Southeastern Geology: Volume 11, No. 1
November 1969

Edited by: S. Duncan Heron, Jr.

Abstract

Academic journal published quarterly by the Department of Geology, Duke University.

Heron, Jr., S. (1969). Southeastern Geology, Vol. 11 No. 1, November 1969. Permission to re-print granted by Duncan Heron via Steve Hageman, Professor of Geology, Dept. of Geological & Environmental Sciences, Appalachian State University.
This journal welcomes original papers on all phases of geology, geophysics, and geochemistry as related to the Southeast. Transmit manuscripts to S. DUNCAN HERON, JR., BOX 6665, COLLEGE STATION, DURHAM, NORTH CAROLINA. Please observe the following:

(1) Type the manuscript with double space lines and submit in duplicate.
(2) Cite references and prepare bibliographic lists in accordance with the method found within the pages of this journal.
(3) Submit line drawings and complex tables as finished copy.
(4) Make certain that all photographs are sharp, clear, and of good contrast.

Proofs will not be sent to authors unless a request to this effect accompanies the manuscript.

Reprints must be ordered prior to publication. Prices are available upon request.

Subscriptions to Southeastern Geology are $5.00 per volume. Inquiries should be addressed to WM. J. FURBISH, BUSINESS AND CIRCULATION MANAGER, BOX 6665, COLLEGE STATION, DURHAM NORTH CAROLINA. Make check payable to Southeastern Geology.
## Table of Contents

Vol. 11, No. 1
1969

1. Alpha-Autoradiography and Morphology of Accessory Zircon Suites  
   Paul C. Ragland ............... 1

2. Geology of the Southwestern Bald Mountains in the Blue Ridge Province of Tennessee  
   Denny N. Bearce ............... 21

3. Phosphosiderite Associated with Nelsonite Rock in Nelson County, Virginia  
   Richard S. Mitchell .......... 37

4. Author-Subject Index  
   Jane T. Tyndall ............... 43
ALPHA-AUTORADIOGRAPHY AND MORPHOLOGY
OF ACCESSORY ZIRCON SUITES

By

Paul C. Ragland
Department of Geology
University of North Carolina
Chapel Hill, North Carolina

ABSTRACT

Zircons were separated from five bentonites and a variety of other rocks, after which they were studied by $\alpha$-autoradiography and standard petrographic techniques. Differences in elongation, rounding, and dispersion of size distributions were found to be useful to distinguish between the various zircon suites. Evidence is offered to demonstrate that: (1) zircons from the five bentonites are apparently from a homogeneous population; (2) $U^{4+}$ and $Th^{4+}$ can occupy regular lattice positions in zircon; and (3) zircons with complex crystal habits are in general smaller than those with less complex habits. Monazite or other highly radioactive impurities, which if present generally make up less than two percent of the zircon suite, can account for more than 50 percent of the radioactivity.

INTRODUCTION

The studies described below were originally undertaken at Rice University as part of a program to date bentonites by the isotopic analysis of the uranium and lead in zircon separated from bentonites. The autoradiographic, petrologic, and mineralogical studies were designed to get some insight into two fundamental questions: 1) What criteria can be used to define a suite of zircon minerals as belonging to one population formed at one time in one geologic environment? 2) What criteria can be applied to define a closed system in the geochronological sense? Some authors conclude that the high precision obtained on the various absolute ages determined on zircon suites separated from Middle Ordovician bentonites (Adams and Rogers, 1961, Adams, et al., 1960) is due in large part to the techniques and selection criteria described here.

The purpose of this paper, therefore, is (1) to compare $\alpha$-autoradiography with morphologic studies as a means of characterizing a zircon suite, and (2) to determine the site of the $\alpha$-emitters in zircons
by autoradiography. Studies of zircon morphology are numerous. Poldervaart and his co-workers, for example, have published several articles concerning zircon morphology and its application to petro-
genetic problems (see Poldervaart, 1955, 1956; Poldervaart and Eckel-
mann, 1955; Larsen and Poldervaart, 1957; Alper and Poldervaart, 
1957). This study utilizes some of their techniques to determine the 
relationship between zircon morphology and radioactivity.

Considerable information is available concerning the total $\alpha$-
activity of zircon suites (e.g., Jaffe, et al., 1959) as well as U and Th 
analyses of zircon suites (Hurley and Fairbairn, 1957; Ahrens, 1965). 
Few data are available, however, concerning the site of the $\alpha$-emitters 
within an individual zircon crystal. Silver and Deutsch (1963) utilized 
the autoradiographic method and some leaching experiments and have 
provided considerable quantitative data on the site of U and Th in zir-
con. It is commonly thought, though not proven, that U and Th exist in 
solid solution, occupying Zr lattice sites in the crystal. However, 
much of the U and Th in felsic igneous rocks has been demonstrated to 
be readily leachable by dilute acid, implying that there are other sites 
than lattice positions in accessory minerals. McIntire (1963) has point-
ed out that in the case of solid solution, autoradiographs should yield a 
uniform track density over the crystal, whereas in the case of occlu-
sion, tracks might be concentrated along certain planes or in patches. 
Other possible sites exist, for the fact that much of the radioactivity is 
readily leachable implies that secondary crack fillings and coatings, 
normally an opaque material resembling hematite or limonite, may be 
highly radioactive. In addition, zircon crystals commonly have many 
inclusions, which may be comparatively radioactive. This paper hope-
fully will answer some of these questions as well as present some new 
information concerning zircon morphology.

Acknowledgments

The writer is indebted to Mrs. Lynn Davis Pollard for her aid 
in collecting the data. John J. W. Rogers and Knut S. Heier kindly re-
viewed the manuscript. John A. S. Adams supplied some of the samples 
and provided help and encouragement throughout the project. A portion 
of the research was sponsored by the Robert A. Welch Foundation 
Grant C-009 to John A. S. Adams and John J. W. Rogers.

PROCEDURE

Zircons were separated from 10 samples by means of the 
standard procedures, heavy liquids (bromoform and methylene iodide) 
and the Frantz isodynamic separator. Sample descriptions and locali-
ties are given in Table 1. The bentonites needed very little crushing, 
for they usually could be disaggregated by elutriation in a large tank of
Table 1. Sample Localities.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Age</th>
<th>Stratigraphy</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>KIN-2</td>
<td>bentonite</td>
<td>Kinnekule, Sweden</td>
<td>Middle</td>
<td>Chasmsops Series, Caradocian</td>
<td>Bystrom-Asklund et al. (1961)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roane Co., Tenn., USA</td>
<td>Middle</td>
<td>Chickamauga Ls.</td>
<td>Hammil (1957)</td>
</tr>
<tr>
<td>JHT-8</td>
<td>bentonite</td>
<td>Culberson Co., Texas, USA</td>
<td>Permian</td>
<td>Maansanita Member, Cherry Canyon Fm</td>
<td>Terrell (1960)</td>
</tr>
<tr>
<td>GH-26</td>
<td>bentonite</td>
<td>Bedford Co., Tenn., USA</td>
<td>Middle</td>
<td>Carters Ls., Stones River Group</td>
<td>Wilson (1949)</td>
</tr>
<tr>
<td>GH-14</td>
<td>bentonite</td>
<td>Roane Co., Tenn., USA</td>
<td>Middle</td>
<td>Chickamauga Ls.</td>
<td>Hammil (1957)</td>
</tr>
<tr>
<td>LAU-1</td>
<td>granite</td>
<td>near Dresden, Saxony, E. Germany</td>
<td>Devonian (?)</td>
<td></td>
<td>Schurmann et al. (1956)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hoppe (1965)</td>
</tr>
<tr>
<td>PCR-65</td>
<td>amphibolite</td>
<td>Mason Co., Texas, USA</td>
<td>Precambrian</td>
<td>Packsaddle Schist</td>
<td>Ragland (1961)</td>
</tr>
<tr>
<td>PCR-25C</td>
<td>granite gneiss</td>
<td>Llano Co., Texas, USA</td>
<td>Precambrian</td>
<td>Red Mountain Gneiss</td>
<td>Boyer and Clabaugh (1959)</td>
</tr>
<tr>
<td>PCR-1</td>
<td>quartzofeldspathic gneiss</td>
<td>Mason Co., Texas, USA</td>
<td>Precambrian</td>
<td>Valley Spring Gneiss</td>
<td>Ragland (1961)</td>
</tr>
<tr>
<td>FBS-1</td>
<td>beach sand</td>
<td>Florida®, U.S.A.</td>
<td>Recent</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*exact location unknown

water. Samples PCR-65, PCR-25C and PCR-1 were passed through a jaw crusher, pulverized to -100 mesh, and elutriated before the zircon separation was performed. Normally 10-50 kilograms of bulk material were processed to obtain one gram of pure zircon.

The problem of breakage of zircons during pulverizing is of concern and should be mentioned. Larsen and Poldervaart (1957) investigated this problem carefully and concluded that there was very little breakage during pulverizing. Such is not the case here, for the relationship between the percent broken crystals and rock type in Table 2 suggests that some crystals are broken during pulverizing. The well-indurated granite and metamorphic rocks received the most vigorous treatment during crushing and the percent broken zircon crystals from these rocks varies from 35-46 percent. With the exception of JHT-8 (39 percent broken zircon crystals) the zircon suites from bentonites contain only 12-18 percent broken crystals. The bentonites were subjected to relatively mild treatment. Moreover, FBS-1, a beach sand, was not pulverized at all and contains only 9 percent broken zircon crystals.

