GEORGIA

STATE DIVISION OF CONSERVATION

DEPARTMENT OF MINES, MINING AND GEOLOGY

GARLAND PEYTON, Director

THE GEOLOGICAL SURVEY

Bulletin Number 60

SHORT CONTRIBUTIONS TO THE GEOLOGY, GEOGRAPHY AND ARCHAEOLOGY OF GEORGIA

(NUMBER II)

ATLANTA

1953

LETTER OF TRANSMITTAL

Department of Mines, Mining and Geology

Atlanta, July 1, 1953

To His Excellency, Herman E. Talmadge, Governor
Commissioner Ex-Officio of State Division of Conservation
Sir:

I have the honor to submit herewith Georgia Geological Survey Bulletin No. 60, "Short Contributions to the Geology, Geography, and Archaeology of Georgia".

This report is published in response to many requests which have followed the enthusiastic reception of Bulletin No. 56, which bears a similar title. The Bulletin consists of forty-four papers with numerous maps, cross-sections, and figures prepared by geologists, geographers, archaeologists, mineralogists, geophysicists, and engineers, engaged in professional earth science work in the University System of Georgia, Emory University, the State Geological Survey, United States Geological Survey, and in industrial mineral production.

The papers here published have been given in various scientific meetings of local or national character and include those presented at the meetings of the Earth Science Section of the Georgia Academy of Science, at Oglethorpe University 1950, University of Georgia 1951, Agnes Scott College 1952, and at Mercer University, 1953. Also, contributions are included which were presented before the Southeastern Mineral Symposium at Emory University in 1951 and at the Southeastern Section of the Geological Society of America and the Southeastern Mineral Symposium at Roanoke, Virginia in 1952, and at Vanderbilt University in 1953.

By subject the contributions to this bulletin may be classified as follows: Regional Geology, 4; Economic Geology, 8; Geophysical Geology 7; Rivers and Surface Water, 6; Engineering Geology, 1; Stratigraphy, 1; Paleontology, 3; Sedimentation and Sedimentary Petrology, 7; Structural Petrology, 1; Mineralogy, 3; and Archaeology, 3.

It is deemed well worthwhile by the staff of the Georgia Geological Survey to thus participate in the activities of these and other earth science groups not only because of the transfer value, which will accrue to the State's mineral industrial picture, but because a suitable medium of publication will greatly encourage further scientific work.

Up to the present time, the organizations referred to above have had no facilities for publishing papers on earth science subjects. The publication of these papers as a bulletin of the Georgia Geological Survey not only represents a broadening of the scope of our usual activities, but, in addition, constitutes a permanent record of valuable scientific information, which will be available to all who may have the need or the desire to refer to it in the future.

Very respectfully yours,

Garland Peyton

GARLAND PEYTON
Director

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

THE OUTCROPPING CRETACEOUS ROCKS OF GEORGIA[1]*

By

D. HOYE EARGLE

U. S. Geological Survey

Introduction

A restudy of the outcropping Cretaceous rocks of Georgia, particularly those in the western part of the State, was begun in 1949 by the U. S. Geological Survey in cooperation with the Georgia Department of Mines, Mining and Geology. Its purpose was to correlate the outcropping rocks with those of other States and to coordinate several interpretations within this State. Such a correlation, it was hoped, would aid in the interpretation of subsurface rocks that are being drilled for oil down the dip in the Southeastern States and would be helpful in ground-water studies and in working out the stratigraphy of the beds that produce high-grade clays in central Georgia.

Although a large part of the area of Cretaceous rocks had been mapped in recent years, and a part of western Georgia mapped in some detail, differences were found between the units mapped in Georgia and those that had been traced to the Chattahoochee River through Alabama. Geologists, particularly those in the oil industry, have explored the Gulf Coastal Plain west of Georgia more carefully and have worked out the stratigraphy and paleontology in greater detail in that region than in Georgia. It is hoped that this project will assist in bringing more uniformity to Gulf Coast nomenclature and help tie the rocks of that region to those of the Atlantic Coast.

Previously the writer (1950) traced the Cretaceous units from central Alabama, where most of the rocks are marine and where much of the section is chalky, to the Chattahoochee River, where the rocks are more difficult to subdivide. The rocks were traced bed by bed with the aid of

[1]Publication authorized by the Director, U. S. Geological Survey.
*Read at the Southeastern Mineral Symposium, Geology Department, Emory University, March 29-31, 1951.

aerial photographs. Each change of facies was generally found to be reflected in the topography and the other geographic features of the region. Working from west to east, it was possible to trace many horizons and to recognize new beds of coarse clastics as they enter the section from the east. From the Chattahoochee River they were traced eastward through Georgia as far as was practicable.

Several men have made this work possible and have added materially in its prosecution. Watson H. Monroe, who had previously worked in the area and recognized the need of such correlation studies, conceived and outlined the project. S. M. Herrick generously gave subsurface information that helped to trace the units down the dip and to show their thickness and relations in that direction. Herrick and H. E. LeGrand spent several days with the writer in the areas where they had previously worked. P. E. LaMoreaux and L. L. Ray provided maps of the areas in which they had worked. F. S. MacNeil allowed the use of his manuscript maps of the Tertiary area, which forms the southern boundary of the area covered in this project.

The first and most detailed stratigraphic work on the area of Cretaceous rocks of Georgia was by Stephenson (1911). Cooke summarized data from this work, added more from his own and others' subsequent observations, and brought the terminology up to date for the State Geologic map (1939) and for a bulletin of the U. S. Geological Survey (1943). In 1941 Monroe traced by reconnaissance the formations then termed the Ripley formation and Selma chalk through Alabama to the Chattahoochee Valley. Thompson and Warren (1943-1944) mapped several kaolin-producing areas of central Georgia as part of a strategic-minerals investigation. Stephenson and Thompson during the same year made a reconnaissance of the clay-producing beds and their equivalents in west-central Georgia; they prepared an administrative report which was not published, but many of their conclusions were corroborated by the more detailed work of the current survey. In 1945 LaMoreaux mapped several counties in east-central Georgia, extending the areas mapped by Thompson and Warren. In 1946 LeGrand extended LaMoreaux's mapping eastward to the Savannah River and then mapped several counties westward from Twiggs County toward the Chattahoochee

River. In 1946 MacNeil mapped the Tertiary rocks, necessarily therefore mapping the southern boundary of the Cretaceous rocks. In 1947 in a detailed study in military geology, Ray mapped the rocks of Fort Benning and vicinity along the Chattahoochee River.

In correlating the various mapped areas and the writer's work in eastern Alabama, and in completing the unmapped areas, it was necessary to remap the western part of the area of Cretaceous rocks inasmuch as boundaries of some units did not coincide in all of the areas previously mapped and did not correspond with the boundaries established in Alabama. The writer was assisted in various parts of the area by C. W. Drennen, L. A. Shirley, Alfredo Rosenzweig and Soli J. Bapuji.

In addition to mapping formational boundaries, the structure of seven traceable horizons was determined by altimetry. The determination of the structure assisted in areal mapping; projection of dip indicated areas in which to search for significant outcrops. In this region, where many contacts look similar, where residual soil cover is so great, where leaching has been so effective, and where weathered products accumulate to great thicknesses by colluvial movement, finding traceable contacts becomes a difficult problem. In hardly any other part of the country may a geologist find such an accumulation of weathered debris to confuse geologic detail as in the sandhills of the Coastal Plain. On the other hand, in hardly any other place may one find outcrops as well exposed as in the valley of the recently rejuvenated Chattahoochee River.

Stratigraphy

The Upper Cretaceous rocks of Georgia crop out in a northeast-trending belt that narrows from about 68 miles in the Chattahoochee River valley on the west to about 22 miles in the Savannah River valley on the east (Figure 1). Locally in eastern Georgia the Cretaceous rocks are entirely concealed by overlapping Tertiary rocks.

The Upper Cretaceous rocks that crop out in the Chattahoochee River valley have been classified as six distinct lithologic units, in ascending order: the Tuscaloosa formation, the Eutaw formation, the Blufftown formation, the Cusseta sand,

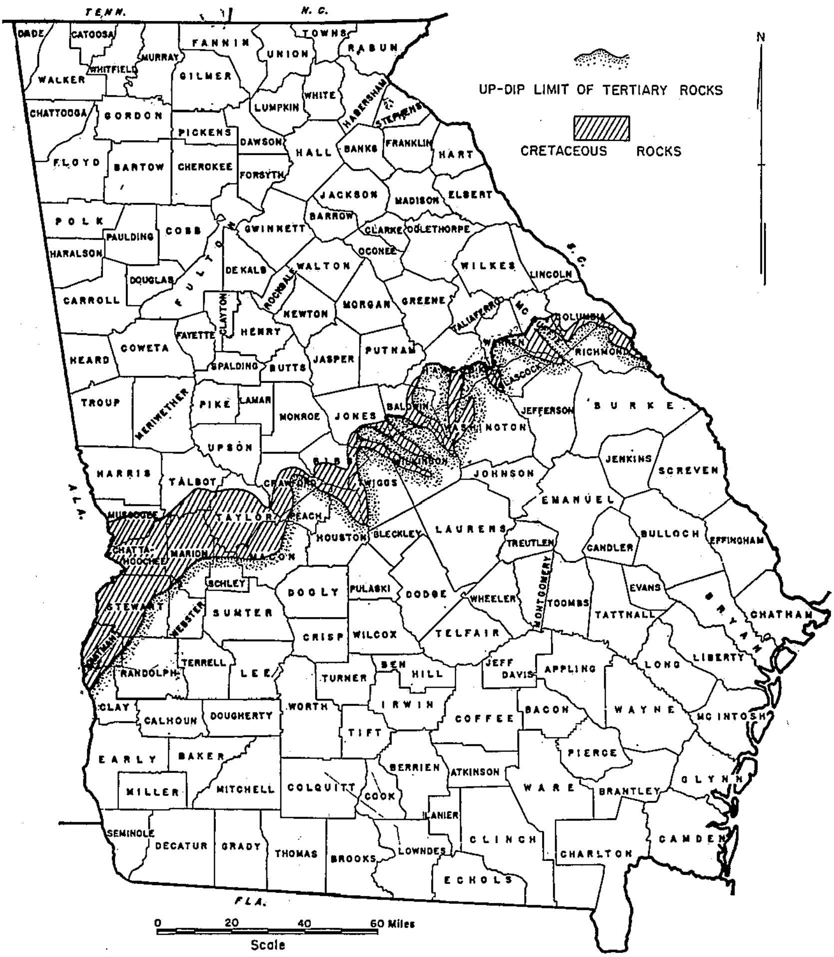


Figure 1. Generalized map of outcropping Cretaceous rocks of Georgia.

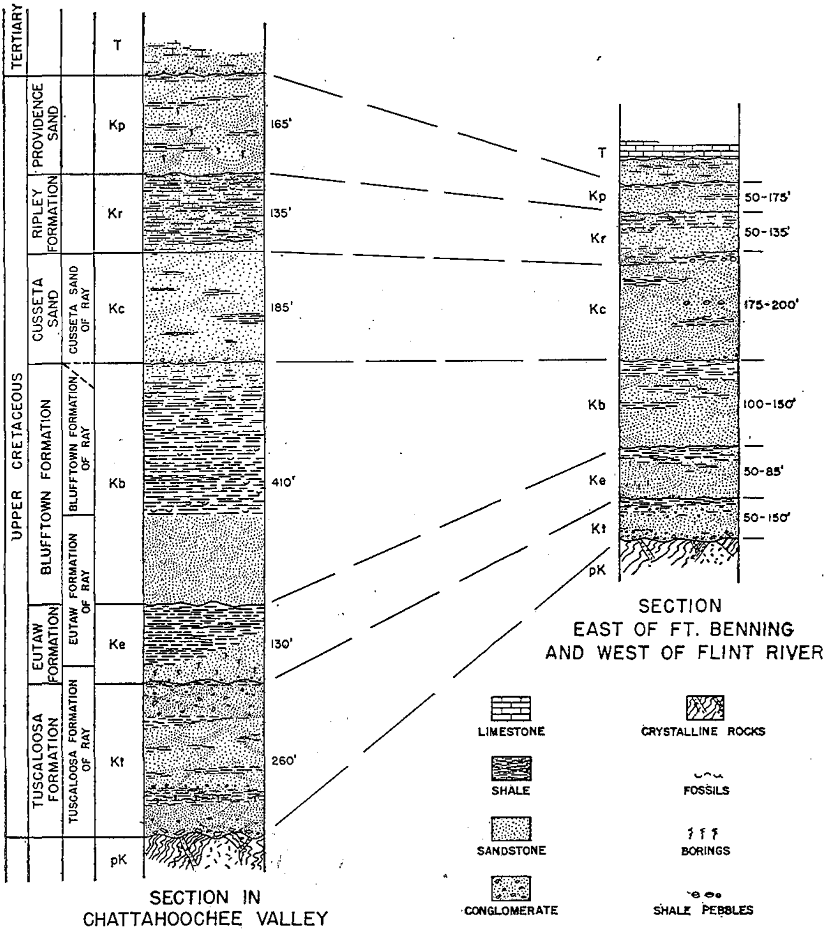


Figure 2. Columnar sections of outcropping Cretaceous rocks of western Georgia.

the Ripley formation, and the Providence sand (Figure 2). Toward the east all these formations grade laterally into a sequence of nearly similar sand and clay. East of the Ocmulgee River the sequence has not been differentiated into formational units.

The Tuscaloosa formation consists chiefly of arkosic sand, generally coarse to gravelly, but contains subordinate amounts of mottled clay and silt. In the Chattahoochee River valley the formation is about 250 feet thick, but eastward the upper part is overlapped by the Eutaw formation so that in Bibb County only about 40 feet of the Tuscaloosa formation is exposed. East of the Ocmulgee River in Bibb County the Tuscaloosa so closely resembles the overlapping Upper Cretaceous rocks that it could not be mapped separately. The basal 30 feet, more or less, of the undifferentiated Cretaceous rocks for many miles east of the Ocmulgee River appears to be equivalent to the Tuscaloosa formation farther west.

The Eutaw formation in the Chattahoochee River valley consists of a basal sand, generally coarse and containing borings of **Halymenites major,** overlain by dark-gray, soft shale interbedded with fine white sand that contains abundant thin fossil shells. The formation is about 125 feet thick in the Chattahoochee Valley but it thins toward the east, possibly in part by overlap, to about 75 feet in Marion County. East of the Flint River the Eutaw formation cannot be differentiated from the overlying Blufftown formation.

The Blufftown formation in the Chattahoochee Valley consists of a basal unit of cross-bedded coarse sand about 150 feet thick, overlain by laminated, more or less sandy, carbonaceous, highly micaceous, fossiliferous clay about 260 feet thick. The clay member in fresh exposures contains abundant soft thin fossil shells. East of the Flint River the Blufftown cannot be differentiated from the underlying Eutaw formation or the overlying Cusseta sand, but as the combined thickness of all three formations is less than 400 feet, it is obvious that the Blufftown portion is much thinner there than in the Chattahoochee region.

The Cusseta sand in the bluffs along the Chattahoochee River consists of glauconitic coarse- to fine-grained sand containing abundant fossil shells. Only a few miles east of the river, upland exposures consist of coarse cross-bedded gravelly sand containing white kaolinitic clay balls and having few evidences of marine origin. Farther east, in Taylor County, the formation contains lenses of kaolin, some of which are of minable thickness. The Cusseta sand is about 185 feet thick in the Chattahoochee region. It appears to maintain about this thickness as far east as the Flint River, but farther east it cannot be distinguished from the underlying Blufftown formation.

The Ripley formation rests conformably on the Cusseta sand. In the western part of Georgia it consists of clayey fine- to coarse-grained sand containing abundant fossil shells. Toward the east it undergoes rapid facies changes but is recognizable as a marine formation by the presence of glauconite, **Halymenites major,** and rippled bedding, at least as far east as the Ocmulgee River. Farther east it cannot readily be mapped separately from other Cretaceous formations, although locally exposures of sand containing borings of **Halymenites major** suggest correlation with the Ripley. The formation is about 135 feet thick in the Chattahoochee River valley, but is not more than 50 feet thick just west of the Ocmulgee River.

The Providence sand, in bluffs along the Chattahoochee River, consists of coarse to fine glauconitic very fossiliferous sand, but in the type area a few miles east of the river in Stewart County it consists of coarse cross-bedded sand containing beds of white to variegated clay. The formation maintains this lithologic character toward the east except that locally between the Flint and Ocmulgee Rivers it contains thicker beds of more or less kaolinitic clay. East of the Ocmulgee River it cannot be certainly recognized, although the large commercial kaolin bodies are possibly in an eastern extension of the Providence sand. The formation is about 165 feet thick in the Chattahoochee River region and about 125 feet thick in southeastern Marion County. From northwestern Macon County eastward the formation is rapidly overlapped by Tertiary rocks.

Structure

The triangular shape of the area of Cretaceous rocks of western Georgia reflects the difference in strike and dip of

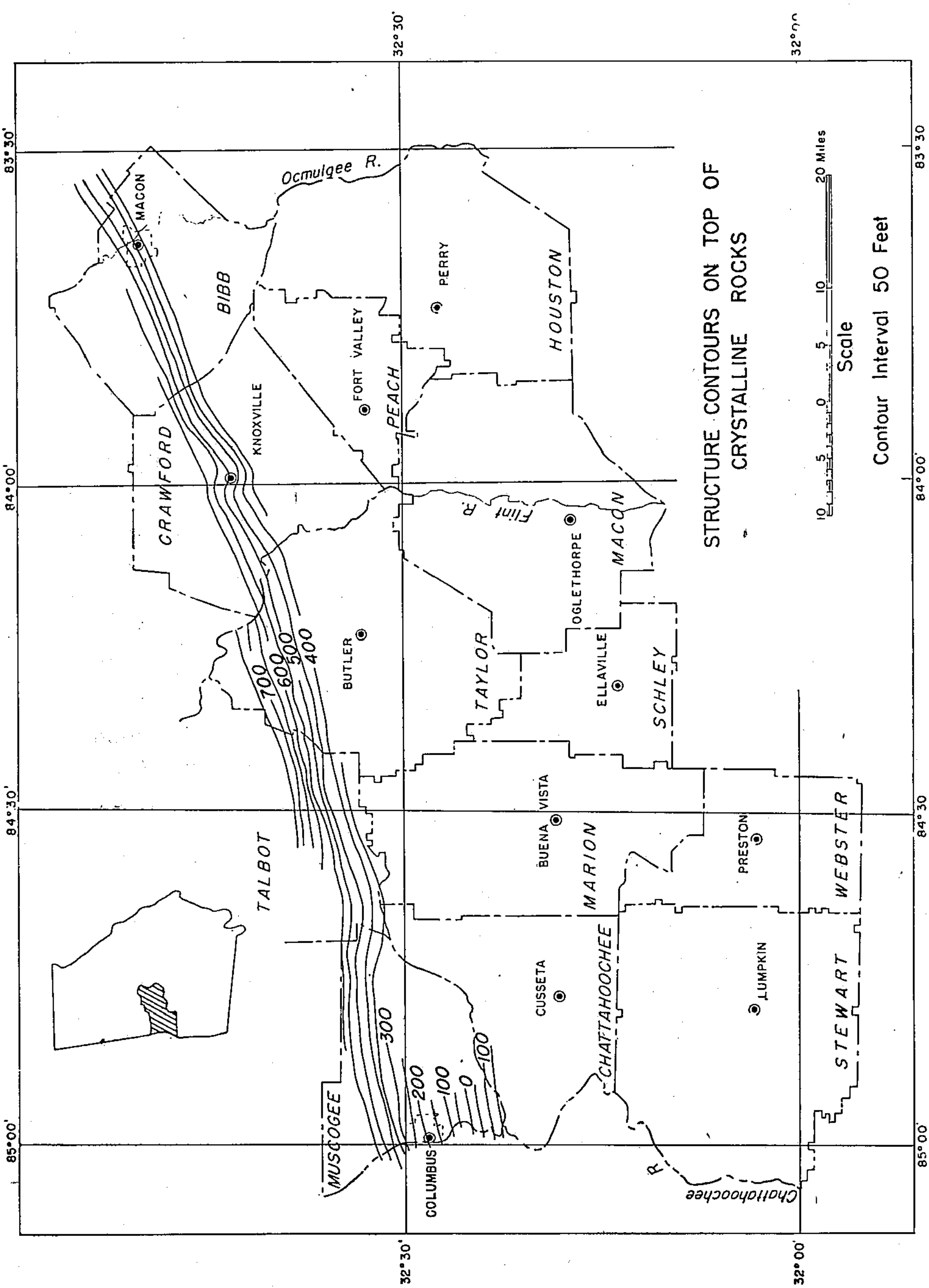


Figure 3. Structure contours on top of crystalline rocks.

the rocks enclosing the Cretaceous. The top of the crystalline rocks of the Piedmont Plateau, on which the Cretaceous rocks were laid down, strikes more easterly and dips more steeply than the rocks of Tertiary age overlying the Cretaceous. The body of Upper Cretaceous rocks, therefore, increases in thickness down the dip.

The surface of the crystalline rocks, on which the basal Coastal Plain rocks lie, changes in strike gradually from N. 77° E. in the western part of the State to N. 55° E. in the eastern part (Figure 3). In Bibb County, halfway across the State, it strikes N. 65° E., but between Macon and Augusta it strikes about N. 55° E.

The southeastward dip of the top of the crystalline rock basement increases in its outcrop area from 55 to 60 feet per mile in the Chattahoochee River region to about 100 feet per mile in southeastern Talbot County, 30 miles to the east (Figure 3). It maintains this steep dip through Taylor and Crawford Counties, but it averages only 70 to 80 feet per mile in Bibb County.

A short distance down-dip from the outcrop, the top of the crystalline rocks plunges more steeply toward the south. This is shown by comparing the dip of that surface from the lowest outcrops near Columbus to wells drilled for water in Fort Benning and for oil farther south. In the bed of the Chattahoochee at Columbus the top of the crystalline rocks is 185 feet above sea level. Herrick (personal communication) reports the top of the crystalline rocks in a deep well at Edison, 65 miles in a down dip direction, 4,912 feet below sea level (Figure 4). In 65 miles, therefore, the surface drops 5,097 feet in altitude, and the average dip is 78 feet to the mile.

This steep southerly dip in down-dip areas, however, becomes more gentle toward the east. Just west of the Ocmulgee River the slope of the crystalline surface averages 69 feet per mile between the outcrop and oil test wells 4 miles south of Perry in Houston County (Figure 5). In Washington County, still farther east, LaMoreaux (1946, p. 40) found that the crystalline surface slopes only about 55 feet per mile on an average between 5 wells drilled for water near Sandersville. Data in his report, however, indicate a dip of a little less than 35 feet per mile between these wells and the surface

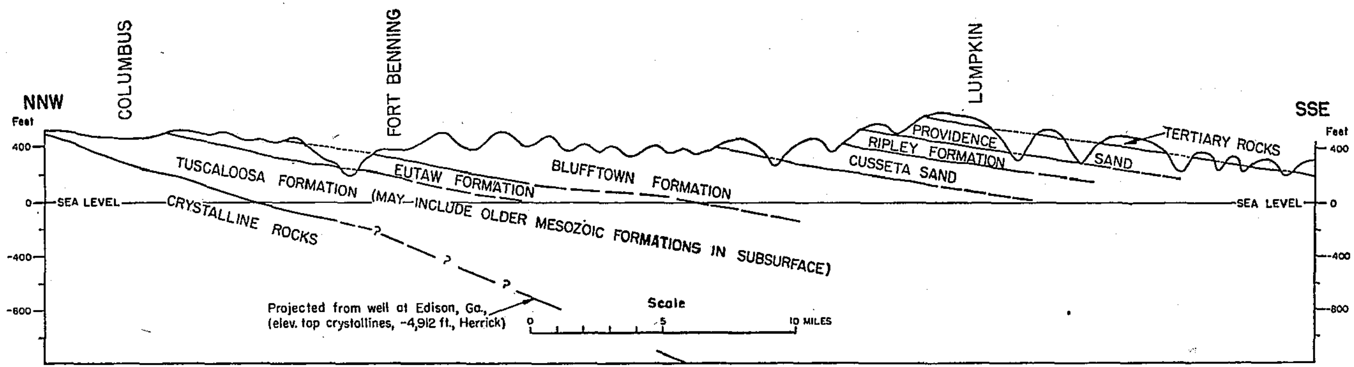


Figure 4. Generalized profile and structure section, Muscogee to Randolph Counties, Georgia.

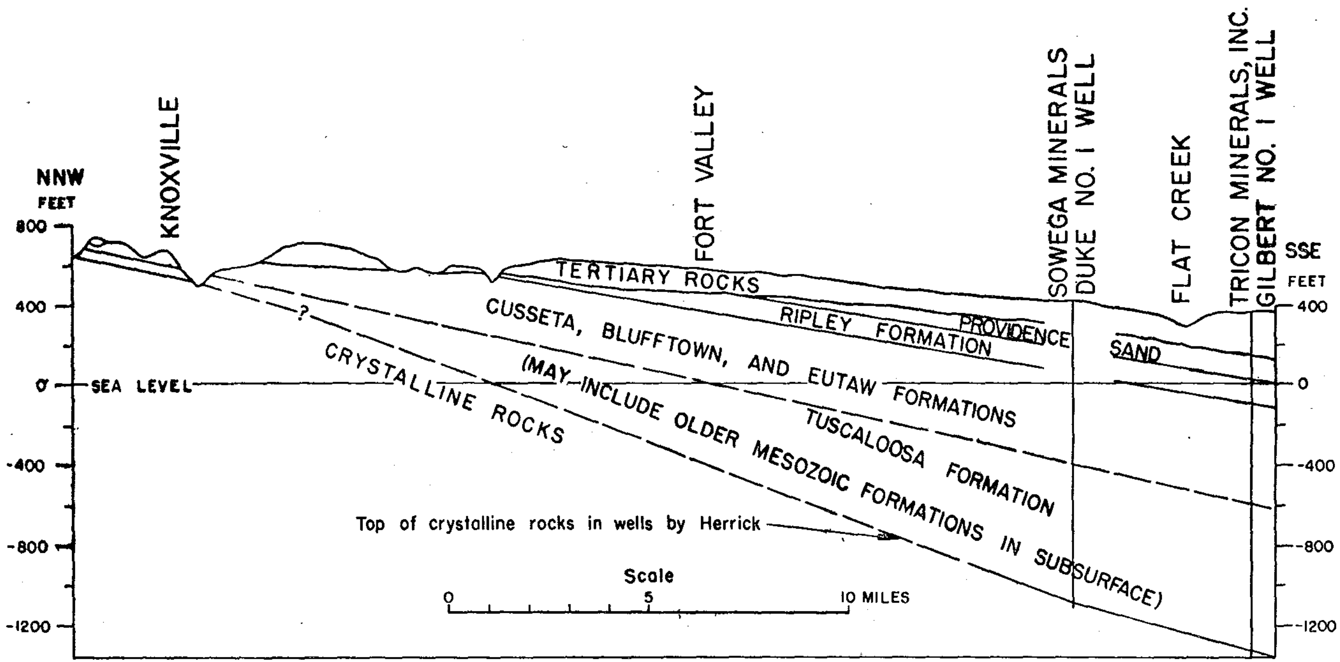


Figure 5. Generalized profile and structure section, Crawford to Houston Counties, Georgia.

outcrop near Carrs Station, almost directly up the dip.

The dip on the top of the crystalline rocks is greater than that of the overlying Coastal Plain beds of the outcrop. In the Chattahoochee region, for example, where the dip on the surface of the crystalline rocks is 55 feet or more to the mile, the dip on the top of the Tuscaloosa formation is only about 40 feet (Figure 6). The thickness of the Tuscaloosa formation thus increases at a rate of about 15 feet per mile in a down-dip direction.

Projection of surface dips into the subsurface and the data from wells show a sharply increasing interval from the top of the Tuscaloosa to crystalline rocks in a down-dip direction. This expanding interval is partly due to an angular unconformity which exists at the top of the pre-Tuscaloosa rocks in the subsurface. These rocks apparently wedge out before they reach the surface in this area. Part of the sharply increasing section of Cretaceous rocks to the south is considered by oil geologists to be Early Cretaceous in age. No definite evidence of rocks of that age was found on the surface, although some of the basal Coastal Plain rocks resemble the Vick formation of western Alabama, described by Conant (1946).

In eastern Alabama, Triassic sediments below beds of Cretaceous age have been reported by Applin and Applin (1947). It is very likely, therefore, that Lower Cretaceous and even lower Mesozoic rocks in places occupy the interval between pre-Mesozoic crystalline rocks and the Upper Cretaceous strata (Applin 1951).

The dip on top of the Tuscaloosa formation varies from about 40 feet per mile to the southeast in the Chattahoochee Valley to about 33 feet per mile in Taylor County and about 32 feet per mile in Crawford County. Beyond that area little information was obtained on the dip of the top of the Tuscaloosa, but from the outcrop pattern east of the Ocmulgee River that approximate dip appears to persist to the east. The strike of the Tuscaloosa in the Chattahoochee Valley is about N. 85° E., but in the eastern end of Chattahoochee County it bends to a slightly more northerly direction, about N. 70° E., which it maintains with minor variations at least as far east as the Flint River.

