Geochemical Reconnaissance Using Heavy Minerals From Small Streams in Central South Carolina

GEOLOGICAL SURVEY BULLETIN 1404

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By HENRY BELL III

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Areas favorable for prospecting the Carolina slate belt evaluated by spectrographic analyses and cluster analyses

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[Plates are in pocket]

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By Henry Bell, III

ABSTRACT

Geochemical reconnaissance using heavy-mineral concentrates panned from coarse alluvium has been carried out in the Cedar Creek-Blythewood area, South Carolina. This area in the central Piedmont is underlain by deeply weathered volcaniclastic and sedimentary rocks of the Carolina slate belt which are metamorphosed to a low grade. Semiquantitative spectrographic analysis performed on the concentrates, combined with a mathematical technique called cluster analysis, is used to classify the small stream drainage basins sampled. Three clusters of drainage basins, each having different characteristics, are indicated by *Q*-mode clustering of the data, and five groups of associated elements can be distinguished by *R*-mode clustering procedures. One of the three clusters of stream drainage basins is characterized by anomalous amounts of boron, lanthanum, and niobium, three elements which together constitute one of the five groups of associated elements. This same cluster of drainage basins is also anomalous in gold, copper, tin, and beryllium. The hydrothermally altered rocks in this cluster of drainage basins contain numerous thin quartz veinlets, disseminated pyrite, and pyrite veinlets; the rocks therefore resemble the altered rocks in the vicinity of gold mines in Lancaster and Kershaw Counties, S.C. The drainage basins of this cluster, therefore, would be exceptionally favorable areas for additional exploration.

INTRODUCTION

Sampling stream sediments for indications of mineral deposits is perhaps the oldest prospecting technique known, but, nevertheless, it is still an important method in modern geochemical exploration schemes. Large areas are now commonly tested for mineralized rock by analysis of stream-sediment samples by rapid semiquantitative chemical or spectrographic procedures. In the Southeastern States both fine-grained alluvium and heavy-mineral concentrates have been collected for these purposes.

The Cedar Creek-Blythewood area contains no known ore deposits. It was suggested, however, as a suitable area for geochemical exploration by Henry S. Johnson, Jr., of the South Carolina State Development Board, because numerous gold-bearing streams were brought to his attention by John Chapman of Columbia, S.C., an enthusiastic amateur prospector. The rocks in this area are part of the Carolina slate belt which elsewhere in the Piedmont of North and South Carolina contains lode gold deposits and massive sulfide deposits. The widespread occurrence of trace amounts of gold suggested that modern geochemical exploration techniques applied to this area might yield indications of valuable mineral deposits. A sampling program, therefore, was carried out on the abundant small streams in the area, and some of the results are described here.

Figure 1 shows the location of the Cedar Creek-Blythewood area. This area in central South Carolina has an average annual rainfall of 48–56 in. and a mean monthly relative humidity of 70–80 percent (U.S. Geol. Survey, 1970). This warm, humid climate favors the growth of forests which are largely composed of loblolly and short-leaf pine mixed with some oak and hickory. Only a small proportion of the area is now cleared and farmed, but the southern part of the area, being only a short distance from the state capital at Columbia, contains growing suburban communities. The topography of the area is characterized by rounded hills, gentle

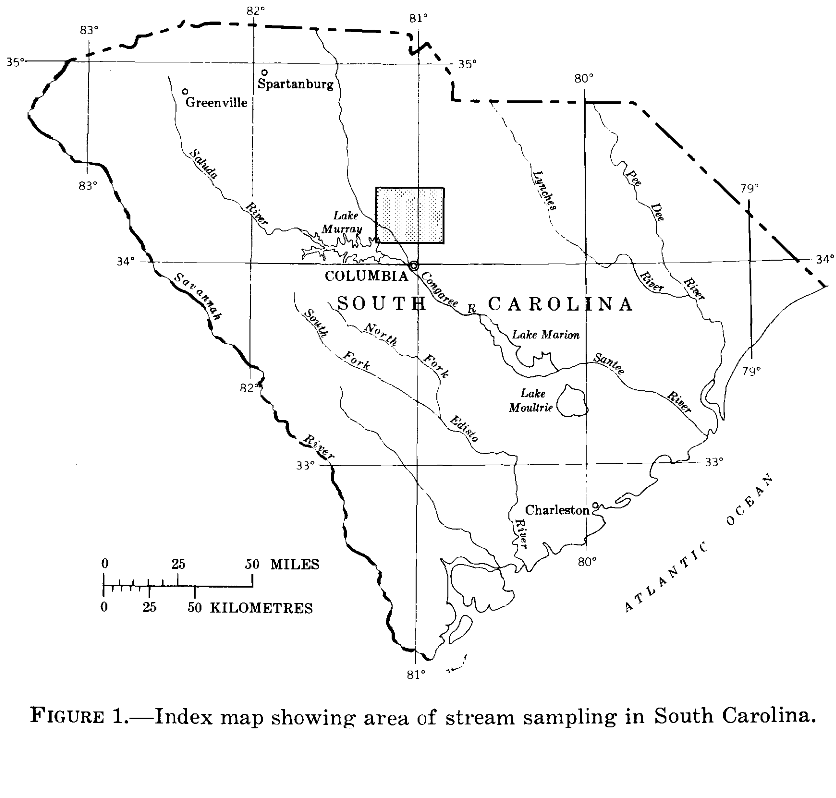


FIGURE 1.—Index map showing area of stream sampling in South Carolina.

slopes, and many small streams tributary to the Wateree River to the east and the Broad River to the west.

The warm, humid climate and abundant forest cover on hills of low relief have promoted deep weathering of rocks. As a consequence, outcrops of rock are sparse except in the beds of small streams. Saprolite, the residuum of weathering in place, is of varied but largely unknown thickness. The forest cover and saprolite tend to conceal the surface expression of ore deposits, making geologic mapping difficult.

Samples of fine-grained alluvium, consisting mostly of silt and clay, have been widely used in geochemical exploration for sulfide-rich ore deposits because silt and clay in the vicinity of ore deposits tends to adsorb and absorb anomalous amounts of metal ions which can be detected by chemical analysis. In the Cedar Creek-Blythewood area, the effect of deep weathering and extensive chemical leaching, to be expected on any near-surface mineralized rock, may reduce the metal content of geochemical anomalies to especially low levels. Some ore minerals or minerals associated with ore deposits, however, are resistant to weathering and accumulate as resistate heavy minerals in alluvium where they have been traditionally used as guides in prospecting for lode ore deposits. In a review of heavy-mineral reconnaissance in the southeastern Piedmont, W. C. Overstreet (1962) points out that previous projects in this area have included the identification of minerals heavier than quartz and feldspar and their quantitative measurement as a prelude to data interpretation. The identification of heavy minerals is generally a laboratory procedure, frequently time consuming and, in the case of fragments of dark-colored or opaque minerals, often difficult; overlooking or misidentifying scarce or unusual ore minerals is a problem. For this reconnaissance, the laboratory identification of all the heavy minerals, except gold and magnetite, has been bypassed in favor of spectrographic analyses to detect unusual concentrations of metals in order to identify chemically, instead of mineralogically, areas worthy of additional exploration for mineral deposits.