The autoradiographs were prepared by impregnating several hundred zircon crystals in nuclear track plates and pouring a liquid nuclear emulsion over each plate (Ragland, 1964). The plates were
Table 2. Summary Data for Zircon Suites.

<table>
<thead>
<tr>
<th>Sample Rock Type</th>
<th>KIN-2</th>
<th>GH-12</th>
<th>JHT-8</th>
<th>GH-26</th>
<th>GH-14</th>
</tr>
</thead>
<tbody>
<tr>
<td>ave. length in mm. -1</td>
<td>0.99 ± 0.040</td>
<td>1.16 ± 0.041</td>
<td>1.01 ± 0.026</td>
<td>1.34 ± 0.054</td>
<td>1.10 ± 0.050</td>
</tr>
<tr>
<td>ave. breadth in mm. -b</td>
<td>0.035 ± 0.009</td>
<td>0.050 ± 0.014</td>
<td>0.047 ± 0.013</td>
<td>0.055 ± 0.024</td>
<td>0.058 ± 0.021</td>
</tr>
<tr>
<td>ave. size - √1b</td>
<td>0.058 ± 0.014</td>
<td>0.073 ± 0.014</td>
<td>0.065 ± 0.019</td>
<td>0.083 ± 0.029</td>
<td>0.079 ± 0.031</td>
</tr>
<tr>
<td>ave. elongation ratio-b/1</td>
<td>0.41 ± 0.15</td>
<td>0.44 ± 0.16</td>
<td>0.48 ± 0.19</td>
<td>0.45 ± 0.21</td>
<td>0.54 ± 0.15</td>
</tr>
<tr>
<td>rounding ratio</td>
<td>3.1</td>
<td>11</td>
<td>1.2</td>
<td>2.5</td>
<td>4.8</td>
</tr>
<tr>
<td>transparency ratio</td>
<td>5.7</td>
<td>5.9</td>
<td>2.0</td>
<td>5.9</td>
<td>3.7</td>
</tr>
<tr>
<td>% broken crystals</td>
<td>16</td>
<td>18</td>
<td>39</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>ave. α/cm²/sec x 10⁻²</td>
<td>0.75</td>
<td>0.52</td>
<td>0.73</td>
<td>0.77</td>
<td>0.81</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Rock Type</th>
<th>LAU-1</th>
<th>PCR-65</th>
<th>PCR-25C</th>
<th>PCR-1</th>
<th>FBS-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>granite</td>
<td>amphibolite</td>
<td>gneiss</td>
<td>gneiss</td>
<td>beach sand</td>
<td></td>
</tr>
<tr>
<td>ave. length in mm. -1</td>
<td>0.088 ± 0.038</td>
<td>0.111 ± 0.035</td>
<td>0.117 ± 0.044</td>
<td>0.119 ± 0.044</td>
<td>0.166 ± 0.050</td>
</tr>
<tr>
<td>ave. breadth in mm. -b</td>
<td>0.040 ± 0.011</td>
<td>0.061 ± 0.021</td>
<td>0.060 ± 0.023</td>
<td>0.080 ± 0.029</td>
<td>0.101 ± 0.033</td>
</tr>
<tr>
<td>ave. size - √1b</td>
<td>0.057 ± 0.019</td>
<td>0.082 ± 0.023</td>
<td>0.084 ± 0.026</td>
<td>0.095 ± 0.035</td>
<td>0.124 ± 0.024</td>
</tr>
<tr>
<td>ave. elongation ratio-b/1</td>
<td>0.46 ± 0.16</td>
<td>0.59 ± 0.15</td>
<td>0.51 ± 0.19</td>
<td>0.67 ± 0.19</td>
<td>0.62 ± 0.21</td>
</tr>
<tr>
<td>rounding ratio</td>
<td>4.0</td>
<td>0.1</td>
<td>19</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>transparency ratio</td>
<td>6.3</td>
<td>0.6</td>
<td>6.2</td>
<td>0.8</td>
<td>3.0</td>
</tr>
<tr>
<td>% broken crystals</td>
<td>41</td>
<td>39</td>
<td>35</td>
<td>46</td>
<td>9</td>
</tr>
<tr>
<td>ave. α/cm²/sec x 10⁻²</td>
<td>1.7</td>
<td>1.2</td>
<td>0.45</td>
<td>0.20</td>
<td>0.49</td>
</tr>
</tbody>
</table>

*average quoted as arithmetic mean + one standard deviation, (x ± s)
1 average quoted as median value
# defined as: euhedral crystals + subhedral crystals
rounded crystals
2 defined as: transparent crystals + translucent crystals
frosted crystals

allowed to expose for a maximum of 59 days before development. The developed slides were placed under a polarizing microscope with a mechanical stage and studied at X210 and X450 magnification. Traverses were made across each slide until a minimum of 100 doubly terminated individual crystals were studied per slide.

Several parameters were measured on each crystal. Length (l) and breadth (b) were measured only on doubly terminated, unbroken crystals. From these measurements, size (the geometric mean, \[ \sqrt{lb} \]), elongation ratio (b/l), and "volume" (b²x1) were calculated. In order to report the α -activity in α/cm²/sec x 10⁻², surface area
was calculated on the basis of three prism faces and the upper faces of the pyramids. Alpha-tracks from the bottom faces cannot be seen so these faces were not included in the measurement of surface area. It was also noted whether the crystal was euhedral, subhedral, or anhedral, as well as transparent, translucent or opaque. All these data are summarized in Table 2. Crystallographic form was recorded for euhedral and subhedral crystals. Color, presence of outgrowth and/or overgrowths, as well as abundance and nature of inclusions were also noted. The sites of the $\alpha$-emitters were recorded on the basis of their partition between inclusions, crack fillings, surface coatings and randomly distributed throughout the crystals.

COMPARISON OF ZIRCON SUITES

Of particular interest in this study is the comparison of zircon suites from bentonites with those from other rock types. These GH zircon suites were used for absolute age dating by the U-Pb method (Adams and Rogers, 1961) and one purpose of the present work was to determine whether or not the suite represented one population formed at one time. Bentonites, representing volcanic ash that has been altered largely to montmorillonite clay, are excellent stratigraphic marker beds in that one unit may commonly extend over a wide geographic area and yet be deposited over a very short interval of geologic time. Indeed, a single bentonite may represent one ash fall and the zircons within it a homogeneous population. Ragland (1964) compared the $\alpha$-activity of zircons from a bentonite with those from a placer sand. He concluded that the zircons from the bentonite represent a single population whereas those from the sand represent multiple populations. Larsen and Poldervaart (1957) point out that the size and elongation of self-nucleating, free-growing crystals is dependent upon their physico-chemical environment, which probably is essentially uniform in a volcanic neck immediately before eruption. Thus it would be expected for zircons in a single ash fall to represent a single, homogeneous population with respect to at least some measured variates.

In addition, zircon suites from bentonites may be compared with those from multiple sources (FBS-1, the beach sand) and with those of questionable origin (PCR-65, PCR-25C, and PCR-1, the metamorphic rocks). Eckelmann and Kulp (1956), for example, concluded that the Cranberry and Henderson "granites" of North Carolina were meta-sediments based upon their zircon morphologies. Many other studies have discussed the use of zircon morphologies to distinguish between metamorphic rocks and granites of sedimentary as opposed to igneous origin. Saxena (1966) gives a comprehensive review of this literature.

The frequency distributions of the $\alpha$-activities for each zircon suite are shown in Figure 1 and the average $\alpha$-activity is given in Table 2. Only "normal" zircons were considered; malacons, hyacinths and
nucleating. The length of the lines are established by graphically eliminating the extreme 2 1/2 percent of the largest and smallest crystals. If the slopes are similar and the points are close together, several statistical tests have been developed to determine differences in zircon suites. These tests are described in the references listed above. Where the reduced major axes are quite different, as they are in Figure 2, visual observations will suffice. Some observations may be made from the data presented in Table 2 and Figure 2:

1. Zircon crystals from the bentonites and granite are generally more acicular, which is in general agreement with the fact that igneous zircons are commonly more acicular than sedimentary zircons, as reported in Poldervaart (1955, 1956).

2. Zircons from the beach sand are considerably larger than those from other rocks, but are still well within the range for zircons from common plutonic rocks Poldervaart, 1956).

3. Unbroken crystals from suites that contain larger grains are on the average more equant than those from suites of smaller grains. Apparently the large, acicular crystals are broken during stream transport or crushing in the laboratory.

4. Dispersion as shown by length of reduced major axes is generally less in the bentonite suites.

This last point was further developed by plotting histograms of "volumes" (l x b²) of zircons from the entire suite, including broken crystals. This measurement was found to be much more diagnostic
that the size data ($\sqrt[3]{b}$) are lognormally distributed. In the case of the elongation ratio there is, for all practical purposes, a lower limiting value of approximately 0.1 and an upper limiting value of 1.0. When the mode of the distribution falls close to the lower limiting value, which is true of the size data, the sample is positively skewed and approximates the lognormal distribution seen in Figure 5. A plot of the volume data will also yield a lognormal distribution. As $\sqrt[3]{b}$ is dimensionally a linear measure, it should be lognormal for growth in a homogeneous medium. Thus the zircon suites probably represent a homogeneous population with respect to size. If the mode is centrally
During the course of the study, it became necessary to quantify the degree of rounding and transparency of the zircon crystal. This was done by calculating a "rounding ratio" and "transparency ratio" for each suite. The rounding ratio is defined as the number of euhedral and subhedral crystals divided by the number of well-rounded crystals; the transparency ratio is defined as the number of transparent and translucent crystals divided by the number of "frosted" crystals. Note that the term opaque is avoided. Zircons that are described in the literature as opaque are referred to as malacons or are metamict. Metamict zircons and malacons are also highly radioactive compared to "ordinary" zircons, which is not the case with the frosted zircons. These frosted zircons are opaque or near-opaque, but this may be accounted for by the diffusion of light from the frosted surface. Observed with an oil immersion objective (total magnification, X1000), the surface of these frosted crystals appear to be pitted and abraded or possibly etched and corroded. Moreover, the euhedral crystals are generally transparent; subhedral crystals are commonly translucent; and rounded crystals are generally near-opaque. Metamict zircons and malacons were rarely observed and will be discussed later in this paper, but were not included in the calculation of rounding and transparency ratios.

