-ATMTM	Thirtynine Mile Andesite (Oligocene) Lower member Laharic breccia from local vents
5	-TMFTM--	Biotite Andesite (Oligocene) Flow-layered dome and domal lavas
28	-TVCTMTC	Tallahassee Creek Conglomerate (Oligocene) Poorly sorted, bouldery, volcanic conglomerate more than 105 m thick in paleovalleys
2	-TRT--WM	Wall Mountain Tuff (Oligocene) Rhyolite ash-flow tuff

TABLE C-4. - (Continued)

Number of sites	Rock code	Geologic unit(s)
58	-TCZ--EP	Echo Park Alluvium (Eocene) Poorly sorted arkosic gravel and conglomerate more than 300 m thick in paleovalleys and grabens
21	-YQMSP--	Quartz Monzonite (Precambrian Y)
76	-XGDBC--	Granodiorite (Precambrian X) Quartz diorite forms borders of granodiorite plutons
21	-X-N----	Metamorphic Rocks (Precambrian X) metagabbro, migmatitic gneiss, biotite gneiss, and metavolcanic and metasedimentary rocks

APPENDIX D -- RESIDUAL ANOMALIES IN THE SOUTHEASTERN AREA

TABLE D-1. - Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Valley and Ridge Province.

Rock units	$\bar{w}_{UR}$	$\bar{w}_{UO}$	$\bar{w}_{ThR}$	$\bar{w}_{ThO}$	$\bar{w}(\bar{w}_{UR}-\bar{w}_{ThR})$	No. of UO values	No. of anom. samples	UR-thresh-old
Entire Valley and Ridge	2.07	3.78	-2.15	9.25	4.21	248	0	-
Lower Cambrian	2.65	4.93	-3.67	13.39	6.31	40	0	-
Middle Cambrian	2.43	4.02	-2.94	9.58	5.37	118	0	-
Upper Cambrian - Lower Ordovician	1.15	2.65	.13	7.05	1.02	42	0	-
Silurian - Mississippian	1.71	3.28	-1.10	6.73	2.82	45	0	-

TABLE D-2. - Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Blue Ridge Province.

Rock units	$\bar{w}_{UR}$	$\bar{w}_{UO}$	$\bar{w}_{ThR}$	$\bar{w}_{ThO}$	$\bar{w}(\bar{w}_{UR}-\bar{w}_{ThR})$	No. of UO values	No. of anom. samples	UR- thresh- old
Blue Ridge (Total)	2.77	7.60	-5.34	29.22	8.11	1164	11	15
Basement (> 1,000 m.y.)								
Gneisses	2.95	6.34	-1.80	18.60	4.75	229	0	-
Metasedimentary rocks (mainly gneisses and schists)	2.63	7.96	-6.31	32.76	8.93	880	10	15
Late Precambrian and Paleozoic Intrusive rocks	4.22	7.21	-4.9	16.74	9.14	55	1	15

TABLE D-3. - Listing of anomalous samples according to rock-type in the Blue Ridge Province.

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
Metasedimentary Rocks ($\bar{w}UR = 2.63$ ppm; $t = 15$ ppm selected from break in slope; 10 anomalous localities)										
NCSU057S1	36.3881	80.6740	14.42	15.94	17.00	1.52	3.00	6.1	5.7	34.0
NCYD031S1	36.1709	80.6316	61.88	22.68	30.40	-39.21	89.00	8.6	.34	2.9
GAFD012S1	34.3153	83.9681	27.01	15.29	51.60	-11.72	266.00	5.8	.19	1.1
GAHA013S1	34.7032	83.5879	48.45	18.92	30.20	-29.53	69.00	7.2	.43	3.2
GAHA014S1	34.6883	83.5593	45.08	15.40	26.80	-29.68	26.00	5.9	1.0	5.9
GAHA026S1	34.6698	83.6008	63.75	22.81	31.80	-40.94	74.00	8.7	.42	3.7
GAHA060S1	34.6914	83.4571	42.53	18.06	46.10	-24.47	97.00	6.9	.47	3.3
GALU016S1	34.6309	83.9894	69.73	19.82	62.00	-49.92	318.00	7.5	.19	1.5
GAUN045S1	34.7711	83.8831	102.21	22.22	39.60	-80.00	225.00	8.4	.18	1.5
GAWI033S1	34.6504	83.8549	109.67	17.85	39.40	-91.82	210.00	6.8	.19	1.3
Late Precambrian and Paleozoic Intrusive Rocks ($\bar{w}UR = 4.22$; $t = 15$ ppm, arbitrarily selected; 1 anomalous locality)										
GAHA015S1	34.6587	83.5402	48.86	19.41	28.30	-29.45	45.00	4.6	.62	2.9

TABLE D-4. - Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Brevard Zone.