ACKNOWLEDGMENTS

Norman K. Olson, South Carolina State Geologist, and his staff in Columbia, S.C., provided assistance both in the field and in their office; this assistance was particularly helpful during the fieldwork.

All the samples collected during the fieldwork were sent to laboratories of the U.S. Geological Survey. E. F. Cooley did the spectrographic analyses on the heavy-mineral concentrates in Denver, Colo. Other analyses were made by E. L. Mosier in Denver and by Carroll Burton and Joseph L. Harris in Washington, D.C.

Donald Hogans and Lester North of the U.S. Geological Survey provided especially helpful expertise and assistance in the use of the computer. Cluster analysis and its possible adaptation to geochemical data was often discussed with Joseph E. Hazel, U.S. Geological Survey, and he generously provided assistance which made possible the use of that technique on the data in this report.

PREVIOUS GEOLOGIC AND GEOCHEMICAL WORK

The geology of the Cedar Creek-Blythewood area is known from the work of Donald Secor and his students at the University of South Carolina. H. D. Wagener has mapped the granite near Winnsboro and the surrounding metamorphic rocks. Their work (Secor and Wagener, 1968; Wagener, 1970, 1973) has been used herein as a basis for the geologic interpretation of the geochemical data. In addition to the sampling reported here, water samples were collected (Bell and Siple, 1973) to test the possibility that the water in small streams might contain unusual amounts of dissolved constituents detectable by field methods and that small streams might be used for hydrogeochemical prospecting. The results of that study indicated that none of the water from the small streams sampled contained sufficiently large amounts of dissolved-mineral constituents to indicate abundant soluble ore or gangue minerals. The study did indicate, however, that groups of streams having characteristic amounts of dissolved constituents could be recognized and related to the geologic formations in the area. Fine-grained alluvium from these small streams was also collected and spectrographic analyses performed on the silt and clay fractions. The analyses showed that some areas contain alluvium anomalous in various elements, but the results gave no clear indication of the type of mineralized rock or geologic associations to be expected at the source of the anomalies.

GEOLOGIC SETTING

Plate 1 is a geologic map of the Cedar Creek-Blythewood area adapted from Secor and Wagener (1968). Carolina slate belt rocks underlie the western and northern parts of the area; these are many thousands of feet of upper Precambrian or Paleozoic fragmental volcanic rocks, tuffs, flow rocks, argillite, and sandstone metamorphosed to a low grade. Northward the rocks of the Carolina slate belt pass into rocks of a higher metamorphic grade, consisting largely of gneiss, schist, and amphibolite. These crystalline rocks have many of the characteristics that P. B. King (1955) noted in rocks near Charlotte, N.C., and which he identified regionally as the Charlotte belt. In the Cedar Creek-Blythewood area, the slate belt rocks have been intruded by masses of adamellite, gabbro, and many Triassic dikes. In the vicinity of Mount Rehovah are sericite schist, light-colored phyllite containing numerous thin gold-bearing quartz veinlets, silicified rocks, disseminated pyrite and pyrite veinlets, and kaolin-rich rocks. These are hydrothermally altered rocks resembling the host rocks for the ore deposits of the Haile mine and other nearby mines in Kershaw and Lancaster Counties. Sedimentary rocks, mostly poorly consolidated sand and clay of Cretaceous and younger age, unconformably overlie the crystalline rocks in the southeastern part of the area.

SAMPLING AND ANALYTICAL PROCEDURES

Coarse-grained alluvium was collected from 72 small streams in the Cedar Creek-Blythewood area. The small streams sampled averaged 1.03 square miles (2.6 km^2) in drainage area, ranging from 3.3 square miles (8.4 km^2) to 0.6 square mile (1.5 km^2). This size drainage area has proved to be most useful for geochemical sampling purposes. The drainage basins of the small streams from which geochemical samples were collected have been labeled from 1 to 73 on all the illustrations and tables. No heavy-mineral concentrate was collected from stream drainage basin No. 67, and this stream basin has not been included in this study.

The alluvium collected generally consisted of gravel, but some coarse sand was also collected. From this alluvium a heavy-mineral concentrate was made at the sample site in a standard gold-miner's pan. Collecting procedures were much like those described by Mertie (1954), Overstreet and others (1968), Theobald (1957), and Bell and Overstreet (1960). At each site 10 quarts (9.5 l) of alluvium weighing about 40 pounds (18 kg) were collected. Each stream sample site was chosen to sample material brought from within the drainage basin by the stream and to be as nearly alike as possible on the basis of grain size and hydraulic conditions. These two criteria were chosen to reduce the factors causing variations in the concentrates. An attempt was made to standardize the hydraulic conditions at the sites by sampling riffle gravels at approximately the same relative position in the stream channels. The weight of the individual heavy-mineral concentrates, panned from an equal volume of material, varied from site to site and this weight reflects the actual abundance of heavy minerals in the coarse alluvium.

A summary of the weights of the 72 heavy-mineral concentrates is given below:

Weight of heavy-mineral concentrates (grams)

Minimum	*Mean*	*Maximum*
2.3	36.9	478

In these small streams, alluvium containing large heavy-mineral concentrates commonly reflects mafic rocks rich in hornblende, epidote, ilmenite, and magnetite. Small heavy-mineral concentrates commonly reflect felsic rocks and hydrothermally altered rocks. In the laboratory the highly magnetic fraction of the heavy-mineral concentrate was removed by hand magnet and weighed; the weights range from less than 0.1 gram to 75 grams, and average about 2 grams. The highly magnetic fraction, consisting predominantly of magnetite, probably also includes minor amounts of ilmenite, or other minerals intergrown with magnetite, grains of other minerals attached to magnetite, and secondary magnetic iron oxides. The range in percent by weight of the magnetic fraction in the heavy-mineral concentrates is:

Magnetic fraction of heavy-mineral concentrates (percent)

Minimum	*Geometric mean*	*Geometric mean × geometric deviation*	*Maximum*
<0.1	1.2	4.5	45.8

The distribution of stream drainage basins in which heavy-mineral concentrates were panned and found to contain 4.5 percent or more magnetite is shown on plate 2. The nonmagnetic fraction of each concentrate was submitted to semiquantitative spectrographic analysis.