Figure 7 is a plot of rounding ratio vs. transparency ratio for the zircon suites and, as expected, a positive correlation is evident. Note that the values for the bentonites and granite suites fall above those for the beach sand and two of the metamorphic suites. The zircons of the beach sand and two metamorphic rocks are in general highly rounded and abraded. They show evidence of considerable sedimentary recycling and reworking. Zircons from sample PCR-25C are the most euhedral, which suggests that this gneiss may be of igneous origin. This interpretation is in keeping with the field relationships for the rock from which PCR-25C was collected (Boyer and Clabaugh, 1959). Of the two indices, the rounding index seems best to characterize the suites, a value of greater than 1.0 indicating an igneous origin.

RADIOACTIVE SITES

Differences in electronegativities and size would indicate that U^{4+} and Th^{4+} have restricted entry into the Zr^{4+} lattice sites in zircons (Table 3). Both ions are roughly 20 percent larger than Zr^{4+} and can be much more easily accommodated in Y^{4+} or Ce^{4+} sites in xenotime or monazite, as evidenced by relatively high concentrations of both U and Th in monazite and xenotime compared with zircon (Hurley and Fairbain, 1957).

Electronegativity values for both U^{4+} and Th^{4+} are the same and are quite similar to that for Zr^{4+}. Reliable ionization potential data for U^{4+} and Th^{4+} are not available, but Taylor (1965) points out that the melting point of ThO_{2} is 3050°C as compared to 2176°C for UO_{2},
which suggests that the Th-O bond is considerably more ionic than the U-O bond. Thus if one takes into account relative bond types, the average Th/U ratio in zircons of a magmatic series should decrease with differentiation. On the other hand, Ahrens (1965) has suggested that U\(^{4+}\) may be preferentially accepted because its ionic radius is closer to that of Zr\(^{4+}\). He cites as evidence the fact that the Th/U ratio is generally much smaller in the zircons than in their host rocks. This reasoning would imply that the Th/U ratio might be higher in zircons from more fractionated igneous rocks. The average Th/U ratio for zircons from granites as reported in Hurley and Fairbairn (1957) is 0.4, whereas the ratio for pegmatitic zircons is 1.0. Assuming that pegmatites are generally late-stage fractionates of granites, it would seem that small differences in ionic size control the preferential entry of U\(^{4+}\) rather than differences in bonding.

The above arguments hold only if Th\(^{4+}\) and U\(^{4+}\) are competing for lattice sites in the zircons. The fact that at least limited substitution does exist is indicated by the data in Table 4, showing the distribution of radioactivity within the zircon suites. In every case over 90 percent of the \(\alpha\)-tracks were observed to project randomly from the crystals. The \(\alpha\)-track density over the crystals was quite uniform. Only in sample PCR-65 were an appreciable number (10.2 percent) emitting from surface coatings and the inclusions were no more radioactive than the surrounding zircon crystals. Silver and Deutsch (1963) made similar observations when they found that little of the \(\alpha\)-activity seems to be localized in an individual zircon crystal. It would appear, therefore, that despite their relatively large ionic radii, U\(^{4+}\) and Th\(^{4+}\) can substitute for Zr\(^{4+}\) in crystal lattices. No local concentrations of \(\alpha\)-activity were seen within a single crystal, suggesting that occlusion did not take place to an appreciable degree.

Another explanation of the higher Th/U ratios in zircons from pegmatites involves the oxidation of U\(^{4+}\) to its more soluble form (UO\(_2\))\(^{2+}\) and its subsequent leaching from the crystal lattice. Such a process may take place owing to oxidative processes believed to be operative during the pegmatitic stage of magmatism (Rogers and Ragland, 1961; Ragland et al., 1967). Thus the relatively high Th/U ratios in pegmatitic zircons compared with granitic zircons may be caused by removal of U during the pegmatitic stage. This U eventually may find its way into secondary minerals or readily leachable material along grain boundaries.

One interesting observation made during the course of the study was that in several samples a relatively few highly radioactive grains accounted for a disproportionately large amount of the \(\alpha\)-activity. Silver and Deutsch (1963) also noted this when they found that less than one percent uranothorite grains in a zircon suite from the Johnny Lyon Granodiorite, Arizona, can account for more than 50 percent of the radioactivity. The pertinent data are given in Table 4. For example, in sample PCR-1 normal zircons accounted for 86 percent of the suite.
but only 8 percent of the radioactivity.

Several possibilities exist as to the nature of these highly radioactive grains. A few of them (less than 10 percent) are apparently zircons. There are three known varieties of zircons, normal or high zircon, hyacinth and malacon or low zircon. Normal zircons are characterized by relatively low radioactivities, high indices of refraction, high birefringences and high specific gravities. They are generally colorless, transparent and euhedral. Malacons are characterized by relatively high radioactivities, low indices of refraction, low birefringences and low specific gravities. They are commonly brown to black in color, translucent to opaque and rounded. Hyacinths are intermediate between the other two varieties of zircons in every respect and are generally pink to purple in color. See Hutton (1950) and Morgan and Auer (1941) for a detailed discussion of the three varieties of zircons. In addition, metamict zircons, those whose crystalline lattices have been destroyed by radiation damage and are now isotropic, are very highly radioactive. Hyacinths, malacons or metamict zircons are not observed in the bentonite suites. A few of the highly radioactive grains in sample PCR-1 are apparently malacons and metamict zircons.

The majority of the highly radioactive grains were not zircons but monazite, which was not separated from the zircons with the magnetic separator and heavy liquids. The identification was confirmed by mounting individual grains in an x-ray diffraction powder camera, exposing the film for 12-24 hours, and identifying the spots on the developed film. Approximately 20 grains were picked randomly and individually analyzed from several suites, and in each case the crystal was identified as monazite.
CRYSTAL HABIT

Hutton (1951) reports that the most common crystal habit for zircon is the development of second-order prisms $a(110)$ terminated by first-order pyramids $p(111)$, with or without third-order pyramidal faces. The prism $m(110)$ was reported generally to be present but was rarely dominant. Less common are the development of second-order prisms with three orders of pyramids. The most simple habit of one prism and a pyramid of the same order, i.e., $p(101) a(100)$ is reportedly uncommon.

The crystal habits of zircons observed in this study can be divided into three general groups, based upon their relative complexities. In order of their increasing complexity, typical examples of each group are: Type I, $p(101) a(100)$; Type II, $p(101) m(110) a(100)$; and Type III, $p(101) m(110) a(100) x(211)$. These examples are illustrated in Figure 8. The drawings were taken from Berry and Mason (1959). Relative percentages of each type are given in Table 5 for those suites that contained an appreciably number of euhedral crystals.

With the exception of JHT-8 and PCR-25C, the simple habit of Type I is uncommon, which is in agreement with the observations of Hutton (1951). The most complex habit of Type III predominates. The data for LAU-1 are in good agreement with the conclusions of Hoppe (1965) concerning crystal morphology of the zircons from the Lausitz Granodiorite.

![Figure 8. Typical examples of zircon crystals from Types I, II, and III. Drawings from Berry and Mason (1959).](image-url)
ship is in agreement with the data in Table 6. Those of Type I should be largest of all but insufficient data are available for all but one suite. In sample PCR-25C the average volume of Type I crystals is 5.4 ± 3.0 mm³ x 10⁻⁴, equal to that of Type II.

CONCLUSIONS

1. Parameters that apparently best characterize a zircon suite and enable it to be distinguished from other suites are elongation ratio, rounding ratio and dispersion of volume histograms.

2. Zircons from the five bentonites are apparently from a homogeneous population with respect to size, elongation and α-activity, indicating that they crystalized under similar physicochemical conditions.

3. Apparently U⁴⁺ and Th⁴⁺ occupy regular lattice positions in zircon.

4. Relatively high Th/U ratios in pegmatitic zircons compared with granitic zircons may be explained by: (1) preferential entry of U⁴⁺ into the zircon lattice during magmatic fractionation; and (2) oxidation of U⁴⁺ to (UO₂)²⁺ and its subsequent leaching during the pegmatitic stage of magmatism.

5. A few grains in some of the suites that were observed to be considerably more radioactive than normal zircons are generally monazite and rarely malacon or metamict zircons.

6. Zircons with relatively complex crystal habits (i.e., they have some faces with comparatively high Miller indices) are in general smaller than those with less complex crystal habits. This observation can be explained by an alternative expression of the law of Bravais.

REFERENCES CITED


Lost Creek Gneiss, Mason and McCulloch Counties, Texas: M. A. Thesis, Rice University.