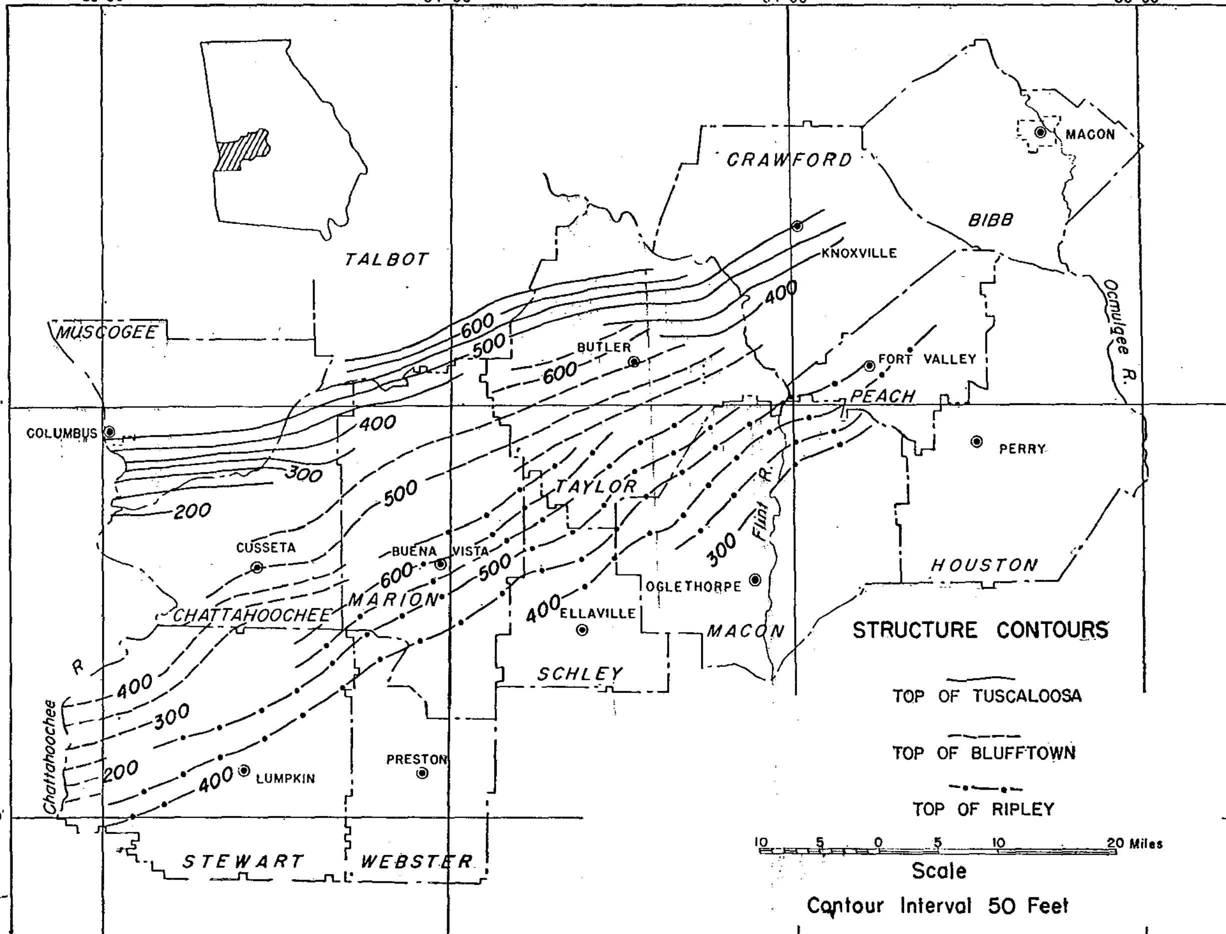


Figure 6. Structure contours on tops of Tuscaloosa, Blufftown, and Ripley formations.

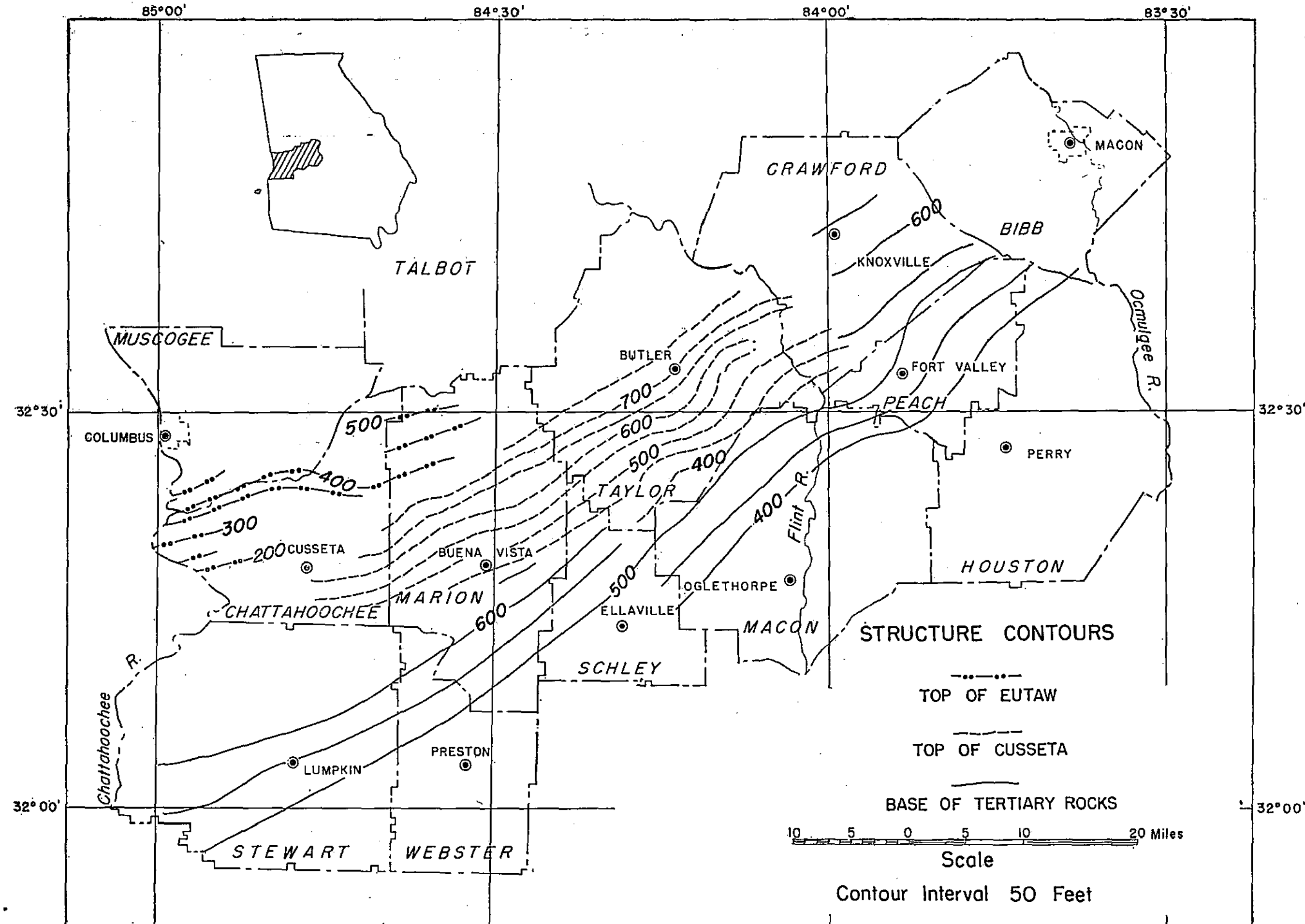


Figure 7. Structure contours on tops of the Eutaw formation and the Cusseta sand, and on base

The structure of the top of the Eutaw formation (Figure 7) seems more irregular and it was less satisfactorily traced than any other Cretaceous horizon. This is partly because the Blufftown and Eutaw contact could not be traced definitely farther east than north-central Macon County. In the area in which it is traceable, however, it seems to maintain a strike of about N. 75° E.

The top of the Blufftown formation in the Chattahoochee Valley strikes approximately N. 67° E. (Figure 6), with minor variations, and maintains that strike as far as Flint River. It dips on the average a little more than 30 feet per mile to the southeast.

Structural data were not obtained on top of the Cusseta sand near the Chattahoochee River owing to lack of exposures, but from eastern Chattahoochee County to the vicinity of Flint River the top of the Cusseta maintains a strike of about N. 60° E. and a dip of 30 or 35 feet per mile toward the southeast.

The top of the Ripley formation, which in the vicinity of the Chattahoochee River seems to be about N. 75° E., maintains a strike of about N. 60° E. throughout most of western Georgia. Reliable control, however, is lacking over a large area.

The base of the Tertiary rocks (the top of the Providence sand in Stewart County) trends about N. 75° E., but in the extreme eastern part of Stewart County it bends more strongly northeast to about N. 55° E. In western Macon County, however, the Tertiary rocks bend even more strongly northerly to about N. 50° E. and in southern Crawford and western Peach Counties overlap the Providence sand completely. Because of the deep erosion of creeks in eastern Peach and Houston Counties, the Providence is exposed as inliers in those counties down the dip from the cuesta front of the Tertiary rocks. The Cretaceous rocks are not differentiated east of the Ocmulgee River, and definite structure on individual horizons, therefore, has not been obtained. Reconnaissance observations east of the river, however, indicate that the dip of the surface of the crystalline rocks beneath the Cretaceous is approximately the same as in the vicinity of Macon or slightly less, and the strike approximately in the same direction as in the vicinity of Macon. The Cretaceous rocks are completely overlapped by the Tertiary rocks on updip interstream areas as close as 12 miles east of the Ocmulgee River. Down the dip the Cretaceous crops out, therefore, only on the flanks and in the bottoms of the valleys, below the level of the interstream upland of Tertiary rocks. This condition prevails throughout eastern Georgia and western South Carolina, but in eastern South Carolina the great Carolina anticline takes the top of the Cretaceous out to the Atlantic Ocean.

In eastern Georgia and western South Carolina in the area of Tertiary overlap there is considerable evidence that a broad ridge of crystalline rocks exists beneath the Coastal Plain sediments. This may have been one of the contributing causes of the Tertiary overlap, the lower formations of the Cretaceous pinching out, or being pushed south by this ridge, and the later Cretaceous and Tertiary rocks finally covering the ridge.

Significant Results of the Survey, and Recommendations for Future Study

Some of the more significant results of this survey are:

1. In the Chattahoochee Valley the formations comprise generally one or more cycles, each cycle consisting of a basal bed of coarse clastics that grades upward into silt and clay, which are generally calcareous and highly fossiliferous. These cyclic deposits have been traced to the east, but east of the area of deeper-water marine rocks, coarse clastics predominate and clay beds form a minor part of each cycle.

2. The kaolin-bearing rocks of central Georgia are definitely post-Tuscaloosa and probably of the age of the Selma group of Alabama. The evidence, however does not rule out the possibility that they are of Tertiary age. The possibility of Selma age is indicated by:

(a) Structural trends of Upper Cretaceous rocks in west-central Georgia, the lower beds striking nearly east to slightly northeast, whereas higher beds strike more strongly northeast. Structural data more specifically indicate that the clay-producing beds may be of Providence and perhaps Ripley age. White clays are found extensively in west-central Georgia in beds that are definitely of Providence age. They are, however, also found in older formations; clays of commercial quality and quantity, in which the mines farthest west were located at the time of the survey, and are in the Cusseta sand (originally assigned to the Tuscaloosa formation) just west of Butler, Taylor County (Smith, 1929).

(b) Recognition of marine borings east of the Ocmulgee River in beds in line with the marine Ripley formation west of the Ocmulgee, and in beds believed to be below the clay-producing beds. The borings were not definitely found in the clay-producing areas.

(c) Plant fossils found by Stephenson (reported by LaMoreaux, 1946a, pp. 6-7), just below the clay lenses in the clay-producing areas in east-central Georgia that appear to Roland W. Brown to be the same as those found by E. W. Berry (1919) in the Coffee sand of Selma age in Tennessee.

3. The tilting of the Coastal Plain in west-central Georgia, causing the strike of the beds to trend more strongly northeast, began early in Late Cretaceous time, about the end of the Tuscaloosa deposition. This change of strike became more northerly in early Tertiary time, and formations of this age completely overlap the Cretaceous in central and eastern Georgia and lie on the crystalline rocks; in fact, younger Tertiary formations overlap older ones. The beginning of this movement, therefore, coincides with the change from continental to marine deposition.

4. White clay deposits are found in formations that are marine, although they may not contain definite evidence of marine conditions in the areas of clay production. Definite evidence of marine origin is found in the Providence sand in western Georgia and in the Cusseta sand in west-central Georgia. Rocks that contain marine borings or even fossils have minable kaolin beds 20 to 30 miles away. Thus it appears that if the sedimentary kaolins were not laid down under marine conditions, the sea was not far away.

This study, although it is of a semi-reconnaissance nature, and therefore may be considered only preliminary, has added the above facts to those already known about the Cretaceous rocks of western Georgia, but it leaves several important questions unanswered. It points to areas that should be searched and to the questions that may be answered there. Studies that may be made in each section of the State are:

1. Western Georgia:

(a) This region of excellent outcrops and prolific fossils is a fertile field for detailed paleontologic studies. Most of the fossils, however, are very delicate thin-shelled mollusks and may require special techniques in collecting and preparing.

(b) Studies of facies changes, which are very profound within short distances, would give valuable information on the geologic history of the region.

2. West-central Georgia:

(a) Where beds of Jackson age overlap the lower Tertiary and the Cretaceous rocks, stratigraphic work will have to be done by subsurface methods and in greater detail than in the past. Herrick and his colleagues have begun such studies, and the publication of some of the results of their work is eagerly anticipated.

(b) Formations should be traced from the surface and the shallow wells down the dip to the areas that are being explored for oil.

3. Central Georgia:

(a) The plant materials associated with the clays should be studied more carefully and compared with those of the Chattahoochee region and farther west. Such material might be obtained from borings and cores made by mining companies active in the region.

(b) A study of the Tuscaloosa formation, both in surface and subsurface, should be attempted. Criteria may be found to distinguish it from other Cretaceous formations.

4. Eastern Georgia and South Carolina:

The Cretaceous should be searched for traceable beds. The Tuscaloosa formation in several wells in southeastern Georgia and in southern South Carolina has been definitely described; and an effort should be made to trace the formation and its recognizable units northward from these wells. At least a part of the answer may be found in eastern South Carolina and in North Carolina along the great anticline that apparently brings up the lower formations of the Upper Cretaceous. The scarcity of good outcrops in eastern South Carolina and the cover of Pleistocene and Tertiary formations make this an extremely difficult task, but subsurface materials from that area should be systematically collected and studied.

In addition to the stratigraphic and paleontologic studies suggested above, significant contributions could be made by more detailed studies of the structure than was undertaken during this reconnaissance survey. The structure of horizons traceable on the surface should be definitely tied to that of the same horizons in the subsurface. Much information can be obtained from carefully logging the deeper wells drilled for water in the upper part of the Tertiary area of Georgia, and correlating the strata with those in wells drilled for oil farther down the dip.

The beds and horizons believed to be most useful for tracing structure on the surface and in the up-dip subsurface are the following: (1) the top of the crystalline rocks, (2) the updip limit of lower Mesozoic rocks, of Early Cretaceous beds, and of the marine Tuscaloosa beds, (3) several horizons within the Upper Cretaceous, and (4) the base of, and zones within, the Tertiary rocks.

References and Selected Bibliography

Applin, P. L., and Applin, E. R., 1947, Regional subsurface stratigraphy, structure, and correlation of middle and early Upper Cretaceous rocks in Alabama, Georgia and North Florida: U. S. Geol. Survey Oil and Gas Inv. Preliminary Chart 26.

Applin, P. L., 1951, Preliminary report on buried pre-Mesozoic rocks in Florida and adjacent States: U. S. Geol. Survey Circ. 91, 28 pp.

Berry, E. W., 1919, Upper Cretaceous floras of the eastern Gulf region in Tennessee, Mississippi, Alabama and Georgia: U. S. Geol. Survey Prof. Paper 112, 177 pp.

Cooke, C. Wythe, 1943, Geology of the Coastal Plain of Georgia: U. S. Geol. Survey Bull. 941, 121 pp.

Conant, L. C., 1946, Vick formation of pre-Tuscaloosa age of Alabama

Coastal Plain: Am. Assoc. Petroleum Geologists Bull. vol. 30, no. 5, pp. 711-715.

Eargle, D. H., 1950, Geologic map of the Selma group of central and eastern Alabama: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 105.

Geologic Map of Georgia, 1939, prepared by the Georgia Division of Mines, Mining and Geology (Atlanta, Ga.).

LaMoreaux, P. E., 1946, Geology and ground-water resources of the Coastal Plain of east-central Georgia: Georgia Geol. Survey Bull. 52, 173 pp.

———, 1946a, Geology of the Coastal Plain of east-central Georgia: Georgia Geol. Survey Bull. 50, pt. 1, 26 pp.

LeGrand, H. E. (in preparation), Geology and ground-water resources of the Macon area, Georgia.

——— (in preparation), Geology and ground-water resources of the Augusta area, Georgia.

MacNeil, F. S., 1947, Geologic map of the Tertiary and Quaternary formations of Georgia: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 72.

Monroe, W. H., 1941, Notes on deposits of Selma and Ripley age in Alabama: Alabama Geol. Survey Bull. 48, 150 pp.

Ray, L. L. (in preparation), Fort Benning, Georgia, and vicinity: Terrain studies in the United States, folio no. 2.

Smith, Richard W., 1929, Sedimentary kaolins of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 44, 482 pp.

Stephenson, L. W., 1911, Cretaceous (rocks of the Coastal Plain of Georgia). Chapter in: Veatch, (J) Otto, and Stephenson, L. W., Preliminary report on the geology of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 26, pp. 66-215.

Thompson, R. M., 1943, Kaolin deposits of Twiggs County, Georgia: U. S. Geol. Survey Strategic Minerals Map.

———, 1944, Kaolin deposits of Washington County, Georgia: U. S. Geol. Survey Strategic Minerals Map.

Warren, W. C., and Thompson, R. M., 1943, Bauxite and kaolin deposits of Wilkinson County, Georgia: U. S. Geol. Survey Strategic Minerals Map.

A PRELIMINARY INVESTIGATION OF THE GEOLOGY OF CLARKE COUNTY, GEORGIA*

ELDON J. PARIZEK

University of Georgia

INTRODUCTION

In the summer of 1950, a geologic reconnaissance of Clarke County, Georgia, was made. Purpose of the investigation was to establish the general distributions of major exposed rock units, and to obtain information bearing directly upon their field relationships. Detailed field study was not undertaken, but a generalized areal lithologic map was completed, and several problems meriting further investigation were revealed. Work was retarded immeasurably because Clarke County is not topographically mapped.

PHYSIOGRAPHY

Clarke County, the smallest county in Georgia, is roughly quadrilateral in outline, and includes an area of 125 square miles. It is located in the Central Upland division of the Appalachian Piedmont (Figure 1). In a physiographic delineation of the Central Upland La Forge placed Clarke County in portions of two subdivisions, a northern Midland Slope, and a southern Washington Plateau (Figure 2). It should be noted that the boundary between the two subdivisions is indefinite, and scarcely determinable in the field.

The county is characterized by a gentle, southeast-sloping upland that has been effectually furrowed by streams. Because of limited latitudinal extent very little decrease in upland elevations is noticeable. Maximum relief approaches 350 feet, but the average is considerably less. The Oconee River flows southeast through the area and forms the major drainage artery for Clarke County and several neighboring counties. Tributaries have combined with the Oconee to isolate the uplands and give the region a somewhat uneven topography. A combination of humid climate and rocks that are moderately susceptible to weathering has resulted in formation of a prominent mantle. Uplands and steeper slopes have

*Read at the Meeting of the Georgia Academy of Science, University of Georgia, April 27, 1951.

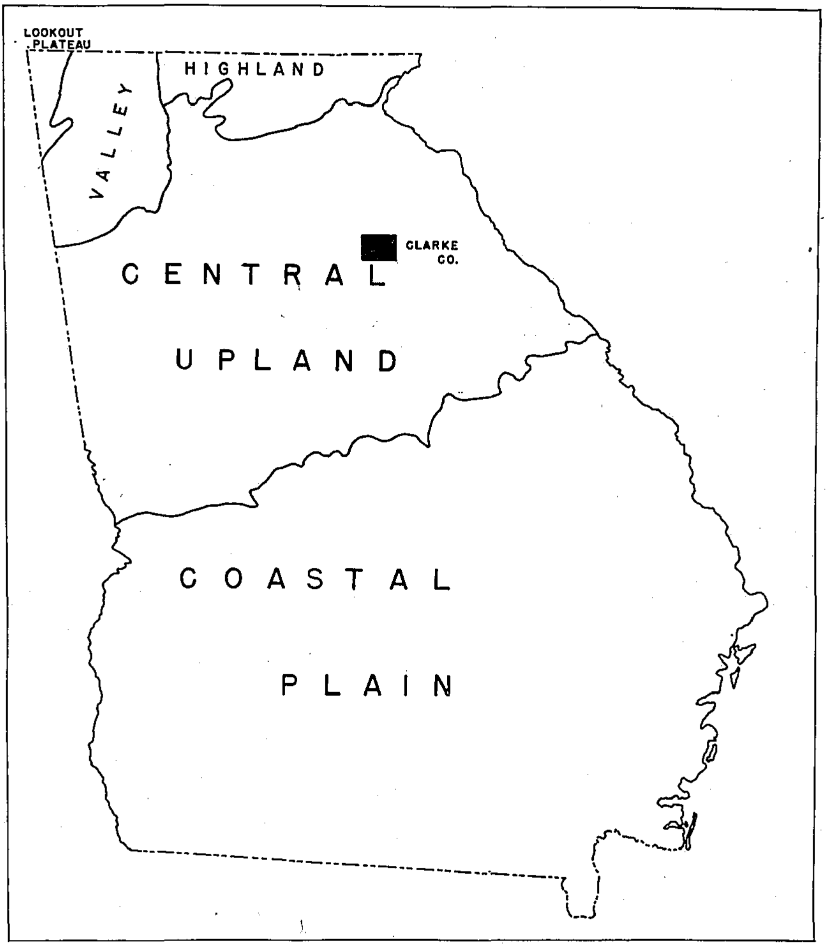


Figure 1. Major Topographic Divisions of Georgia.

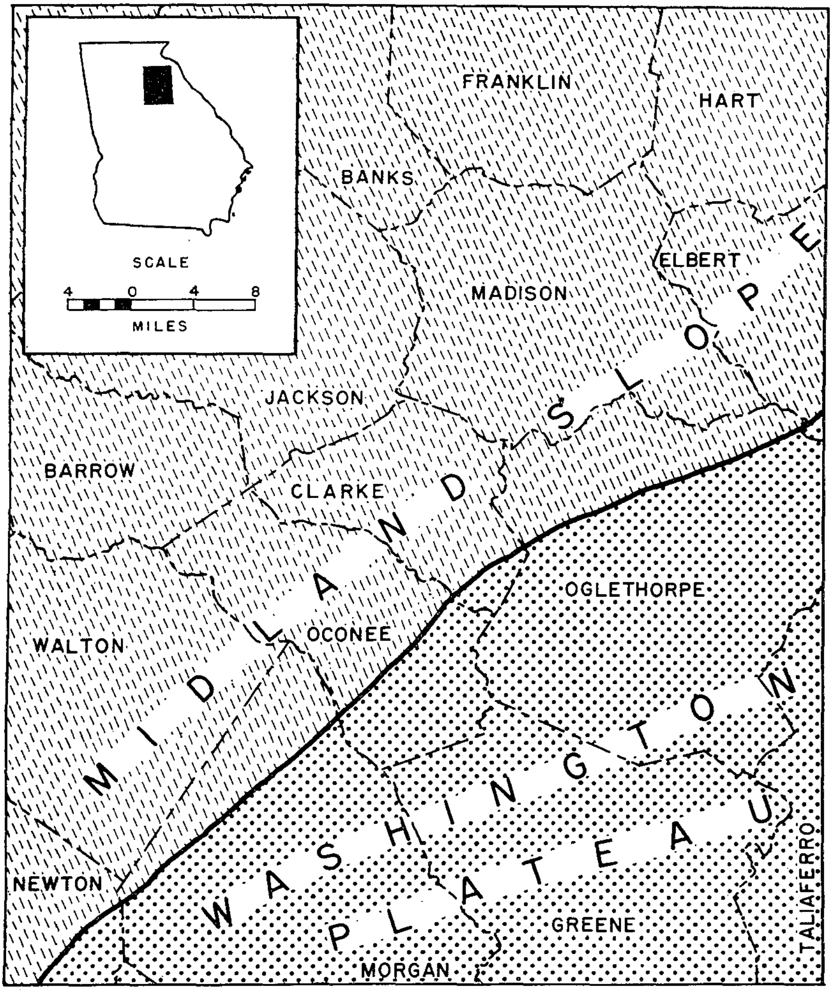


Figure 2. Topographic Divisions in the Central Upland Province of Georgia.

thin soils and are comparatively free of forest growth, while lowlands have a thicker mantle and are often heavily wooded.

GEOLOGY

Field work has disclosed, with limited detail, the outlines of a partially exposed discordant granite body (Figure 3). Areal extent and field relations of the granite suggest that it is part of a plutonic mass with dimensions comparable to a batholith. The Carolina schists form the country rock in Clarke County. They are metamorphosed beds of unknown but probable Pre-Cambrian age. Other rock units occur near the contact between granite and schists: (1) a deep reddish-brown, highly distorted garnet-bearing, mica-schist ("Carolina contact-phase"), (2) migmatite rocks, resulting from magma injections into layered older rocks and perhaps partial replacement of older rocks by igneous solutions, and (3) medium to coarse grained gneissoid granites, displaying strongly developed primary flow structures.

The granite is for the most part massive, medium to coarse-grained, and occasionally porphyritic. Some fine-grained

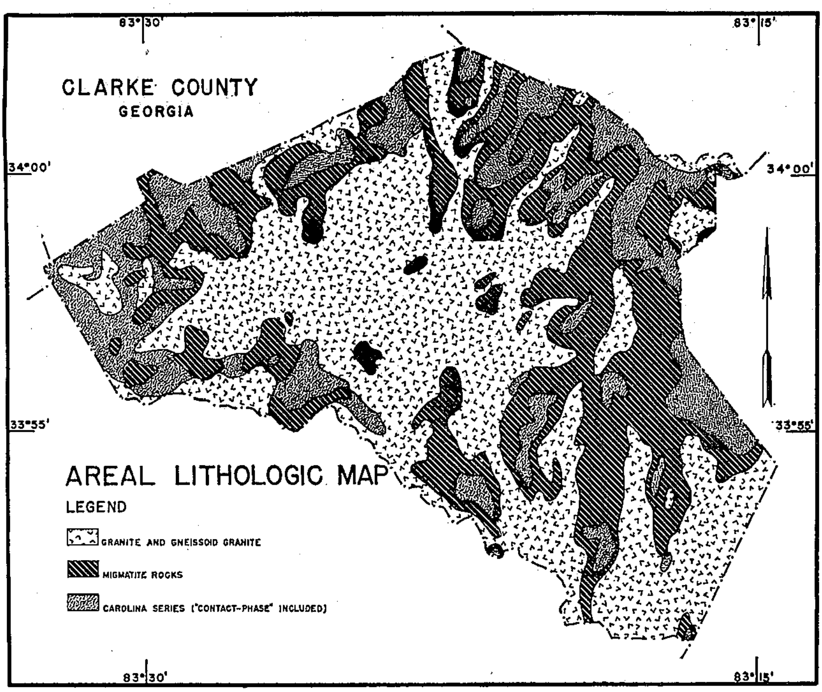


Figure 3.

granites are present in smaller masses. Principal minerals are quartz, perthite, orthoclase, soda plagioclase, muscovite and biotite. Recognized accessories are zircon, monazite, tourmaline, rutile and magnetite.

The granite is light to dark gray when fresh, but weathers to a light brown and shows a marked decrease in hardness; kaolinization of the feldspars is very common in surface exposures. Chemical and mechanical weathering are both active and as a result a considerable regolith has formed. Surficial material is thickest above granite in the valleys, and thinnest on steep slopes and uplands. Moisture penetrates bed rock easier in the valleys so that decomposition occurs more rapidly than decomposed rock can be removed.

Bare or sparsely covered granite exposures often show sheeting, with individual layers usually less than 6 inches thick. Penetration of water along the separation planes has assisted in the formation of saprolite horizons.

Most of the uneven topography in Clarke County is in the area of granitic exposures.

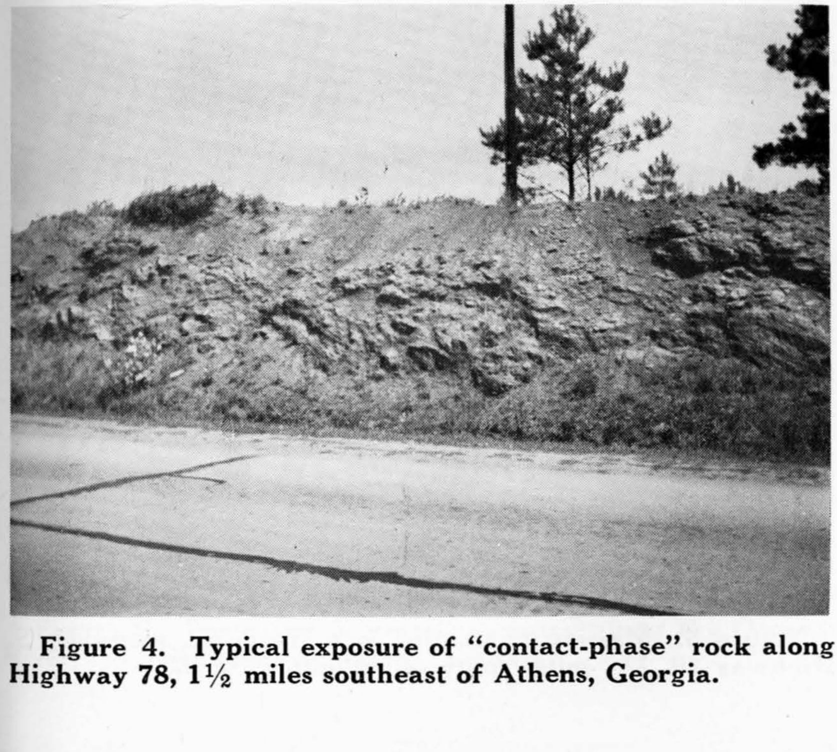


Figure 4. Typical exposure of "contact-phase" rock along Highway 78, 1½ miles southeast of Athens, Georgia.