The six-step method of spectrographic analysis for 30 elements was used to analyze the nonmagnetic fraction of the heavy-mineral concentrates (Grimes and Marranzino, 1968). Twenty-two of the 30 elements searched for by this method were detected in the samples. The results of the analyses are summarized in table 1. In addition, each heavy-mineral concentrate was carefully searched for fine particles of gold while the concentrate was still in the gold pan. Visual identification of gold in the gold pan is the most sensitive analytical method for its detection; a particle of gold weighing 0.1 gram is conspicuously visible in a gold pan. The detection of such a particle in about 40 pounds (18 kg) of coarse alluvium is approximately equivalent to an analytical value of 0.05 parts per million. Because such small particles could not be systematically separated from the concentrates and weighed, only the presence or absence of gold particles was recorded in the field. Spectrographic analysis may fail to detect gold even though the heavy-mineral concentrate contains several small gold particles. The particulate nature of the gold causes a low probability that any will be included in the small amount of material used for the analysis. Plate 2 shows the distribution of streams containing alluvium in which gold was detected by panning.

TABLE 1.—*Summary of spectrographic analyses of 72 heavy-mineral concentrates from small streams in the Cedar Creek-Blythewood area, South Carolina*

[Analyst: E. F. Cooley. Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth]

	Lower limit of determination [1]	Geometric mean	Geometric mean × geometric deviation	Maximum
		Percent		
Fe	0.05	15	20	20
Mg	.02	.2	.5	1
Ca	.05	2	10	20
Ti [2]	.002	------	------	>1
		Parts per million		
Mn	10	1,000	2,000	5,000
B	10	200	700	1,500
Ba	20	50	150	1,000
Be	1	.5	10	50
Co	5	20	50	100
Cr	10	300	500	1,000
Cu	5	20	30	150
La	20	300	700	1,000
Mo	5	7	15	20
Nb	10	100	200	700
Ni	5	1	3	10
Pb	10	50	100	150
Sc	5	70	100	100
Sn	10	50	1,000	20,000
Sr	100	300	700	1,500
V	10	300	500	700
Y	10	100	150	200
Zr [2]	10	------	------	>1,000

[1] Approximate visual lower limits of determination for elements analyzed by the six-step spectrographic method.

[2] All values reported are above the optimum range of determination; therefore, no statistical parameters were calculated.

NOTE.—Elements searched for but not detected or detected below the limit of determination: Ag, As, Au, Bi, Cd, Sb, W, and Zn.

DATA PROCESSING

The results of the spectrographic analyses have been processed by electronic computer to categorize streams and samples having similar characteristics.

In order to select the unusually high, or anomalous, analytical values by a systematic and uniform method, the geometric mean and the geometric mean multiplied by the geometric deviation have been calculated (table 1) for most of the elements detected in the heavy-mineral concentrates. The results of analyses of geochemical samples commonly are positively skewed and show a lognormal distribution (Ahrens, 1954); in the Cedar Creek-Blythewood area some elements show these characteristics but others do not. Nevertheless, a logarithmic rather than an arithmetic procedure has been used. The spectrographic method used to test the samples has a lower limit of determination (table 1) and an optimum range of determination for each element. Values above and below the optimum range are qualified as greater than (>) or less than (<). The computations of the geometric mean and the geometric deviation were made using unqualified values above the lower limit of determination. The distribution of analytical results for many elements is cut off or "censored" at the lower limit of determination, and the geometric mean and deviation have been adjusted for these censored distributions. The procedure used is from Cohen (1959, 1961) and is discussed by Miesch (1967). The results of analysis for some elements contain values qualified as "greater than"; the statistics for these elements have been calculated using only unqualified values.

GEOCHEMICAL THRESHOLD

The geochemical threshold has been used to prepare maps showing stream drainage basins with anomalously high values for the elements. The geochemical threshold for an element, as defined by Hawkes (1957, p. 233), is the limiting value below which variations represent only normal background effects and above which they have significance in terms of possible mineral deposits. Analytical values above the geochemical threshold are called anomalous. The threshold value for a given element varies for each rock type, and a single value may be too high for some rock types and too low for others. For this study the geometric mean multiplied by the geometric deviation has been chosen as the geochemical threshold; as a result about 84 percent of the samples are not anomalous and 16 percent are anomalous. Plate 3 shows small drainage basins with threshold or greater amounts of the various elements in the nonmagnetic fraction of the heavy-mineral concentrates as determined by spectrographic analysis.

ANALYSIS OF RESULTS

In order to make interpretations about possible significant mineral deposits, the drainage basins ought to be classified into categories having special characteristics. The large amount of data resulting from spectrographic analysis makes this difficult. Unusually high values for individual elements may be easily determined by inspection of the analytical data. However, groups of associated elements or clusters of stream basins characterized by groups of anomalous elements are more difficult to recognize and categorize without a systematic procedure. A group of anomalous elements in a stream basin may be more significant than any single anomalous element; a group of elements may provide clues about possible types of mineral deposits. The identification of such groups may be approached through the mathematical procedure of multivariate analysis. In applications of multivariate analysis to paleontology, zoology, and sedimentary petrology, the method of cluster analysis has proved to be useful. Cluster analysis is a nonparametric technique for the classification of large amounts of quantitative multivariate data; it seems to have value for geochemical studies also. Its use and application in geology have been discussed by Miller and Kahn (1962), Parks (1966), Harbaugh and Merriam (1968), Hazel (1970), and Davis (1973).