Terrell, J., 1960, Separation of zircon and biotite from bentonite and absolute dating possibilities for dating certain West Texas bentonites: M. A. Thesis, Rice University.

GEOLOGY OF THE SOUTHWESTERN BALD MOUNTAINS IN THE
BLUE RIDGE PROVINCE OF TENNESSEE

By

Denny N. Bearce
Department of Geology
Birmingham-Southern College
Birmingham, Alabama

ABSTRACT

The southwestern Bald Mountains in eastern Tennessee are part of the western margin of the Blue Ridge Province in the southern Appalachians.

Two major thrust sheets occur in the southwestern Bald Mountains: the Buffalo Mountain thrust sheet and the Del Rio thrust sheet. Both thrust sheets are composed largely of clastic sedimentary rocks of the Precambrian Ocoee Series and the Lower Cambrian Chilhowee Group.

Synclines in both the Buffalo Mountain and Del Rio thrust sheets indicate post-fault folding of the thrust sheets. Imbricate thrust faulting developed during the folding of the larger thrust sheets. A greater intensity of folding is expressed at the surface in the Del Rio thrust sheet than in the overlying Buffalo Mountain thrust sheet.

Small windows in the Del Rio thrust sheet indicate that the imbricate thrust faults within the sheet become subhorizontal at a relatively shallow depth and are folded. The Del Rio thrust sheet probably thins northeastward by wedging out from the base upward beneath the Buffalo Mountain thrust sheet. Possibly, only the lower portion of the Del Rio thrust sheet, the most deformed portion nearest the sole fault of the thrust sheet, remains; the upper portion may have been bevelled by the over-riding Buffalo Mountain thrust sheet and subsequently further reduced by erosion. Deformational intensity increases near the southwest end of the Buffalo Mountain thrust sheet where it wedges out over the Del Rio thrust sheet. The increased degree of deformation in the thinned southwest end of the Buffalo Mountain thrust sheet and the even greater deformation in the northeasternmost exposed portion of the Del Rio thrust sheet suggest that the northeastern exposed portion of the Del Rio thrust sheet is a surface representation of the structural nature of the Buffalo Mountain thrust sheet at depth.

A more or less continuous synclinal trend with minor intervening warps is postulated to extend from the synclinorium, between the Holston Mountain and Iron Mountain thrust faults of northeasternmost
Figure 1. Location of southwestern Bald Mountains (in black).

Figure 2. Major structural features of northeast Tennessee and western North Carolina. Present study area outlined in stipple pattern. Geology outside present study area after Rodgers (1953).

Tennessee for assistance and to W. A. Thomas of Birmingham-Southern College for review of the article.

STRATIGRAPHY

Ocoee Series

General. The Ocoee Series (Safford, 1869, p. 183-198) is a
southwest end of the Buffalo Mountain thrust sheet (Plate 1). The northeastern facies is found in a different thrust block within the Buffalo Mountain thrust sheet northeast of State Highway 70 (Plate 1). The northeastern facies is typified by units 50 to 1,000 feet thick of light brown to light grey, medium- to massively-bedded, vitreous in part, fine- to coarse-grained quartzite containing intervals of granular arkosic quartzite, and units approximately 300 feet thick of dark greenish-grey, massively-bedded, fine- to medium-grained, spheroidally weathering, arkosic sandstone containing intervals of platy to thin-bedded siltstone and shale (Figure 3, Ocoee Series, Camp Creek Bald). The southwestern facies is composed of pale greenish-grey and greenish-brown, massively-bedded (beds as much as 20 feet thick), fine- to coarse-grained arkose with intervals of conglomeratic arkose up to five feet thick, and grey to black, laminated shale and siltstone (Figure 3, Ocoee Series, Paint Creek). No distinctive lithology can be traced from one facies into the other, and thrust faulting prevents a comparison of thickness between the two facies (Figure 3).

Sandsuck Formation. The Sandsuck Formation (Keith, 1895, p. 3) in the southwestern Bald Mountains comprises 2,500 feet of dark-
quartzite and arkose, brown to greenish-grey, medium- to thick-bedded, fine-grained, pyritic sandstone, and minor intervals of dark-grey, platy siltstone (Figure 3). The lower half of the formation becomes increasingly more arkosic and granular toward the base, and generally ten to seventy feet of arkosic conglomerate with white quartz and yellow feldspar pebbles forms the lowermost beds of the formation.

The Unicoi is overlain conformably by shale and siltstone of the Hampton Formation. It is distinguished from the underlying Sandsuck Formation by the preponderance of shale and siltstone, and by the occurrence of dolomite beds or dolomite cement in arkosic intervals, within the Sandsuck.

Hampton Formation. The Hampton Formation (Keith, 1903, p. 5) in the southwestern Bald Mountains is comprised of about 2,000 feet of shale, siltstone, and sandstone (Figure 3). The sandstone is mainly dark-brown to grey, as are the shale and siltstone which form the major portion of the formation. Typical Hampton sandstone is fine-grained, massively-bedded and pyritic, and weathers to smooth, rounded ledges. Intervals of arkose and feldspathic quartzite similar to Unicoi lithology are present in the Hampton, but they constitute only a small percentage of the formation. The shale and siltstone of the Hampton are identical to the shale and siltstone in the major portion of the Erwin Formation. However, the Hampton contains no ferruginous quartzite or tan vitreous quartzite, the two lithologies which are distinctive of the Erwin in the southwestern Bald Mountains. Thus, the Hampton Formation is best delimited locally in terms of the more distinctive beds of the Unicoi and Erwin formations below and above it.

The Hampton Formation has essentially the same lithologic character in both the Buffalo Mountain and Del Rio thrust sheets. In the Del Rio sheet, however, a laterally persistent interval of feldspathic quartzite is present in the middle portion of the formation and is mapped as the Hampton Quartzite Member (Plate 1). The lower Hampton, present and used as a mapping unit (Ferguson, 1951, p. 28) in other portions of the Del Rio thrust sheet, is not exposed in the portion of the Del Rio thrust sheet mapped by the writer.

Erwin Formation. The Erwin Formation (Keith, 1903, p. 5) in the southwestern Bald Mountains is a 2,500 foot thick sequence of bluish-grey, finely-laminated siltstone and shale and light-gray, thin-bedded, fine-grained, pyritic sandstone with distinctive intervals of dark-red, medium- to massively-bedded, fine- to coarse-grained, ferruginous quartzite and light-brown, vitreous, massively-bedded quartzite (Figure 3). The latter two lithologies serve to differentiate the Erwin from the Hampton. The writer has mapped the base of the Erwin as the base of the lowest ferruginous quartzite in the southwestern Bald Mountains.
TECTONICS

Principal Structural Features of the Unaka Range in

Northeastern Tennessee and Western North Carolina

Major thrust sheets. The dominant structural features of the Unaka Range are thrust faults which dip generally 30 degrees to 40 degrees toward the southeast. Because of shallow dip and great topographic relief the faults are commonly sinuous in trace and form branching or anastomosing patterns. The thrust planes generally cut across stratigraphic horizons at low angles.

The Holston Mountain thrust fault (Stose and Stose, 1944, p. 380) may be traced along the front of the Unaka Range for tens of miles in northeast Tennessee (Figure 2). It is a low-angle, southeast-dipping fault along which Precambrian and lower Cambrian rocks have moved relatively northwest over Ordovician rocks of the Valley and Ridge Province. The Holston Mountain fault is replaced southwestward as the boundary of the Blue Ridge Province, by the Buffalo Mountain fault which in turn is replaced further southwest by the Meadow Creek Mountain fault (Figure 2).

The Buffalo Mountain overthrust (Keith, 1907, p. 8-9) in the northeast part of the Bald Mountains bounds a tongue-shaped body of rocks called the Buffalo Mountain thrust sheet (Figure 2) Ordway, 1959, p. 623). The overthrust dips gently to the southeast on the northwest side and almost vertically on the southeast side of the thrust sheet (Rodgers, 1953, p. 142). On the southeast side of the tongue the Buffalo Mountain fault trace merges with the Rector Branch fault and for a small distance borders the southwest end of the Mountain City window (Figure 2). The Buffalo Mountain thrust fault forms the northwest boundary of the Bald Mountains as far southwest as Hayesville (Plate 1), where it arches back into the mountains.

At Hayesville the Buffalo Mountain fault is replaced as the west boundary fault of the Blue Ridge Province by the Meadow Creek Mountain thrust fault. The Meadow Creek Mountain and Mine Ridge thrust faults (Figure 2) delimit the Del Rio thrust sheet (Ferguson and Jewell, 1951, p. 40-44). The two faults may be separate exposures of a single folded fault. The Del Rio thrust sheet is cut into blocks by lesser, apparently steeper thrust faults, and contains the same formations as the Buffalo Mountain thrust sheet which overlies it. The Del Rio thrust sheet is in part overridden by the Buffalo Mountain thrust sheet and probably wedges out northeastward beneath the Buffalo Mountain thrust sheet.

Folds. King et al. (1944, p. 11), in describing the geology of northeast Tennessee, believed that thrust sheets had moved many miles northwest along low-angle thrust faults. He postulated that during or shortly after thrusting the thrust sheets were folded broadly into a
synclinorium to the northwest, between the Holston Mountain and Iron Mountain thrust faults, and an anticlinorium to the southeast, between the Iron Mountain and Stone Mountain thrust faults (Figure 2). King et al. (1944, p. 12) reported that the highest and youngest thrust sheet of the series of thrust sheets in northeastern Tennessee, the Buffalo Mountain thrust sheet, lies within the trend of the synclinorium (Figure 2).