The Carolina series is composed of buff to red-brown micaceous quartzose schists and gneisses. It is probable that portions of the series were originally igneous rocks, whereas others were certainly sedimentary. The rocks are thin-bedded and schistose, and are separated in places by discontinuous mica layers. In addition, interlayered thin quartz seams of fine aggregate are present. Quartz, feldspars and micas comprise the major minerals. The beds are often closely folded and show confirmation of uniform slipping throughout the mass.

An irregular thickness of rock occurs at and near the contact of granite and Carolina schist. It is part of the Carolina series, but with an aspect so distinctive that it has been used in places for contact mapping. It is tentatively called "Carolina contact-phase". (Figure 4). The rock is mostly reddish-brown, intensely sheared, crushed and folded. Garnets, probably almandite, lie along the shearing surfaces. Quartz veins, a few inches to more than a foot wide, both terminate within and pass through the "contact-phase". In some areas the only visible proof of contact determination are quartz fragments

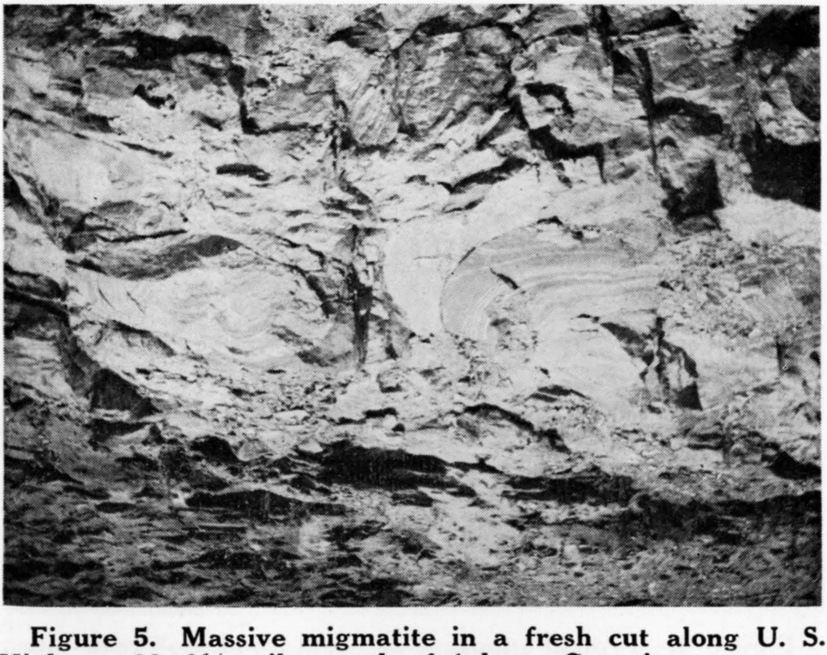


Figure 5. Massive migmatite in a fresh cut along U. S. Highway 29, 1½ miles south of Athens, Georgia.

and boulders lying on the surface.

Migmatite rocks are exposed near the contact zone in many places throughout Clarke County. They were formed from intrusive magmas that penetrated certain layers of earlier gneisses and schists. (Figure 5). Comprising the migmatites are bands of light-colored, medium to coarse-grained granites that alternate with dark hornblende-biotite layers. Ptygmatic folds and a well developed book to ribbon structure are common in the migmatite exposures.

Gneissoid granites with flow patterns dominate portions of certain exposures. These rocks were not separated from the granites on the Areal Map of Clarke County (Figure 3), because of close genetic relation and the gradations between the two. Gneissoid rocks are best developed near the granite margins. Inclusions and prismatic minerals comprise for the most part the directional properties of the gneissoid granites, and they serve as the basis for consideration of these rocks as the result of primary flow.

Figure 6. Pegmatite in granite exposed along the Oconee River, one mile south of Athens, Georgia.

PEGMATITES

Numerous pegmatites of coarsely-crystalline orthoclase, albite, quartz and muscovite penetrate the contact aureole of the granite. They form dikes, sheets, vein networks and irregular masses (Figure 6). Some pegmatites were injected along fractures in the periphery of the earlier consolidated granite body; others invaded schistose and fissile rocks with dike-like and lit-par-lit design. Several areas were soaked to a small degree by pegmatitic fluids and gases. The areas are now exposed as gray-buff masses that contrast with nearby reddish-brown schists.

INCLUSIONS

Structures genetically related to the country rock are exposed in the contact granite. Properly they should be designated as "inclusions", though field criteria suggest many may well be "sedimentary zenoliths" (Figure 7).

The inclusions possess variable shapes and sizes, although

Figure 7. Inclusion embedded in granite in Clarke County, Georgia. The hammer lies parallel to bedding planes and the long direction of the fragment.

the majority are rectangular. Some show a positive orientation directed by flow of the host magma. Magmatic reactions and additions have not masked the sedimentary appearance of some.

In several areas of granitic exposures, arcuate trends in the alignment of inclusions can be observed (Figure 8). Else-

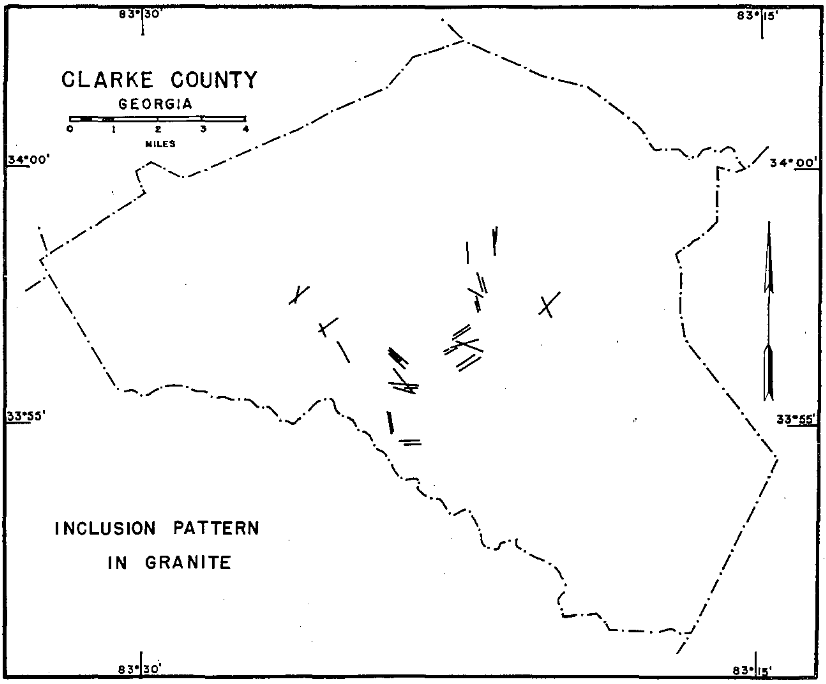


Figure 8.

where the long axes of inclusions generally strike uni-directional, most often roughly north-south.

Chemical analyses have not been made of the inclusions, but in some cases field and laboratory study indicates a mineral composition similar to the host granite. This is logical and expected as shown by Bowen's studies of the physical chemistry of magma inclusions, as well as descriptions of inclusions from many district. Inclusions in granite rocks could have igneous compositions, with the exception of those incorporated at so late a period that sufficient time did not remain for reaction to occur.

Sharp contacts are notable in many instances, but interlocking and gradational contacts between inclusion and host material are also apparent. Many inclusions show biotite-rich zones with mica plates oriented parallel with the long direction of the fragment.

Occasional small lumps, interpreted as segregations, occur in the granite. Although flow structures do not exist in these masses, they do show a mineral composition similar to that of the granite. Segregations are not common in granite rocks, and the lumps may well be additional inclusions.

DIKES

Basic dikes crop out in Clarke County. For the most part, they are uniform in appearance, composition, and steepness of dip. Dikes considered similar in genesis and age have been described from the Piedmont of Georgia and isolated localities from Virginia to Florida. In Georgia the period of dike formation cannot be determined. Elsewhere, stratigraphic relationships suggest the dikes to be possibly late Triassic in age. In Clarke County the dikes are regularly dark in color, fine to medium-grained and very resistant. Calcic plagioclase, pyroxenes, and amphiboles comprise their mineral composition. Fresh dike materials are extremely hard and massive, but weathering causes a concentric peeling or exfoliation and a prominent iron oxide coating. The presence of a dike is suggested frequently by blocks and fragments of basic igneous material scattered on the surface.

STRUCTURAL GEOLOGY

Little attempt was made during the reconnaissance to obtain information relevant to the general structural pattern. Most of Clarke County is underlain by rocks so intricately crushed, folded, and metamorphosed that considerable detailed work must be completed before positive statements can be presented.

The country rock possesses a schistosity primarily parallel to bedding planes. Slippage has been pronounced along the planes as stresses were adjusted or relieved easier in such directions.

In the contact zone, the dips of bedding and schistosity have been disturbed by the intrusion, but away from contact areas the dips of the country rock vary from 25° - 70°, in a southerly direction.

Tension joints are common in the granite, usually striking normal to any linear structure. The joints vary in size, some being but a few inches in length and others traceable for tens of feet along their strike. Dips of joint planes range from 35° - 90°. Drag folds, with fold axes striking north to northeast, are often prominent in schistose exposure. Rock cleavages are locally well developed in the Carolina series.

AGE

The age of rock units in Clarke County is indefinite. In the writer's opinion the proposed Pre-Cambrian age for the Carolina series is valid, and unless contrary evidence can be shown, it should be accepted. Field work has indicated that any suggestion at this time with respect to the period of granitic intrusion is not warranted.

SUMMARY

In summary, five rock units, granite, Carolina series, migmatite, gneissoid granite and "Carolina contact-phase" comprise the bedrock of Clarke County. The igneous material is part of a large, partially-exposed pluton that forms the most significant geologic feature in the area. Pegmatites, inclusions and dikes are abundantly present. The stuctural relations and age of rock units are indefinitely known at this time. Classification may be possible in the future and additional field investigation is projected for this purpose.

COMMENTS ON THE GEOLOGY OF THE ELLIJAY QUADRANGLE, GEORGIA–NORTH CAROLINA–TENNESSEE*

A. S. FURCRON

Georgia Geological Survey

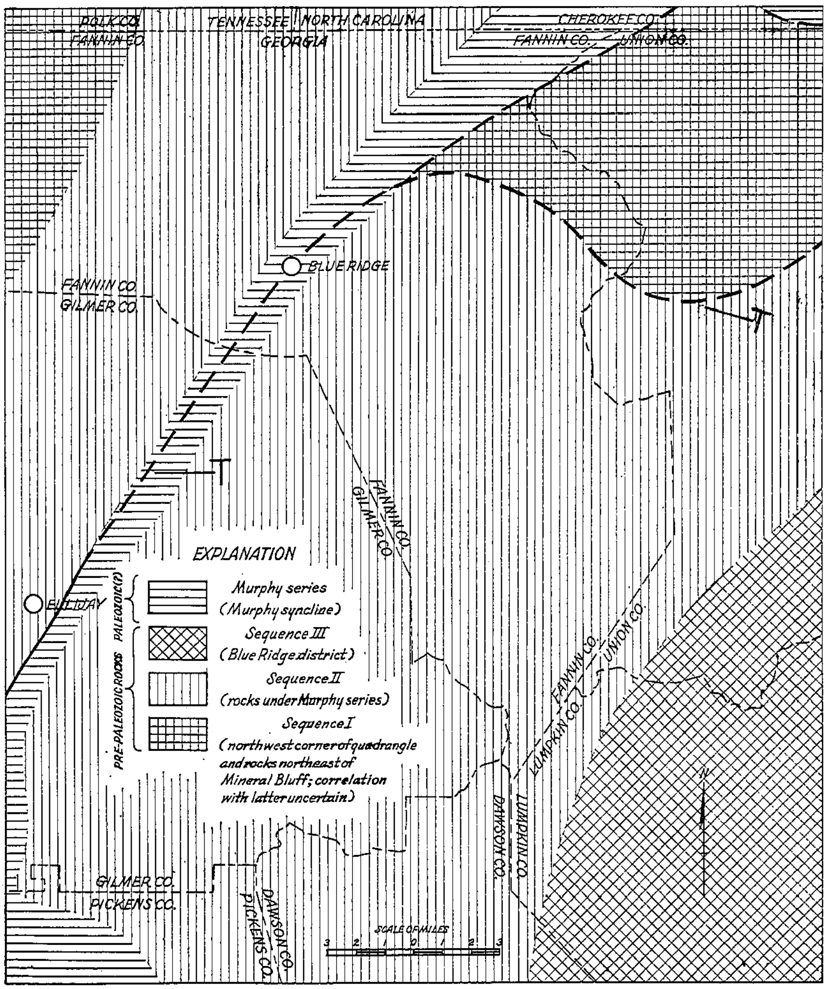
GENERAL DISCUSSION

The Ellijay folio is the first important study in areal geology to be published upon the crystalline rocks of Georgia. The geology of this area was done by Laurence LaForge after Hayes had worked (but did not publish) upon the more western and southwestern Georgia crystallines; it is later than the work of Arthur Keith, which is just northeast of this district in North Carolina (1907, and unpublished Murphy folio). LaForge followed the classification of Keith. The small scale of the map is totally inadequate for portrayal of the geology of the Murphy series; nevertheless, his delineation of formations and localization of structural features stand up well under the test of time.

LaForge divided the metasediments into two great divisions, the oldest, regarded as "Archean" and referred to as "Carolina gneiss", composes about half of the quadrangle, cropping out in its eastern and southeastern parts. Over this complex are his sedimentary schists and gneisses referred to as the "Great Smoky formation" of Lower-Cambrian age. Upon this formation rests a synclinal belt of rocks generally referred to as the Murphy series, which Keith regarded as younger Lower-Cambrian. LaForge discovered fewer units of the Murphy series on this quadrangle than were recognized to the northeast by Keith. The formations above the Great Smoky formation, described on the Ellijay folio, are from older to younger: the black Nantahala slate, white Tusquitee quartzite, "ottrelite" schist and slate known as Brasstown schist, Valleytown formation—chiefly slate and phyllite, the Murphy marble, and Nottely quartzite. LaForge pointed out (1913, p. 5) that the distinction between the Great Smoky formation and the Carolina gneiss is a more or less arbitrary one based upon

*Read before the Southeastern Section of the Geological Society of America and Southeastern Mineral Symposium, Vanderbilt University, April 2, 1953.

theoretical grounds. In practice, he seems to have drawn the boundary east of the Murphy series, connecting up points where granites begin to appear in the paragneisses. Granites have not been noted west of the Murphy series on this quadrangle and it is probable that the general increase in granitization eastward encouraged the view of that day that the more eastern metasediments must be older. Work in recent years by this writer has discovered no proof thus far of an old shield or ancient complex pre-Cambrian basement to the southeast in Georgia.



Geology of Ellijay Quadrangle, Georgia-N. C.-Tenn.

The hornblende gneisses were regarded as of igneous origin —Roan gneiss (Keith 1907, LaForge 1913), and it is true that they are much more abundant locally east of the Murphy belt, but they are quite common in gneisses west of that belt on this quadrangle, **where** they were not mapped on the Ellijay folio; irrespective of their origin, they have not been of much assistance thus far in an age or sequence classification for the crystallines, possibly because their varying petrology has not been studied or connected with the stratigraphy of the crystalline area. Their study may be related to the pseudodiorite problem.

The classification of rocks proposed here is offered as a tentative one, based upon reconnaissance; thus, it is expected that later work will modify the views here expressed. Mr. Vernon J. Hurst will begin a detailed study of these rocks in Georgia, south of Copper Hill, this summer. He will use the Epworth and Mineral Bluff quadrangles as base for a thesis at Johns Hopkins University. The work will be sponsored by the Georgia Geological Survey.

As may be seen from the submitted outcrop map, rocks beneath the Murphy series are all regarded here as part of a great pre-Cambrian series which crops out west eand east of the limits of this quadrangle.

SEQUENCES RECOGNIZED

Sequence I*

These rocks are mapped in the northeast and northwest parts of the quadrangle and thus far it has not been possible to correlate the two occurrences stratigraphically; thus, they may not represent rocks of the same age. The northwestern occurrence represents rather low rank metamorphism up to the isograd of biotite; but in the northeast corner of the quadrangle these rocks are the most metamorphosed of the district, containing abundant kyanite and sillimanite. The north-

*Because the rocks here discussed constitute but a small part of our crystalline area, numbers here given to sequences are intended to apply only to the Ellijay quadrangle.

western rocks are dark slates interlayered with granulite** (generally fine-grained). In the upper part of that sequence, dark slates become rare and there is gradation upward into Sequence II. Deeply weathered bands of hornblende gneiss, interlayered with slates and granulites are characteristic of this transition zone.

The northeastern facies consists of mica schists, garnet-mica schist, biotite granulite, graphite, sillimanite, and kyanite schists. Pseudodiorite beds are prominent locally. The rocks are locally granitized and numerous pegmatites and small granite bodies have been mapped (LaForge, 1913). On the Ellijay folio these northeastern rocks are classified as Carolina gneiss, the northwestern ones are regarded as a part of the undifferentiated Great Smoky formation.

Sequence II

This sequence directly underlies the Murphy series. West of that series on the Ellijay folio, it was considered as a part of the Great Smoky formation, and a narrow belt of it was mapped east of the series to conform to the interpretation of the times. The occurrence of conglomerates suggested at that time a Cambrian age; thus an area of such rocks east of the Murphy belt was mapped by LaForge as a synclinal Lower Cambrian remnant over the "Carolina series". Most of the rocks cropping out east of the Murphy series, here referred to as Sequence II, LaForge regarded as belonging to the Carolina gneiss. These rocks are characteristically fine-grained metasedimentary biotite gneisses or granulites, mica schists, garnet-mica schist, staurolite gneiss, kyanite schist, with abundant beds of pseudodiorite of varying composition. Granite intrusions come into the sequence and become more abundant eastward, but only narrow bands and small lens-like bodies have been observed on this quadrangle.

Sequence III

This sequence is shown in the southeastern corner of the quadrangle, and was classified as Carolina gneiss on the Elli-

**The Scotch geologists have found this term useful for a similar, widespread variety of paragneiss. As here used, the rock is medium to fine-grained, equigranular biotite gneiss with feldspars ranging between oligoclase and andesine, and potash feldspar usually present; beds range from a few inches to several feet in thickness. With decrease of feldspar and increase of muscovite the rock becomes a mica schist, and with decrease in mica and feldspar the layers may be classified as quartzites.

jay folio. The rocks are massive beds of fine-grained granulites, and massive biotite quartzite interlayered with mica schists; hornblende gneisses are locally abundant. Pseudodiorite is generally unimportant. Aplite stringers and bands, and some pegmatites invade these rocks (Furcron and Teague, 1943), but igenous intrusions of mappable size do not occur.

Murphy Series

This series is discussed in detail on the Ellijay folio, and in other reports (Keith, 1907, Bayley, 1928, Van Horn, 1948); it thus will not be described in this brief statement. The Nantahala slate uniformly composes the basal formation, and the Valleytown formation or rocks, so mapped, is the most prominent formation of the series. There are two belts of marble on the quadrangle, both mapped as Murphy marble on the folio. The westernmost belt is associated with "Nottely" quartzite, and is the belt within which pure white talc occurs in North Carolina and Georgia. The quartzite formation is persistent and occurs near marble or white talc; it has been observed by the writer as far southwest as Whitestone and by Teague and Furcron west of Ball Ground on the Tate quadrangle where it follows this western marble belt of the series. Less is known about the stratigraphy of the marble of the eastern belt, or marble bodies which occur in schist or phyllite not associated with quartzite. In the opinion of the writer, the position of these marbles in the series is not well established because some crop out as if they were marble beds in Valleytown slates. However, marble associated with pure white talc and the marble at Whitestone, Georgia seem to belong to the "Nottely" quartzite belt. At Whitestone, the "Nottely" quartzite bed lies between the dolomite and a lower high-calcium marble.

Two of the most important facts to be determined about the Murphy series are its structure and its relation to underlying crystalline rocks. The series is synclinal and thrust-faulted, as indicated by LaForge. Where the presence of faulting can be discounted, these rocks seem to lie conformably upon beds of underlying paragneisses in many places, particularly along their western contact from the North Carolina line nearly to Ellijay; but where these rocks are traced for distances southwest of Ellijay, the composition of the basement rock changes; thus, unconformity is suggested. Locally, the Nantahala overlies a coarse conglomerate at its base. This conglomerate can be seen on both sides of the syncline at Ellijay and has been traced southward by the writer to the vicinity of Talking Rock; and fragments of Nantahala slate are found in the conglomerate.

Geologic Age: First of all, the synclinal position of the series indicates that it is younger than the underlying rocks. Also, its composition and metamorphic grade indicate a younger age. The series differs markedly in composition from the Great Smoky of LaForge, resembling Paleozoic rocks of the Great Valley, a point stressed by Keith and LaForge; however, the oldest Paleozoic rocks upon any given terrane are not necessarily Cambrian. The series is mostly a basal dark slate formation (Nantahala) with overlying phyllites which contain garnet and staurolite porphyroblasts. Because of complex structure, more highly metamorphosed rocks very likely have been included in past mapping with this series locally, both north and south of this quadrangle. The underlying metasediments to the west contain kyanite, and those to the east of the series on this quadrangle are characterized by kyanite and sillimanite. Pseudodiorite is common to all of the metasediments of the quadrangle except those of the Murphy syncline where it is absent but has been rarely discovered in the Nantahala formation.

Lithologic variations at the base of the series, for example, the conglomerates which occur on the Ellijay sheet, suggest an unconformity. It seems likely that some of the dark slates mapped as Nantahala on the Nantahala folio (Keith, 1907) are really dark slates in his Great Smoky series. If this be the case, the Murphy series in that section may be underlaid by rocks which differ in stratigraphic position from those beneath it on the Ellijay sheet. Stose and Stose write that the Nottely quartzite associated with the Murphy marble does not resemble Ocoee quartzite but is clean, white to blue quartzite, resembling those of established Paleozoic age.

The writer has traced the Murphy series southward from this quadrangle through the Allatoona area where the belt is narrow but not cut out by thrusting, and is continuous into Alabama. Southwest of Allatoona in Bartow County it is a wide belt, becomes less metamorphosed, loses its porphyroblasts, and lies directly against the Cartersville fault, where it composes what is referred to as undifferentiated Talledega upon the present State geologic map of Georgia. There, its difference in composition and metamorphism from other more crystalline rocks, and its juxtaposition to established Paleozoic rocks suggest a Paleozoic age for it in Georgia. At the Georgia-Alabama State line, the Murphy series corresponds exactly with the Talladega slates as mapped upon the geologic map of Alabama (1926), where portions of that series are known to contain Paleozoic fossils. Thus it would appear that if there is no prominent unconformity under the Murphy series, the Great Smoky formation and the other crystalline rocks of the quadrangle are Paleozoic in age. If this series is Paleozoic and unconformable upon underlying rocks, the structural theory tentatively proposed in this paper is strengthened, because absence of Murphy rocks under the latest pre-Cambrian sequence of the Blue Ridge synclinorium would be expected.

In conclusion, the Murphy series seems to represent a Paleozoic sequence preserved by folding and by thrust faulting, pitching out in North Carolina near Hewetts, and narrowed to the southwest in places where it is overthrusted; it becomes a wide belt, only slightly metamorphosed southwest of Allatoona, Georgia, to merge with the Talledega series of Alabama. (Alabama Geol. Survey, 1926).

Continued discovery of Paleozoic rocks by drilling under the Georgia Coastal Plain strengthens the view that this series as well as its possible correlative, the Brevard series further east, may be Paleozoic. Also, the Little River series of the Fall Belt in Georgia is very slightly metamorphosed locally, and has supported a brick industry at Augusta. Most of its metamorphism is produced by local granite intrusions. Thus, from the north Georgia mountains to the Cretaceous basement of South Georgia where Paleozoic rocks are known to occur, there are numerous belts of rock less metamorphosed, and of different composition from their basement; they are essentially unintruded by granites in the western part of the State; are younger than the so-called "Ocoee", "Great Smoky", or "Carolina gneiss" rocks; thus, they may be of Paleozoic age.

STRUCTURE

The beds of granulite, graphite schist, mica schist, and pseudodiorite, between Chatsworth and Ellijay, belong to the eastern limb of an anticlinorium, which is overthrust upon Paleozoic rocks of the Great Valley. Near this overthrust, folds are overturned and sliced through more or less parallel to their axial planes. Sequence I in the northwest corner of the map being essentially a slate is very much folded, and in Sequence II, west of the Murphy syncline, the beds dip rather consistently southeast toward the Murphy series, but northwest dip of beds may be observed locally. The best indicator beds are usually pseudodiorite and locally, massive granulite beds.

The synclinal character of the Murphy series can be well studied in East Ellijay. Here, this series occurs in a tight, overturned syncline, sheared on its western limb, but not thrust out against the Great Smoky formation to the west. On the west side of the syncline east of the railroad depot (road to Dahlonega) conglomerate is sheared into stretched pebbles, but on the east limb of the fold the conglomerate is massive.

No attempt is made here to portray the fault structures associated with the Murphy syncline. The two thrusts indicated on the accompanying map are believed to be of more general importance. LaForge finds other overthrusts to be present; thus, thrusting played an important role in preservation of the Murphy series. The westernmost thrust, indicated on the accompanying map, is justified by physical evidence of faulting near Ellijay, and because the rocks of Sequence I are thrown against the Murphy series. It would appear that the less resistant and slaty character of the Murphy series has caused it to absorb a considerable amount of movement. The fault between Sequences I and II in the northeast section seems to be justified on the basis of lithology. Actually, this thrust is a continuation of the thrust brought in from the Murphy quadrangle by Keith and LaForge. The problem requires detailed structural study.

The major element of Blue Ridge structure southeast of the Murphy series is a very large synclinorium to which Sequences II and III belong.

References

Alabama Geological Survey, Geologic Map of Alabama: 1926.

Bayley, W. S., Geology of the Tate quadrangle, Georgia: Georgia Geol. Survey, Bull. 43, 1928.

Crickmay, G. W., Status of the Talledega series in southern Appalachian stratigraphy: Geol. Soc. Amer., Bull., vol. 47, 1936, pp. 1371 - 1392.

Crickmay, G. W., Geology of the Crystalline Rocks of Georgia: Ga. Geol. Survey, Bull. 58, 1952.

Furcron, A. S., Stratigraphy and structure of Georgia crystalline rocks; Geol. Soc. Am. (abstract) vol. 62, No. 12, pt. 2, Dec. 1951, p. 1551.

Furcron, A. S., and Teague, Kefton H., Mica-bearing Pegmatites of Georgia: Georgia Geol. Survey, Bull. 48, 1943, pp. 7, 125, and 134.

Furcron, A. S., and Teague, Kefton H., Sillimanite and massive kyanite in Georgia: Georgia Geol. Survey, Bull., 51, 1945.

Georgia Division of Mines, Mining and Geology, Geologic Map of Georgia: 1939.

Jonas, A. I., Structure of metamorphic belt of southern Appalachians: Am. Jour. Sci., 5th ser., vol. 24, 1932, pp. 228-243.

Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Nantahala folio: No. 143, 1907.

Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Murphy folio: unpublished.

King, P. B., The base of the Cambrian in the southern Appalachians: Am. Jour. Sci., vol. 24f, 1949, pp. 513-530, 622-624.

LaForge, L. and Phalen, W. C., U. S. Geol. Survey Geol. Atlas, Ellijay folio: (No. 187), 1913.

Prindle, L. M., Kyanite and Vermiculite deposits of Georgia: Georgia Geol. Survey, Bull. 46, 1935.

Stose, George W. and Stose, Anna Jonas, The Chilhowee Group and Ocoee Series of the Southern Appalachians: Am. Jour. Sci., vol. 242, July, 1944, pp. 367-390; and vol. 242, Aug. 1944, pp. 401-416.

Van Horn, E. C., Talc deposits of the Murphy marble belt: N. C. Dept. Cons. and Dev., Bull. 56, 1948.

INTERPRETATION OF FLORIDA GEOLOGY*

by

HERMAN GUNTER, ROBERT O. VERNON and JAMES L. CALVER

Florida Geological Survey

INTRODUCTION

In area Florida ranks in size with Georgia, the largest state in the southeastern United States, and contains 58,666 square miles of land surface within its boundaries. This area is approximately 210 square miles less than that assigned to the

*Read at the Southwestern Mineral Symposium, Geology Department, Emory University, March 29-31, 1951.

State of Georgia. The distance across the State from the Perdido River that forms the boundary with Alabama on the west to the Atlantic Ocean on the east, is approximately 380 miles, and the length of the State from the St. Marys River on the north to the southern tip of the Peninsula is approximately 425 miles. Within this area a total relief of 345 feet has been measured. Although only 40 per cent of the State has coverage by standard topographic maps, the highest elevation on these maps, 345 feet, lies in the northern portion of Walton County in western Florida.

Situated wholly within the Coastal Plain Province, Florida is underlain by 4,000 feet or more of sedimentary rocks that overlie a basement of older sedimentary, metamorphic and igneous rocks. The oldest rock exposed at the surface of the State is the Avon Park limestone of Middle Eocene age. This formation, together with the Ocala limestone, Upper Eocene, and the younger formations of the Oligocene, Miocene, Pliocene, Pleistocene and Recent age represent a stratigraphic section of about 1,800 feet. Sedimentary rocks older than the Middle Eocene limestones do not crop out and are known only through cuttings, cores, and records of wells that penetrate them.

Florida forms the emerged portion of the Floridian Plateau that separates the deep waters of the Gulf of Mexico from the deep waters of the Atlantic Ocean and includes not only the State of Florida, but also the adjacent ocean floor that is less than 300 feet below sea level.