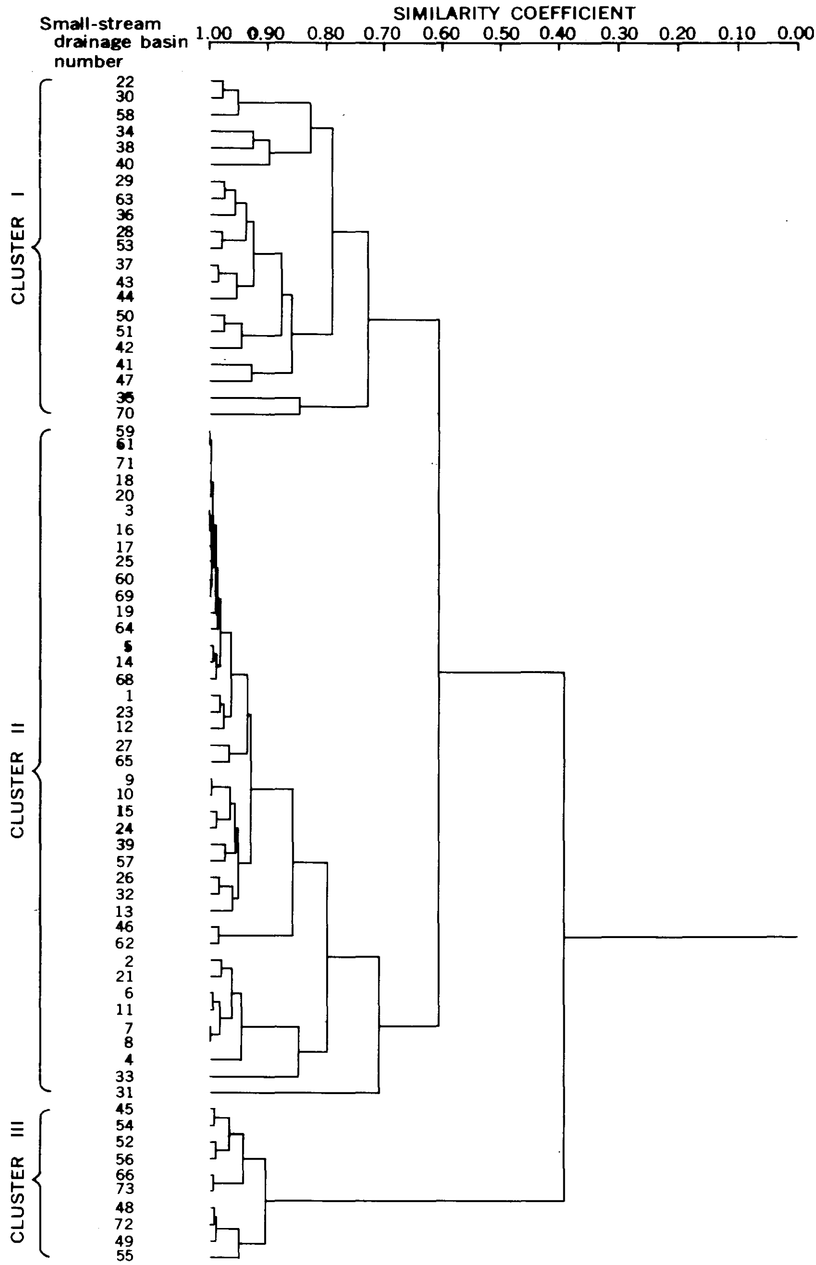
The classification and clustering procedure begins by calculating similarity coefficients between each item in the data and all other items. One method is the so-called *Q*-mode technique which, in this case, consists of comparing each stream basin with every other stream basin on the basis of the elements each contains. Or, using another method, the association of each element with every other element may be compared in each stream basin; this is the *R*-mode technique. Both *Q*-mode and *R*-mode cluster analyses have been performed on the heavy-mineral data from the Cedar Creek-Blythewood area. From the *Q*-mode and the *R*-mode matrices of coefficients, respectively, clusters of stream-drainage-basin samples and groups of elements have been selected using a clustering technique. The results of the clustering are displayed in a two-dimensional plot called a dendrogram which shows a hierarchy of association in the data.

Q-MODE CLUSTER ANALYSIS

Q-mode cluster analysis has been performed on the data from 72 heavy-mineral samples. On these samples, spectrographic analysis yielded results on 19 elements which varied enough to be used to classify the samples. The measure used to form the similarity matrix is the coefficient of proportional similarity (cos θ) of Imbrie and Purdy (1962). The clustering technique used is the unweighted pair-group method (Sokal and Michener, 1958). The results of the clustering are displayed in a dendrogram (fig. 2). This arrangement shows the similarity of association of the clusters on a scale ranging from 0 to 1.00, with those closest to 1.00 being the most similar. Different measures of similarity and different procedures for selecting clusters could have been chosen; these would give a slightly different dendrogram. Parks (1966) discusses some of the various combinations of coefficients and clustering procedures and the resulting differences in the dendrograms. The procedures used here, however, are common and give clusters that faithfully reflect the similarity matrix from which the clusters were derived. The computer program used to perform the cluster analysis was coded in FORTRAN IV by G. F. Bonham-Carter (1967). This program has been modified by Paul Zabel and Lester North of the U.S. Geological Survey for the IBM 360/65 computer and for use with multistate data.

The dendrogram resulting from the *Q*-mode clustering shows three conspicuous clusters of drainage basin samples whose average similarities are greater than 0.70. These are labeled with Roman numerals, as Cluster I, Cluster II, and Cluster III, and the distribution of the basins in each cluster is shown on plate 4. The clusters consist of 21, 41, and 10 drainage basins. The drainage basins in each of the clusters are largely contiguous, as might be expected if the clustering procedures reflect natural conditions overlapping from basin to basin as a result of underlying geologic formations. The distribution of thin Coastal Plain sedimentary rocks is also shown on plate 4. Most of the drainage basins of Clusters I and II contain at least some of these sedimentary rocks along the divide between basins. Stream drainage basin No. 54, included in Cluster III, is composed of two drainage basins, Nos. 72 and 73, which have been sampled individually. These two drainage basins also are shown on the dendrogram in Cluster III. Cluster II is composed of drainage basins underlain almost completely by crystalline rocks. Also shown on plate 4 are the stream drainage basins in which streams have water with 50 micromhos or less specific conductance; these drainage basins are mostly in Clusters I and II.

FIGURE 2.—Dendrogram resulting from *Q*-mode cluster analysis of spectrographic data from heavy-mineral concentrates, Cedar Creek-Blythewood area, South Carolina. The coefficient of proportional similarity (cos θ) and the unweighted pair-group clustering method were used for the cluster analysis. Numbers within clusters are keyed to drainage basins on plates 2–5.



R-MODE CLUSTER ANALYSIS

For *R*-mode cluster analysis the association of each element is compared with each of the other elements in all the samples of heavy-mineral concentrates. Nineteen elements and 72 samples were used. Again, the proportional similarity coefficient and the unweighted pair-group method of clustering was used. The dendrogram resulting from this clustering is shown in figure 3.

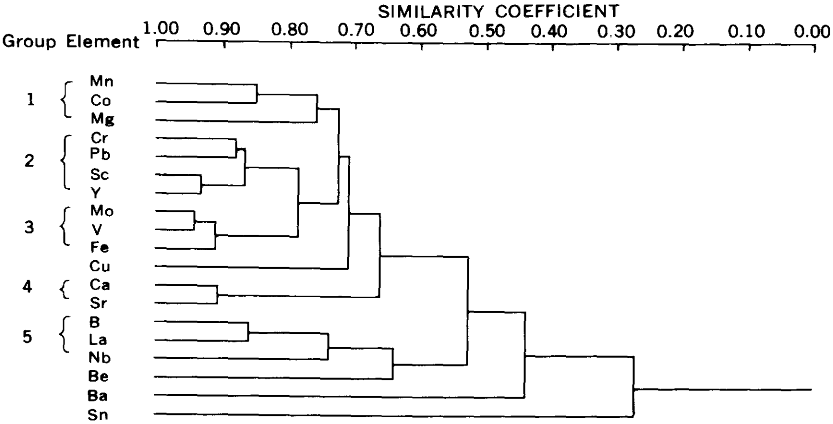


FIGURE 3.—Dendrogram resulting from *R*-mode cluster analysis of spectrographic data from heavy-mineral concentrates, Cedar Creek-Blythewood area, South Carolina.