The Rich Mountain syncline (Shekarchi, 1959) lies in the same trend as the synclinorium described by King between the Holston Mountain and Iron Mountain thrust faults (Figure 2). The smaller Greene Mountain and Paint Creek synclines southwest of the Rich Mountain syncline lie in the same trend as the Rich Mountain syncline. Thus, King's synclinorium appears to extend southwestward from northeasternmost Tennessee to the southwest end of the Buffalo Mountain thrust sheet.

Windows. The great horizontal displacement of thrust sheets of the Blue Ridge province is proven by windows that lie as much as 12 miles southeast of the edge of the thrust sheets.

The Mountain City window lies on the anticlinorium trend between the Iron Mountain and Stone Mountain thrust faults (Figure 2). The window exposes Precambrian granites and gneisses and lower Cambrian sedimentary rocks of the Chilhowee Group, Shady Formation and Rome Formation. Rocks within the window are cut by many thrusts dipping both southeast and northwest.

The Hot Springs window is encompassed by four different thrust faults. Rocks within the window range in age from the Cambrian Shady Formation to the Precambrian Snowbird Formation. The window trends east-west in contrast to the northeast alignment of most Appalachian structures (Figure 2). Oriel (1949, p. 156) reported a southwest-plunging anticline within the window. He proposed that the anticline formed within and after emplacement of an early thrust sheet, the Pulaski thrust sheet, which underlies the Buffalo Mountain and Del Rio thrust sheets.

Structural Features of the Buffalo Mountain and Del Rio

Thrust Sheets Within the Southwestern Bald Mountains

Thrust faults. The Buffalo Mountain thrust fault is a low-angle fault dipping at the surface from 4 to 35 degrees to the southeast and flattening at depth (Figure 4). Stratigraphic relationships between hanging wall and footwall vary along the Buffalo Mountain thrust fault. The Snowbird rests on Cambrian Shady Dolomite at the southwest end of the thrust sheet and the Sandsuck and Unicoi rest on Ordovician Sevier Shale and Knox Limestone at the northeast end of the area of study. Never the less, stratigraphic displacement appears to be consistently of a magnitude of about 10,000 feet along the length of the fault. The

29
southwestward along the trace of the fault.

The Del Rio thrust sheet, bounded by the Meadow Creek Mountain thrust fault, protrudes from beneath the Buffalo Mountain thrust sheet at its southwest end. Arkose of the Sandsuck Formation at the southwest end of the Buffalo Mountain thrust sheet is faulted onto a thin wedge of Shady Dolomite which in turn is carried by the Meadow Creek Mountain fault onto Sevier Shale of the Pulaski thrust sheet (Plate 1). Northeast from Hayesville, Sandsuck beds of the Buffalo Mountain thrust sheet lie directly on Sevier Shale of the Pulaski thrust sheet (Plate 1). The intermediate thin wedge of Shady Dolomite marks the northeasternmost exposure of the Del Rio thrust sheet that probably wedges out from its base upward beneath the Buffalo Mountain thrust sheet (Figure 5). The Buffalo Mountain thrust fault, replaced at the mountain front at Hayesville by the Meadow Creek Mountain thrust fault, assumes a more south-southwesterly course into the mountains across the Del Rio thrust sheet (Plate 1) and continues into North Carolina.

Numerous lesser thrust faults are found within the Buffalo Mountain and Del Rio thrust sheets. At the surface the lesser faults of the Buffalo Mountain thrust sheet generally dip about 45 degrees to the southeast (Figure 4). Thrust faults within the Del Rio thrust sheet are much more sinuous in trace than are those within the Buffalo Mountain thrust sheet, probably because the fault planes within the Del Rio thrust sheet do not dip so steeply as those within the Buffalo Mountain thrust sheet. Instead, fault planes within the Del Rio thrust sheet appear to form undulating surfaces at relatively shallow depth (Figure 4, Sections E-E' and F-F').

Stratigraphic displacement ranges to a maximum of about 3,500 feet for all but the southeasternmost fault of the Buffalo Mountain thrust sheet, slightly northwest of and roughly parallel to the Tennessee-North Carolina state line (Plate 1). Along the southeasternmost thrust fault of the Buffalo Mountain thrust sheet, quartzites and shales of the Snowbird Formation are faulted onto rocks as young as the Erwin Formation. The fault may be another imbricate thrust within the Buffalo Mountain thrust sheet; however, lack of resemblance of rocks in the hangingwall of the southeasternmost thrust fault to rocks elsewhere within the Buffalo Mountain thrust sheet may indicate that this is a separate major thrust sheet, higher and later than the Buffalo Mountain thrust sheet.

Synclines. The southwest nose of a northeast-plunging syncline, referred to herein as the Greene Mountain syncline (Bearce, 1966) occurs in the Buffalo Mountain thrust sheet (Plate 1 and Figure 4, Sec. B-B'). The northwest flank of the syncline, containing beds as young as the Erwin Formation, continues northeast beyond the northeast end of the area mapped by the writer. The southeast flank of the Greene Mountain syncline is concealed beneath higher thrust blocks from the upper Paint Creek headwaters northeastward (Plate 1). The southeast flank appears to project northeastward under the Rich Mountain syncline (Figure 2).
Figure 5. Block diagram between structure sections B-B\textsuperscript{'} and C-C\textsuperscript{'} showing northeastward wedge-out of Del Rio thrust sheet and southwestward thinning of Buffalo Mountain thrust sheet.

At the southwest end of the Buffalo Mountain thrust sheet is the northeast-plunging nose of the Paint Creek syncline (Bearce, 1966), a broad, faulted, and folded syncline containing beds at least as old as Snowbird and as young as the Unicoi Formation. One of the minor thrust faults in the Buffalo Mountain thrust sheet separates a large portion of the Paint Creek syncline from the Greene Mountain syncline.

The bedding attitude of the southwest nose of the Paint Creek syncline directly controls the map configuration of the eroded southwest end of the Buffalo Mountain thrust sheet; bedding strike is in part parallel to strike of the southwesternmost 2 miles of the Buffalo Mountain fault shown on Plate 1.

Minor shallow synclines within the Del Rio thrust sheet have axial trends that are inconsistent with the northeast trend of synclines in the Buffalo Mountain thrust sheet. Strata in the Del Rio thrust sheet are more intensely folded than strata of the Buffalo Mountain thrust sheet.

Windows. Two small windows, exposing rocks of the Erwin Formation and completely surrounded by quartzite and shale of the middle portion of the Hampton Formation, are found in the Del Rio thrust sheet in the lower Paint Creek-French Broad River area (Plate 1). The northernmost window, confined to the bottom of a deep stream
valley cut into Hampton beds, is approximately 3,200 feet long and is estimated to be 900 feet wide at its mid-point (Figure 4, Sec. E-E'). Rocks within the window consist of typical Erwin quartzites that dip 20 degrees to 35 degrees to the south. The second window lies on the south side of the French Broad River and is estimated to be about 450 feet in diameter. Rocks in the window are typical Erwin Formation, and the rocks surrounding the window are middle and upper Hampton (Figure 4, Sec. F-F'). Although exposures are few, the anomalous east dip of the quartzite within the window in contrast to the northwest dip of the surrounding Hampton beds, and the topographic location, at the bottom of a draw cut into Hampton beds, demonstrate a window.

Deformation within thrust blocks. In the portion of the Buffalo Mountain thrust sheet under consideration surficial deformation increases southwestward, reaching a maximum in the Paint Creek syncline. From the northeastern border of Plate 1 southwestward to the southwest nose of the Greene Mountain syncline, bedding attitudes reflect only broad warping of the blocks forming the Buffalo Mountain thrust sheet (Figure 4, Sections A-A' and B-B'). Southwest of the Greene Mountain syncline pronounced changes in degree of dip and reversals in direction of dip indicate more intense folding of the thrust blocks of the Buffalo Mountain thrust sheet (Figure 4, Sections C-C' and D-D').

Surficial evidence of increasing folding intensity southwestward in the Buffalo Mountain thrust sheet is accompanied by an increase in the development of fracture cleavage. Cleavage is absent northeast of the southwest nose of the Greene Mountain syncline. Cleavage is confined to Ocoee strata and reaches a maximum development in the Paint Creek syncline. The majority of cleavage attitudes have dips averaging from 50 to 75 degrees to the southeast and strikes averaging from N 10° E to N 30° E.

The thickness of strata overlying the Buffalo Mountain thrust fault in the Paint Creek syncline at the southwest end of the Buffalo Mountain thrust sheet is apparently less than it is further to the northeast in the thrust sheet. Southwestward thinning of the thrust sheet is due in part to erosion. Surface elevations along streams in the Buffalo Mountain thrust sheet from State Highway 70 northeastward are mostly above +2,000 feet; southwest of State Highway 70 they are generally between +1,500 feet and +2,000 feet (Plate 1). The Buffalo Mountain fault is conjectured to flatten at depth at an elevation between -1,000 feet and -2,000 feet (Figure 4, Sections A-A' and B-B') northeast of State Highway 70. The fault plane probably rises southwest of State Highway 70 over the northeast end of the Del Rio thrust sheet (Figure 4, Sections C-C' and D-D' and Figure 5). Thinning of the thrust sheet southwestward is thus mainly a result of wedging out above the Del Rio thrust sheet.