The Eocene and younger sedimentary rocks of the Floridian Plateau are arched into a broad anticline that trends northwest-southeast and plunges toward the northwest and the southeast. The fold may be traced from Madison County southward to Hardee County. The oldest of the sedimentary beds cropping out in Florida, the Avon Park limestone, is exposed along the crest of this fold in Citrus and Levy counties. The younger formations on the flanks of the fold dip at low angles toward the Atlantic Ocean and the Gulf of Mexico. They crop out on the floor of the Ocean or Gulf some distance offshore and some possibly crop out on the edge of the plateau. The Ocala uplift is separated by a shallow synclinal trough from a similar northward trending anticlinal structure found in northwest Florida in Jackson,

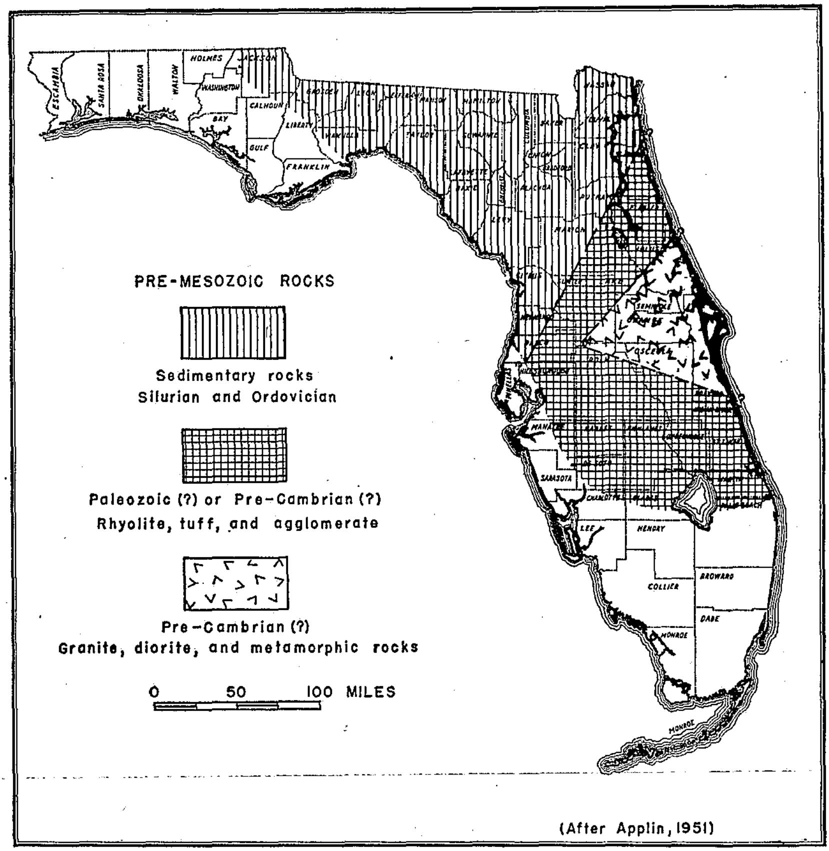


Figure 1. Subsurface distribution of pre-mesozoic rocks in Florida.

Holmes, Walton and Washington counties. This anticline is the southward extension of the Decatur arch, along the crest of which the Ocala limestone lies near the ground surface and is the oldest rock exposed.

By far the greatest portion of the State is covered by a surface mantle which has an estimated maximum thickness of 200 feet of Recent and Pleistocene sands and soils. Tertiary rocks are exposed around the borders of this mantle and in areas where the cover is thin, or absent, as a result of erosion. The oldest of these, as already stated, is the Avon Park limestone of Middle Eocene age, and is exposed in Citrus and Levy counties. There the upper portion of the formation, which has a total thickness of about 650 feet, has been found in a series of outcroppings. As a result of the mantle of Recent and Pleistocene sands and soils, the accumulative thickness of stratigraphic sections actually exposed in outcrop in the entire State measures roughly 900 feet. The maximum thickness of these formations including the upper few feet of the Avon Park limestone is approximately 1,800 feet.

To summarize these generalizations, it is sufficient to say that within the 58,666 square mile area of Florida, there is a total relief of 345 feet. The sedimentary formations are so flat lying that only 1,800 feet of section lies near the surface while only half of this section may be examined in outcrop.

SURFACE FORMATIONS

Methods of Study

To study the details of the surface geology of the State, it is essential that every outcrop be examined. In many areas these outcroppings are so widely separated, it becomes necessary to study cuttings and cores obtained from well-drillers and samples from auger holes to secure details of bedrock geology. In order to utilize the information thus obtained, accurate elevations for each well or auger hole must be determined. Well and auger samples are recovered from 10-foot, or preferably 5-foot intervals, and these are washed and examined in detail. While lithologic studies of such samples are important, very often the paleontologic determinations of the microfauna are the only means by which certain formations can be distinguished.

Minor Structures

Through a study of samples obtained from auger holes and wells, it is possible to distinguish small faults which have vertical displacements of as little as four or five feet. Furthermore in areas where such detailed studies have been made, the fault or joint pattern thus obtained correlates almost exactly with the pattern of trend lines observed on mosaics of airplane photographs. Faults that have stratigraphic displacements as great as 160 feet have been discovered by detailed study of all known outcroppings and all available well sample data.

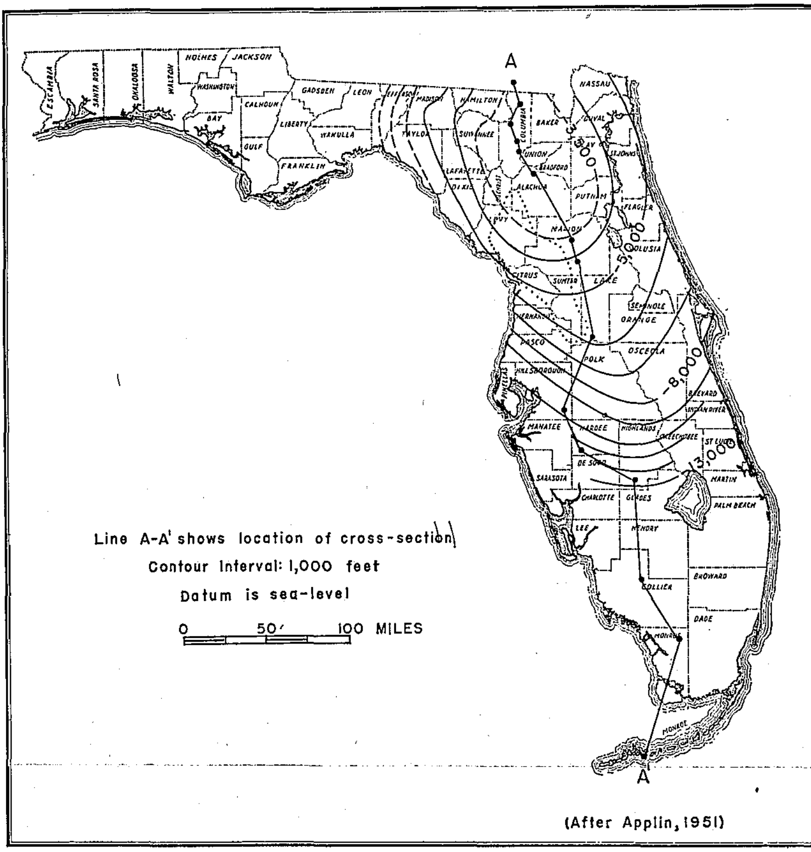


Figure 2. Configuration of the surface of the pre-mesozoic rocks of Florida.

Major Structure

Mention has already been made of the anticlinal structures that have expression on the surface. The largest of these has been named the Ocala uplift inasmuch as the structure is exposed in the vicinity of Ocala, Florida, and the Ocala limestone crops out along the central portion of this doubly pitching anticline. This structure, as well as other structures of lesser magnitude, are confined to Middle Eocene and younger formations. The formations of early Eocene age as well as the Cretaceous and older sediments are not involved in this folding and their structure bears little or no relationship to structure found in the outcropping formations. It is therefore impossible to study the main portion of the rock structure of Florida by examination of the formations that outcrop.

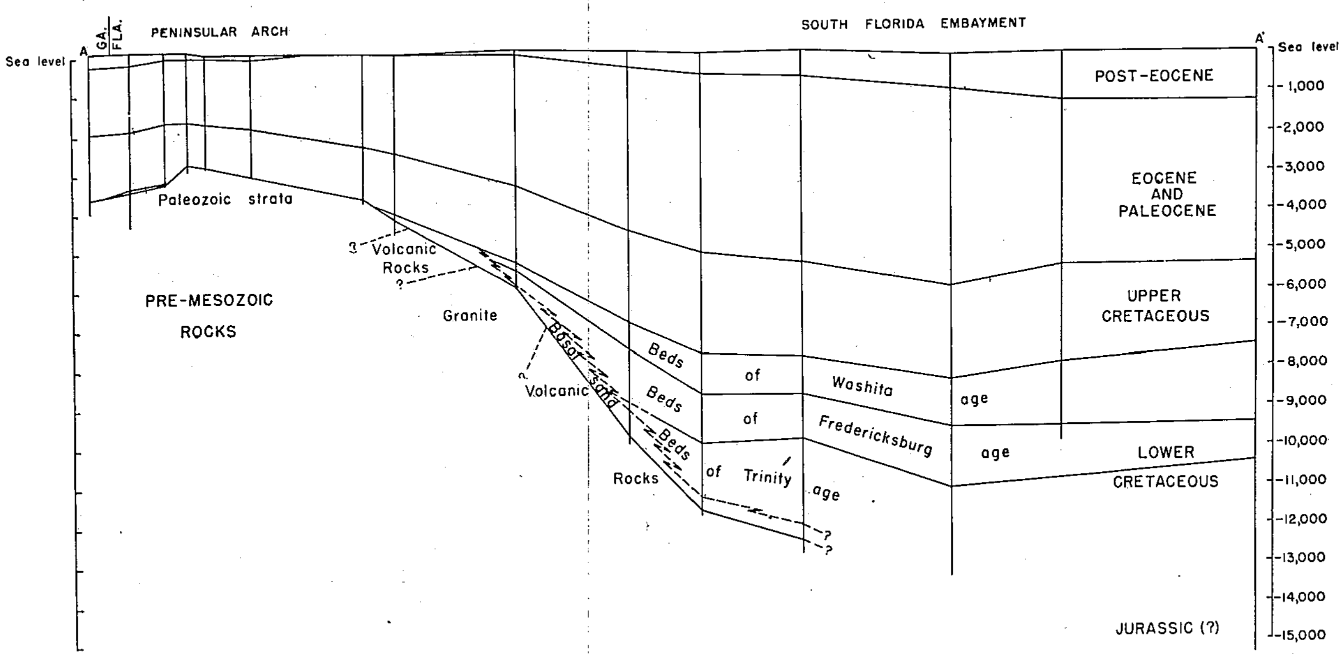
SUBSURFACE FORMATIONS

The term subsurface formations is used here to include all of the rocks assigned to the Lower Eocene and the Paleocene of the Tertiary system, as well as those of the Mesozoic, Paleozoic and pre-Cambrian systems. These subsurface formations are known only from cuttings and cores obtained during the drilling of deep water wells and test wells drilled in the search for petroleum. In the past ten years, and particularly during the past three years, studies of these well samples by a number of geologists have increased our knowledge concerning the subsurface of Florida and have substantiated the complexity of its structure and history. Details of this history are still lacking, nevertheless broad relationships have been determined. The work of Mr. and Mrs. Paul Applin of the U. S. Geological Survey is outstanding in this study, particularly of the Mesozoic and pre-Mesozoic rocks and structures. However, the contributions made by the professional geologists connected with petroleum exploration companies that have been active in the State should not be minimized.

Rock Column and Structural Features

The Cenozoic and Mesozoic formations range in thickness from 2,800 feet in the northern part of the Peninsula to more than 15,000 feet in the region of Florida keys. In western Florida these formations are somewhat thicker and range from 8,450 feet in Jackson County to an estimated 15,000 to 20,000 feet in Escambia County. The buried Paleozoic strata are not less than 3,000 feet in thickness and may be as much as 6,000 feet.

Crystalline rocks that are possibly pre-Cambrian in age have been encountered in three wells in central Florida at depths ranging from 5,900 to 8,000 feet. Lavas, rhyolites, basalts, and tuffs of pre-Cambrian or early Paleozoic age have been encountered in eleven wells in the central part of the Peninsula. In northern Florida 37 wells have penetrated several thousand feet of clastic strata of Paleozoic age. These rocks are of marine origin and are principally unaltered quartzitic



(After Applin, 1951)

Figure 3. Geologic cross section extending south from the crystalline rocks of Georgia to Big Pine Key, Monroe County, Florida.

sandstones, sandstones and shales. According to paleontologic studies made by Drs. Josiah Bridge and Jean M. Berdan of the U. S. Geological Survey, the Paleozoic rocks beneath central and northern Florida include strata from Early Ordovician to Early or Middle Devonian age. The distribution of these rocks is shown in figure 1.

The early geologic history includes the following sequence of events: (1) pre-Cambrian or early Paleozoic volcanic activity; (2) deposition of the Paleozoic sedimentary series of rock; (3) emergence accompanied by faulting and folding; and (4) a long period of erosion, peneplanation; and (5) warping of the peneplane surface to form the structure which Mr. Applin has tentatively named the Peninsular arch. This structure is the prominent feature shown on the contour map of the pre-Mesozoic surface as illustrated in figure 2.

Upon the surface produced during peneplanation, accompanied by downwarping of the Floridian plateau in the south, a thick deposit of marine and deltaic sediments, largely carbonates, ranging in age from possible Triassic to Recent, have formed. Mr. Applin in his studies recorded that an extensive submergence began at the south end of the Peninsula during the early Cretaceous and possibly Jurassic. This is indicated in the Gulf Oil Corporation well, located on Plantation Key, in Monroe County, which penetrated more than 15,000 feet of limestone, dolomite and anhydrite of Tertiary, Upper Cretaceous, Lower Cretaceous and questionable Jurassic sediments, whereas the Sun Oil Company Bishop well in Columbia County penetrated only beds of Tertiary age and those equivalent to the Austin of the Upper Cretaceous.

The submergence advanced northward along the Peninsula because the series of wells north of Sunniland, Collier County, in which beds of Trinity age are penetrated at 13,000 feet show that beds of the Lower Cretaceous, Trinity, Fredericksburg and Washita age, encroach progressively upon pre-Mesozoic rocks.

These definitely marine beds interfinger northward into a clastic facies of red and green shale, sandstone and siltstone that occupies the south flank of the pre-Mesozoic high and are correlatives of Trinity and Washita sediment, the Comanche Series of the Lower Cretaceous. The cross section, figure 3, illustrates this progressive overlap of the Cretaceous sediments on the eroded pre-Mesozoic surface, which is highest in an arch centered at Union County, Florida. The "Ocala uplift" has been restricted to the structure developed in Tertiary rocks of the Western Peninsula of Florida.

In summary, the Ocala uplift, a minor basin in the Southern Peninsula called the South Florida embayment, the Decatur arch and the trough between it and the Ocala uplift are all structures developed in Tertiary rocks, and are exposed at the ground surface. These structures have been outlined by surface geology and detailed by well penetrations. They bear no relationship with structures developed in Cretaceous and older rocks. A well drilled high on these structures may be abandoned at an horizon that is low on older structures, or the well may start in a basin and end in an anticline.

The arch developed in pre-Mesozoic rocks and the overlap on it by Cretaceous sediments is known only from well penetrations and the limited information available prevent detailed analyses of both structure and geology.

THE ROLE OF THE BUREAU OF MINES IN STRATEGIC-MINERAL INVESTIGATIONS IN THE SOUTHEAST[1]*

J. R. THOENEN

U. S. Bureau of Mines

Organization

The field organization of the Bureau is made up at present of eight regions in continental United States and Alaska, and a ninth region that covers Bureau activities in foreign countries.

Region VII includes the 7 states in southeastern United States, namely, Mississippi, Alabama, Georgia, Florida, Tennessee, North Carolina, and South Carolina.

These seven States, according to the 1948 Minerals Year-

[1]Authorized for publication by the Director, United States Geological Survey.

*Read at the Southwestern Mineral Symposium, Geology Department, Emory University, March 29-31, 1951.

book, account for 4.3 percent of the value of the national mineral production, or roughly, $675 million. Of the minerals constituting the major production from the States of Region VII, iron ore is the only one of strategic status listed in the Minerals Yearbook. Hence, the title of this paper may be somewhat misleading.

However, there is some strategic-mineral production from the Region, although it must be classed as of minor importance when compared with the greater production of nonstrategic minerals. For example, we have bauxite and graphite from Alabama, titanium minerals from Florida, bauxite and kyanite from Georgia, mica from North Carolina, and Georgia, topaz from South Carolina, and others.

To serve these seven States, the bureau has Regional Headquarters set up at Norris, Tenn. Regional Director Hewitt Wilson operates from there, and his office has taken over many of the administrative duties originally handled from Washington.

At Norris, also, is the Electrotechnical Laboratory, in which various primary research studies are conducted.

Tuscaloosa, Ala., is the home of the Southern Experiment Station, comprising office quarters for engineers and metallurgists and very complete ore-dressing, metallurgical, and coal and coke laboratories.

At Raleigh, N. C., the Bureau has a station originally designed to serve Virginia and Kentucky as well as North and South Carolina. This Station was set up to study pyro- and hydrometallurgical problems, but, with the reorientation of regional boundaries, it is planned to center much of the nonmetallic research here.

At Gorgas, Ala., the Bureau is conducting extensive experiments in burning coal in place and collecting the gases therefrom, of which probably all of you have heard.

Birmingham, Ala., and Jellico, Tenn., are the headquarters for stations concerned with coal-mine inspections and first-aid training of miners, all for the purpose of promoting the health and safety of miners.

Activities

Regional activities are segregated into seven groups, namely, mining, metallurgy, coal preparation, nonmetallics, mineral research unclassified, safety, and economics and statistics, each of which has several subgroups.

Mining is broken down into State mineral inventories, mineral examinations, development projects, and mining research.

Metallurgy comprises research in ore dressing, pyro- and hydrometallurgy, and work is planned for electrometallurgy.

Coal preparation involves removing ash-making impurities from coal. This division also investigates coals and coal blends for the best coke-making properties, and studies gasification of coal in place at Gorgas.

In nonmetallics, studies are conducted looking to the beneficiation of raw materials, testing mineral samples for use, production of synthetic minerals, and ceramic research.

Mineral research unclassified covers a multitude of investigations such as actual mining to determine the most economical method for a particular set of conditions, development of new tools and methods for drilling ore bodies, devising new ore-dressing methods and new applications of metallurgical processes, and originating new and more accurate methods of chemical analyses for minerals.

The promotion of health and safety in mining needs no elaboration for this audience.

Very likely, many of you are familiar with the questionnaires sent out by our economic and statistics group. Information so obtained is used in compiling the Bureau's Mineral Yearbook, with which I know all of you are familiar.

MINING

Mineral Inventory

The State mineral inventories are compiled from all available sources, including State and national geological reports, the technical press and reports from our own engineers. Each deposit recorded is card-indexed, and then its location and condition are verified in the field by a mining engineer. Thereafter, the deposits are recorded in office albums and located on maps for ready reference. The albums provide quick reference for the location and study of all known mineral deposits of the State. They also provide a base for planning technical examinations looking to recommendations for development programs.

Examinations of Mineral Samples and Deposits

Mineral organizations are made for two reasons—(1) to provide information required by the local, regional, or national office of the Bureau and (2) at the request of private or public individuals.

Field offices are frequently called upon by regional or national headquarters to prepare reports on the mineral possibilities of stated deposits or areas, thus calling for field examinations to supplement filed information.

Private individuals pick up samples of rock or ore and send them to us, usually with a request for chemical analysis.

The Bureau is forbidden to make chemical analyses for private individuals, but we do examine each sample received and identify the mineral or minerals contained therein. In this way we can usually satisfy the inquiry.

It is of interest to note that 1,132 examinations of mineral deposits have been made in the seven States, of which 1,009 were on 26 different strategic minerals. Considering that of these only iron ore is considered to be of major production importance, it is obvious that the variety is great and the coverage has been wide.

Development Projects

Each year recommendations are sent from field offices to the Regional Office and from there to the National Office for projects that warrant expenditure of public funds for the benefit of the national economy. The National Office weighs these recommendations and, in view of the ever-changing National requirements, selects the most important. Funds appropriated by the Congress are allocated to the several Regions on a national-interest basis. These allocations are then reallocated to the recommended projects by the Regional Office.

Criteria for recommending projects is based on their benefit to the national economy. Suggested projects that obviously will benefit a single private owner are scrutinized carefully and recommended only when the benefit to the nation is considered to exceed that to the individual. Projects are not recommended when only the individual will benefit.

Since 1939, 57 projects have been set up and completed in the Region. Of these, 43 have been on strategic minerals. The total cost of these projects was something over $2 million.

Now, what about the other side of the ledger? The minerals developed were, roughly—

Bauxite, high-alumina clay, copper ore, corundum, manganese, tin, iron, lead, zinc, molybdenum, mica, tungsten, graphite, titanium, and zircon.

The total tonnage developed was, roughly 153,000,000. Thus, the cost was 1⅓ cents a ton.

However, much of this tonnage was low-grade and either not commercial or of questionable value at this time.

On the other hand, approximately 16,000,000 tons was commercial ore and has been put in production since our development.

Charging the total development cost for all minerals against the commercial ore found, the cost per ton was 12 cents.

In many of these development projects the Bureau of Mines has had the active help and cooperation of the U. S. Geological Survey, whose geologists have worked closely with our field engineers. In others, the staffs of State Geological Surveys and T. V. A. have contributed both time and advice.

Mining Research

Little work has been done on mining research in this Region. However, we have done some experimenting in drilling methods and designing new drilling tools. At present we are cooperating with the Applied Physics Branch of the Bureau in some blasting research in a granite quarry near Atlanta. The basic objective of this research is to correlate the physical properties of various explosives with the physical properties of rock. This study has no direct connection with strategic minerals but falls in the class of fundamental research.

METALLURGY

Alabama iron ores are relatively low grade (35 - 40% Fe, compared to 50 - 52% Fe from Misabi) and can be used economically only because the ore, coke, and limestone flux are all obtainable within a 25-mile radius of the furnaces. Mining at increasing depths has increased costs, and the grade of the ore has decreased. Foreseeing this, Bureau metallurgists have conducted major studies relative to the concentratability of not only the currently mined ores of decreasing grade but also on highly ferruginous sandstones not previously mined.

One gravity concentration mill in the Birmingham district produces, roughly, 300,000 tons of hematite concentrate annually from low-grade ores by processes originally developed at the Tuscaloosa laboratory. Bureau metallurgists are continually working with this mill to improve the process further.

Extensive studies have been conducted both in batch tests and pilot-plant scale on the flotation method of concentrating local low-grade ores and ferruginous sandstone. These processes are successful on pilot-plant scale, but large-scale tests must be made to prove the economics.

During the last war, extensive research was conducted in North Carolina and Tennessee in an attempt to produce sponge iron economically.

Milling processes for the recovery of crucible-grade flake graphite have been developed. Three Alabama and one Pennsylvania mill used these processes successfully during the last war.

A workable process for flotation recovery of premium grade bauxite from marginal ores was developed, but never was applied commercially, because a combination leaching-sintering process developed by industry appeared more economical.

An electric furnace process (Pederson) was studied for the recovery of alumina from low-grade bauxite and clay.

The flotation of fluorspar ores was originally developed by

Bureau engineers in collaboration with industry. At present, roughly 150,000 tons (about half the present production) of fluorspar is recovered by flotation.

Low-grade sillimanite-kyanite ores of the southeast have been beneficiated successfully by the laboratory. These processes are available for commercial use when required.

The Bureau developed a successful flotation process for recovering feldspar from pegmatites and granites, later improved by industry. Roughly, 200,000 to 300,000 tons are so recovered annually.

Much experimental work has been done on the beneficiation of ores of magnetite, limonite, phosphate rock, barite, talc, manganese, tungsten, vanadium, ilmenite, rutile, zircon, pyrrhotite, lead, zinc, and others.

Provision is now being made to increase research into pyro- and hydrometallurgical beneficiation processes.

Metallurgists cooperate closely with mining engineers in their examination and development projects. Several methods have been developed whereby the engineer in the field can reach approximate but close evaluation of samples or drill core in the field without having to wait for detailed chemical analyses from the laboratory.

COAL

Coal is not a strategic mineral. However, production of iron and steel depends on coal or coke produced from coal. Coal is one of the South's major resources, and the principal objective of the coal—that each decrease of 1 percent of the ash in coke used in the blast furnace permits the increase of 5 percent in the pig iron produced. The present steel shortage is almost directly traceable to the inability of our present blast furnaces to produce enough pig iron. Hence, by proper preparation of coal, better coke can be produced, thereby increasing the blast-furnace efficiency and steel production with present equipment.

Another section of the Coal Division is concerned primarily with increasing the coking-coal reserves of the region. A coking coal is defined as a coal that has been carbonized successfully to a suitable coke. There are many ranks and grades of coal. Many of these have never been tested for their coking qualities, and, until so tested, they are classed as non-coking. The section is testing these and has determined that some which were thought to be non-coking are actually good coking coals, thereby adding to our reserves.

Studies are being made, also, in which coals found to be noncoking are blended with others of good coking quality and the blend is carbonized. Numerous such blends have been found to produce satisfactory coke, thus further increasing potential reserves.

Most producers of foundry coke in the Southeast import West Virginia Pocahontas coal for their blends at an estimated annual freight cost of $750,000. Two methods are under investigation whereby it is hoped to produce substitute blends from local coal and thereby reduce this expenditure for freight appreciably.

Other investigations indicate the possibility that by correctly adjusting the known variables in the coking procedure additional tonnage can be produced without sacrifice of grade.

Just as there are numerous types, grades, and ranks of coals, there are cokes with widely variable qualities. The end objective of the coke investigations is to relate coke quality to blast-furnace performance.

To conduct the coal and coke investigations enumerated, the laboratory at Tuscaloosa maintains a complete coal-washing unit and an experimental, electronically controlled coke oven.

At Gorgas, the Bureau, in collaboration with the Alabama Power Co., is burning coal in the ground. The objective of this test is to determine whether coal seams that, for one reason or another, are uneconomical to mine, can be gasified in place and the products utilized economically.

NONMETALLICS

Most nonmetallic minerals fall outside the classification of strategic. However, many so classed, like coal, are necessary for the utilization of strategic minerals. I refer to common fire clay and silica brick refractories in the manufacture of iron and steel, molding sands for foundries producing armaments, and drilling muds and cracking media for the oil industry, without which our present economy would slow down to a walk, porcelains for high-tension power lines, radio insulators, and spark plugs, and probably many other items that will occur to you. Although not classed as strategic themselves, they are vitally necessary in the preparation of those materials that are strategic. Virtually all the nonmetallic minerals used in the ways mentioned are found and produced in the southeast for use not only locally but throughout the nation. The station at Tuscaloosa is continually studying nonmetallic raw materials and their beneficiation so that they will be suitable for these and other uses.

Some of the nonmetallics, on the other hand, are strategic in themselves, such as sheet mica, certain types of asbestos, corundum, industrial diamonds, graphite, jewel bearings, kyanite, quartz crystal, and steatitic talc, to name the most important.

The electrotechnical laboratory at Norris, Tenn., is conducting intensive research into the production of synthetic nonmetallic minerals, such as sheet mica, asbestos, industrial diamond substitutes, and super-refractories for the ever-increasing temperature requirements of modern industry. Much of this research, in cooperation with the Bureau of Ships and the Atomic Energy Commission, however, is classified and not subject for publication. I believe, however, that I am not divulging secrets in saying that interesting progress is being made in all of these studies.

MINERAL INDUSTRY IN GEORGIA 1940-1950*

A. S. FURCRON

Georgia Geological Survey

The mineral resources of Georgia are mostly non-metallic; coal mining is negligible, and we have not yet discovered petroleum. It seems unlikely at this time that large metal industries will be developed in the southeast; also, there will

*Read at the Southeastern Mineral Symposium Meeting jointly with Southeastern Section Geological Society of America, Hotel Roanoke, Virginia, May 1-3, 1952.

be a tendency to go beyond the boundaries of this country for metals. However, there is no general need for extensive imports of non-metallic resources with which Georgia and other southeastern states are well supplied; also, it is desirable that non-metallics be used near the source of supply; thus it is reasonable to predict that we will have opportunity in the future of continuously expanding our production of non-metallic minerals.

In 1940 kaolin and clay products amounted to $7,144,826 or approximately 44% of our mineral production. Other minerals in order of their importance were granite, portland cement, marble, fullers earth, limestone, barytes, sand and gravel, talc and iron ore. In 1950 kaolin and clay products amounted to $28,234,718, a total of approximately 50% of our mineral production. Other important minerals in descending order of value were granite, portland cement, fullers earth, marble, limestone, sand and gravel, talc, iron ore and barytes.

Georgia, as some other Atlantic states, includes portions of the Atlantic Coastal Plain, the Piedmont and Blue Ridge Provinces of crystalline rocks, and folded Paleozoic rocks of the Great Valley Province. The Coastal Plain comprises about 60 per cent of the area of the State, and also has the largest mineral production, amounting to $7,566,325 in 1940, and $32,602,435 in 1950, a percent increase of 430. The Piedmont and Mountain area of crystalline rocks comprises 30 per cent of the territory, and contains the oldest mining industries. It had a production of $5,769,387 in 1940 and $16,360,797 in 1950, a total increase of 283%. The much smaller area of Paleozoic rocks in northwest Georgia embracing 10 per cent of the area of the State, ranges third in mineral production which amounted to $3,544,591 in 1940 and $5,775,315 in 1950, a total increase of 162 per cent. Increase in production for the entire state within this ten year period was 332%.

In general, increase in mineral production for Georgia over this period is due to increase of production among established industries.

Increase in Coastal Plain figures came from stepping up production of kaolin and clay products in general. Soft kaolin is used principally as a filler and coating for paper, and the hard kaolins are used as filler in rubber; also, there has been a steady increase in production of fullers earth because of expanded uses of that product. No new mineral industries added materially to the increase.

Increase in figures from the Crystalline area came from the expansion of the granite industry, particularly in crushed stone. In 1940 dimension and monumental stone amounted to $1,211,597 and crushed stone $1,992,571. By 1950 dimension and monumental granite amounted to $3,087,249 but crushed stone for aggregate totaled $6,642,698. Also local development of new minerals such as feldspar and mica for grinding increased the figure.