The *R*-mode dendrogram shows five clusters of associated elements consisting of two to four elements. These have been labeled Group 1 to 5 to distinguish them from Cluster I to III in the discussions that follow. The clusters chosen have similarity coefficients greater than 0.70. In addition, the dendrogram shows that elements Cu, Be, Ba, and Sn are associated with Groups 1 to 5 at a much lower level; each of these, therefore, is considered as a group of one. Some of the groups consist of elements that might be expected to occur together on a chemical basis, such as Ca and Sr, and Mg, Mn, and Co. Other groups may reflect the heavy minerals characteristic of certain rock types.

Plate 5 shows the location of the small-stream drainage basins characterized by each of the five groups of elements. Because all 19 elements were detected in all the stream basins, only those basins are indicated in which all the elements in each group are anomalous. Five of the six stream basins in which Group 1 elements (Mg, Mn, and Co) are all above the threshold for these elements are in areas underlain predominantly by slate in the Richtex Formation where this formation is cut by abundant Triassic diabase dikes. The stream basins in which Group 2 elements (Cr, Pb, Sc, and Y) are all anomalous are few in number and widely scattered. Group 3 elements (Mo, V, and Fe) are all above the threshold for these elements in a northeast-trending band of largely contiguous basins underlain by the Persimmon Fork and Wildhorse Branch Formations. These formations are predominantly volcaniclastic rocks. Group 4 elements (Ca and Sr) are anomalous in nine drainage basins, most of which are clumped together west of the Broad River where they may reflect some unrecognized local condition in the bedrock. Group 5 elements (B, La, and Nb) are all anomalous in largely contiguous basins where Coastal Plain sedimentary rocks are conspicuous.

SUMMARY OF CLUSTER ANALYSIS

Table 2 summarizes the *Q*-mode and *R*-mode cluster analyses. Although it was not included in the cluster analyses, gold has been included in table 2 because it is widely distributed throughout the area even though it was not detected in the spectrographic analyses. Table 2 summarizes the relationships between the three clusters of similar drainage basins and the groups of associated elements. For example, for Cluster I, table 2 shows that five of the drainage basins in this cluster contain particles of gold. This is 24 percent of the drainage basins in this cluster. In Cluster II, among the 41 drainage basins of this cluster, seven (17 percent) contain gold. Table 2 also shows that Cluster II contains 35 percent of all the stream basins containing gold. The elements in Group 1 (Mg, Mn, and Co) are all anomalous as a group only in stream drainage basins in Cluster II. Similarly, more stream drainage basins in Cluster II are anomalous in Groups 2, 3, and 4 than the stream drainage basins in Cluster I. Most of the stream drainage basins anomalous in Cu and Ba are also in Cluster II.

Cluster III is unique because the only group of elements anomalous in this cluster of similar drainage basins is Group 5, B, La, and Nb. In this cluster, 44 percent of the drainage basins are anomalous in this group of elements. In addition, 89 percent of the drainage basins in this cluster contain gold, 78 percent are anomalous in beryllium, 56 percent are anomalous in copper, and all of them are anomalous because they contain 1,000 ppm or more tin. In contrast, only 29 percent of the drainage basins in Cluster I are anomalous in Group 5 elements, and the percentage of Cluster I basins anomalous in Au, Cu, Sn, and Be is much smaller. (A similar situation is true for Cluster II also.) The drainage basins in Cluster III, therefore, are characterized by anomalous amounts of Group 5 elements (B, La, and Nb) and by gold, copper, tin, and beryllium; the Cluster III area would be favorable for additional exploration for mineral deposits characterized by these elements.

TABLE 2.—*Summary of* Q-*mode and* R-*mode cluster analysis*

Clusters of drainage basins on *Q*-mode dendrogram having similarity coefficient greater than 0.70	Groups of elements on *R*-mode dendrogram having similarity coefficient greater than 0.70															Elements on *R*-mode dendrogram having similarity coefficient less than 0.70, or elements not included in cluster analysis														
	Group 1 Mg, Mn, Co			Group 2 Cr, Pb, Sc, Y			Group 3 Fe, Mo, V			Group 4 Ca, Sr			Group 5 B, La, Nb			Au[1]			Cu			Sn			Be			Ba		
	Percent Cluster[2]		Percent Group[3]	Percent Cluster		Percent Group	Percent Cluster		Percent Group	Percent Cluster		Percent Group	Percent Cluster		Percent Group	(2)		(3)	(2)		(3)	(2)		(3)	(2)		(3)	(2)		(3)
Cluster I (21 drainage basins).	--	-	---	5	1	20	14	3	27	5	1	11	29	6	55	24	5	25	5	1	6	14	3	21	43	9	45			
Cluster II (41 drainage basins).	15	[4] 6	100	10	4	80	20	8	73	20	8	89	2	1	9	17	7	35	29	12	67	5	2	14	10	4	20	15	6	86
Cluster III (9 drainage basins; drainage basin 54 not included).	--	-	---	--	-	--	--	-	--	--	-	--	44	4	36	89	8	40	56	5	28	100	9	64	78	7	35	11	1	14
Total drainage basins anomalous in element or group of elements.		6			5			11			9			11			20			18			14			20			7	

[1] Not included in cluster analysis.

[2] Percent Cluster is number of drainage basins anomalous in an element or group of elements divided by total drainage basins in the cluster of similar drainage basins multiplied by 100; for example (6/21) ×100=28.

[3] Percent Group is number of drainage basins in a cluster of similar drainage basins anomalous in an element or group of elements divided by the total number of drainage basins anomalous in the element or group of elements; for example (6/11) ×100=54.

[4] Number of drainage basins in cluster of similar drainage basins anomalous in an element or group of elements.

Of the nine drainage basins in Cluster III, two, Nos. 49 and 72 (pl. 3), are anomalous in all these elements. The six-step spectrographic analyses of the heavy-mineral concentrates from these two drainage basins are given in table 3.