The intensity of folding is even greater in the northeasternmost
steeply as thrust faults within the Buffalo Mountain thrust sheet, and in addition they are warped. Their sub-horizontal, warped nature is indicated by small windows and by erratic traces.

Factors contributing to the surficial structural differences between the two thrust sheets are:

1. The Del Rio thrust sheet apparently wedges out from the base upward northeastward in the southwestern Bald Mountains, pinching out beneath the southwest end of the Buffalo Mountain thrust sheet.

2. The northeastern end of the Del Rio thrust sheet was over-ridden and presumably bevelled by the Buffalo Mountain thrust sheet.

3. Surface drainage in the Del Rio thrust sheet, more highly developed than in the Buffalo Mountain thrust sheet, has dissected and thinned the Del Rio thrust sheet to a greater extent than the Buffalo Mountain thrust sheet.

Thrust faults within the Buffalo Mountain thrust sheet probably flatten at depth before intersecting the Buffalo Mountain thrust fault. Both the Buffalo Mountain and Del Rio thrust sheets are deformed most at their bases by folds and small-scale thrust faults that attenuate upward. The northeasternmost exposed portion of the Del Rio thrust sheet is probably a surface representation of the structural nature of the Buffalo Mountain thrust sheet at depth.

The Buffalo Mountain thrust sheet is synclinal in structure in the southwestern Bald Mountains; synclines have been faulted and imbricated.

REFERENCES CITED


PHOSPHOSIDERITE ASSOCIATED WITH NELSONITE ROCK

IN NELSON COUNTY, VIRGINIA

By

Richard S. Mitchell
University of Virginia

ABSTRACT

Greenish cryptocrystalline phosphosiderite occurs in hydrothermally altered ilmenite-nelsonite dike rocks in Nelson County, Virginia. Strengite, dimorphous with phosphosiderite, also occurs but it is much rarer. Indexed X-ray powder data are given for both minerals. In addition to ilmenite and apatite which are essential to the nelsonite, associated minerals are talc, chlorite, anatase, and wavellite.

INTRODUCTION

The relatively rare mineral phosphosiderite (also called meta-strengite or clinostrengite) occurs in altered ilmenite-nelsonite dike rocks in Nelson County, Virginia. Although the mineral has not been reported from the area previously it was referred to by Watson and Taber (1913, p. 106) as an unknown "compound of bluish-green color." A recent examination of nelsonite specimens in Lewis Brooks Museum (University of Virginia), as well as new materials in the field, has shown that phosphosiderite is quite common, especially at one locality near Jonesboro.

DATA FOR PHOSPHOSIDERITE

Green to bluish-green cryptocrystalline phosphosiderite occurs in nelsonite either as thin crusts with small botryoidal structures, or as seam fillings, or intimately associated with talc as powdery coatings. The mineral is brittle, has a conchoidal fracture, a hardness of 4.5, and a pale greenish-yellow streak. Thin fragments are translucent.

A pure sample of phosphosiderite was submitted for semiquantitative spectrographic analysis. The chief elements detected are iron and phosphorous. Trace amounts of numerous other elements were found, but only Al₂O₃, 1.5 percent, and TiO₂, 0.75 percent, are significant. This analysis verified phosphosiderite and eliminated any
Table 1. X-ray powder data for phosphosiderite, Nelson County, Virginia. Filtered copper radiation. Cameras of 11.46 cm diameter.

<table>
<thead>
<tr>
<th>hkl</th>
<th>d (calc.) Å</th>
<th>d (meas.) Å</th>
<th>I (obs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>011</td>
<td>6.49</td>
<td>6.50</td>
<td>mw</td>
</tr>
<tr>
<td>020</td>
<td>4.90</td>
<td>4.93</td>
<td>m+</td>
</tr>
<tr>
<td>110</td>
<td>4.66</td>
<td>4.66</td>
<td>m+</td>
</tr>
<tr>
<td>101</td>
<td>4.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>4.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>002</td>
<td>4.34</td>
<td>4.36</td>
<td>vs</td>
</tr>
<tr>
<td>021</td>
<td>4.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>4.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>4.09</td>
<td>4.10</td>
<td>vw</td>
</tr>
<tr>
<td>012</td>
<td>3.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>3.60</td>
<td>3.60</td>
<td>ms</td>
</tr>
<tr>
<td>121</td>
<td>3.33</td>
<td>3.32</td>
<td>vvw</td>
</tr>
<tr>
<td>121</td>
<td>3.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>022</td>
<td>3.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>3.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>3.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>031</td>
<td>3.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>130, 122</td>
<td>2.78</td>
<td>2.78</td>
<td>ms</td>
</tr>
<tr>
<td>013</td>
<td>2.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>2.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>131, 200</td>
<td>2.65</td>
<td>2.65</td>
<td>vvw</td>
</tr>
<tr>
<td>131</td>
<td>2.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>032</td>
<td>2.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>210</td>
<td>2.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>2.55</td>
<td>2.55</td>
<td>ms</td>
</tr>
<tr>
<td>103</td>
<td>2.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>023</td>
<td>2.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>113</td>
<td>2.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>211</td>
<td>2.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>040, 211, 113</td>
<td>2.45</td>
<td>2.44</td>
<td>vvw</td>
</tr>
<tr>
<td>041</td>
<td>2.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>132</td>
<td>2.35</td>
<td>2.35</td>
<td>vvw</td>
</tr>
<tr>
<td>132, 220</td>
<td>2.33</td>
<td>2.33</td>
<td>vvw</td>
</tr>
<tr>
<td>202</td>
<td>2.27</td>
<td>2.27</td>
<td>vww, vwww</td>
</tr>
<tr>
<td></td>
<td>2.12</td>
<td></td>
<td>vww</td>
</tr>
<tr>
<td></td>
<td>2.07</td>
<td></td>
<td>vww, vwww</td>
</tr>
<tr>
<td></td>
<td>2.01</td>
<td></td>
<td>w</td>
</tr>
<tr>
<td></td>
<td>1.81</td>
<td></td>
<td>vww</td>
</tr>
<tr>
<td></td>
<td>1.76</td>
<td></td>
<td>vww</td>
</tr>
<tr>
<td></td>
<td>1.71</td>
<td></td>
<td>vww</td>
</tr>
<tr>
<td></td>
<td>1.66</td>
<td></td>
<td>vww</td>
</tr>
</tbody>
</table>

39
southeast of Jonesboro. Float pieces are common near the barn, and very rich phosphosiderite specimens occur in place at a deep roadcut in the barnyard.

Bright green phosphosiderite covers large joint planes of the nelsonite rock. In addition to porcelaneous masses, often with small botryoidal surfaces, the mineral also occurs as narrow veins in the nelsonite, and as cellular replacements of apatite grains in the rock, and very commonly mixed with talc to form light green powdery surfaces on the rock. Very thin bluish-white, white, and tan crusts overlying deep emerald-green phosphosiderite crusts were shown by X-ray study also to be phosphosiderite. Strengite is very rare at the Hughes farm. Here it occurs as light gray greasy masses and crusts with botryoidal development within the small subspherical cavities formerly occupied by apatite grains in nelsonite.

In addition to ilmenite and apatite, which are the essential minerals of the nelsonite matrix rock, talc is the most common associated mineral at the Hughes locality. It occurs as earthy to micaceous masses and especially as coatings on joint planes. Individual plates up to 2.5 mm across were noticed. It varies from white to green, the green being due to admixed phosphosiderite. Yellowish micaceous chlorite occurs in some specimens. One nelsonite piece was found in which black ilmenite is replaced by greenish-brown anatase in such a way as to retain the original texture of the rock. In this one the essential apatite was not appreciably changed. In many other specimens, however, apatite is deeply etched and altered. Fine-grained white wavelite, stained brown, was found on some weathered spongelike nelsonite masses from which the apatite was removed. The writer has been unable to identify some additional minerals, one a thin yellowish-green botryoidal crust and another a small globule of white radiating needles.

Phosphosiderite and strengite have obviously formed from the alteration of nelsonite, iron coming from ilmenite and phosphate from apatite. The close association of these minerals with talc suggests that the alteration was hydrothermal. Studies of nelsonite dikes also led Hillhouse (1960, p. 124) to conclude that slight hydrothermal activity continued after the deposition of the dikes and resulted in the alteration of nelsonite minerals. However, he did not mention the secondary phosphates described here. In contrast, the writer did not find phosphosiderite in the numerous very weathered float specimens of nelsonite he examined.