Increase in the Paleozoic area comes from the expansion in production of existing industries. However, at present, this small district offers more obvious possibilities for increase of mineral production than do the other districts.

It is not out of place here to mention briefly some general policies of the Georgia Geological Survey which are dictated by the stage of our geologic knowledge, and by the character of our mineral resources.

We find it advisable to be on the lookout for new uses of established mineral deposits. For example with an expanding economy, and increase in the building industry, it seems economical to consider today the manufacture of lightweight aggregate. Thus, recently the establishment of the Georgia Lightweight Aggregate Company at Rockmart, in Polk County, represents a new use for an old mineral—slate.

The Rockmart slate is a dark slate formerly used extensively for roofing. However, with the increased cost of labor, and the development of extensive substitutes for roofing slate, it has not been so used since 1938. During the decline of its use it was discovered that good shale brick could be made from it, and this led to the establishment of the Rockmart Shale Brick and Slate Company. Recently, extensive tests upon this slate indicate that in both, the weathered and fresh condition it is suitable for manufacture of lightweight aggregate, and it is quite accessible to the Atlanta markets.

In a large district where non-metallic minerals lead, the discovery of new minerals is an important function of a Geological Survey; by this I mean minerals new to production or to production in our state. Such minerals must be discovered, uses for them must be developed and the advisability of exploiting them must be sold to industry. Obviously, this is a long and difficult procedure, the most difficult part of which is selling the idea to industry—and most geological surveys are not equipped to engage in this type of promotional activity.

The story of sillimanite is applicable here. We discovered and mapped extensive sillimanite deposits in Hart County, Georgia, and published a report upon them in 1945. At the same time the U. S. Bureau of Mines responded wholeheartedly in concentrating the sillimanite ore, and in making it into refractory brick. Sillimanite can be used as a substitute for andalusite or massive kyanite, the latter being imported from India. Both andalusite and kyanite must be calcined to produce mullite, and in that stage are essentially equivalents of sillimanite; thus, it was found that by taking this particular schist apart a substitute for this calcined product could be produced as well as an appreciable by-product of flake graphite. The results of all this work are now well known but how are we to sell them to industry? We believe that eventually it will be done, and for that reason we have prepared ourselves further to meet the questions of industrialists.

William H. Grant is just completing a very thorough study of Hart County, thus when industry becomes interested we will have the details of this mineral worked out. Actually, his report will be a doctor's thesis under Professor Ernst Cloos of Johns Hopkins.

Figures supplied by the State Chamber of Commerce indicate that industrial development in Georgia has increased 500% during this decade. Water is fast becoming our number one problem because of rapid growth of urban districts, and the advent of textile and paper industries. Increased development produces additional responsibilities for a State Geological Survey, and we would like to acknowledge here the all out cooperation of the Surface and Ground Water Branches of the Water Resources Division of the United States Geological Survey.

The Georgia Geological Survey needs a mineral beneficiation or mineral testing laboratory. For years we have maintained a chemical laboratory and assay office which have been of great service to the State, and which undertake work ranging all of the way from ordinary assays to water analyses. The sympathetic cooperation of the U. S. Bureau of Mines in the examination of ceramic materials and in the general laboratory study of our non-metallics, has been of very great value to us, because it has enabled us to extend a service which otherwise we would be unable to give. There would be a decided advantage for us however, if the geologist could bring rocks which he finds in the field directly into a small well equipped laboratory and take them apart in search of possible uses suggested at the time.

We are finding that the best long range program for the discovery of new minerals, and for the discovery of additional supplies of our old minerals, is the maintenance of a plan for continued detailed field work of an areal nature. The long series of reports of the Georgia Geological Survey have covered every known economic mineral in the State, and some of them have been covered by more than one bulletin. Thus to discover additional minerals of economic value, we must now come back to basic research, and the results of such a program started in a small way with us, only a few years ago, have begun to bear fruit.

GOLD DEPOSITS OF GEORGIA*

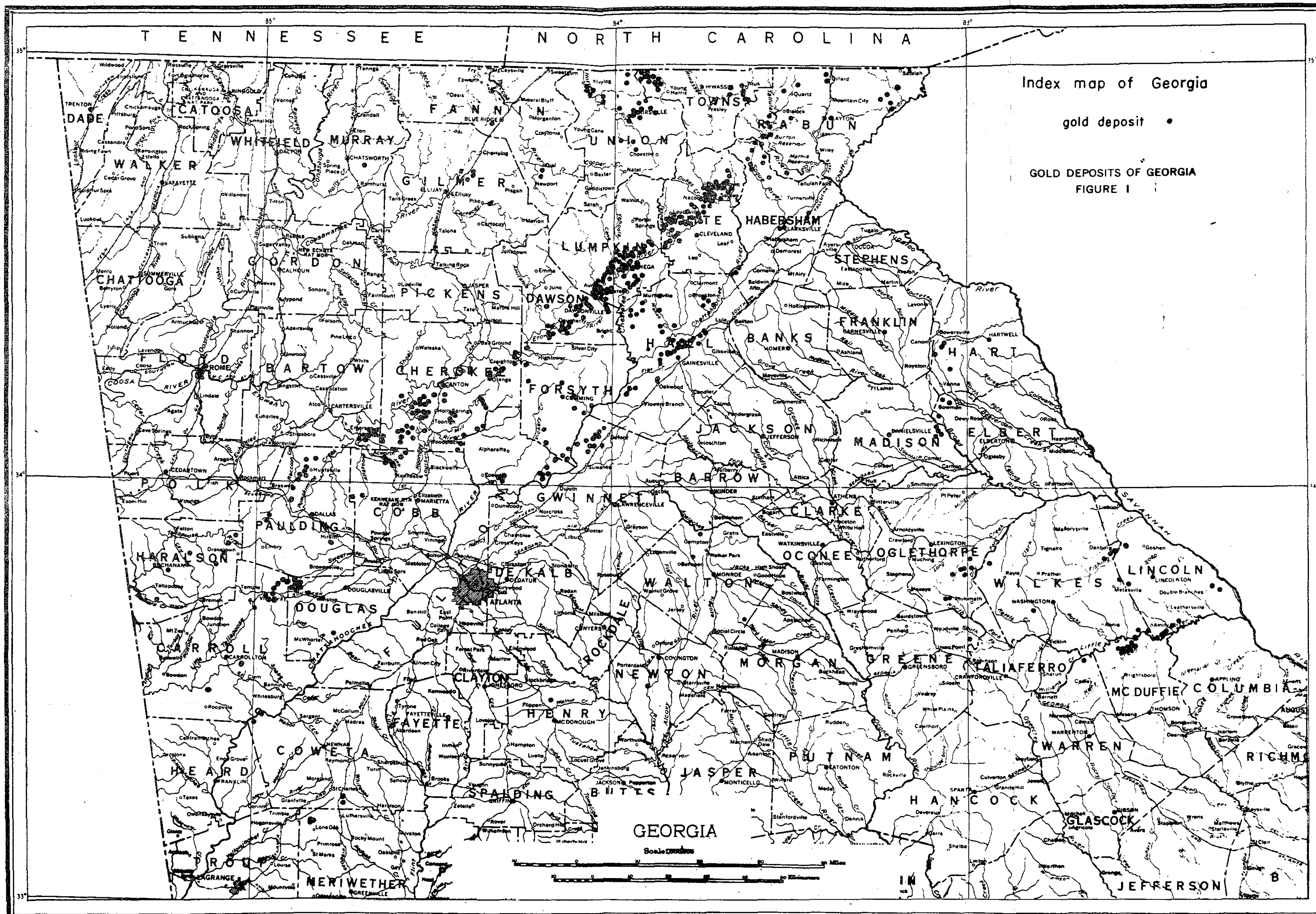
C. F. PARK, JR.

U. S. Geological Survey

Geologic Setting

The gold deposits of Georgia are part of a more or less mineralized region that extends from Great Falls on the Potomac River to the Coastal Plain of Alabama. The mineral deposits of this region have many features in common and are generally associated with silicified sheeted zones or sheared zones that may represent faults of considerable throw. Approximately 500 properties in Georgia are known

*Publication authorized by the Director, United States Geological Survey.



GOLD DEPOSITS OF GEORGIA
FIGURE I

to be gold-bearing, and the general distribution of the deposits is shown in Figure 1.

The country rocks include a wide variety of schists and gneisses; in the Lumpkin County gold belt two formations are recognized—the Carolina gneiss and the Roan gneiss. The Carolina gneiss consists of crystalline schists and gneisses that are commonly micaceous. It includes mica schist, garnetiferous mica schist, quartzite, conglomerate, kyanite schist, and, locally, small bands and lenses of marble and graphitic schist[1]. The Roan gneiss was defined by Keith[2] as hornblende schists, hornblende gneisses, and schistose diorites that are found as sheet-like or intrusive masses in the Carolina gneiss. Crickmay agrees that many of the hornblendic masses are intrusive[3], but in several mines small hornblende nodules and thin sheets not of intrusive origin are found in the Carolina gneiss. This hornblende is thought to result from a rearrangement of the mineral components in the Carolina gneiss.

In the eastern part of the State the gold deposits are in the "slate belt", which extends into North and South Carolina. The rocks of this belt are mostly schistose volcanic tuff[4, 5]. A little gold is found in other metamorphic rocks, mainly schists [6, 7], in addition to that in the three rock series mentioned.

The gold-bearing rocks are intruded by numerous dikes and masses, which have granitic or pegmatitic textures. The intrusive rocks are of widely different compositions and exhibit all degrees of metamorphism and hydrothermal alteration. Diabasic dikes of post-ore age are fairly common.

Structural Features

The detailed structure of the metamorphic rocks has been studied but little thus is imperfectly known. Foliation planes range widely in attitude, but trend in general about N. 45 E., and dip steeply either northwest or southeast. The recognizable remnants of bedding may diverge widely from the strike and dip of the schistosity although in places the two features nearly coincide. Folding has been mapped locally, and widespread faulting is recognized in two well-defined systems, one trending northeast, about parallel to the trend of regional schistosity and the other transverse to this feature.

The northeastward striking breaks are zones, in places up to several hundred feet wide; they are characterized mainly by more intense shearing and better developed schistosity than the enclosing country rock and are mineralized in many places. The transverse or northwestward trending faults are generally well defined fractures that may or may not contain quartz veins, a few of which are gold bearing. Some of the fractures are filled with diabasic dikes.

Quartz greatly predominates in the gangue and some large bodies are found; generally, however, the quartz is in small (-4′ thick) stringers and lenses. A few well-defined veins such as that at the Columbia mine in eastern Georgia (McDuffie County) are known, and elsewhere, as at the 301 Mine (Cherokee County) the ore is in a silicified zone, the boundaries of which are not sharp.

Mineralization

Hypogene: A few gold deposits in Georgia have been worked well below ground-water level, where the conditions apparently preclude supergene enrichment of the gold. At the Creighton (Franklin) mine an ore shoot was mined continuously on a 53° incline for more than 900 feet[8]. The gangue of the deposits consists mainly of quartz and ankerite, but other somewhat unusual minerals are found. These include garnet, kyanite, tourmaline, staurolite, chlor-apatite, gahnite, muscovite and biotite, chlorite, ilmenite, epidote, and magmetite. All of these minerals are seldom present in any one deposit and in some prospects they are scarce or absent.

The most common ore mineral is pyrite, which is generally scattered irregularly along cracks through the quartz and may or may not be gold bearing. At the Creighton mine and a few other properties pyrite forms massive, almost solid bodies. At the Battle Branch mine in Lumpkin County exceptionally high-grade pockets or lenses of gold with galena and other sulphides and coarse-grained silicates were found about 245 feet vertically below the surface. The bottom of this deposit has not been reached[9]. At the Field, Lockhart, Benning, Jumbo, Etowah, and probably many other prospects, the deposits contain pyrrhotite, most of which is not gold-bearing. A little arsenopyrite was seen in ore from the Etowah and Kin

Mori mines, and chalcopyrite is found in small grains in nearly all ore.

Supergene: The opinion is widely expressed among mining men that the gold deposits of the Southern Appalachians are "pockety" and of low grade except where enriched near the surface. It is true that in many places the near surface ores were richer than those in depth through profitable shoots of deep ore have been mined. The study of the problem of supergene gold is difficult in Georgia because of the small extent of accessible underground workings. The problem is further complicated by the decomposed condition of much of the country rock. Such weathered rock, in which the original texture is largely preserved, is known as saprolite and is commonly from 35 to 150 feet in depth. It is very porous and allows free circulation of descending waters; some specimens show more than 50 percent pore space. The upper part or soil zone of the saprolite is disturbed by plant roots and organisms and by soil creep; the original texture is destroyed. In the permeable soil and saprolite that overly the gold deposits the upper few inches, or even a few feet, are leaner than the ground below. This is interpreted as due mainly to mechanical settling of the heavy gold particles. Definite evidence of the amount of mechanical enrichment is lacking, although in places it is probably of economic importance.

Although some gold in the Georgia deposits has probably been dissolved, transported, and reprecipitated, the amount thus transferred seems to depend upon local conditions. Near the surface the nuggets that are recovered appear to be, on the average, larger than the particles found in depth. These nuggets possibly have been enlarged by the addition of gold from solutions. From a gold deposit in Alabama (Hog Mountain) gold is reported concentrated near the water level[10] and in North Carolina (Gold Hill) a specimen of basalt, probably of Triassic (post-ore) age, was seen coated with gold[1].

Features of Local Control in Mines

In all the mines and prospects examined quartz accompanies the gold, and where the richer bodies of gold ore are found, quartz is more abundant than elsewhere. At the Findley mine (Lumpkin County) the quartz bodies are elongated rods and pipes, with their long dimensions parallel to grooves that lie in the planes of schistosity. In many ways these quartz bodies resemble saddle reefs, with their external form controlled by grooves and furrows rather than by openings at the crests of folds in bedding. The rods and pipes range in length up to about 200 feet, and in horizontal section have a width from 2 inches to a known maximum of about 6 feet. In vertical section they have a depth in places comparable to the width; elsewhere they pinch out downward (and upward), generally within a few feet. They appear to be localized where quartz stringers cut the grooves and some are connected to other nearby quartz bodies by irregular quartz stringers. The grooves are particularly conspicuous in the Carolina gneiss (mica schist) and at many mines the ore bodies are in this gneiss next to the contact with metamorphosed diorite (?) (Roan gneiss). On Findley Ridge the contact between the Carolina gneiss and Roan gneiss swings from nearly east-west to about N. 30° E. and at the point of the bend the dip changes from north to southeast. As the ore bodies are near this contact it follows that the zone of pipes and rods dips either to the north or east, depending upon the location, but individual rods pitch persistently northeast. Away from the contact the quartz bodies gradually pinch out and become less numerous; at 100 to 200 feet from the contact they were too scarce to be profitably "hydraulicked."

The localization of the gold in quartz pipes, rods, and stringers in the Carolina gneiss along a contact with the Roan gneiss is a common feature in Georgia. The deposits on Findley ridge from the Lockhart mine to the Capps mine are along such a contact. At the Creighton mine, the Franklin pit is on a contact between Roan and Carolina gneiss, and the workings at the White County or Thompson property are also mostly in the Carolina at the Roan-Carolina contact. This relationship probably exists at other prospects where it has not yet been recognized.

At the Barlow, Whim Hill, Ivy, McDonald, Singleton, Consolidated and other properties gold is in quartz stringers, which are irregularly distributed through sheared granitic dikes. The dikes range in thickness from about an inch to about 50 feet. The quartz stringers are generally confined to the sheared dikes, but locally project for a few feet into the adjacent rock. Throughout North Georgia bodies of intrusive granite and gneiss are common, but only a small proportion of the bodies is mineralized.

At other mines such as the Battle Branch, Betz, the properties seen in the McDuffie County belt, Kin Mori, and many prospects in White and Dawson Counties, the ore bodies are in a crystalline micaceous schist, and do not appear to be along contacts. The ore bodies in these places are localized on sheeted or sheared zones, particularly where these zones are silicified and cut by later fractures. This feature was well shown at the Battle Branch mine, where the ore was richer in the more fractured parts of the lode, at or near the crests of small rolls. The shoots were pod-shaped or cylindrical, with the pods pinching and swelling down the dip. Notable irregularities in the outlines of the shoots are caused by pre-ore seams. In places the ore bodies terminate abruptly against the seams; elsewhere, the mineralizing solutions were deflected by the seams into new channels. Generally the ore shoots are less than 6 feet wide and 2 feet thick, although exceptional bodies are larger. The lengths reach a known maximum of about 100 feet, although in the longer bodies the ore forms a series of pockets connected by gold-bearing streaks. The ore in the shoots consists predominantly of quartz, galena, ankerite, and gold. Red almandite garnet is generally found near the borders of the ore and some shoots were bounded by thin tube-like shells of garnet. Small bunches of kyanite were found near the bottoms of two of the shoots. An interesting and significant feature of the deposit is that almandite garnet, biotite, muscovite, kyanite, tourmaline, and staurolite are found both in the lode and the surrounding country rock. Near the ore bodies these minerals become coarser grained; the garnet ranges from 1/8 inch diameter in the country rock to 1½ inches diameter in the lode, and kyanite, which is in microscopic crystals in the country rock, was found in crystals up to 3 inches long in one shoot. The minerals that are constituent of both the lodes and the country rocks are coarser in the lodes. This characteristic appears to be a common though not a universal feature of the gold deposit from Lumpkin County, southwest as far as the Franklin mine in Alabama, but to the northeastward and in eastern Georgia is not conspicuous.

General Features

The three types of ore shoots discussed, namely, those localized in the Carolina gneiss along contacts with the Roan gneiss, those concentrated in shear granitic dikes, and those found in silicified sheeted zones, have many features in common. They are all in hard, brittle rocks, and the surrounding material is generaly soft and readily flows under pressure without fracturing. The localization of the shoots appears to be dependent upon the physical properties of the rocks rather than upon their chemical nature.

The texture and structures of the quartz in the gold ore shoots are of considerable interest. The gold-bearing quartz at and near the surface is usually iron-stained and sugary, and platy or laminated structures accentuated by thin layers of sericite are common. Some lodes, such as the Sulphurette vein at the Kin Mori mine, although sugary at the surface, are bluish gray massive quartz below the thoroughly oxidized material. A few veins, such as those of the McDuffie County belt, are platy, but the sugary texture is not well-developed. Barren quartz is generally white, massive and vitreous.

Depth of Original Cover

The depth of the original mineral deposition is difficult to estimate. Becker[11] remarked that the southern veins had been subjected to long continued erosion and that the present croppings are far below the original ones, possibly as much as 15,000 or 20,000 feet. Lindgren[12] seems to concur in this belief without definite commitment as to depth of cover. The prevailing mineral associations and coarse textures indicate deposition under conditions that ordinarily are thought to prevail in the hypothermal or deep vein zone.

Selected Bibliography

[1]Pardee, J. T., and Park, C. F., Jr. Gold deposits of the Southern Piedmont: U. S. Geol. Survey. Prof. Paper 213, 1948.

[2]Keith, Arthur, U. S. Geol. Survey Atlas, Roan Mountain folio (no. 151), p. 3, 1907.

[3]Crickmay, G. W., Status of the Talladega Series in Southern Appalachian stratigraphy: Geol. Soc. Am. Bull. 47, pp. 1371-1392, 1936.

[4]Pardee, J. T., Preliminary report on gold deposits in North Carolina and South Carolina: U. S. Geol. Survey Memo. for the Press P.W. 29021, 1935.

[5]Laney, F. B., The Gold Hill mining district, North Carolina: North Carolina Geol. and Econ. Survey Bull. 21, 1910.

[6]Yeates, W. S., McCallie, S. W., and King, F. P., A preliminary report on a part of the gold deposits of Georgia: Geol. Survey, Georgia Bull. 4-A, 1896.

[7]Jones, S. P., Second report on the gold deposits of Georgia: Geol. Survey, Georgia, Bull. 19, 1909.

[8]McCallie, S. W,. Creighton Gold Mining Co., Cherokee County, Georgia: Rept. to the Company, 1907.

[9]Park, C. F., Jr., and Wilson, R. A., The Battle Branch gold mine, Auraria, Georgia: Econ. Geol. vol. 31, pp. 73-92, 1936.

[10]Aldrich, T. H., Jr., personal communication, 1934.

[11]Becker, G. F., Gold fields of the Southern Appalachians: U. S. Geol. Survey 16th Ann. rept., pt. 3, pp. 251-331, 1895.

[12]Lindgren, Waldemar, The gold deposits of Dahlonega, Georgia: U. S. Geol. Survey, Bull. 293, pp. 119-128, 1906.

DEVELOPMENT OF A CRUSHED STONE OPERATION NEAR LITHONIA, DEKALB COUNTY, GEORGIA*

NELSON SEVERINGHAUS

Consolidated Quarries Corporation

Each year recently, the Atlanta Metropolitan area has used some four million dollars worth of crushed stone for its expanded construction work. This stone is the major ingredient of mixes for concrete and asphalt pavements, concrete foundations, and concrete building products. Almost one-half of the delivered cost is incurred in transportation from quarries to use points. The nearest substantial aggregate plants are some twenty miles away. The railroad freight rate to this market is 65¢ per ton or trucking cost about $1.50 per ton.

In this locality, stone is all around us. It would be hard to locate any point more than a few miles from some outcrop indicating a sizeable deposit of apparently satisfactory rock to produce crushed stone.

It would seem that quarries should have sprung up at many places close about Atlanta. Instead, some closer-in operations have actually closed down. This discussion explores the factors which rule in this instance, for those factors are impor-

*Read at the Southeastern Mineral Symposium, Geology Department, Emory University, March 29-31, 1951.

tant in the proper location and development of most aggregate operations.

The trend has been away from small plants for crushed stone. Small crushers require more labor per unit of production and small operations are difficult and expensive to mechanize for elimination of hard work. Light equipment does not stand up so well when handling tough and abrasive stones.

It is evident that a large plant will require a relatively large deposit of rock to sustain the operation long enough to amortize installation costs. High capacity from a quarry requires a good sized area of rock opening for movement of shovel and haulage equipment, and blasting of rock to keep that equipment busy. In this area as in most others, there are not too many outcrops which can be developed into extensive quarries without excessive removal of overburden or expensive excavation.

Most quarries are developed to supply a particular need for aggregate. When this need is created by a single engineering project, such as a large concrete dam, specifications for materials are detailed by the sponsoring agency. These specifications generally include durability or soundness as measured by freezing and thrawing or sodium sulfate tests, toughness measured by Los Angeles Rattler ar Devall abrasion methods, weight per solid cubic foot, absorption and sizing. Recently, mineral and chemical composition of aggregates have been given more attention. These properties have an effect on durability through chemical reaction with other ingredients and through differential thermal expansion. Where specifications are so clearly defined, likely deposits can be sampled and tested to determine if they meet requirements.

Where a deposit developed to supply a varied market, the problem of specifications to be met is not so simple. Perhaps the best guide will generally be State Highway Department specifications. These cover a range of qualities or classes of stone suitable for various uses. After tests have been made on a sample of stone, highway specifications will indicate for what types of work it can be used.

In Georgia, the Highway Department divides aggregates into three classes according to toughness. Only the most resistant is allowed in surface treatment pavement where abrasion and crushing will be severe. Few rocks in the Atlanta area meet this requirement. The second class is that used in concrete and in mixed asphalt pavements. This class of stone fills most construction requirements. The third class is used only for base material to be covered with something more durable. The famous Stone Mountain granite is on the border line between Classes II and III. Stones now produced in this area are well within Class II. Good performance in use for an extended time is a reliable guide on quality.

Failure to produce a consistently satisfactory and reliable quality product has caused the closing of many quarries.

A deposit may be of large extent and satisfactory in quality yet be unworkable for crushed stone. Some of the things which may hinder operations are:

(1) Damage to and complaints from surrounding property holders may enjoin production. Quarries are noisy operations. Blasting is at its best annoying, at its worst produces structural damage from ground vibration, flying fragments, and air concussion. Dust is another nuisance product difficult to abate. Distance rapidly minimizes these factors. It would be folly to introduce a regular blasting operation into the center of a heavily built and populated district. This is probably the principal reason why there are no large crushed stone plants close to the center of the large Atlanta market.

(2) Overburden and contamination of the deposit by clay or decomposed rock may be excessive. Most quarries have some overburden to remove but when the ratio of waste to available rock becomes too great, the cost of removal cannot be tolerated. Where overburden takes the form of partially decomposed rock which must be drilled and blasted before removal by mechanical equipment, costs increase. Where soft materials on top extend downward in pockets and seams, their removal to leave specification stone is often difficult, sometimes almost impossible. Where stone is not available for open pit mining, it is sometimes possible to use underground quarrying. Generally underground costs are considerably higher than those for open pits.

(3) Some rocks are too good for economical production. At one time we operated an underground quarry in North Georgia producing aggregate from a dense gneiss. It was

probably the finest crushed stone ever produced in the State, tough enough to meet any specifications. It was so tough that Jackhammer drills penetrated about two inches per minute instead of the ten inches they will do in good granite. The frame of a standard Jaw crusher would weave back and forth instead of crushing. Such things carry costs beyond the competitive point. Most jobs do not need rock that good.

(4) In producing crushed stone from deposits containing substantial amounts of quartz, abrasion of equipment becomes a major item of cost. Crusher parts which last many years with good tough limestones will wear out in a few months with abrasive granites. Some types of crushing equipment such as the hammer will work well on non-abrasive rock but give prohibitive replacement parts cost on abrasive varieties.

Where only abrasive rocks are available within economical haulage distance, relatively large equipment is indicated to minimize wear. At Rock Chapel, working with an abrasive granite, we operate one 60″ x 48″ primary jaw crusher and another one 42″ x 30″. Cost per ton crushed for manganese steel liners in the large machine is about one-fifth of that for the smaller crusher.

(5) Adequate transportation to use points at a minimum cost must be available. Few large plants exist without rail transportation. At Rock Chapel we now move about 4,000 tons per day, 60% of it by rail and 40% by truck. Truck haulage is steadily improving in competitive position. When we started operations in 1929, all of our product moved by rail. Wherever a large enough quantity moves to one point to justify installation of unloading and handling equipment, rail haulage generally proves cheaper than transportation by truck. Smaller quantities moving to scattered points are better handled by truck. Water haulage is not available hereabouts but where it can be used, as in New York State, it is more economical than any other means.

It is seldom possible to overcome substantial differences in transportation costs with economies in operation. Direct production costs for fixed quarries of reasonable size will probably all fall within a range no greater than 20¢ per ton. This amount will move stone no farther than four to eight miles by truck. If grades from the site are adverse, it may not be possible to obtain rail transportation for products and truck haul will be more expensive.

We have shipped large quantities of jetty stone from Lithonia to New Orleans. Freight in this case often costs more than twice the quarry price for the stone, but there is no stone of satisfactory quality for this use much closer.

Obviously, the nearer you can locate a satisfactory operation to the center of market, the better chance that operation will have. We think that Rock Chapel has about the minimum cost of transportation that can be obtained for the large Atlanta market without running into damage complaints or high exploitation costs.

(6) Physical geography of the area to be worked can have an important influence on operating costs though new equipment tends to minimize this factor. It costs money to elevate materials out of a pit, but not as much as it did before the advent of the diesel truck. Pumping water from a pit lacking gravity drainage can cause delays in operations and be costly if quantity of rain or seepage is large, but the efficiency and reliability of modern pumps has largely overcome this difficulty.

Horizontal progress into the side of a hill gives the most desirable quarry operation where it is available, but a downward incline is not prohibitive if other factors are favorable. It is quite possible to run into quarry faces of unworkable height. High faces are difficult to trim for safety of work on the floor below them. A high face may give a high pile of broken rock which will endanger men and equipment by caving or sliding. Horizontal work into Stone Mountain would soon produce such a situation, for it rises about 650 feet above the surrounding terrain.

(7) Some stones break relatively poorly with explosives. Most of the stones in the Atlanta area fall into this class. Without a large primary crusher, excessive secondary breaking will be required on the quarry floor. Even with a 60″ x 48″ jaw crusher, secondary breaking accounts for about 15% of direct operating costs at Rock Chapel. This is one more reason for the scarcity of smaller crushing plants close to scattered centers of use.

(8) If a crushed stone plant is to supply a varied market for highway and commercial stone, it will have to produce a rather large number of sizes. This again implies a large plant with a number of screens, multiple stock piles and extensive blending and loading out equipment. At Rock Chapel we make seven basic sizes and an almost infinite number of blends of these sizes. We have shipped carloads of rocks weighing almost twenty tons apiece and others which would all pass a 1/8″ screen opening. This variety cannot be handled with a few pieces of small equipment.

In summary, where a number of possible sites are to be investigated to find the one most desirable for development, it would be well to set up a sort of balance sheet containing values for the following factors for each site:

(1) Distance to center of probable markets or points of use.

(2) Modes of transportation available.

(3) Specifications to be met and ability of deposit to meet them.

(4) Physical geography of area about a deposit and its effect on plant design.

(5) Adaptability of deposit to cheapest method of quarry attack.

(6) Extent and dimensions of deposit.

(7) Nature of breakage with explosives.

(8) Abrasiveness and difficulty of crushing.

(9) Availability of space about the area of operations without housing or other buildings.

(10) Amount and character of stripping required.

(11) Availability of water for washing or fine sizing by hydraulic methods.

(12) Availability of space for disposal of unmarketable fine sludge or screenings.

(13) Quantity and quality of labor which can be employed.

There is no such thing as the perfect crushed stone quarry.

The one which rates best when evaluated by the above points should have the best chance of survival. Of course all factors do not have the same value and their relative importance will change with time and place. Crushed stone is a highly competitive enterprise and the balance sheet of possible competition must always be studied carefully. The amount of capital investment required for complete development at the present time would be about $400 per ton of daily capacity, so that a 2,500 ton per day plant would cost about one million dollars. Where so large an amount is involved, we can afford few mistakes in location and development.