TABLE 3.—*Spectrographic analyses of heavy-mineral concentrates (minus highly magnetic fraction) from alluvium in small streams, Richland County, S.C.*

[Analyst: E. F. Cooley]

Element	Stream drainage basin sample number[1] 49	72
Percent		
Fe	10	[2] 20
Mg	.1	.15
Ca	.1	1
Ti	>1	>1
Parts per million		
Mn	700	1,000
Ba	<20	<20
Be	[2] 20	[2] 20
Co	10	20
Cr	300	500
Cu	[2] 50	[3] 30
La	[2] >1,000	[2] >1,000
B	[2] 700	[2] 1,000
Mo	<5	<5
Nb	[2] 200	[2] 200
Ni	<5	<5
Pb	[2] 100	70
Sc	[2] >100	[2] >100
Sn	[2] 2,000	[2] 2,000
Sr	<100	100
V	300	200
Y	[2] >200	[2] >100
Zr	>1,000	>1,000

[1] Sample numbers keyed to figures.
[2] Equal to or above threshold value.

GEOLOGY OF STREAM DRAINAGE BASINS IN CLUSTER III

CRYSTALLINE ROCKS

The stream basins in Cluster III are near the eastern edge of the geologic map (pl. 1) and partly in the southeast portion of the area mapped by Wagener (1970). The basins are underlain principally by rocks of the Richtex Formation but also in a small part by the Persimmon Fork–Wildhorse Branch Formations where these have not been differentiated. Thin layers of sand and gravel, which may be remnants of Coastal Plain sedimentary rocks, occur along the ridges between drainage basins.

The Richtex Formation, as mapped and described by Secor and Wagener (1968), is composed of an upper and lower division. The lower part is a thick sequence of 30–50 percent andesitic and basaltic tuffs and amygdaloidal flows interlayered with thinner units of felsic meta-arenites or metasiltstones. The mafic rocks consist of dense, black aphanitic rocks composed of porphyroblasts of green hornblende, plagioclase, opaque oxides, epidote, and various amounts of tremolite. Some patches of feldspars resemble deformed amygdules. The interlayered felsic units are light colored and very fine grained to aphanitic. They consist of quartz, much untwinned feldspar, muscovite, and biotite. The rocks in the lower part of the Richtex Formation probably extend eastward from the area mapped by Secor and Wagener along the road between Smallwood and Mount Rehovah. Along this road, however, the rocks are deeply weathered saprolite which crops out in roadside ditches and cuts.

The upper part of the Richtex Formation consists of slate or fine-grained phyllite and some interlayered feldspathic sandstone. The bedding is characteristically finely laminated and is cut by a well-developed cleavage transverse to the bedding. These rocks, which elsewhere have been called argillites, have been compared to the Tillery Formation of Conley and Bain (1965) in North Carolina. Phyllites, quartz-rich phyllites, and quartzo-feldspathic phyllites like those described by Wagener (1970, 1973) make up a large part of the formation where stream basins in Cluster III occur. These phyllites consist mostly of quartz and muscovite with chlorite, epidote, and opaque oxides. In some areas, such as near Mount Rehovah, where there are numerous thin quartz veinlets, disseminated pyrite, and pyrite veinlets, the rocks appear to be hydrothermally altered. They resemble the altered rocks in the vicinity of the Haile mine and other nearby mines in Kershaw and Lancaster Counties, S.C. The quartz veinlets and the more silicious phyllites are gold bearing. X-ray diffraction analysis of some of the light-colored phyllites containing gold and quartz veinlets show kaolin and well-crystallized 2*M* mica. Degraded micas resulting from prolonged weathering are not conspicuous. Most of the altered rocks in the Richtex Formation occur south of the road connecting Smallwood with Mount Rehovah. Other similarly altered rocks in the vicinity of Mount Rehovah may be part of the unit of undifferentiated Persimmon Fork or Wildhorse Branch Formations which Secor and Wagener have mapped near Ridgeway.

SAND AND GRAVEL

Overlying the crystalline rocks are unconsolidated sands, clayey sands, and gravel. Isolated patches and thin layers of these rocks occur along divides between the drainage basins in Cluster III. These may be remnants or outliers of one of the sedimentary formations of the Coastal Plain and possibly part of the Upper Cretaceous Middendorf Formation. The Middendorf Formation is the oldest of the Coastal Plain sedimentary rocks in South Carolina. Heron describes (1960) the Middendorf as consisting of "loose sand, poorly indurated sandstone, thin layers or lenses of mudstone, poorly sorted clayey sands and laminated layers of sand and mudstone." These rocks probably represent a fluvial environment. Swift and Heron (1969, p. 213) state that locally there are younger sedimentary rocks, some of which are reworked Middendorf sands, gravels, and clays, and these can easily be mistaken for the Middendorf Formation. Presumably, they would be Tertiary or younger in age. Locally two subdivisions of the Middendorf Formation have been mapped (Paradeses and others, 1966). These are a poorly consolidated unit of coarse sand and medium sand with considerable kaolin matrix and a similar lower unit containing some pebbly beds. In addition to rounded quartz pebbles, there are angular quartz fragments, lithic fragments, chips and angular fragments of clay, and small kaolinitic masses that probably are thoroughly weathered feldspar grains.

The heavy-mineral suite is described (Paradeses and others, 1966) as consisting predominantly of tourmaline, rutile, magnetite, ilmenite, and zircon, together with traces of muscovite, garnet, and limonite. In addition, Dryden (1958, p. 402) reports as much as 7.7 percent monazite in heavy-mineral concentrates from samples of Coastal Plain rocks in this area.

A heavy mineral concentrate containing gold was panned from an orange-brown, medium-coarse sand that is probably in the lowest unit of the Middendorf Formation. The orange-brown sand has many pebbles and cobbles of quartzite, quartz, and muscovite, and other quartz-rich rocks. The gold-bearing concentrate and heavy-mineral concentrates from seven other similar samples, where coarse sand or conglomeratic sands overlie crystalline rocks in the area of Cluster III, were submitted to spectrographic analysis. The results of the spectrographic analysis of these gold-bearing concentrates are shown in table 4, together with the range in values from all eight similar samples. These results show some of the samples to be high in phosphorous and the rare-earth elements. Both the rare-earth elements and phosphorous probably are derived from monazite. Three of the samples were found to contain from 0.4 to 1.8 parts per million gold by a combined fire assay-atomic absorption technique of analysis.