REFERENCES CITED


Hillhouse, D. N., 1960, Geology of the Piney River-Roseland titanium
Rock Analyses in the Carolina Slate Belt and the Charlotte Belt of Newberry County, South Carolina

The Stratigraphic Paleontology of the Chickamauga Group of the Red Mountain Area, Alabama

Recent Root Casts in Sediments of the Apalachicola Delta, Florida

A Biostratigraphic Evaluation of the Snow Hill Member, Upper Cretaceous of North Carolina

A Review of Regional Heavy-Mineral Reconnaissance and its Application in the Southeastern Piedmont

Environmental Studies of the Cretaceous Mount Laurel and Wenonah Sands of New Jersey

The Sediments of the Beaufort Inlet Area, North Carolina

Bouguer Gravity Map of North Carolina

Airborne Radioactivity Surveys -- A Geologic Exploration Tool

Geology of the Elk Knob Copper Deposit and Vicinity, Watauga County, North Carolina

A Supplementary Catalog of Type Localities of Coastal Plain Stratigraphic Units

The Beaufort, South Carolina, Magnetic Low

Digital Computer Program for Identification of Minerals by X-ray Diffraction

Geomorphology and the Sediment Transport System

Paleoecology of the Pamlico Formation (Late Pleistocene): Nixonville Quadrangle, Horry County, South Carolina

Rocks of the Carolina Slate Belt in Orange County, North Carolina

Configuration of the Cretaceous-Tertiary Boundary in the Delmarva Peninsula and Vicinity

Nature and Origin of the Slump Structures in the Black Mingo Formation of South Carolina

Stratigraphy of the Neogene Deposits, Lower Neuse Estuary, North Carolina

Table of d Spacings from 2,000° to 60,975° 2θ in 0.025 Degree Increments Copper Kα Radiation

A Report on Geological and Ground-Water Investigations in Pigeon Roost Watershed, Marshall County, Mississippi

The Cretaceous-Tertiary Boundary at the Type Locality of the Castle Hayne Formation

Paleoecology of the Type Waccamaw (Pliocene?) Outcrops: South Carolina

Isolated Fault Scarps on the Continental Slope of Southwest Florida

Pleistocene "Coquina" at 20th Avenue South Myrtle Beach, South Carolina, and other Similar Deposits

Chemical Analyses of Rocks of the Carolina Slate Belt

Filled Submarine Spring Vents in Cretaceous Rocks of Alabama

Rock-Stratigraphic Distribution of the Surry Scarp in Central South Carolina

Gravity Studies in the Concord Quadrangle, North Carolina

Notes on Marine Geology off the Mouth of the North Edisto River, North Carolina

Hydrogeologic Framework of the Gulf and Atlantic Coastal Plain

The Pungo River Formation, a New Name for Middle Miocene Phosphorites in Beaufort County, North Carolina

An Unusual Radioactive, Rare Earth-bearing Sulfide Deposit in Cabarrus County, North Carolina

The Elberton Batholith
Clay Mineral Assemblages in a South Carolina Lake-River, Estuary Complex

Geologic Profiles of a Georgia Barrier Island

Geologic Section Along a Carolina Bay, Sumter County, S. C.

Barrier-and-Lagoon Sets on High Terraces in the Florida Panhandle

Geomorphic Elements of the Area between the Cape Fear and Pee Dee Rivers, North and South Carolina

Areal Modal Variation in the Farrington Igneous Complex, Chatham and Orange Counties, North Carolina

Virginia Metamict Minerals: Comments on a Uranium-Niobium Oxide from Powhatan County

Compositions of Minerals Within the Wall Rocks of a Granitic Batholith

Geology of the Carolina Slate Belt West of the Deep River-Wadesboro Triassic Basin, North Carolina

The Use of X-ray Diffraction for the Quantitative Analysis of Naturally Occurring Multicomponent Mineral Systems

Bathymetry of the Miami Terrace

The Stratigraphic Significance of an Upper Miocene Fossil Discovery in Jefferson County, Florida

Frequencies of Infaunal Invertebrates Related to Water Content of Chesapeake Bay Sediments

Laumontite-Leonhardite from Durham County, N. C.

Ultramylonite Zones in the Western Carolinas

Petrography of the Soapstone Deposits near Old Dominion, Albemarle County, Virginia

Marine Terraces: Pre-Pleistocene(?)

The General Absence of Blue Quartz in Sedimentary Rocks of the "Folded Appalachians" of Southwestern Virginia

Notes on Technique for Sampling Suspended Sediments

Bottom Topography of the Georgia Continental Shelf

Submerged Beach on a Zero-Energy Coast

Abundance of Pollen and Spores in Marine Sediments off the Eastern Coast of the United States

Faulted Alluvial and Colluvial Deposits Along the Blue Ridge near Saluda, North Carolina

The Surry Scarp from Fountain to Potters Hill, North Carolina

Clay Mineralogy, Stratigraphy, and Structural Setting of the Hawthorn Formation, Coosawhatchie District, South Carolina

Sediments of the Choptank River, Maryland

Stratigraphy of the Jackson Group (Eocene) in Central Georgia

Trace Metals in Quartz by Atomic Absorbtion Spectrophotometry

Geomorphology of River Valleys in the Southeastern Atlantic Coastal Plain

Paragonite-bearing Phyllites in the Central Virginia Piedmont

The Midway-Wilcox Boundary in Kemper and Lauderdale Counties, Mississippi

Porosity Index

Notes on Five Marine Pleistocene Localities in Northeastern North Carolina

The Clay Minerals of a Traverse on the North Carolina Continental Margin and Bermuda Rise

Density Sorting as Indicated by Departure from Gaussian Curve

Coastal Plain Stratigraphy and Geomorphology near Benson, North Carolina

Virginia Metamict Minerals: Allanite
Vertical Profiles of Modern Sediments Along the North Carolina Coast
Carbonate Sediments on the Continental Shelf, Cape Hatteras to Cape Romain
Sedimentary Framework of the Continental Terrace off the East Coast of the United States

Late-Pleistocene Peats from Long Beach, North Carolina
Barite Nodules in the Athens Shale in Northeastern Tennessee and Southwest Virginia
Rockbridge in Iron Phosphate Nodules from Polk County Florida
Marine Fossiliferous Pleistocene Deposits in Southeastern North Carolina

Petrography and Geochemistry of a Mafic Granofels in Newberry County, South Carolina
Thorium and Uranium in Detrital Monazite from the Georgia Piedmont
X-ray Analysis of Rocks of the Carolina Slate Belt, Union County, North Carolina
Topography of the Continental Margin off the Carolinas
Surge Flow: A Model of the Wall Layer
Structural Features of the Coastal Plain of Georgia

The Nature of Granodiorite under Triaxial Stress and a Possible Model for Seismic Disturbances
Pollen Analysis of an Organic Clay from the Interglacial Flamer Beach Formation, Craven County, North Carolina
Spatial Variation of Flood Frequencies as Related to Hydraulic Geometry
Bibliography and List (1900-1965) of the Families Constellariidae and Dianellitidae (Ectoprocta, order Cystoporata)
Quartz Leached Graphic-Granite from Monticello, Georgia

Beach Changes at the Location of Landfall of Hurricane Alma
Stratigraphy of the Carolina Cretaceous
Rubidium-Strontium Age Study of Middle Devonian Tioga Bentonite

AUTHOR INDEX

Adams, R. D.
Allen, E. P.
Askren, L. T., Jr.
Asmussen, Loris E.
Bain, George L.
(See Conley, J. F.)
6.3.1
9.3.1
3.3.3
5.1.1, 8.4.3

Baker, N. M.
(See Clarke, James W.)
Bates, John D.
(See Tanner, William)
Bates, Robert G.
Batten, R. W.
Beardsley, Donald W.
(See Dubar, Jules R.)
Bell, Henry III
(See Sundelius, H. W.)
Billings, Gale K.
(See Ragland, Paul)
Blackwelder, Blake W.
(See Milliman, John)
Blanchard, Frank N.
Bloss, Donald
Bottino, Michael L.
(See Fullagar, Paul)
Brett, C. Everett
Broughton, Paul L.
Brown, Bahngrell
Brown, Charles Q.
(See Preston, Charles)
Brown, Henry S.
Burdick, Glenn A.
Busby, Roswell
(See Rucker, James B.)
Butler, James R.
(See Snipes, David S.)
Carpenter, John R.
(See Libby, W. G.)
Carpenter, Robert H.
Carrington, Thomas J.
Carver, Robert E.

9.4.4
9.4.5
10.1.1
10.1.2
10.1.3
10.1.4
10.2.1
10.2.2
10.2.3
10.2.4
10.2.5
10.2.6
10.3.1
10.3.2
10.3.3
10.3.4
10.3.5
10.4.1
10.4.2
10.4.3
9.1.4
9.3.3
9.3.6
5.1.1, 8.4.3
6.3.1
9.3.1
7.1.4
3.4.2
3.3.3
2.3.2
5.4.3
6.2.3
9.4.5
10.1.3
1.1.4
10.4.3
3.2.1
9.3.5
8.2.4
1.3.2, 6.1.3
3.4.3
4.1.2
8.1.1
4.2.1, 4.3.2, 5.2.3
10.2.1
8.1.2, 10.1.2
8.1.3
7.2.4, 9.2.4