Rock units	$\bar{w}UR$	$\bar{w}UO$	$\bar{w}ThR$	$\bar{w}ThO$	$\bar{w}(\bar{w}UR-\bar{w}ThR)$	No. of UO values	No. of anom. samples	UR-thresh-old
Brevard zone	3.63	7.59	-3.30	19.85	6.94	82	3	14

TABLE D-5. -Listing of anomalous samples according to rock-type in the Brevard Zone.

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{\bar{w}ThO}$	Priority value
Brevard Zone ($\bar{w}UR = 3.63$; $t = 15$ ppm, selected from break in slope; 3 anomalous localities)										
SCOC103S1	34.9294	82.9859	6.35	28.39	45.10	22.04	45.00	7.8	1.00	7.8
SCOC125S1	34.9150	83.0676	53.91	20.47	63.20	-33.43	191.00	5.6	.32	1.8
SCOC091S1	34.9294	82.9859	26.73	14.05	21.70	-12.68	5.00	3.8	2.81	10.7

TABLE D-6. - Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Smith River Allochthon - Sauratown Mountain Anticlinorium.

Rock units	$\bar{w}UR$	$\bar{w}UO$	$\bar{w}ThR$	$\bar{w}ThO$	$\bar{w}(\bar{w}UR - \bar{w}ThR)$	No. of UO values	No. of anom. samples	UR- thresh- old
Smith River Allochthon, Sauratown Mts. Anticlinorium	3.78	6.02	-4.47	14.44	8.25	90	0	-

TABLE D-7. - Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Kings Mountain Belt.

Rock units	$\bar{w}_{UR}$	$\bar{w}_{UO}$	$\bar{w}_{ThR}$	$\bar{w}_{ThO}$	$\bar{w}(\bar{w}_{UR}-\bar{w}_{ThR})$	No. of UO values	No. of anom. samples	UR-thresh-old
Kings Mtn. Belt (Total)	.91	4.50	2.99	14.62	-2.09	147	0	-
High Shoals Granitic Gneiss	2.05	7.44	5.21	25.80	-3.16	15	0	-
Schist, gneiss, quartzite, marble	1.66	4.04	2.34	12.42	-1.52	128	0	-

TABLE D-8. - Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Charlotte Belt.

Rock units	$\bar{w}_{UR}$	$\bar{w}_{UO}$	$\bar{w}_{ThR}$	$\bar{w}_{ThO}$	$\bar{w}(\bar{w}_{UR}-\bar{w}_{ThR})$	No. of UO values	No. of anom. samples	UR-thresh-old
Charlotte Belt (all)	1.97	5.52	.44	15.4	1.53	1085	13	15
400 m.y. old plutons	2.43	4.68	1.83	7.73	.61	15	0	-
300 m.y. old plutons	5.56	11.26	6.38	20.38	-.82	69	2	20
Charlotte belt granites (age unknown)	3.13	8.23	5.16	20.84	-2.04	281	3	25
Gabbro	3.21	2.69	-15.43	6.59	18.65	42	1	20
Diorite Tonalite Gneiss	1.55	3.93	-.13	10.28	1.67	219	0	-
Schist, Gneiss, Quartzite	3.76	6.28	-.74	17.32	4.50	39	0	-
Felsic Metavolcanic Rocks	.51	1.39	.38	3.22	.14	10	0	-
Mafic Metavolcanic Rocks	.95	1.98	-.26	4.28	1.21	7	0	-
Metagranites	.78	3.08	1.27	10.85	-.49	14	0	-
Undivided gneisses (mainly)	1.27	5.28	.42	16.14	1.23	414	6	10
Metagabbro, amphibolite	1.45	3.49	-4.63	11.71	.58	59	1	10

TABLE D-9. - Listing of anomalous samples according to rock-type in the Charlotte Belt.