THE GEORGIA MINERAL LABORATORY*

L. H. TURNER

Chief Chemist, Department of Mines, Mining, and Geology

Introduction

Since 1937, the Georgia Department of Mines, Mining and Geology has operated a minerals testing laboratory, which at the present time is housed in Room 131, State Capitol Building. The laboratory through the years has greatly expanded its program, so that at the present time it engages in many branches of mineral chemistry. Many types of analyses are requested by the field geologists of the Georgia Geological Survey, and many types of service analyses are made for people all over the State. An important function of the Department of Mines is to assist the people to become familiar with their mineral resources, and to encourage them to bring in samples for identification. If their samples contain metals of importance, the percentage composition is determined in the mineral laboratory and sent to the person submitting the sample.

The value of a quantitative analysis depends greatly upon the method whereby the sample is collected. For this reason, property owners are urged to discuss methods of sampling with the geologist. Many samples submitted by laymen are not satisfactory for chemical analysis because they are not representative of the deposit in question. In some cases, grab

*Read at the Meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

samples are adequate, and in other cases, channel samples are necessary.

Minerals Investigated

Georgia has more than 35 known commercial minerals, metals and rocks. Many of these are already mined, whilst other as yet have undeveloped industrial possibilities. Before any mineral deposit can be developed, representative specimens of the ore or mineral must be analyzed to establish the mineral content; the deposit must be prospected to determine its extent; and, if needed, capital must be found to finance its development and market its products.

Among the various minerals, ores, and clays submitted for assay are the following: asbestos; barite, or heavy spar; bauxite; bentonite; calcite; chalcopyrite; chert, which is a form of flint; chlorite; chromite; clays of many varieties; coal; feldspars; copper-bearing minerals; dolomite; fluorspar; fullers earth; occasionally galena, or lead sulfide; gold-bearing ores of every description; gypsum; iron ores of every description; kyanite; lime rock, manganese minerals; mica minerals; phosphate rock; quartz; pyrite; sandstone; sands of every description; serpentine; talcs of many varieties; titanium minerals; and graphite-bearing rocks.

During the past eight years, 3,942 samples of various ores and minerals have been prepared for assay, which consists in drying the material, if wet, crushing to a uniform size in a jaw crusher, and grinding the crushed material to a fine powder, 100-mesh, or finer if necessary. It is then ready for fire assay or wet assay.

During this same period, 1,180 physical determinations have been made which consist chiefly in milling, panning the material to make a concentrate or to separate the metals in the sample by selective flotation, or making expansion tests in a furnace at a high temperature.

Gold Assays

Within the past eight years, 1,296 fire assays have been made for gold or silver, principally for gold. This is a branch of quantitative analysis in which metals are determined in ores by extracting and weighing them in the metallic state.

The method employed invokes slag-melting temperatures, and the use of reducing, oxidizing and fluxing reagents. Some fluxing reagents have only one property, as, for instance, silica, and acid flux; others have several different properties, as litharge, a basic flux, but also an oxidizing and desulphurizing agent.

A flux converts compounds infusable at a certain temperature into others which melt at this temperature. For instance, quartz by itself is fusable at a very high temperature, 1420 deg. C., but if some sodium carbonate is added to the pulverized quartz, it can easily be fused at a temperature easily obtained in the assay furnace. Silica is an acid flux and should be used for ores which are basic in character, such as calcite, dolomite, barites, fluorspar, also for ores containing large quantities of iron oxides and carbonates with little or no silica. It also protects the crucibles from the action of the litharge.

Research Projects

To keep pace with the expanding demand for new and additional mineral products, and as a means of procuring new sources of increased income for Georgia's people, research experiments are carried on in the mineral laboratory in an effort to determine new uses for certain rocks and their minerals.

Besides the large number of subjects covered during the past ten years, considerable research work has been done on the following projects:

Investigation of the several components of chalcopyrite (Copper Pyrites) and a chemical assay of the small amounts of nickel, cobalt, manganese, iron, and alumina contained therein.

The recovery of alumina from very low-grade bentonite clays, with the possibility of utilizing these large deposits for the production of alumina as a postwar project. The acid treatment and fire treatment of kyanite and sillmanite in order to ascertain if these materials could be used in the manufacture of high refractory ceramic products. The utilization of sap brown in combination with certain clays, as a filler for ceramic manufacture. Sap Brown is principally used in making Van Dyke brown, which is used in the manufacture of paint, wood stains, and inks, or to mix with aniline dyes. Sap brown is a peculiar silica sand, believed to be formed by the precipitation of azo-humic acids dissolved in stream or ground water by iron salts, sea-water, and organic material.

A considerable amount of work was devoted to many so-called "physical" tests, such as milling, panning various metallic and non-metallic materials, and selective flotation experiments on mica, graphite, and sericite schists, as well as countless fire tests in the furnace on miscellaneous clays, schists and granites, to determine their relative expansion or shrinkage properties, to ascertain their value and use in the manufacture of pottery and other ceramic products.

An improved method was used for the determination of sulphur in pyrite, using liquid bromine, carbon tetrachloride and nitric acid for oxidization. Sulphur is oxidized to a bromine compound in the carbon tetrachloride treatment. Subsequent addition of nitric acid causes the oxidization of this to sulfate. Silica is then dehydrated out, the iron originally present in the sample is reduced by boiling with powdered aluminum, removed by filtration and the sulphur precipitated in the usual manner with barium chloride. Formerly, in the conventional old method, the pyrite is decomposed by fusion in a nickel or iron crucible with sodium carbonate and an oxidizing agent such as potassium nitrate or sodium peroxide, thus contaminating the sample with the Na or K ion, and the fusion mixture also attacks the iron or nickel in the crucible.

During 1947, a special investigation of Georgia talc made with many chemical analyses of same, also a special research investigation was made on forty-one limestones to determine their physical and chemical constituents and their adaptability to agricultural and chemical uses.

During 1948, many samples of pyrite from the Copper-Pyrite deposits were submitted by the U. S. Bureau of Mines, for our examination and assay. Much time was devoted in a special investigation for the Georgia State Highway Department, consisting of many flotation experiments to determine the cause of movement or so-called "slipping" of the materials used in filling in the holes and depressions in various public highway localities, culverts and sidewalls under repair and construction.

During the past year, many samples of gold-bearing pyrite were submitted to the Department, to determine if the gold content could be recovered at the mine without shipping the crude ore or concentrate to a smelter or refiner. After much investigation, a chlorination process was adopted. This required the complete desulphurizing of the ore, which was then treated with chlorine gas, by passing the gas through the ore in a special apparatus. In these particular ore samples, this chlorination process was very effective, and a recovery of 97.4 per cent of the assay value was accomplished.

Considerable research work was done on the investigation of the character of the material in the fill used in the roadbed of the State-owned railroad, the N. C. & St. L. located near the Allatoona dam. This was the then existing old roadbed which the U. S. engineers in charge claimed would not be affected by contact with any water pressure from the dam.

During the latter part of 1949, we received the somewhat unusual request to test Chattahoochee River water for its gold content (if any). Two large samples of five gallons each were submitted for analysis. One sample was evaporated to bone dryness, and the dry residue was then fire-assayed for gold by the usual method. Absolutely no gold was recovered. However, the other sample was treated with powdered wood charcoal, which acted as a collector of the extremely minute gold particles. After prolonged treatment, the charcoal was removed by filtration and assayed for gold. The result showed merely a trace, so minute that it was too small to be weighed or estimated.

During April and May of 1949, the greater part of these months were devoted to the fire and chemical assay of 90 samples of ore obtained from the Magruder mine, located in Lincoln County, Georgia. These samples were shipped to us from the U. S. Bureau of Mines, Raleigh, N. C. Assays both by fire and wet methods were made for gold, silver, copper, lead and zinc.

During the last year research was done on uranium-bearing rocks. A reliable and accurate technique was developed, especially for complex material in which the percentage of uranium is present in small amounts.

Clay Investigations

During the past few years, the clay mining industry in Georgia has shown remarkable progress. The shales of northwest Georgia have found extensive use in the manufacture of bricks and tile. The brick and tile industry using the alluvial clays of middle Georgia have greatly increased. The production of sedimentary kaolin from middle Georgia as filler and coating clays has greatly increased.

Clays have a variety of uses, as in the manufacture of china, white porcelain and sanitary ware, also, as a filler or coating material in paper, wallpaper, rubber, paint, window shades, oil cloth, textiles, kalsomine, plaster and plaster products, pottery, terra alba and stone ware, building brick, both face bricks and ornamental; also, in the manufacture of sewer and drain pipe, and roofing tile.

Bentonite is an extremely plastic clay, used as a bleaching clay in filtering mineral and vegetable oils, also, as a plastic agent in ceramic work and foundry moulds, and in cheap grades of scouring soap. Georgia produces an excellent type of bleaching clay used in bleaching vegetable oils. It is a very plastic clay.

The composition of hematite is Fe_2O_3 and it would contain, if pure, 70 per cent iron and 30 per cent oxygen. This ore is the source of most of the iron produced in the United States. The characteristics of these ores for smelting in the blast furnace depends largely on their physical structure. The hard, lumpy ores are less reducible than soft ores or ores which are fine and sandy. They are highly valued, however, because they permit the free passage of ascending gas current in the furnace stack. They present less surface to the action of the gas than the very fine ores and their condition in the furnace changes more gradually, causing the furnace to work better. These ores are the most highly valued of all varieties of iron ore.

Magnetite is ferric ferrous oxide (Fe_3O_4), and contains, if pure, 72.4 per cent iron, which is higher than any other oxide occurring in nature. Being strongly magnetic, it separates well from the gangue, and since phosphorous is present in the gangue of the ore, magnetic concentration can be applied to decrease the phosphorous content, thus simultaneously increasing the iron content.

Limestone Analyses

Limestone mining in Georgia has increased by leaps and bounds. The primary source of lime rock is caused by the decomposition of igneous rocks by carbonated waters, calcium carbonate and magnesium carbonate are thus produced, which pass into solution in ground water, springs, and streams, and is later withdrawn by a variety of processes, depositing as a chemical sediment, and much of the dissolved carbonate is precipitated as a cement in other rocks, sandstone being a good example.

Limestones which contain little or no magnesium carbonate, and only a small percentage of impurities are known as high-calcium limestones. If they contain a small per cent of potash and phosphates, they are excellent for agricultural purposes, and if the stone is hard and not easily powdered after being burned, it is good material for the manufacture of lime for building purposes.

Lime Rock for road material should contain a minimum of 80 per cent total carbonates, the remaining 20 per cent should be free from organic matter or clay and should consist mainly of silica.

Limestone in the language of the blast furnace operators is called "fluxing stone". It is a basic flux and is added to the blast furnace charge to form a slag with the silica and alumina, otherwise the impurities would unite with the iron oxides to form double silicates of iron and alumina involving a heavy loss of iron, hence a good lime rock for the manufacture of pig iron should contain the least possible amount of impurities, such as silica, alumina, and sulphur, and contain high "available carbonate". Impure lime rock forms additional slag, which requires extra fuel consumption, and the extra slag requires extra coke, thus increasing the cost of manufacture.

Water and Water Analysis

Water is our most important natural resource, and enormous quantities are used for domestic, industrial and agricultural purposes. The suitability of water for such purposes depends on its content of impurities, either in solution or suspension. Many water supplies require purification or treatment to render them fit for the purpose intended. One Department undertakes to analyze the multitude of water samples as submitted, in order to determine the quality of the water, indicate the type of treatment needed, and suggest to the consumer whatever is necessary to improve the water for the particular use intended.

The greatest complaint that we have is odor or taste, or both, and that fish die in ponds or lakes at certain times of the year. Water is never found pure in nature. Rain water is the nearest approach to chemically pure water, but it contains small amounts of organic matter and dissolved gases, principally oxygen and carbon dioxide taken from the air. The composition of the ground over which it flows after falling to the earth will determine the additional impurities that it absorbs. The earth's surface contains large amounts of mineral salts, such as the carbonates and sulphates of lime and magnesia, which are dissolved by water. Underground water will usually contain more dissolved minerals than surface water but less suspended matter, the latter having been filtered out in percolating through the earth.

The impurities in water may be grouped under three headings: dissolved, suspended and colloidal. The substances commonly found in solution consist principally of the chloride and nitrate of calcium; chloride, sulphate and bicarbonate of magnesium; chloride, bicarbonate and sulphate of sodium; iron and manganese compounds; alumina; and various trade wastes.

The suspended impurities include mud and sand, clay, vegetable and animal organism, trade waste and sewage, and bacteria. Colloidal suspensions consist of material so finely divided that it cannot be seen under the microscope and existing in a state intermediate between true suspension and solution, but removable by filtration.

The color of water may be due to a number of conditions. Mineral matter, such as finely divided silica, flint, sand, often impart a turbidity or haziness; sandy particles or clay in suspension often cause a yellowish-white turbidity; and an excess of iron will impart an amber color to the water. Mineral matters of various hues in the soil over which water percolates or flows, as the usual causes of discoloration and turbidity. If peroxide of iron is present, or much organic matter is present, as water from bog lands, a brown color will be imparted in the water. The total dissolved mineral solids, often called "mineral debris" affords a clue to the nature of the strata or soil through the water may pass.

Odors, which at times occur in water, are produced by the growth, death, and decay of minute organisms known as algae; but, however objectionable these odors and tastes may be from an aesthetic standpoint, it has not been proved that they are productive of disease. Other disagreeable odors may result from decaying vegetable matter such as leaves. Well waters may have offensive odors due to the presence in solution of hydrogen sulphide. Wastes from manufacturing plants, including gas works, coke ovens, oil refineries, paper mills, canneries, are frequently present in surface waters and are responsible for bad taste and odor.

The hardness of water is an important fact for industrial use. Hard water deposits scale in pipe lines and boilers and is the cause of vast economic waste. In the laundry industry, there is a waste of 1.7 lbs. of soap per 1,000 gallons of water for each grain per gallon of hardness, and the precipitates that are formed stick to the fabrics, leaving unsightly stains on the clothes that are washed, and giving them a grayish color.

In canning, hard water causes a toughening of beans and peas; and in textile finishing, in fact in every department of the textile industry, it is advantageous to have soft, colorless water. Brewing, distilling, rayon manufacture, paper making, and artificial ice manufacture require soft water. The large amount of available soft water in Georgia is given as one important reason for the continued movement of textile and other industries to the State.

Water that passes through calcareous or magnesium rocks, such as limestone, marble, gypsum, chlorite and talcose schists will yield hard water. The granites, gneisses, many sandstones and slates would furnish soft water. Sandstones in which the cementing material is carbonate or sulfate of lime produce hard water, while, on the other hand, if the cementing material is feldspar, such as orthoclase or even gelatinous silica, the water will probably be soft.

Our common food and game fish die in water which lacks oxygen. Where oxygen deficiencies occur in ponds, lakes or streams, the fish either die or retreat into the mouths of tributaries and back waters where there is more oxygen. Fish usually die during the night when algae and other green plants use oxygen rather than produce it by photosynthesis as they do in the sunlight. Most common food and game fish require about three parts per million of dissolved oxygen at all seasons of the year, with the exception of the black bullhead. Certain kinds of fish which live in small swift streams may require four or more parts per million. Organic waste from factories which pollute a stream will stimulate the growth of bacteria, which reduce oxygen below the lethal point for fish. In polluted lakes and ponds which show thermal stratification in summer, or are covered over with ice in the winter, the oxygen deficiency is most pronounced.

DIFFERENTIAL THERMAL ANALYSIS OF SOME PALEOZOIC SHALES*

ROBERT W. DARLING

Emory University

The purpose of this investigation was to determine the validity of differential thermal analysis in the correlation of Paleozoic shales. They were selected only because their high clay content renders them ideal for this type of analysis. There is no reason why this same analytic procedure could not be used upon other materials such as the insoluble residues of limestones. The formations considered in this report are the Gizzard, Red Mountain, and Chattanooga shales. All samples were taken in the Cooper Heights area of Lookout Mountain in Northwest Georgia and are composite samples across the exposure.

Figure 1 indicates the areas from which samples were

*Read at the Meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

taken. Number 1, 2 and 3 are Gizzard shale; 4, 9, 10, and 11 are Red Mountain shale; and 5 and 8 are Chattanooga black shale. A greater number of samples were actually collected and more than one determination made of each, but for brevity and clarity only representative determinations are described.

Briefly described, the differential thermal analysis method is based upon the principle that many substances exhibit chemical and physical changes when heated. These changes are indicated by exothermic or endothermic reactions. Loss of water or carbon dioxide yields an endothermic reaction whereas crystallization and the burning of organic matter liberates heat and gives exothermic reactions. By heating a sample along with an inert control, relative temperature differences may be secured throughout the heating range that are characteristic of the sample material.

Figure 2 is a schematic diagram of the differential thermal analysis equipment. The apparatus consists basically of a nickel block containing three thermocouples. Two thermocouples are connected differentially to a galvanometer where the relative temperature differences are read. A sample is placed in one of these thermocouple cells and a blank such as aluminum oxide is placed in the other. The third is con-

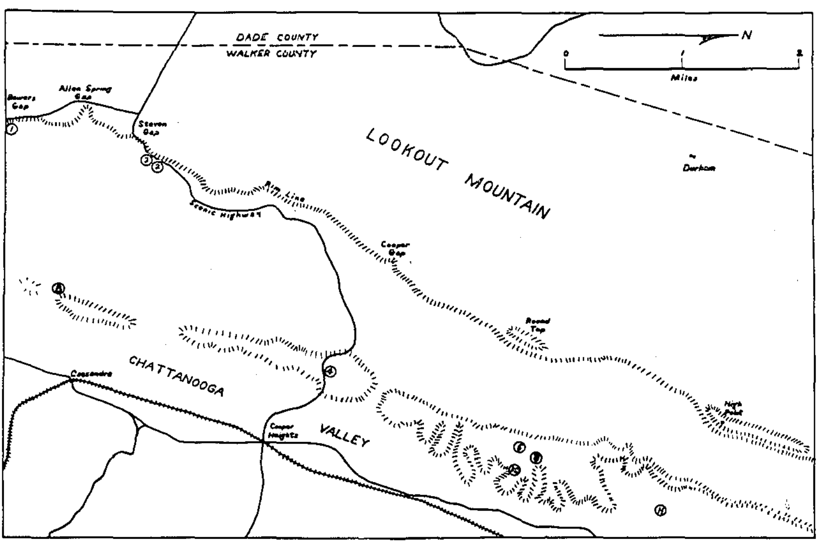


Figure 1. Outline Map of the Area.

nected directly to a milliammeter for reading the temperature of the block. By plotting relative temperature differences as indicated upon the galvanometer, against the temperatures of the whole block a characteristic curve is secured for the sample. Standardization of procedure is essential because of the many variables, such as thermal lag, induction, voltage fluctuations, fineness of sample, and rate of temperature rise. The goal of differential thermal analysis is simply the elimination of all variables except the one sought.

Samples should be finer than 100 mesh. To secure material of this fineness the shale samples were crushed, ground in a ball mill, rough screened, and elutriated. Elutriation consisted of allowing a well mixed suspension of the rough-screened material to stand for 15 minutes. This interval was sufficient to allow the grains greater than .015 mm. to settle. The supernatant suspensoid was then decanted off and allowed to stand overnight. All material obtained from this second residue was used for the analysis. Drying under gentle heat and disentegration of lumps was all the additional treatment necessary.

Figure 3 illustrates the final curves. It should be noted

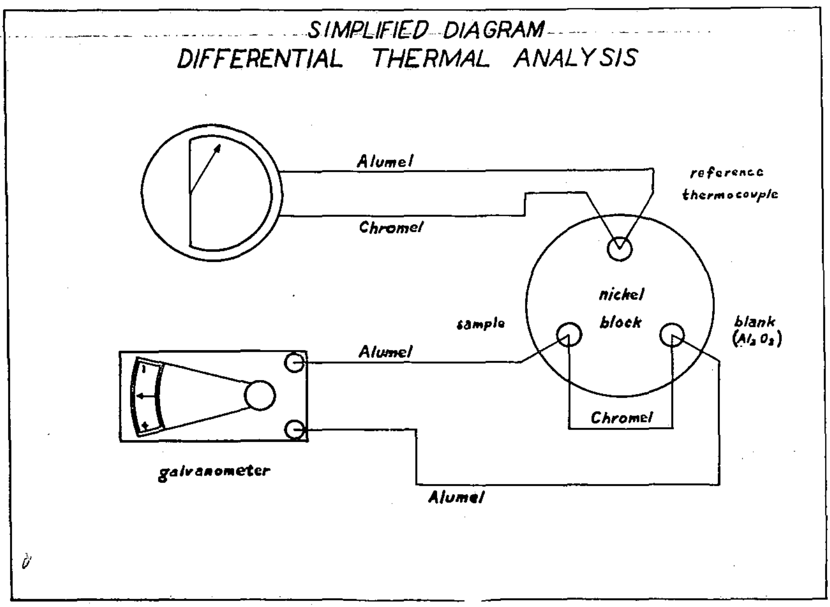


Figure 2.

that no identification of mineral constituents was attempted. Curves are interpreted solely on a mutually comparative basis.

The first set of curves is typical of the Gizzard shale from the top of Lookout Mountain. All curves on this shale were similar. The only pronounced variation occurs at the 700° exothermic peak. Its width appears to vary according to the stratigraphic elevation of the sample. The widest peak is from a sample taken at Bower's Gap on the rim of the mountain, and the narrowest is from the lowest stratigraphic sample taken along the scenic highway.

The second set of curves is typical of the Red Mountain shale. They are again similar to each other. The 560° endothermic peak appears consistently as with the Gizzard shales but the lows are not so pronounced in amplitude and the final exothermic peak is not evident. The Gizzard and Red Mountain shales are very easily distinguished on the basis of curve characteristics.

The last set of curves is typical of the Chattanooga black shale. This shale exhibits a comparatively strong endo-

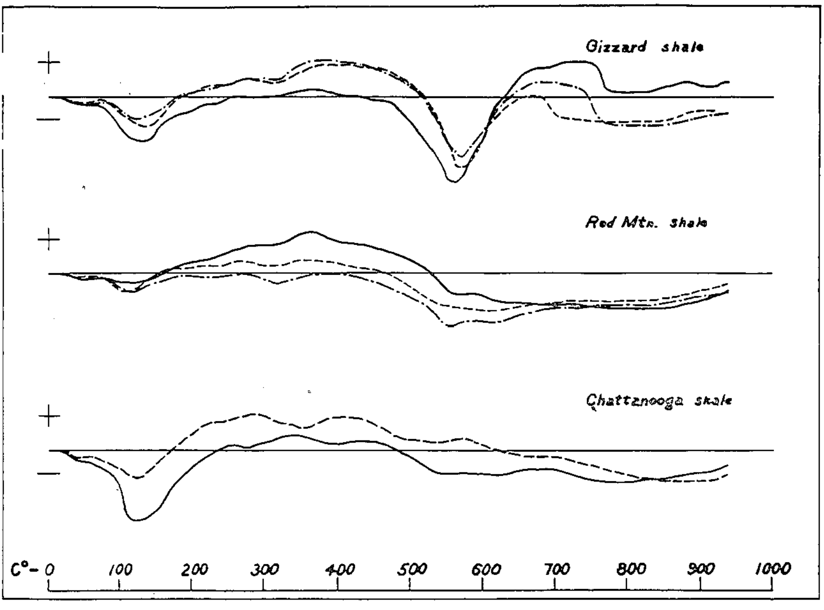


Figure 3. Thermal Analysis of Shales.

thermic low at about 120° C. Little variation is evident beyond this initial peak. The long steady exothermic high, gradually declining at higher temperatures, is interpreted as the burning of carbonaceous matter within the shale. This is supported by the change in color after the analysis. Before heating the Chattanooga is black, but after heating to about 940° C, it becomes brick red.

It can be seen from the graphs that the shales considered may be distinguished and identified upon the basis of comparative differential thermal curves. The thermal characteristics of one shale do not necessarily hold true for another, on the contrary many differences are noted which may be duplicated upon samples of the same formation.

Although this investigation was of a preliminary character and the results, therefore, not necessarily conclusive, the favorable results obtained indicate that further work should be undertaken. Whereas a basis for rough shale correlation has been tentatively established within a limited area, further investigation should determine the validity of thermal analysis as applied to formations other than shales. The value of this method must also be determined for greater areal correlations and for finer more detailed correlations within a given formation.

Bibliography

Hendriks, Sterling B., Goldrich, Samuel S., and Nelson, Reuben A.—*A Portable Differential Thermal Analysis Unit for Bauxite Exploration.* Economic Geology, Vol. 41, p. 64, 1946.

Speil, Sidney; Berkelhamer, Louis H.; Pask, Joseph A.; and Davies, Ben,—"Differential Thermal Analysis—Its Application to Clays and Other Aluminous Minerals" U. S. Dept. of the Interior, Bureau of Mines, Technical Paper 664, 1945.

CLAYS OF GEORGIA: PROGRESS AND PLANS*

D. W. GATES

Georgia Institute of Technology

Wilson (1927) stated "although clay-working is one of the oldest industries of man and has progressed through the centuries, yet its technical development has been slow when

*Read at the Meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

compared with many younger industries which might be called the children of modern engineering and chemical research. This is probably due to the inadequacy of the contemporary general research when applied to the ceramic problems of suspensions, plastic working conditions, and silicate fusions. . . . The artistic side of pottery ceramics was developed centuries ago and the original potter's wheel is thought by some to have been man's first machine. . . . Practical experience and 'cut and try' methods are still the principal factors in commercial research."

Colloid chemistry, close measurement and control of high temperatures, the electron microscope, and advanced x-ray techniques now seem to offer a solution. We hope with this project to characterize samples by several methods of examination, and to relate the characteristics of the processed clay to both the raw material and effect of the process. Usefulness and market value of Georgia clays may be extended by more fundamental knowledge of the constituents and of the impurities. Under Dr. H. H. Cudd, Head of the Chemical Sciences Division of the State Engineering Experiment Station, there are four groups working in cooperation. They are:

1. Chemical
2. Electron & Optical Microscopy
3. X-Ray Diffraction
4. Ceramic

These groups are studying the relation between cause and effect in material phenomena, rather than starting with an intention to apply, and thus, the clay project might be called fundamental research.

THE PURPOSE OF THE CHEMICAL ANALYSIS OF CLAYS

There are two methods of quantitatively analyzing clay. One is known as the rational analysis and the other as the chemical or ultimate analysis.

In rational analysis, composition is expressed in terms of mineral compounds present, such as:

Kaolinite		62.40%
Orthoclase	5.56%	

Anorthite	2.74%	
Total feldspar		8.30%
Quartz		28.00%
Limonite		1.30%

Several methods have been proposed for the rational analysis of clays, but most, if not all, are unsatisfactory. Calculations of rational composition are made from chemical or ultimate analysis but this method is open to criticism.

The ultimate or chemical analysis of clay is tedious and exacting, but the results may give valuable information about the clay.

All the constituents of a clay influence its behavior in one way or another, their effects often being noticeable when only small amounts are present. The various accessory constituents in clays have different effects. Many promote fusion, but some are more active than others. Some are influential in developing color. In a general way, the finer the accessory minerals and the more evenly they are distributed, the greater their effect in producing changes.

The chemical analysis of a clay may give some indication of its behavior or suitability for a given use, but its value may be limited because it does not show the exact minerals in which the elements are combined, the fineness of the grain, and other factors upon which physical properties depend. Some examples may serve to illustrate the value of chemical analysis.

Hydrous iron oxide has both a coloring effect and a fluxing effect in firing. The presence of even a small percent is often sufficient to produce a noticeable color in a fired clay and, hence, is an injurious constituent of kaolins for certain uses. Concretions of hydrous iron oxide cause fused blotches and black specks that are detrimental to the ware. In general, a clay containing less than 1% Fe_2O_3 fires practically white; between 1 and 2% fires to a cream color; increasing amounts over 2% fire to cream buff to red colors. The color to which a clay will fire cannot, however, always be accurately predicted from the amount of Fe_2O_3. Other factors may be involved.

Rutile, TiO_2, appears to be a wide-spread mineral in clays, but never in large amounts or in large grains. It is usually observed in the form of microscopic grains or needles. The chemical analyses of the Georgia kaolins all show TiO_2, usually between 1 and 2%, but it is probable that all the TiO_2 is not derived from rutile. It may be present as titonite, Ca $TiSiO_5$, or ilmenite, $FeTiO_3$.

Titanium seems to have both a fluxing and a coloring action. Even small amounts will lower the pyrometric-cone equivalent of a clay a cone or two. TiO_2, under reducing conditions, gives the fired clay a bluish grey color and, under oxidizing conditions, a yellowish color. The bluish color is somewhat less pronounced in the presence of free silica. Final color and depth of shade depend upon several things:

(1) The amount of iron in the clay

(2) The minerals or chemical combination in which the iron is present.

(3) The size of the particles

(4) The presence of other minerals which may influence color

(5) The temperature of firing

(6) The degree of fusion

(7) The conditions of the kiln atmosphere

ELECTRON MICROSCOPY

The electron microscopy laboratory includes: an electron microscope for viewing samples at magnifications between 1000 x and 100,000 x; a shadowing device for vacuum metal evaporation and deposition of thin films; and optical microscopes including phase contrast, steroscopic, vertical illumination, and bright and dark field as well as optical comparator for fine measuring. By means of the enumerated apparatus we hope to gain fundamental information from samples of Georgia clays. From these several clays, a possible "typical clay" will be determined and this will be examined by all the means at our disposal and cut into fractions for particle size distribution. The various size fractions will be studied again by the same methods.

Some of the methods of separation might be: a centrifuge for high speed work; an air elutriator if wetting upsets a particular measure; and screens for those particles larger than 325 mesh. Stokes law is used as a basis for sedimentation methods and the centrifuge. Screen separation is of small use for clay particle size determination because between 50 and 80% of the material may be under 2 microns in size. A number 325 mesh screen, which is about the smallest mesh opening practical, passes 44 micron particles. A 200 mesh screen, often set as the lower mesh-opening size in plant work, passes a 74 micron particle.