TABLE 4.—*Spectrographic analysis of heavy-mineral concentrate from coarse sand overlying weathered crystalline rocks and range in values from eight samples*

[Analyst: Joseph L. Harris]

Element	Sample 69-HB-77	Range of values from eight samples		Number of samples in which element not detected
		From	To	
Percent				
Fe	1.5	1.5	3	--
Mg	.07	.007	.3	--
Ca	.05	.005	.05	--
Ti	7	7	10	--
P	1.5	(1)	1.5	4
Parts per million				
Mn	1,000	1,000	1,000	--
B	700	N	5,000	1
Ba	20	20	70	--
Be	N	N	50	6
Bi	15	N	15	4
Cr	50	50	300	--
Cu	5	2	70	--
La	30,000	N	30,000	1
Mo	N	N	3	5
Nb	200	70	200	--
Ni	200	70	200	--
Pb	100	30	300	--
Sc	150	50	150	--
Sn	30	10	30	--
Sr	10	11	15	1
V	150	100	300	--
Y	2,000	500	2,000	--
Zr	50,000	20,000	50,000	--
Ce	10,000	1,500	10,000	--
Ga	5	3	30	--
Th	2,000	500	2,000	--
Yb	200	50	200	--
Pr	1,000	N	1,000	1
Nd	7,000	N	7,000	1
Sm	700	N	700	1
Eu	700	N	700	4
Gd	1,000	70	1,000	--
Dy	500	70	500	--

[1] Not detected.

SAPROLITE

The crystalline rocks underlying these sands and gravels are deeply weathered. Some of the phyllites near Mount Rehovah show reddish-brown and yellowish-brown colors gradational to very light brown and nearly white saprolite in which thin, steeply dipping quartz veinlets and faint laminations can still be detected. Concentric color banding and iron-oxide-filled fractures occur. All these features indicate extensive and probably prolonged weathering. Henry S. Johnson, Jr., of the South Carolina State Development Board, augered a hole near State Highway 34 at Mount

Rehovah and penetrated 48 ft (14.6 m) of saprolite without encountering unweathered rock. This auger hole penetrated reddish, light-yellowish-brown, and white phyllite with purplish stains which contained numerous quartz veinlets commonly less than 0.25 in. (0.63 cm) thick. Minerals in samples from this auger hole were identified by the author using X-ray diffraction methods. In addition to quartz, muscovite, and kaolin, the samples contain abundant anatase and some actinolite. Cuttings from the auger hole analyzed for gold and copper showed 0.06 ppm gold and 220 ppm copper in the upper 9 ft (2.7 m) of the hole. The values for both gold and copper decrease with depth, but copper values in the deepest part of the hole are nearly as high as those in the upper part of the hole. Spectrographic analyses showed 0.5 ppm silver and 10 ppm molybdenum at 30–40 ft (9–12 m) from the surface. The high values for gold in the upper part of the hole, and decreasing values with depth, suggest a surface enrichment of gold derived from the thin quartz veinlets and the quartz muscovite phyllites, a phenomena noted by Kinkel and Lesure (1968) in nearby Kershaw County. In addition, fine gold may have infiltrated the upper surface of the crystalline rocks from the overlying gold-bearing sands and gravels at the time these were deposited or during subsequent weathering.

CONCLUSIONS

The geochemical sampling and the geologic setting of the small stream drainage basins in Cluster III reveal many similarities to other hydrothermally altered areas in the Carolina slate belt. It seems likely that the tin-bearing minerals in this area are in felsic volcanic rocks, perhaps in deposits of the fumarole type as described by Sainsbury and Reed (1973, p. 644). Although cassiterite has not been identified in heavy-mineral concentrates from stream basins in Cluster III, it is the common ore mineral of tin and a possible source of the high tin values. The occurrence of cassiterite in rocks of the Carolina slate belt not far from the Cedar Creek-Blythewood area supports this possibility, indicating two possible types of mineral deposits that might be expected in the area drained by streams in Cluster III. Cassiterite has been reported at Little Mountain, a monadnock-like hill supported by kyanite quartzite, in Newberry County about 15 miles (24 km) west. It has also been reported at the Brewer mine in Chesterfield County about 35 miles (56 km) east of the Cedar Creek-Blythewood area. The Brewer mine is a gold mine in silicified breccia and quartz sericite schist derived from felsic fragmental volcanic rocks. Some of the silicified rocks in the Brewer mine have been replaced by massive topaz. Kyanite, andalusite, and pyrophyllite, together with rutile, have been identified during studies of the economic possibilities of high-aluminum minerals (Peyton and Lynch, 1953). Cassiterite has been reported in the Brewer mine by Clarke and Chatard (1884), and spectrographic analyses of samples collected from a drainage tunnel showed tin values in several samples as high as 200 and 700 parts per million. Near the Brewer mine are closely associated placer deposits which contain fragments of the massive topaz, kyanite, ilmenite, zircon, iron oxides, staurolite, gold, and rutile (Fries, 1942).

Little Mountain and nearby ridges in Newberry County are held up by kyanite quartzite and hematite quartzite in an area of abundant quartz sericite schists and phyllites which are part of the Carolina slate belt. The major constituents of the quartzites are quartz, kyanite, and mica (McKenzie and McCauley, 1968). Muscovite, paragonite, and pyrophyllite have also been identified. The kyanite is disseminated in veinlets and elliptical pods. The pyrophyllite is disseminated with micas and as radial aggregates along joint surfaces with quartz veins. Pyrite, rutile, ilmenite, hematite, lazulite, corundum, cassiterite, and garnet are accessory minerals. Rutile occurs as black crystals disseminated throughout the quartz-kyanite rock in minor amounts and as large scattered crystals as much as 2 in. (5.0 cm) in length and 0.5 in. (1.2 cm) in diameter. Espenshade and Potter (1960) consider the deposits of high-aluminum minerals to be replacement deposits in rock probably hydrothermally altered, perhaps by solfataric activity associated with volcanism, and later subjected to regional metamorphism. Kesler (1972) also attributes these rocks to hot spring activity which produced siliceous sinter and kaolin in an area of volcanism.

The occurrence of anomalous amounts of beryllium and tin in the same small drainage basins of Cluster III presents the possibility that beryllium also occurs in felsic volcanic rocks, perhaps as a replacement deposit. The copper in the area drained by streams in Cluster III probably is in veins or with gold in a deposit similar to other nearby deposits in the Carolina slate belt. All these associations suggest that the crystalline rocks in the Cedar Creek-Blythewood area should be investigated further for tin and beryllium deposits, and the minerals in which these elements occur in the heavy-mineral concentrates should be identified.

The overlying Coastal Plain sedimentary rocks are rich in ilmenite, monazite, and zircon (Dryden, 1958; Paradeses and others, 1966), minerals which could provide a source for the high titanium, zirconium, and lanthanum values found in the heavy-mineral concentrates.

REFERENCES CITED

Ahrens, L. H., 1954, The lognormal distribution of the elements: Geochim, et Cosmochim. Acta, pt. 1, v. 5, p. 49–73; pt. 2, v. 6, p. 121–131.

Bell, Henry, 3d, and Overstreet, W. C., 1960, Geochemical and heavy-mineral reconnaissance of the Concord quadrangle, Cabarrus County, North Carolina: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–234.