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
300 m.y. plutons ($\bar{w}UR = 5.56$; $t = 20$ ppm, selected from break in slope, 2 anomalous localities)										
SCUN025S1	34.8416	81.6353	-1.72	34.99	48.60	36.71	49.00	6.3	1	6.3
SCFA041S1	34.3748	81.1515	24.50	30.99	51.40	6.49	49.00	5.6	1	5.6
All Charlotte Belt granites ($\bar{w}UR = 3.13$; $t = 25$ ppm, selected from break in slope, 3 anomalous localities, including the two given above for 300 m.y. plutons. Additional anomalous locality given below)										
NCDV065S1	35.9068	80.3268	10.54	37.03	53.20	26.49	54.00	11.83	1	11.8
Charlotte Belt Gabbros ($\bar{w}UR = 3.21$; $t = 20$, selected arbitrarily)										
NCCA049S1	35.3905	80.6262	394.27	61.95	6.60	-332.31	26.00	19.3	.25	4.8

TABLE D-9. (Continued)

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
Undivided (mainly gneisses) ($\bar{w}UR = 1.27$; $t = 10$ ppm, selected from break in slope, 6 anomalous localities)										
SCFA044S1	34.3414	81.1764	-15.65	18.18	53.70	33.83	102.00	14.3	.53	7.5
SCLU115S1	34.3806	81.9867	15.64	11.09	20.60	-4.54	31.00	8.7	.66	5.8
SCNE034S1	34.2232	81.8790	11.99	10.89	21.10	-1.10	17.00	8.6	1.24	10.7
SCNE089S1	34.3761	81.6253	15.63	14.64	18.60	-.99	23.00	11.5	.81	9.3
SCNE105S1	34.4771	81.6080	-29.33	19.32	43.00	48.65	80.00	15.2	.54	8.2
SCUN065S1	34.5631	81.5294	16.88	11.04	18.60	-5.85	16.00	8.7	1.16	10.1
Metagabbro, amphibolite ($\bar{w}UR = 1.45$; $t = 10$ ppm, selected arbitrarily, 1 anomalous locality)										
SCCS028S1	34.6372	81.2870	62.57	11.08	2.40	-51.49	3.00	7.6	.80	6.1

TABLE D-10. -Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Slate Belt Province.

Rock units	$\bar{w}_{UR}$	$\bar{w}_{UO}$	$\bar{w}_{ThR}$	$\bar{w}_{ThO}$	$\bar{w}(\bar{w}_{UR}-\bar{w}_{ThR})$	No. of UO values	No. of anom. samples	UR-thresh-old
Entire Slate Belt	1.53	7.34	3.95	33.50	-2.41	508	($>t_2$) 2 ($>t_1$) 1	$t_1 = 10$ $t_2 = 20$
Granites in Slate Belt	3.08	19.36	9.68	77.86	-6.59	37	2	15
Uwharrie, Wildhorse Branch, Persimmon Fork Formations	1.75	5.38	.79	19.10	.97	100	1	15
Slate Belt, Undivided	1.03	2.31	-.45	6.16	1.47	71	0	-
Tillery, Richtex Formations	2.08	5.01	.34	18.46	1.73	103	0	-
Yadkin Graywacke	.51	1.55	.77	4.31	-.26	18	0	-
McManus Fm.	1.04	9.98	8.67	54.48	-7.63	179	2	12

TABLE D-11. - Listing of anomalous samples according to rock-type in the Slate Belt.

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
Granites in Slate Belt ($\bar{w}UR = 3.08$; $t = 15$ ppm UR, selected at break in slope; 1 anomalous localities)										
SCKE070S1	34.4234	80.7162	59.35	16.72	10.30	-42.63	11.00	5.4	.94	5.0
Uwharrie, Wildhorse Branch, Persimmon Fork Formation ($\bar{w}UR = 1.75$ ppm; $t = 15$ ppm, selected at break in slope; 1 anomalous locality)										
SCRI065S1	34.1895	81.0068	-5.52	49.77	129.50	55.29	451.00	28.4	.28	8.1
McManus Fm. ($\bar{w}UR = 1.04$; $t = 12$ ppm UR, selected from break in slope; 2 anomalous localities)										
SCKE091S1	34.4142	80.5757	-2.51	15.87	56.60	18.38	200.00	15.2	.28	4.3
SCKE098S1	34.5035	80.5624	-3.94	13.24	80.90	17.19	415.00	12.7	.19	2.4

TABLE D-12. - Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Triassic Basins.