We now have pictures illustrating the plate-like crystals of clay. These are thought to be alternate layers of alumina and silica bonded together through oxygen bridges. The mechanism of building up of these layered particles into stacks is not clearly understood, but the inter particle layer may consist of a gel.

X-RAY

The Station has available geiger-counter spectrometer-gonimeter, in addition to the usual powder cameras. It is expected that the relatively high resolution of the spectrometer will make the instrument useful at low angles of diffraction. In general, it is in these low angles where differentiation between clay minerals is best made. The accurate intensity measurements possible with this instrument might conceivably make quantative evaluation possible. Attempts will be made to establish the standard diffraction patterns. This work will be guided by that done by Brindly (1951), H. W. van der Marel (1950), and the American Petroleum Institute (1950).

CERAMICS

The ceramics laboratory has available: reflection and glossometers; PCE furnaces for measuring melting and firing characteristics; furnaces for firing sample objects; viscosometer and pH meters for determining rheological properties; and differential thermal analysis apparatus for evaluating the effect of heat on clays and identification of type. We hope to gain clues to geophysical-chemical relationships in formation and physical characteristics of clay in a plastic and dry condition. The effect of heat and resultant chemical and physical changes will be examined with melting, fusion, and crystallizations of silicates as primary focus.

Georgia kaolin deposits are one of the state's more valuable mineral resources and are presently used in rubber manufacture, paper products, adhesives, insecticides, and ceramics. In the fine-china field, the usefulness and market value has been extended by every advance in fundamental knowledge of the principal constituents and impurities. Knowledge of the efflorescence and scumming of structural products, and the process and products of vitrification, are becoming more and more essential. Properties of ceramic mixes, as used in many fields, depend upon plasticity, particle size, shape, and distribution, and chemical additives. Handling and purification are of interest with a view toward extending the quantity of higher grade clays recovered and making that fraction recovered more suitable for use.

Rational analysis is only of relative value; chemical analysis may give sufficient data for known compounds, but only modern colloid-physics, x-ray, and electron microscope make possible identification of montmorillonite clays and halloysite. Differential thermal analysis is becoming of greater value as equipment is improved and is especially useful in combination with the above methods.

In essence, man has thus far applied clay and associated materials only to those uses for which it is obviously and superficially fitted. With the logical application of basic research and the abolition of pre-conceived limitations, these materials may possibly display yet-unknown features. New horizons of fundamental application may be opened by a determination of the exact basic nature of these materials and their use in science and industry may be more accurately realized. Although it is hoped that the information will eventually be of practical value, the problem is being attacked in a systematic manner to enlarge fundamental knowledge.

It is apparent from the foregoing discussion that every ability, technique, and facility at the Engineering Experiment Station will be utilized in adding to the basic knowledge of the physical and chemical structure of clays and clay minerals.

References Cited:

1. Brindly, G. W. (1951) *X-Ray Identification and General Structures of Clay Minerals.* Mineralogical Society, British Museum (Natural History), Cromwell Road, S.W.T. Oxford University Press.
2. Kerr, Paul F., Hamilton, P. K., Pill, R. J., (July 1950) *Analytical Data on Reference Clay Materials.* Columbia University, New York, Preliminary Report No. 7, American Petroleum Institute, Project 49, Clay Mineral Standards.
3. van der Marel, H. W., (August 1950), Identification of Minerals in Soil Clay by X-Ray Diffraction Patterns. (1927) *Soil Sci. Log*—136, 70, 2.
4. Wilson, Hewitt, *Clay Technology,* McGraw-Hill Book Company.

THE UTILIZATION OF LITHONIA MIGMATITE IN AGRICULTURE*

A. T. NAVARRE

Georgia Institute of Technology

Previous Use of Granitic Material. The use of granitic rocks for agricultural purposes dates back more than half a century. Hensel (1894), a German chemist interested in plant nutrition, noted the difference between plants growing in virgin soil, near the base of the Harz mountains, and others grown in worn-out soil. He decided to try finely ground granite dust with lime and gypsum. His mixture consisted of ten parts granite, three parts lime, and two parts gypsum. The soil so treated not only produced well, but the vegetation was of superior quality, and free from parasitic growth. The root systems of the plants grown on soil treated with granite dust, lime, and gypsum produced extraordinary development. Hensel deduced that parasitic pests so common to plant life might owe their origin in impoverished soil, upsetting nature's equilibrium. He noted the spurious growth made by unbalanced nitrogen fertilization in the lodging of wheat and other cereals.

Hensel was faced with the old claim that granite dust is insoluble in soil water, which no longer bears argument since the discovery that cation exchange takes place in soil solutions quite readily (Kelley, 1948; Lyon and Buckman, 1943). Davidson (1951), coowner of the Stonemo Quarries, at Li-

*Read at the meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

thonia, Georgia, made experiments with crushed migmatite on fruit trees, grasses, and grain crops. These experiments confirm the fact that significant benefit is derived from the use of the granitic dust through better plant growth, healthier root systems, greater resistance to disease and frost.

Chemical Elements Required In Plant Growth. Nitrogen, phosphorus, potassium, iron, manganese, copper, carbon, calcium, magnesium, sulfur, zinc, and boron are required by most plants. A few require others. It is not the intention of the writer to enter into descriptions of the functions of each of the aforesaid elements in plant nutrition. The reader is referred to Lyon and Buckman (1943) for a detailed description of the function of each.

Most chemical fertilizers usually supply nitrogen, phosphorus, and potash according to a specified formula guaranteed by the manufacturer. The three elements are not, however, a complete fertilizer in the sense that they fail to furnish some of the lesser elements needed by plants for healthy growth. Some fertilizer corporations are gradually coming around to Kelley's (1948) and Lyon's and Buckman's (1943) viewpoint, that lesser elements like magnesium, copper, zinc, sulfur, boron, manganese, and others are necessary in a proper balance for specified agricultural crops.

Collings (1948) states: "Up until a few years ago most of the complete fertilizers found on the American market were acid forming, and their use led to an increase in the acidity of the soil." Non-acid forming fertilizers are now manufactured, so that the physiologically acidic and physiologically basic carriers of nutrient materials will balance each other in cation exchange.

Migmatite Dust is Neutral in Distilled Water. Migmatite dust is neutral when left standing for 48 hours in distilled water in contact with blue and red litmus paper at ordinary air temperatures. This is true of granite dust (Eaton, 1951). When subjected to leaching in heated distilled water for 48 hours under controlled conditions, Ingolls and Navarre (1952) discovered that the pH of the average Lithonia migmatite was 9.3. This count of pH is distinctly alkaline, indicating that alkali elements sodium and potassium, and alkaline earth elements, calcium and magnesium, were released under heated-water conditions. This same analysis showed the presence of 30 milligrams per 100 grams water of dissolved calcium and magnesium present in the controlled solution of average leached Lithonia migmatite dust.

Elements Present in the Average Migmatite Dust. Twenty-one elements were found to be present in the Lithonia migmatite dust when crushed to 80 mesh. Phosphorus, nitrogen, fluorine, and so forth do not show up in a spectroscopic analysis.

The elements ascertained present in a spectographic analysis were Al, Si, Ca, K, Na, Fe, Mg, Ti, Mn, Cr, V, Cu, Pb, Zn, Zr, Ni, Ag, and Y. The strength of these elements and their comparison with other granite dusts analyzed spectrographically by Spicer (1951) are shown in Table I.

TABLE I
Comparative Analyses of Granites

Element	Lithonia Migmatite Average	Cammack Granite Ga.	Mt. Airy Granite North Carolina	Barre Granite Vermont	Lithonia Migmatite, Garnet Phase
Al	S	S	S	S	S
Si	S	S	S	S	S
Ca	S	S	S	S	S
Na	S	S	S	S	S
K	S	S	S	S	S
Fe	M	M	M	M	M
Mg	less than S	S	M	M	M
Ti	S	S	M	M	M
Mn	M	M	F	M	V.S.
Sr	F	W	T	M	?
Cr	T	T	T+	W	X
V	T	F	F	F	X
Ba	X	T	F	W	X
Cu	T	T	T	T	X
Pb	W	T	W	W	T
Zn	T	W	T	W	T
Zr	W	W	W	W	M
Ni	W	W	T	W	X
Ag	T+	?	T	T	M
Y	W	X	X	X	X
Sn	?	?	X	W	X
Co	X	X	X	X	T

Source: Spectrographic Analyses made by W. M. Spicer, Chemistry Department, Georgia Institute of Technology.

TABLE II

Comparative Analyses Granites & Gneisses

(%)

Rock	Locality	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5
Granite	York County S. Carolina	70.77	14.89	.75	1.24	.43	2.08	4.47	4.70	Trace
Granite	Laurens Cy. S. Carolina	68.80	15.73	2.14	1.57	1.16	1.64	3.45	4.54	Trace
Granite Gneiss	Conyers, Ga.	75.45	13.71	.92	......	.18	.94	3.87	4.30	....
Granite Gneiss	Lithonia, Ga.	72.96	14.70	1.28	......	.07	1.28	4.18	4.74	....
Granite	Stone Mt. Georgia	71.66	16.05	.86	......	.17	1.07	4.66	4.92	Trace
Granite	Barre, Vt.	68.89	15.08	1.04	1.46	.66	2.07	4.73	4.29	Trace
Granite Gneiss	Lexington N. Carolina	73.10	13.82	.93	1.43	.51	1.72	3.04	5.06	Trace
Granite Gneiss	Lithonia, Ga.	75.16	13.74	.91	......	.17	.91	3.76	5.05	....
Granite	Cammack, Ga.	75.64	13.82	1.62	......	.01	.85	4.32	2.31	....
Granite	Mt. Airy N. Carolina	66.01	17.44	5.62	......	1.11	1.44	5.06	3.16	....

Source: Washington, U. S. G. S. Prof. Paper 99.

Rechecks were made on previous analyses of some of the granites and gneisses complied by Washington (1917) showing the oxide components made by regular quantitative chemical procedure (Table II).

The Lithonia migmatite in the two analyses compare very favorably with other gneisses and granites in potassium content. The Lithonia (average phase) is quite variable in different parts with respect to potassium content, when such is made spectrographically. The two volumetric analyses bear out this observation. The same variability holds true for lime, magnesia, and other components, regardless of method of analysis.

History of Trace Element Necessity in Plant Nutrition: Research in the utilization of trace element requirements by plants dates back some 20 years, during which time some very important discoveries have been made as to the function played by each element in plant growth. Collings (1948) and Lyon and Buckman (1943) discuss the value of trace elements in plant nutrition very fully, including the effect of lack of trace elements on plant diseases. Medical men are, likewise, interested in trace element research as to its effects on human nutrition, including tendencies toward certain diseases produced by a diet constantly lacking in the required small amount of such elements.

Lack of Required Trace Elements in Soils. Many soils, in their virgin state of fertility, once contained many of the required elements. Others never contained many of them due to their geologic origin. It behooves the agriculturist, therefore, to study his soil origin and the proper requirements of the various chemical elements in the soil where his plants grow. Horticulturists are, likewise, convinced that certain trace elements can be very beneficial to tree types grown by them and in preventing the inroads of malnutritional diseases now infiltrating their orchards.

Florida Experiment With Lithonia Migmatite. A plantation owned by a Fort Lauderdale, Florida, planter and situated four miles west of Boca Raton, on the eastern coast of Florida, was the site of an experiment during 1951. A portion was treated with a combination of 1000 pounds of finely-ground raw phosphate rock and 2000 pounds of "Hybro-Tite", migmatite dust, from Stonemo Quarries, Lithonia, Georgia. Another portion was untreated.

The soil was poor and supported little vegetation. It is a white, medium-grained sand, containing a trace of calcium carbonate. Large parts are "sand barrens", which support no vegetation. Elsewhere, native flora consists of a few scarred pitch pines, puny palmettos, and sparse grass. About 80 acres was a four-year-old orange grove.

On the experimental acreage, a limespreader charged with the migmatite-phosphate combination was followed by a disc harrow. The experimental plot consisted of about 200 acres of cleared, scrub-pine land and a portion of the orange grove. The former was then sowed to pangola grass, a non frost-resisting member of the Bermuda family.

Table III shows the results of analyses of soil samples collected before the experiment and afterward. The former were by Dewitt (1951) and the second under the direction of King (1952).

The results of the experiment are startling. The material applied was supposed to be inert (non-water-soluble). Nevertheless, it is obvious that a large quantity of plant food had been released in the course of the experiment. The figure for

TABLE III
Analyses of Boca Raton Soil
pounds/acres

Lab. No.	Field No.	pH	Phosphate P_2O_3	Potash K_2O Before[1]	After	Lime CaO	Magnesia MgO
30	1[2]	7.4	200	57-92	96	1800	15
31	2[2]	5.2	210	57-92	96	1000	20
32	3[2]	6.0	192	57-92	96	1100	20
33	4[3]	5.6	220	57-92	192	2120	20

[1]Dewitt (1951) previous to application of any fertilizer. Average of a number of analyses.

[2]From experimental area planted to pangola grass after 1000 pound pound phosphate-2000 pound migmatite application.

[3]From experimental orchard plot after treatment with 1000 pound phosphate-4000 pound migmatite application.

Source: King (1952) Director, Ga. Coastal Plain Exp. Sta., Tifton, Georgia.

lime needs explanation. The migmatite contributed about 20 pounds and the collophane (phosphate rock) about 1100. The excess must be credited to limy impurities is the rock as dredged from stream bottoms.

Vegetal growth was promoted in remarkable manner. On the control plots, the grass remained scragly and poor (Figure 1). Cattle did not fatten upon it. The pangola did not establish itself to a satisfactory degree. It grew to the bellies of the cattle on the treated section (Figure 2). The matted network of roots was profuse. The orchard control showed less rapid growth than the experimental part. The leaves on the latter were a darker green and the roots more profusely matted.

Nitrogen Content of the Average Lithonia Migmatite. Ingolls and the writer (1952) investigated the nitrogen factor in the ground waters of Georgia, in relation to the old suggestion that all nitrogen, ammonia, nitrates, and nitrites, found in such waters, come from sources of contamination, such as stockyards, and sewage infiltration. Startlingly, the source of the nitrogen was found to be otherwise. Samples of igneous rock material, some fresh, some weathered, not only from over Georgia, but from Vermont, North Carolina, South Carolina, and the island of Hawaii were examined. The Hawaiian specimen was a fresh basalt taken from the 14,000-foot level of last year's flow of Mouna Loa. The basalt ran true to form with granites and granite-gneisses sampled, leached, and analyzed for leachable components. The igneous rock content in nitrogen, therefore, had to come from nitrogen in the magma at the time of crystallization. This origin for nitrogen in igneous rocks is perhaps substantiated by the presence of N_2 in the composition of certain meteorites, as one of their lesser constituents.

The nitrate experiment was carried out by the method of solution chemistry, in the same way that the pH factor of leachable components, and the leached out magnesium and calcium components were obtained.

Neither the spectrograph in the excited electric arc nor the ordinary method of volumetric analysis suffices for this detection of nitrogen. It is not surprising that the nitrogen content of granite has not been well studied because its content of 25 parts per million is certainly lower than the normal analytical procedure of geochemistry would demonstrate.

The Lithonia migmatite ranked sixth among eight specimens studied, in nitrogen content. Unweathered granite from Conestee, South Carolina, ranked first with 8 mg/100g. distilled water containing the leached-out components. Unweathered granite from Mt. Airy, North Carolina ranked second with 5.4 mg/100 g. water; unweathered aplite from Atlanta, Georgia, third with 2.8 mg/100 g. H_2O; fresh basalt from Hawaii, fourth with 2.3 mg/100 g. H_2O; unweathered granite from Isle, Minnesota, fifth with 2 mg/100 g. H_2O; and Lithonia sixth with 1.8 mg/100 g. water.

Phosphorus Component of the Lithonia Migmatite. Tests on several granites besides the Lithonia for comparison were made in the mineralogical laboratory of Georgia Tech. All samples were crushed to 80 mesh, from which 10 grams were selected, labeled and placed in different pyrex tubes. Sodium Carbonate, dry reagent, was used to fuse each sample, to make sure that the phosphorus would dissolve in HNO_3. Each labeled sample was treated with 20 ccs. of conc. HNO_3, heated slightly and treated with 20 ccs. of ammonium molybdate reagent. Blank tests were run to detect traces of arsenic or antimony, using the Marsh test for arsine and stibine AsH_3 and SbH_3. These samples were negative for these elements. The results were carried out on a comparative basis of color intensity of precipitated yellow phospho-ammonium molybdate. The results were as follows:

Average Lithonia migmatite
P content strong yellow
Lithonia—Pegmatite phase
P content mere faint trace
Lithonia—Partially assimilated
biotite xenolith
P content negative
Mt. Airy granite
P content—trace—3 tests
Barre, Vermont granite
P content fairly strong—2 tests
Cammack granite
P content fairly strong—2 tests
Stone Mountain granite

P content strong but somewhat
weaker yellow intensity than
Lithonia

Undoubtedly traces of boron, fluorine, arsenic and other elements could be detected in the Lithonia if samples were gathered in the spots where tourmaline, fluorite, arsenopyrite, molybdenite, and apophyllite occur. However, the smaller variable trace phases of the Lithonia were omitted in making out the composite analyses both spectrographically and chemically.

The Lithonia average migmatite with the following elements—sodium, aluminum, iron, potassium, magnesium, calcium, lead, zinc, silver, yttrium, vanadium, chromium, copper, strontium, titanium, silicon, manganese, nickel, zirconium, nitrogen, and phosphorus—spread rather uniformly throughout its mass should act as a good soil conditioner from the standpoint of supplying an abundance of trace elements needed in plant nutrition. Our knowledge of the function of some of these trace elevents, such as zirconium, yttrium, and vanadium, waits upon future soil research to determine their proper value in plant nutrition.

References–Cited

Collings, Gilbeart H. (1948) *Commercial Fertilizers,* The Blackiston Company, p. 341.

Davidson, C. (1951) Personal communication, November 28.

Dewitt, M. (1951) Personal communication, November 28.

Eaton, Frank S. (1951) Granite stone meal as a source of potash, *The Shade Tree,* Kearney, New Jersey, vol. 24, no. 4, April.

Hensel, Julius (1894) *Bread from stones,* A. J. Tafel, 1011 Arch Street, Philadelphia, Pa.

Ingolls, Robert H., and Navarre, A. T. (1953) Polluted water from the leaching of igneous rocks, *Science,* 116, 595.

Kelley, Walter P. (1948) *Cation exchange in soils,* A. C. S. Monograph, No. 109, Reinhold Pub. Co., N. Y.

King, Frank P. (1952) Letter, dated August 2.

Lyon, Lyttleton T., and Buckman, Harry O. (1943) *The nature and properties of soil,* The MacMillan Company, N. Y., chapt. 2.

Spicer, W. M. (1951) Spectrographic analyses reported from the Chemistry Department, Georgia Institute of Technology.

Washingon, H. S. (1917) *Quantitative classification of igneous rocks,* U. S. G. S., Prof. Paper 99.

GEOPHYSICAL AND STRATIGRAPHIC INVESTIGATIONS ON THE ATLANTIC COASTAL PLAIN*

By

HORACE G. RICHARDS
Academy of Natural Sciences, Philadelphia, Pa.

and

H. W. STRALEY, III
Georgia Institute of Technology

Introduction

Interest in possible production of oil on the eastern seaboard was stimulated during the shortages of World War II. This resulted in the Sunniland field, Florida, 1943, and the Gilberton field, Alabama, 1944. Attempts were made to find oil in the Atlantic costal plain and, at the same time, geological and geophysical summaries were attempted by the present writers. Richards was aided by the Geological Society of America and Straley, by the American Association for the Advancement of Science.

Stretching from New York to southern Florida, the Atlantic coastal plain is similar to areas both west and south. The sedimentary rocks are those of the Gulf Coast, with modifications. Structural trends are largely Appalachian.

Geology

The surface exposures consists of Cretaceous and Cenozoic deposits. Beneath this thin veneer lie old crystalline rocks. There may be troughs in the basement which were filled with Triassic sediments and subsequently buried beneath younger formations (MacCarthy, 1936). Jurassic microfossils have been reported from a deep well at Cape Hatteras (Swain, 1950) and it is probable that rocks of this age occur off shore. The correlation of Atlantic coastal plain formations is shown in Table I.

NEW JERSEY. Formations range in age from Raritan (basal Gulf series) to Cape May (upper Pleistocene). There

*Read at the 1950 meeting of the Georgia Academy of Science, Oglethorpe University.

are similarities between the stratigraphic units here and those of the Gulf Coast, but all formations are thinner in the east. Some are better represented in subsurface than outcrop. For example, a well at Salem, New Jersey, penetrated non-marine sediments of the Potomac Group (Lower Cretaceous) and one at Brandywine Light House bottomed in sands of Jackson (Upper Eocene) age; neither formation occurs in outcrop in New Jersey.

Structure. The basement complex slopes, in general, southeastward about 65 feet per mile; toward the coast, the gradient increases (Ewing and Vine, 1939) and Woollard (1939), on geophysical evidence, suggests a depth of over 5,000 feet at Avalon, Cape May county. A water well at Atlantic City bottomed in Mount Laurel-Wenonah (Gulf series) at a depth of 2306 feet. Fault troughs, filled with Triassic sediments, may be traced across New Jersey from the Highlands to the Delaware River. At Runyon, Middlesex County, a thin, Triassic, red shale overlies the basement at 310 feet (Richards, 1948, p. 43).

Petroleum. There have been numerous unsuccessful test wells for oil and natural gas, but none by a major company using modern methods. These have been supplemented by a large number of water wells.

DELAWARE. The geology of Delaware is similar to that of New Jersey except that there are fewer outcrops, other than Pleistocene. The Cretaceous is well exposed in cuts of the Chesapeake and Delaware canal and Eocene crops out near Middletown and Odessa.

Structure. Except in the extreme northern part of the state (near Wilmington) where basement rocks occur in shallow wells, little is known about the dip of the crystallines. A well near Bridgeville did not reach basement at a depth of 3000 feet.

Petroleum. Three closely spaced oil tests were drilled near Bridgeville, in 1935, but no gas or oil was discovered.

MARYLAND. In general, the same Cretaceous and Cenozoic formations occur in Maryland as farther north. The Monmouth-Matawan thins southward and pinches out in northern Virginia. The Raritan (Tuscaloosa) thickens and becomes more marine toward the Virginia line.

Structure. There is a conspicuous depression in the basement beginning at the present coast and passing through Berlin and Salisbury to the vicinity of the District of Columbia. It exhibits pronounced thickening of Cretaceous sediments (both Upper and Lower); beneath these are non-marine shales and sandstones referred to the Triassic. This depression may represent an ancestral Chesapeake Bay, Potomac River, or fault. Cretaceous sediments (both Upper and Lower) thicken notably in this depression, which Richards (1948, p. 53) called the Salisbury Embayment (Figure 1).

Petroleum. Between 1945 and 1946, three deep oil tests were drilled in this embayment (near Salisbury, Berlin, and Ocean City). No positive traces of oil or gas were reported. There were, also, two or three previous oil tests in the state, one of which (near Parsonburg, Wicomico County) is reported to have obtained limited supplies of gas (probably methane from informations near the surface).

VIRGINIA. Monmouth-Matawan (Upper Cretaceous) pinches out in northern Virginia and the Raritan is reduced to some 70 feet, known only from wells. The predominant Cretaceous deposits are those of the Potomac Group, at least partly Lower Cretaceous. Spangler and Peterson (1950) have recently expressed the view that the Raritan and Potomac are approximately contemporaneous and represent both Lower and Upper Cretaceous. There is a conspicuous thickening of the Eocene in the subsurface north of James River, a fact which may be explained by faulting (Cederstrom, 1945) or embayment, similar to the Salisbury Embayment.

Structure. Geological and geophysical data show that the basement rock slopes at a rate of about 30 feet per mile from the Fall Zone, near Petersburg, to about 20 miles east of Cape Henry, beyond which it increases so that approximately 60 miles at sea, off Cape Henry, the basement may be at 12,000 feet (Ewing, Crary, and Rutherford; Miller).

The relatively few wells reaching basement in eastern Virginia reveal crystalline rocks close to the surface under the Capes (Richards, 1945). Spangler and Peterson (1950) have recently published generalized isopleths over this elevation

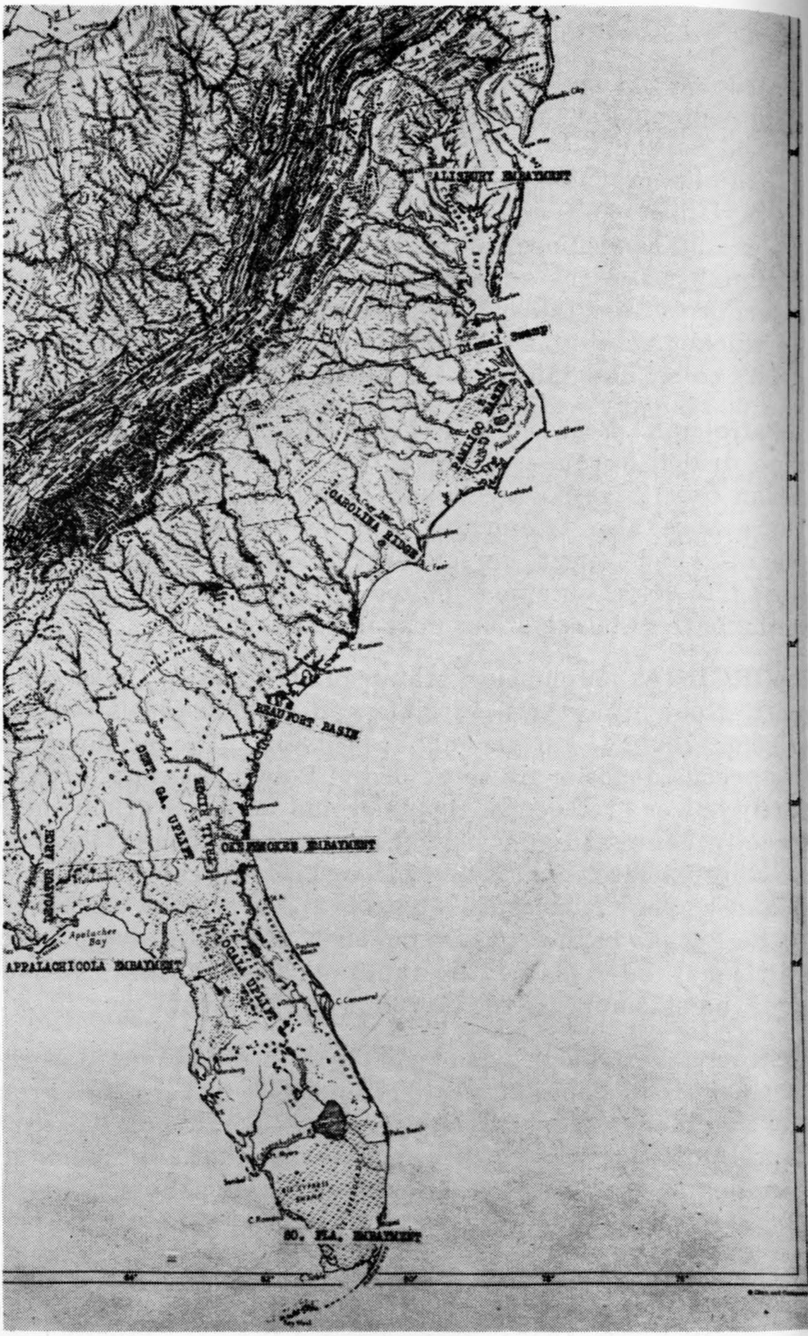


Figure 1. Map of Atlantic Coastal Plain showing structural features.

which it is here proposed to call the Fort Monroe High (See Richards and Straley, 1948).

Petroleum. The only oil test in the coastal plain of Virginia was drilled near Mathews, in 1929. Gas (methane?) was reported from the upper 100 feet.

NORTH CAROLINA. The Cretaceous crops out in a wide band along the Carolina Ridge, but is buried farther north. The Tuscaloosa thickens toward the coast and becomes marine as indicated by marine fossils from wells in Dare and Carteret counties and vicinity. It is generally regarded as basal Upper Cretaceous (Raritan), but apparently grades downward into the Lower Cretaceous for fossils of both stages have been found in well samples from Hatteras. Peedee (Navarro) and Black Creek (Taylor) crop out south of the Neuse River, but pinch out against the Carolina Ridge and Fort Monroe High.

The unconformable Eocene behaves in a similar manner. Wilcox-Claiborne (Middle Eocene) has been identified in the subsurface and is found in outcrops near Clayton, Garner, Lillington, and Raleigh (Richards, 1948a). The Castle Hayne (Jackson; late Eocene), which crops out south of the Neuse River and along the Carolina Ridge, continues over the arch into South Carolina, where it is known as the Santee and Cooper formations.

Structure. The basement, although irregular, slopes toward the sea with the same sharp increase in gradient noted elsewhere. From the Fall Zone to the vicinity of Havelock, Craven County, it averages about 14 feet per mile, whereas from New Bern to Cape Hatteras it is about 122 feet per mile (Prouty, 1946; Berry, 1948; Spangler, 1950; Richards, 1948).

Several irregularities occur in the surface of the basement; for example, there are "hills" near Fountain and Smithfield, where granite occurs at the surface but is buried on all sides.

On the basis of geophysical work, Johnson (1938, 1953, personal communication) detected a low ridge west of Edenton and Plymouth, North Carolina, with a valley between it and the Fall Zone. The relief was of the order of 300 feet which is borne out by the surficial geology in Pitt County and elsewhere.

Petroleum. Some 20 unsuccessful wells have been drilled in North Carolina, of which 13 were between 1945 and 1949. The deepest, at Cape Hatteras, reached basement at 9878 feet, thus indicating a decided low between the Fort Monroe High and the Carolina Ridge.