47
Cate, Robert B., Jr.
Cazneau, Charles J.
Chaplin, James R.
Clarke, James W.
Colquhoun, D. J.
Conley, James F.
Connell, James F. L.
Conrad, Eric H.
Cramer, Howard R.
Daniels, R. D.
Davis, Terrance L.
(See Whitehead, D. R.)
Dendy, Farris E.
(See Asmussen, Loris)
Dietrich, Richard B.
Doyle, Michael V.
(See Whitehead, Donald)
Drummond, Kenneth
(See Conley, James)
DuBar, Jules R.
(See Cazneau, Charles)
(See Johnson, Henry)
Duncan, D. A.
(See Colquhoun, D. J.)
Emery, K. O.
Fagan, James M.
(See Carpenter, R. H.)
Fallaw, Wallace
Ferenczi, Istvan
Folks, Homer C.
Fortson, Charles W.
Fullagar, Paul D.
Furbish, W. J.
(See Clarke, James)
Gamble, E. E.
(See Daniels, R. D.)
Gietgey, Ronald R.
(See Mitchell, Richard)
Giardini, A. A.
Giles, Robert T.
(See Pilkey, Orrin)
Gorsline, Don S.
(See Pilkey, Orrin)
(See Kofoid, John W.)
Greenberg, S. S.
(See Milici, R. C.)
Greenhous, L. Ray
Grubbs, David M.
Hale, Robin C.
(See Carpenter, R. H.)
Harrison, W.
Henry, V. J., Jr.
Heron, S. D., Jr.
(See Clarke, James)
(See Wilson, J. B.)
Howard, James F.
(See DuBar, Jules)
Hoyt, John H.
(See Henry, V. J.)
Huddleston, Paul
(See Gremillion, R. L.)
Hughes, R. J., Jr.
Ingram, Roy L.
Johnson, Henry S., Jr.
(See Heron, S. D., Jr.)
(See Cazneau, Charles)
(See DuBar, Jules)
Johnson, Robert W.
Jones, Clark
(See Milici, R. C.)
Jordan, G. F.
(See Kofoid, H. W.)
Jordon, Robert R.
Kimrey, Joel O.
Kock, Henning F.
Kofoid, John E.
(See Cazneau, Charles)
LeGrand, Harry E.
Libby, W. G.
Ludlum, John C.
Lund, Ernest H.
(See Cazneau, Charles)
Luternauer, John L.
(See Pilkey, Orrin)
McCarthy, Gerald R.
McCauley, John F.
Mckinney, Frank K.
Malloy, Richard J.
(See Kofoid, John)
Manheim, F. T.
Mann, Virgil L.
(See Morgan, B. A.)
Matthews, Vincent III
(See Salotie, Charles)
Michael, Gayle E.
(See Heron, S. D., Jr.)
Milici, R. C.
(See Greenberg, S. S.)
Milliman, John D.
Mitchell, Richard S.
Moore, Charles A., Jr.
Morgan, Benham A.
Navarre, Alfred T.
Nerlton, W. T.
(See Daniels, R. B.)
Newton, John G.
Odom, Howard T.
Overall, C. H.
Parker, Harry N.
Phillips, William H.
Plummer, E. A.
Pilkey, Donald H.
Pirie, J. B.
Pressey, J. C.
Proctor, W. H.
Rae, Alexander G.
Ragland, J. E.
Raffa, J. L.
Rall, Harold C.
Relini, John H.
Reynolds, S. D.
Rick, Larry R.
Rice, T. D.
Roberts, H. S.
Robinson, W. R.
Rogers, W. H.
Rudolph, H. K.
Salmon, R. A.
Schultz, H. H.
Sipler, J. W.
Smith, T. W.
Solberg, G. W.
Spiel, G. W.
Tanner, John W.
Taylor, J. W.
Thomson, H. B.
Tobias, J. A.
Toro, J. M.
Tsay, S. K.
Tuttle, B. T.
Tyrrell, R. G.
Uebelacker, M. J.
Van der Velden, W. C.
Van Der Waal, J. P.
Vann, R. H.
Vernon, J. B.
Walkins, B. G.
Warford, W. H.
Watson, W. H.
Webb, G. H.
Wells, W. B.
<table>
<thead>
<tr>
<th>Volume</th>
<th>Issue</th>
<th>Article</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.1</td>
<td>10.2.2</td>
<td>Stiles, Newell T.</td>
</tr>
<tr>
<td>3.3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.4.2</td>
<td></td>
<td>Straley, H. W., III</td>
</tr>
<tr>
<td>8.3.1</td>
<td></td>
<td>Sundelius, Harold W.</td>
</tr>
<tr>
<td>8.3.2</td>
<td></td>
<td>Swift, D. J. P.</td>
</tr>
<tr>
<td>3.1.3</td>
<td>6.1.2</td>
<td>Tanner, William F.</td>
</tr>
<tr>
<td>7.1.3</td>
<td>8.1.4</td>
<td>(See Burdick, Glenn)</td>
</tr>
<tr>
<td>9.4.5</td>
<td>10.2.4</td>
<td>(See Gremillion R.)</td>
</tr>
<tr>
<td>6.1.3</td>
<td></td>
<td>Temple, A. K.</td>
</tr>
<tr>
<td>7.3.1</td>
<td>9.1.3</td>
<td>Terlecky, P. Michael</td>
</tr>
<tr>
<td>6.2.3</td>
<td>7.3.1</td>
<td>Thom, B. G.</td>
</tr>
<tr>
<td>9.1.3</td>
<td></td>
<td>(See Adams, R. D.)</td>
</tr>
<tr>
<td>5.4.4</td>
<td></td>
<td>Uchupi, Elazar</td>
</tr>
<tr>
<td>10.2.3</td>
<td></td>
<td>Wagoner, H. D.</td>
</tr>
<tr>
<td>2.1.3</td>
<td></td>
<td>Walker, K. R.</td>
</tr>
<tr>
<td>1.2.4</td>
<td></td>
<td>Warnke, Detlef A.</td>
</tr>
<tr>
<td>2.2.2</td>
<td></td>
<td>Warr, Jesse J., Jr.</td>
</tr>
<tr>
<td>1.1.2</td>
<td>7.3.6</td>
<td>(See Overstreet, W. C.)</td>
</tr>
<tr>
<td>6.1.2</td>
<td></td>
<td>Wass, Marvin L.</td>
</tr>
<tr>
<td>8.3.2</td>
<td></td>
<td>(See Harrison, W.)</td>
</tr>
<tr>
<td>1.1.1</td>
<td></td>
<td>Weaver, Charles E.</td>
</tr>
<tr>
<td>2.4.2</td>
<td>3.1.2</td>
<td>Wheeler, Walter H.</td>
</tr>
<tr>
<td>9.2.5</td>
<td></td>
<td>(See Fallaw, Wallace)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(See Daniels, R. B.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(See Brett, Everett)</td>
</tr>
<tr>
<td>3.2.1</td>
<td>5.1.2</td>
<td>White, Amos M.</td>
</tr>
<tr>
<td>7.4.3</td>
<td>10.1.4</td>
<td>Whitehead, Donald R.</td>
</tr>
<tr>
<td>8.1.3</td>
<td></td>
<td>Wigley, Perry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(See Cerrington, T. J.)</td>
</tr>
<tr>
<td>1.1.5</td>
<td></td>
<td>Wilson, Charles W.</td>
</tr>
<tr>
<td>4.4.4</td>
<td></td>
<td>Wilson, Jo E.</td>
</tr>
<tr>
<td>6.1.1</td>
<td></td>
<td>Wilson, Patricia G.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(See Heron, S. D.)</td>
</tr>
<tr>
<td>10.2.2</td>
<td></td>
<td>Wilson, William F.</td>
</tr>
<tr>
<td>10.1.1</td>
<td>10.3.2</td>
<td>Yon, J. William, Jr.</td>
</tr>
<tr>
<td>6.3.4</td>
<td></td>
<td>Young, Keith K.</td>
</tr>
<tr>
<td>9.1.2</td>
<td></td>
<td>(See Daniels, R. D.)</td>
</tr>
<tr>
<td>2.4.1</td>
<td></td>
<td>Zablocki, Frank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(See Mann, Virgil)</td>
</tr>
</tbody>
</table>

**SUBJECT INDEX**

(Volume, Issue, Article)

- **Aeromagnetic**, 2.3.1
- **Alabamas**, 1.2.1, 2.4.2, 3.1.2, 5.2.4, 6.1.3, 9.3.7
- **Allanite**, 7.4.4
- **Apalachicola Delta**, 3.1.3
- **Athens Shale**, 10.1.2
- **Atlantic Coastal Plain**, 1.4.2, 5.4.1, 7.3.2, 8.2.6, 8.2.7
- **Atlantic Continental Margin**, 9.4.3
- **Atomic Absorption Spectrophotometry**, 7.3.1
- **Bahamas**, 8.1.1
- **Barian Florencit**, 9.3.4
- **Barite, Nodules**, 10.1.2
- **Barrier and Lagoon Sets**, 6.1.4
- **Basement**, 1.4.2
- **Bathymetry**, 6.3.3
- **Bay Sediments**, 1.1.1
- **Beach Changes**, 10.4.1
- **Beach Profiles**, 6.1.2
- **Beaufort Inlet Area**, 3.3.3

49
Thorium, 10.2.2
Tivola, 1.2.2
Tongue of the Ocean, 8.1.1
Topography, 10.2.4
Trace Metals, 7.3.1
Triassic, 2.4.1, 6.3.1
Triaxial Stress, 10.3.1
True Dip, 2.1.4
Type Localities, 2.2.1, 4.1.1, 5.1.2
Type Waccamaw, 5.1.3
Ultramylonite Zones, 6.4.3
Upper Coastal Plain, 1.4.5
Uranium, 10.2.2
Uranium-Niobium Oxide, 6.2.2
Virginia, 2.2.2, 6.4.4, 7.1.1, 7.4.4, 8.3.4
         9.2.5, 9.3.4, 10.1.2
Virginia Piedmont, 7.3.3
Wall Layer, 10.2.5
Washington, D. C., 9.3.5
Watershed Engineering, 8.4.3
Weinschenkite, 9.3.4
Wenonah Sands, 3.3.2
Western Carolinas, 6.4.4
West Virginia, 1.1.3
Withlacoochee Valley, 1.2.3
Worm Burrows, 1.4.3
X-Ray Analysis, 8.3.3, 10.2.3
X-Ray Diffraction, 4.2.1, 6.3.2
York River, 1.3.2
Yorktown Formation, 8.3.2
Zero-Energy Coast, 7.1.4