Rock units	$\bar{w}UR$	$\bar{w}UO$	$\bar{w}ThR$	$\bar{w}ThO$	$\bar{w}(\bar{w}UR-\bar{w}ThR)$	No. of UO values	No. of anom. samples	UR-thresh-old
Triassic Basins	1.86	4.63	.32	26.8	1.54	52	1	10

TABLE D-13. - Listing of anomalous samples according to rock-type in Triassic Basins.

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
Triassic Basins ($\bar{w}UR = 1.86$ ppm; $t = 10$ ppm, selected arbitrarily; 1 anomalous locality)										
NCDE015S1	36.0146	80.6296	9.36	10.98	14.20	1.63	15.00	5.9	.94	5.6

TABLE D-14. - Summary of average uranium and thorium concentrations (ppm) in minus 100-mesh alluvium in the Coastal Plain Province.

Rock units	$\bar{w}UR$	$\bar{w}UO$	$\bar{w}ThR$	$\bar{w}ThO$	$\bar{w}(\bar{w}UR - \bar{w}ThR)$	No. of UO values	No. of anom. samples	UR- thresh- old
Entire Coastal Plain	6.19	24.93	11.43	95.73	-5.23	221	6	25
Black Mingo Fm.	6.23	20.93	8.11	74.39	-1.88	38	1	20
Middendorf Fm.	6.31	26.91	13.11	105.03	-6.79	166	4	30
Duplin Marl	5.56	13.60	-.10	44.88	5.66	17	1	10

TABLE D-15. - Listing of anomalous samples according to rock-type in the Coastal Plain.

Sample number	Latitude	Longitude	UR-ThR	UR	UO	ThR	ThO	$\frac{UR}{\bar{w}UR}$	$\frac{UO}{ThO}$	Priority value
Black Mingo Fm. ($\bar{w}UR = 6.23$; $t = 20$ ppm, selected at break in slope; 1 anomalous locality)										
SCLE001S1	34.1521	80.3139	-16.82	50.19	177.70	67.01	703.00	8.1	.25	2.0
Middendorf Fm. ($\bar{w}UR = 6.31$; $t = 30$ ppm, selected at break in slope; 4 anomalous localities)										
SCKE015S1	34.1679	80.4826	10.53	46.26	124.90	35.74	393.00	7.3	.32	2.3
SCLE003S1	34.2210	80.3517	.25	52.78	157.30	52.53	572.00	8.4	.28	2.3
SCLE015S1	34.2677	80.2816	34.53	43.94	104.60	9.41	373.00	7.0	.28	2.0
SCRI090S1	34.0128	80.7038	9.34	30.94	90.70	21.60	354.00	4.9	.26	1.3
Duplin Marl ($\bar{w}UR = 5.56$; $t = 10$ ppm, selected at break in slope; 1 anomalous sample)										
SCLE028S1	34.0720	80.1682	9.44	30.14	101.90	20.71	418.00	5.4	.24	1.3

37°N

PRINCIPAL GEOLOGIC FEATURES

VR	Valley and Ridge
BR	Blue Ridge
GFW	Grandfather Mtn. Window
BZ	Brevard Zone
SRA	Smith River Allochthon
SMA	Sauratown Mtn. Anticlinorium
IP	Inner Piedmont
KMB	Kings Mtn. Belt
CB	Charlotte Belt
SB	Slate Belt
TRB	Triassic Basin
CP	Coastal Plain

34°N

80°W

84°W

PLATE 17 - Southeastern area, basic geology. Winston-Salem quadrangle (northernmost), Charlotte quadrangle (central), Spartanburg quadrangle (southeast), and Greenville quadrangle (southwest).

PLATE 18 - Generalized geologic map of
the Sequin quadrangle (after Arendt and
others, 1978, p. 17).

PLATE 19 - Geological sketch, Pueblo Quadrangle. Geological symbols: (Xgn) Migmatitic gneiss; (Xgd) Granodiorite; (Ysi) San Isabel granite; (Ygm) Quartz Monzonite; (Ypp) Pikes Peak granite; (P) Paleozoic Sedimentary rocks; (M) Mesozoic Sedimentary rocks; (TQvs) Tertiary volcanics and sediments, Quaternary sediments; (T) Tertiary intrusive rocks; (Q) Quaternary alluvium. The eastern part of the map area, in the Great Plains province, is underlain by Cretaceous and Cenozoic sedimentary rocks.