Bell, Henry, 3d, and Siple, G. E., 1973, Geochemical prospecting using water from small streams in central South Carolina: U.S. Geol. Survey Bull. 1378, 26 p.

Bonham-Carter, G. F., 1967, FORTRAN IV program for *Q*-mode cluster analysis of nonquantitative data using IBM 7090/7094 computers: Kansas Geol. Survey Computer Contr. 17, 28 p.

Clarke, F. W., and Chatard, T. M., 1884, Mineralogical notes from the laboratory of the U.S. Geological Survey: Am. Jour. Sci., 3d ser., v. 28, p. 25.

Cohen, A. C., Jr., 1959, Simplified estimators for the normal distribution when samples are singly censored or truncated: Technometrics, v. 1, no. 3, p. 217–237.

——— 1961, Tables for maximum likelihood estimates—singly truncated and singly censored samples: Technometrics, v. 3, no. 4, p. 535–541.

Conley, J. F., and Bain, G. L., 1965, Geology of the Carolina slate belt west of the Deep River-Wadesboro Triassic basin, North Carolina: Southeastern Geology, v. 6, no. 3, p. 117–138.

Davis, John C., 1973, Statistics and data analysis in geology: New York, John Wiley and Sons, Inc., 550 p.

Dryden, A. L., Jr., 1958, Monazite in part of the southern Atlantic Coastal Plain: U.S. Geol. Survey Bull. 1042–L, p. 393–429.

Espenshade, G. H., and Potter, D. B., 1960, Kyanite, sillimanite, and andalusite deposits of the southeastern states: U.S. Geol. Survey Prof. Paper 336, 121 p.

Fries, Carl, Jr., 1942, Topaz deposits near the Brewer mine, Chesterfield County, South Carolina: U.S. Geol. Survey Bull. 936–C, p. 59–78.

Grimes, D. J., and Marranzino, A. P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geol. Survey Circ. 591, 6 p.

Harbaugh, J. W., and Merriam, D. F., (compilers) 1968, Computer applications in stratigraphic analysis: New York, John Wiley and Sons, Inc., 282 p.

Hawkes, H. E., Jr., 1957, Principles of geochemical prospecting: U.S. Geol. Survey Bull. 1000–F, p. 225–355.

Hazel, J. E., 1970, Binary coefficients and clustering in biostratigraphy: Geol. Soc. America Bull., v. 81, no. 11, p. 3237–3252.

Heron, S. D., Jr., 1960, Clay minerals of the outcropping basal Cretaceous beds between the Cape Fear River, North Carolina, and Lynches River, South Carolina, *in* Swineford, Ada, ed., Clays and clay minerals—Proceedings of the 7th National Conference on Clays and Clay Minerals, Washington, D.C., Oct. 20–23, 1958: New York, Pergamon Press, p. 148–161.

Imbrie, John, and Purdy, E. G., 1962, Classification of modern Bahamian carbonate sediments: Am. Assoc. Petroleum Geologists Mem. 1, p. 253–272.

Kesler, T. L., 1972, The Little Mountain syncline in the South Carolina Piedmont: Southeastern Geology, v. 14, no. 3, p. 195–201.

King, P. B., 1955, A geologic section across the southern Appalachians—an outline of the geology in the segment in Tennessee, North Carolina, and South Carolina, *in* Russell, R. J., ed., Guides to southeastern geology, p. 332–373.

Kinkel, A. R., and Lesure, F. G., 1968, Residual enrichment and supergene migration of gold, southeastern United States: U.S. Geol. Survey Prof. Paper 600–D, p. D174–D178.

McKenzie, J. C., and McCauley, J. F., 1968, Geology and kyanite resources of Little Mountain, South Carolina: South Carolina Div. Geology Bull. 37, 18 p.

Mertie, J. B., Jr., 1954, The gold pan—a neglected geological tool: Econ. Geology, v. 49, no. 6, p. 639–651.

Miesch, A. T., 1967, Methods of computation for estimating geochemical abundance: U.S. Geol. Survey Prof. Paper 574–B, p. B1–B15.

Miller, R. L., and Kahn, J. S., 1962, Statistical analysis in the geological sciences: New York, John Wiley and Sons, Inc., 483 p.

Overstreet, W. C., 1962, A review of regional heavy-mineral reconnaissance and its application in the southeastern Piedmont: Southeastern Geology, v. 3, no. 3, p. 133–173.

Overstreet, W. C., White, A. M., Whitlow, J. W., Theobald, P. K., Jr., Caldwell, D. W., and Cuppels, N. P., 1968, Fluvial monazite deposits in the southeastern United States, with a section on mineral analyses by Jerome Stone: U.S. Geol. Survey Prof. Paper 568, 85 p.

Paradeses, William, McCauley, J. F., and Colquhoun, D. J., 1966, The geology of the Blythewood quadrangle: South Carolina Div. Geology Map Ser. MS–13.

Parks, J. M., 1966, Cluster analysis applied to multivariate geologic problems: Jour. Geology, v. 74, no. 5, p. 703–715.

Peyton, A. L., and Lynch, V. J., 1953, Investigation of the Brewer topaz deposit, Chesterfield County, S.C.: U.S. Bur. Mines Rept. Inv. 4992, 19 p.

Sainsbury, C. L., and Reed, B. L., 1973, Tin, *in* Brobst, D. A., and Pratt, W. P., eds., United States Mineral Resources: U.S. Geol. Survey Prof. Paper 820, p. 637–651.

Secor, D. T., and Wagener, H. D., 1968, Stratigraphy, structure, and petrology of the Piedmont in central South Carolina—Carolina Geol. Soc. Field Trip, Oct. 18–20, 1968: South Carolina Div. Geology Geol. Notes, v. 12, no. 4, p. 67–84.

Sokal, R. R., and Michener, C. D., 1958, A statistical method for evaluating systematic relationships: Kansas Univ. Sci. Bull., v. 38, p. 1409–1438.

Swift, D. J. P., and Heron, S. D., Jr., 1969, Stratigraphy of the Carolina Cretaceous: Southeastern Geology, v. 10, no. 4, p. 201–245.

Theobald, P. K., Jr., 1957, The gold pan as a quantitative geologic tool: U.S. Geol. Survey Bull. 1071–A, p. 1–54.

U.S. Geological Survey, 1970, The national atlas of the United States of America: Washington, D.C., U.S. Geol. Survey, 417 p.

Wagener, H. D., 1970, Geology of the southern two-thirds of the Winnsboro 15-minute quadrangle, South Carolina: South Carolina Div. Geology Map Ser. MS–17.

——— 1973, Petrology of the adamellites, granites, and related metamorphic rocks of the Winnsboro quadrangle, South Carolina: Charleston, S.C., The Citadel, Mon. Ser., no. X, 75 p.