SOUTH CAROLINA. The surface geological formations south of the Carolina Ridge are similar to those to the north, except that Gulf Coast affinities are more prominent. In the subsurface, geomagnetic work near Florence has outlined a southwest-northeast trending basin, probably filled with Triassic sediments (Alexander and MacCarthy, 1934; MacCarthy, 1936; McCarthy, Prouty, and Alexander, 1933; MacCarthy and Straley, 1937, 1938; Straley, 1948). Wells at Florence and Summerville have penetrated rocks questionably referred to the Triassic (MacCarthy, 1936; Richards, 1945; Straley, 1948a).

A number of wells give information about the Beaufort, South Carolina basin, lying between Charleston and Walterboro, South Carolina, and Savannah, Georgia. At Charleston, the greatest depth was 2015 feet, with the bottom of the well in the Black Creek formation. The Parris Island, South Carolina, well bottomed in Tuscaloosa at 3454 feet with a marine horizon between 3115 and 3445. The top of the Cretaceous is about 400 feet lower at Savannah, Georgia, indicating a southward deepening.

Structure. The Carolina Ridge near the North Carolina-South Carolina border, the outstanding tectonic feature of the Atlantic Coastal Plain, is aligned subparallel with some Antillean structures. It may be interpreted in terms of basement topography or structure. The basement complex rises to within 1100 feet of the surface near Wilmington, North Carolina, and drops at a relatively sharp angle to both north and south. The arch may represent pre-Cretaceous topography against which later formations feather out or it may represent Cretaceous folding along an axis transverse to the Applachian geosyncline. In either event, it was above water or only slightly submerged during part of the Cenozoic.

MacCarthy and Straley (1937, 1938) mapped a series of plunging, sharp-crested geomagnetic anomalies subparallel with Appalachian trends (Figure 1). They attributed them to structural peculiarities (lithologic variations) in the basement rocks or to topographic irregularities of an unusual nature (probably lithologically controlled).

Between the Santee River and the Carolina Ridge lie two reconaissance—geomagnetic anomalies that may represent basement features of either topography or structure. One is an elevation at Conway which is almost as prominent as the Ridge. The other is a low, almost east-west high just north of the Santee. Both are subparallel with structural alignments in the Antillean region.

It was south of the Carolina Ridge that Alexander and MacCarthy (1934) first noted a change in gradient of the basement. Other workers have confirmed the general thesis without mentioning detailed profiles.

Petroleum. Several oil tests have been drilled in South Carolina, mostly on the south flank of the Carolina Ridge, but none have produced positive results.

GEORGIA and FLORIDA. South of the Savannah River are several significant subsurface differences. The Tuscaloosa formation becomes more marine south of the Central Georgia Uplift, whereas non-marine Comanche appears and thickens westward. Marine Jurassic, present in Clarke County, Alabama, may underlie southwestern Georgia.

General deepening continues into Florida. At Hilliard, Nassau County, Florida, questionable Paleozoic was encountered at 4795 feet. Farther south, in Dixie County, Florida, definite Paleozoic (probably Lower Ordovician) sedimentary rocks were met at a depth of 3668 feet (Howell and Richards, 1949). This occurrence can probably be correlated with the Ocala uplift (Figure 1). Other wells, in Levy and Suwanee counties, Florida, and Early County, Georgia, have reached Paleozoic sediments beneath the Cretaceous. South of the Ocala Uplift, the basement complex was found below the Cretaceous with no intervening Paleozoic. In extreme southern Florida, wells of the Sunniland field bottom in Lower Cretaceous at depths greater than 11,000 feet.

Structure. Detailed profiles have not been made public south of the Santee River, either in South Carolina or Georgia, and geophysical work in Florida (Lee and Swartz, 1940) indicates no continuation of the basement-surface gradient change previously mentioned. It is possible that it may have passed off shore as it did in the neighborhood of Cape Henry, Virginia.

Structurally, Florida is divided by the Ocala Uplift (Figure 1) which traverses the state from Osceola County northwestward to its termini in Taylor, Hamilton, and Nassau counties. To the southwest, lies the Florida basin (Pressler, 1947). In the western panhandle is the Appalachicola Embayment, through which passes the Decatur Arch. The Okefenokee Embayment lies northeast of the Ocala Uplift, with its center near Jacksonville, Florida.

Western Georgia is bordered by the Decatur Arch that follows the trend of the Chattahoochee River. The Central Georgia Uplift, which may be a northward extension of one of the branches of the Ocala Uplift, separates the Atlantic from the Gulf coastal plain. Trail Ridge, a physiographic feature, which extends roughly north-south east of the Okefenokee Swamp, has been interpreted as another branch of the Ocala.

Petroleum. Oil occurs in commercial quantities in the Sunniland field, Florida, where it is obtained from the Lower Cretaceous. Elsewhere, drilling has proven disappointing. Wells in northern Florida and southern Georgia have failed to penetrate oil-rich rocks.

The recently discovered field in the neighborhood of Brewton, Alabama, west of the Decatur arch, may stimulate interest in adjacent southwestern Georgia and northwestern Florida.

Geophysics

Geophysical investigations have been conducted on the Atlantic Coastal Plain by three groups. Columbia, Lehigh, and Princeton universities cooperated in gravitational, magnetic, and seismic work, with assistance from the United States Coast and Geodetic Survey, mostly north of the Dismal Swamp. The University of North Carolina and the United States Department of the Interior, never officially in cooperation, have led geomagnetic activity south of the swamp. Thirdly, several oil and/or contracting companies have operated, from time to time, in the region. Recent geophysical work by such companies, especially the Standard Oil Company of New Jersey, has undoubtedly added much information, but unfortunately only a summary report has been published (Skeels, 1950).

GRAVITATIONAL and SEISMIC. There are three gravity-seismic profiles across the coastal plain, two in New Jersey and one in Virginia. In addition, submarine work has been conducted off the coasts of New Jersey, Florida, and Virginia (Ewing, et al, 1946, 1950).

Starting from the known Piedmont, work advanced into the unknown coastal plain. The gradient of the basement rocks shows a sharp increase coastward. In the Barnegat Bay area, New Jersey, it is about 65 feet per mile, in Virginia about 30 (Woollard, 1941; Ewing, Crary, and Rutherford, 1937; Miller, 1937; Swick, 1937). In New Jersey, steepening begins a short distance inland with a greater increase just beyond the shore line. In Virginia, the steepening begins some 20 miles off shore. Such structures as have been found are subparallel with Appalachian trends and topographic relief of the order of 150 feet is indicated.

The most significant feature of the emerged New Jersey plain is a double crested high (Ewing and Vine, 1939). Originating in a crystalline outcrop in Massachusetts, it trends southward into the coastal plain. It may be attributed to a basic intrusion at considerable depth within the basement. The medial low is probably due to granite, such as was encountered in a well at Rockaway Beach, Queens County, New York, at 976 feet.

Other features have been observed. An off-coast gravity low (Ewing and Vine, 1939) has been variously interpreted as: (1) a downwarp of sial into sima; (2) a thickening of sedimentary rocks under which a granitic shell thins; and (3) a Paleozoic downwarp. The increase of seaward gradient of the basement complex may represent: (1) warping that foundered Appalachia (Miller, 1937); (2) drag from a profound fault that foundered Appalachia (Miller, 1937); (3) the continental divide of Appalachia; or (4) the subsiding flank of an Atlantic geosyncline (Dunham). The presence of three velocity layers indicated to Miller that the basement was overlain by Jurassic, Triassic, and Cenozoic and Cretaceous sedimentary rocks.

MAGNETIC. Although Woollard contributed, the University of North Carolina and the United States Department of the Interior bore the lion's share of the geomagnetic work. They did not confine themselves to this province, but the University envisaged a grandiose research, which was suspended in 1939. Conclusions are, on the whole, in agreement. Balsey, *et al* (1946), Johnson (1938, 1953), MacCarthy (1937, 1938), and Straley (1937, 1938, 1948, 1953) interpreted the higher anomalies, which are often aligned, as reflecting basement lithology (geological structure).

South of the Carolina Ridge, not all anomalies are subparallel with the grain of the continent. The Ridge, for example, is transverse to both coast and geosyncline. The Conway high (Figure 2), in which the core is almost as high as at Wilmington, North Carolina, on the Ridge, stands at about 45°. It appears to be connected with the arch both by geography and genesis. The Georgetown anomaly (Figure 2) and

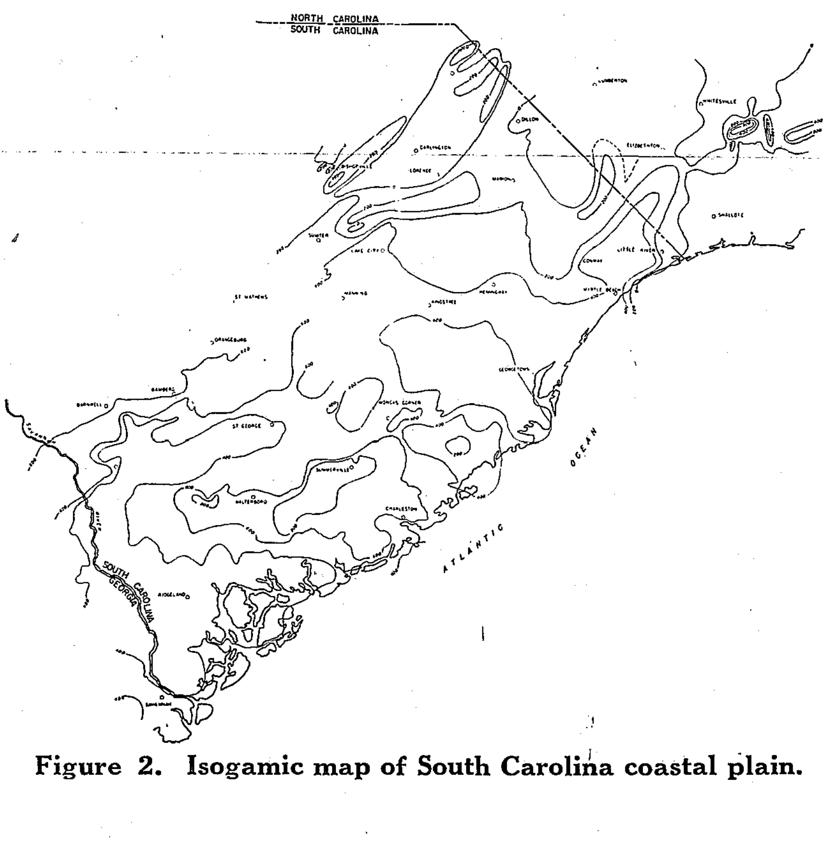


Figure 2. Isogamic map of South Carolina coastal plain.

depression to the south trend almost east-west. Balsey, *et al* (1946) mapped similar trends in the neighborhood of the Salisbury embayment.

In Florida, the Department of the Interior considered basement topography as a controlling factor. They interpret the configuration of the basement complex in terms of ridges and structural wrinkles, most of which plunge southwest. They divide the peninsula into three zones. From Georgia to St. Petersburg, the basement surface is crossed by topographic elevations and depressions subparallel with the Appalachians and with folds in the complex. Southward to Lake Okechobee, the surface is as complex as the structure and insufficient data are available to permit interpretation. It is transitional from Appalachian to Antillian control. The southern part has both ridges and folds oriented in conformity with tectonic patterns of Cuba and other West Indian islands (Lee and Swartz, 1940).

Petroleum Possibilities

The writers are of the opinion that the Atlantic Coastal Plain cannot be written off as a potential source of oil without further exploration. Although it is not the purpose of this contribution to select the more favorable areas, a few comments on these portions that deserve more adequate testing may be appropriate:

(1) Salisbury Embayment, Maryland. The predominantly non-marine character of the sediments may be discouraging. The increase in thickness of marine sediments toward the east, however, together with the overall thickness and possible structure suggested by geophysical work are factors that should encourage further drilling.

(2) Pamlico Sound, North Carolina. There is a great thickness of section and, unlike the Salisbury Embayment, the sediments are predominantly marine. The failure of the wells in eastern North Carolina, including the two deep Esso wells, is a discouraging factor, but not necessarily final.

(3) Beaufort Basin, South Carolina. Along the Atlantic coast, near the South Carolina-Georgia border is an increased thickness of sediment, but unfortunately the little drilling in the area has been discouraging.

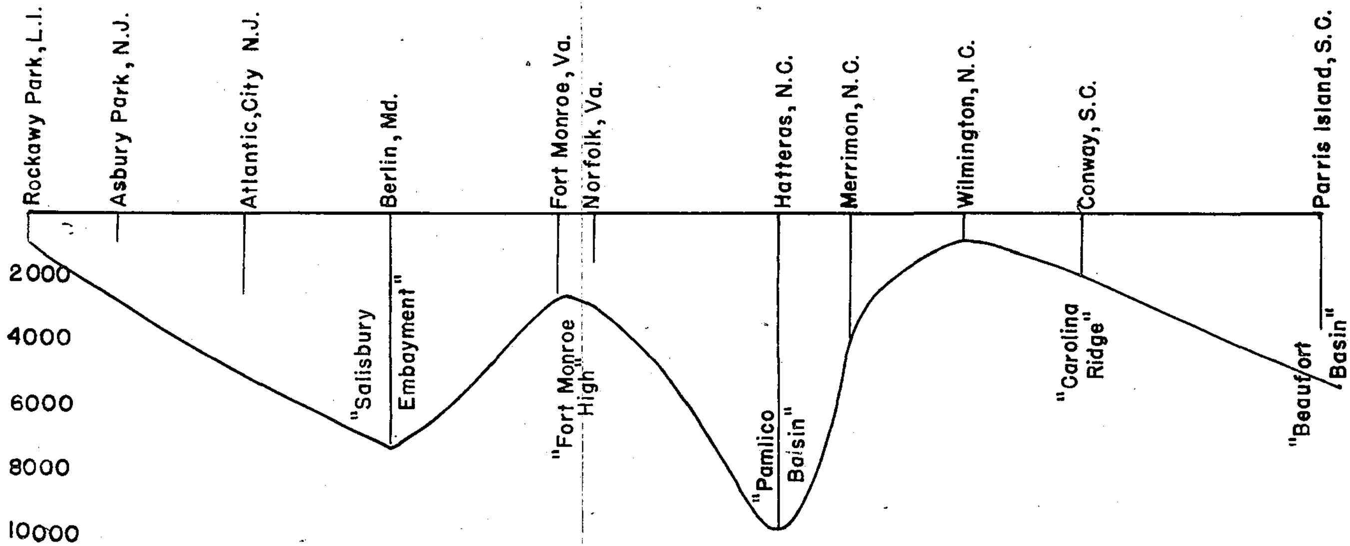


Figure 3. Basement Profile from Long Island to Parris Island, S. C.

(4) Okefenokee Basin, Georgia and Florida. Here lies another area of increased thickness that has not been tested.

(5) Southwestern Georgia. West of the Central Georgia Uplift sediments drop off to the west and it is possible that oil may be found. Wells so far drilled have produced negative results. Across the Decatur Arch, in Alabama, oil has been discovered recently at Brewton, which will stimulate further activity in southwestern Georgia and the western panhandle of Florida.

(6) Florida. Florida is not considered in this paper since its geology and structure are more closely related to Cuba and the Gulf Coast, and constitute, therefore, separate problems.

(7) Off Shore Oil. There is also the possibility of undersea petroleum. Several areas of the continental shelf are favorable for future work. Among these may be mentioned the seaward extension of the Salisbury Embayment of Maryland, and the Beaufort Basin of South Carolina and Georgia, for here thicknesses approaching those of the Gulf Coast can be found not too far east of the present shore line.

Reference Cited

Alexander, S. A., and MacCarthy, G. R. (1934) What lies under the coastal plain? *Jour. E. Mitch. Sci. Soc.*, 30, 50.

Balsey, J. R. *et al* (1946) Magnetic maps of Worchester County and part of Wicomico County, Maryland, U.S.G.S. *Oil and Gas Prelim. Map*, 46.

Berry, G. W. (1948) North Carolina coastal plain floor, *Bull, G.S.A.*, 59, 87-89.

Cederstrom, D. J. (1945) Structural geology of southeastern Virginia, *A.A.P.G. Bull.*, 29, 71-95.

Dunham, Robert, Personal communication.

Ewing, W. M., Crary, A. P., and Rutherford, H. M. (1937) Geophysical investigations in the emerged and submerged Atlantic coastal plain, part I, geophysical studies, *Bull., G.S.A.*, 48, 753-802.

Ewing, W. M., Woollord, G. P., and Vine, A. C. (1939) Geophysical investigations in the emerged and submerged Atlantic coastal plain, part III, *G.S.A. Bull.*, 50, 257-296.

Ewing, W. M. *et al* (1946) Geophysical investigations in the emerged and submerged Atlantic coastal plain, part V, *G.S.A. Bull.*, 57, 11-96.

Ewing, W. M., *et al* (1950) Geophysical investigations in the emerged and submerged Atlantic coastal plain, part IV, *G.S.A. Bull.*, 61, 877-892.

Howell, B. F. and Richards, H. G. (1949) New Paleozoic linguloid brachiopod from Florida, *Wagner Free Inst. Sci. Bull.*, 24, 35-37.

Johnson, W. R., Jr. (1938) Geomagnetic reconaissance of the coastal plain of northeastern North Carolina, *Bull. G.S.A.*, 49, 1951.

Johnson, W. R., Jr., and Straley, H. W., III (1953) Geomagnetics of the North Carolina coastal plain: Aritcle published in this bulletin.

Lee, F. W. and Swartz, J. H. (1940) Magnetic studies of the Florida peninsula, *Trans. Amer. Geoph. Union,* 21, 297-301.

Lee, F. W., Swartz, J. H. and Hemberger, S. J. (1945) Magnetic survey of the Florida peninsula, *U.S.B.M. Rpt. Inv.* 3810, 49 p.

MacCarthy, G. R. (1936) Magnetic anomalies and geologic structures of the Carolina Coastal plain, *Jour. Geol.,* 44, 396-406.

MacCarthy, G. R. and Alexander, J. A. (1932) What lies under the Coastal Plain, *E. Mitch. Sci. Soc. Jour.,* 50, 50.

————, Prouty, W. F., and Alexander, S. A. (1933) Some magnetic observations in the coastal plain area of South Carolina, *Journal. E. Mitch. Sci. Soc.,* 49, 20-21.

———— and Straley, H. W., III (1937) Magnetic anomalies near Wilmington, North Carolina, *Science,* 85, 362-364.

———— (1938) Geomagnetic reconaissance of the Carolina coastal plain, *Bull. G.S.A.,* 49, 1953-1954.

Miller, B. J. (1937) Geophysical investigations in the emerged and submerged Atlantic coastal plain, part ii, geological significance of geophysical data, *Bull. G.S.A.,* 48, 803-812.

Pressler, E. D. (1947) Geology and occurrence of oil in Florida, *A.A.P.G. Bull.,* 31, 1851-1861.

Prouty, W. F. (1946) Atlantic coastal plain floor and continental slope of North Carolina, *A.A.P.G. Bull.,* 30, 1917-1920.

Richards, H. G. (1945) Correlation of Atlantic coastal plain Cenozoic formations, a discussion, *Bull. G.S.A.,* 56, 401-407.

————(1945a) Subsurface stratigraphy of Atlantic coastal plain between New Jersey and Georgia, *A.A.P.G. Bull.,* 29, 885-955.

———— (1948) Studies on the subsurface geology and paleontology of the Atlantic coastal plain, *Proc. Acad. Nat. Sci. Phila.,* 100, 39-76.

———— (1948a) Tertiary invertebrate fossils from newly discovered locations in North and South Carolina, Acad. Nat. Sci. Phila., *Notulae Naturae,* 207, 11p.

———— (1950) Geology of the coastal plain of North Carolina, *Trans. Amer. Philos. Soc.* 40, 1-83.

———— and Straley, H. W., III (1950) Atlantic coastal plain, *Int. Geol. Cong., Rpt. 18th Session,* Gt. Brit., vi, 86-89.

Skeels, D. C. (1950) Geophysical data on the North Carolina coastal plain, *Geophysics,* 15, 409-425.

Spangler, W. B. (1950) Surface geology of Atlantic coastal plain of North Carolina, *A.A.P.G. Bull.,* 34, 100-132.

———— and Peterson, J. J. (1950) Geology of Atlantic coastal plain in New Jersey, Delaware, Maryland, and Virginia, *A.A.P.G. Bull.,* 34, 1-99.

Straley, H. W., III (1948) Coastal plain of North Carolina, *Jour. E. Mitch. Sci. Soc.,* 64, 250-252.

———— (1948a) The South Carolina coastal plain, *S.C. Acad. Sci.,* April.

Straley, H. W., III, (1953) Geomagnetic profile along Savannah River, article published in this bulletin.

Swain, F. M. (1950) Mesozoic ostracoda from subsurface of eastern North

Carolina, *Program and Abstracts*, A.A.P.G. meeting, Chicago, 45.

Swick, C. K. (1937) Gravity in southeastern Virginia, *Bull. A.A.P.G.*, 21, 333-337.

Woollard, G. P. (1940) Trans continental gravitational and magnetic profile of North America and its relation to geologic structure, *Bull. G.S.A.*, 51, 1954.

——— (1941) A comparison of magnetic, seismic, and gravitational profiles across the Atlantic coastal plain, *Trans. A.G.U.*, 21, part i, 301-309.

———(1941a) The surface and subsurface exploration of continental borders, *Trans. A.G.U.*, 21, part iiiA, 805-815.

——— (1943) Geophysical methods of exploration and their application to geological problems of New Jersey, *N.J. Dept. Cons., Geol. Ser. Bull.*, 54, 88p.

GEOMAGNETIC PROFILES ALONG THE SAVANNAH RIVER*

H. W. STRALEY, III

Georgia Institute of Technology

Introduction

Early in 1950, the projected erection of a large plant at Edenton, South Carolina, was announced. Before the area could be closed to scientific investigation by Congressional edict, military pronouncement, or man-made alterations of the terrestrial magnetic field, a survey was initiated. In order to connect with regional work, undertaken under the leadership of the present writer at the University of North Carolina, during the 1930s, it was continued to the lower part of the Savannah valley, where it intersected earlier traverses within the coastal plain of South Carolina, prior to the Cooper-River project, in that state.

Work was done with a vertical-field balance, Schmidt type (Askania Werke). Observations were made at one or two mile intervals along highways. Corrections were applied for temperature variation, diurnal change of the terrestrial field, geographic position, and drift of instrument. No depth determinations were attempted.

The project was cooperative. Transportation costs, in Georgia, were guaranteed by the Georgia Department of Mines,

*Read at the meeting of the Georgia Academy of Science, University of Georgia, April 27, 1951.

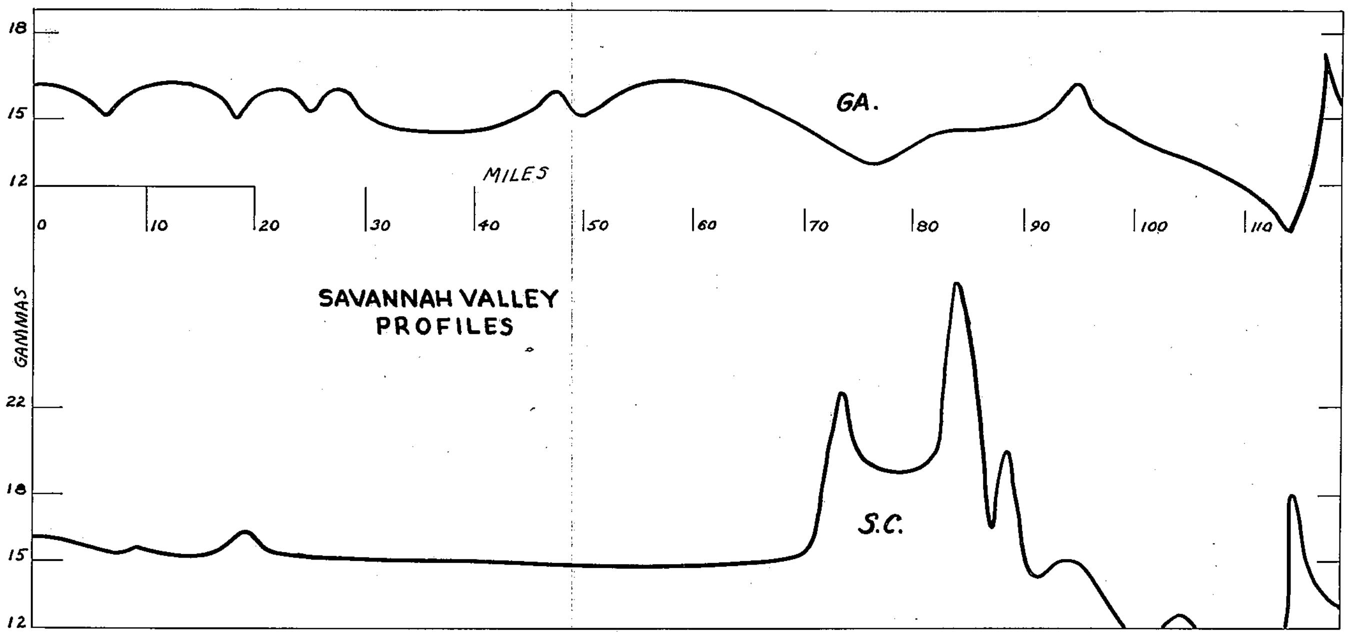


Figure 1. Magnetic Profile Along the Savannah River in Georgia and South Carolina.

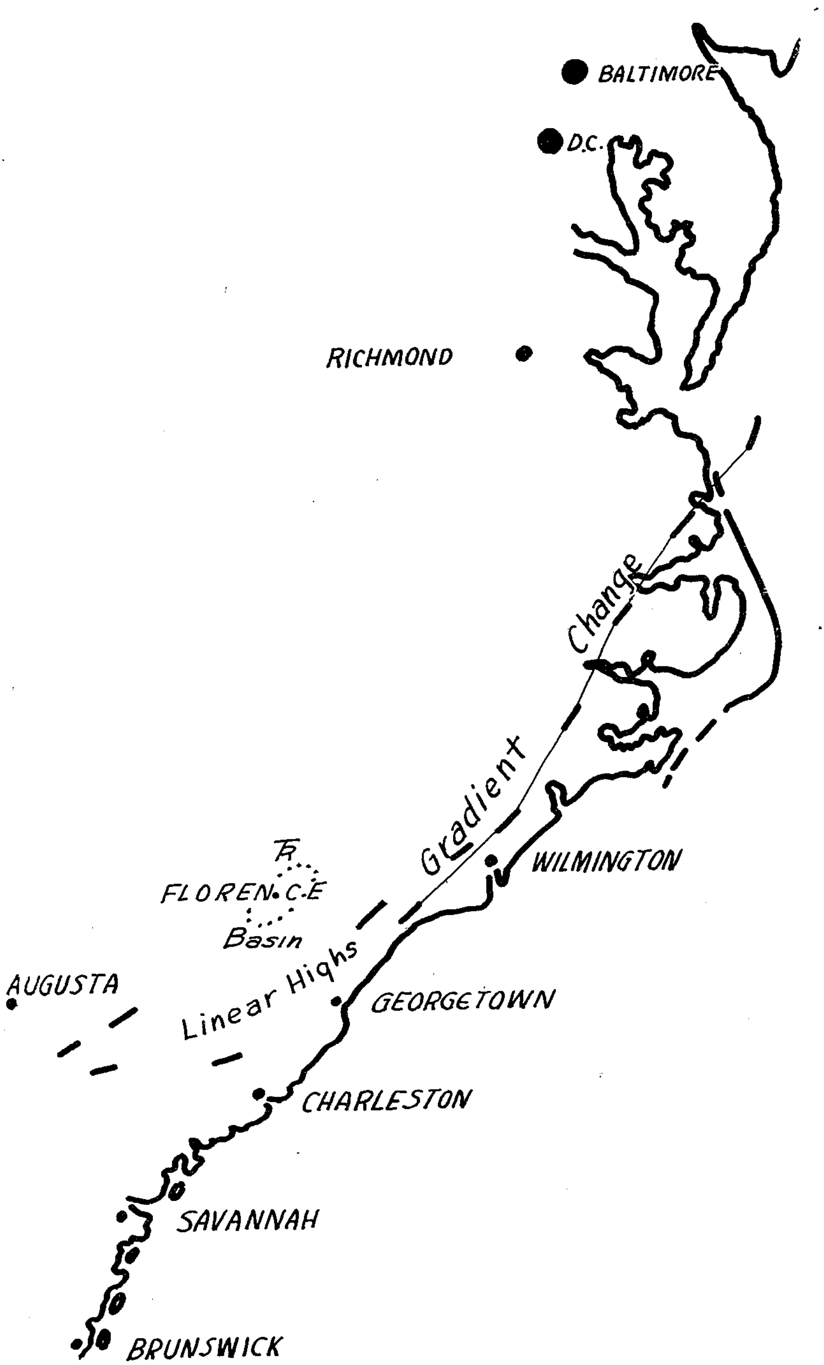


Figure 2. Prominent Magnetic Highs and Lows Along Atlantic Coast.

Mining, and Geology. Other field expenses were paid by a grant-in-aid from the Georgia Academy of Science and the American Association for the Advancement of Science. Instruments were loaned by Research.

Results are portrayed by figures and maps. Figure 1 is a profile along the valley of the Savannah, showing the geomagnetic anomalies and gradients at various places. Distances have been adjusted to straight line mileage measured by automobile odometer from the present coast, at the mouth of the Savannah. Figure 2 is a map of the Atlantic Coastal Plain from Chesapeake Bay to Florida, showing certain features noted in previous work.

Conclusions

The survey added detail to the regional geomagnetic map, initiated in 1935. It does not, however, bear out all of the generalizations of previous work or bring new ones to light.

The change of gradient in the surface of the basement complex noted elsewhere (Alexander, Berry, Johnson, MacCarthy, Prouty, Straley, Richards) is conspicuous by its absence. A glance at a map of the Atlantic coastal plain indicates a possible reason. This great feature, whatever may be its cause, probably lies beneath the water-covered portion of the plain in the great embayment south of the Carolina Ridge.

Noticeable linear highs and lows, discovered farther northeastward (Alexander, Johnson, MacCarthy, Richards, Straley) appear about 75 or 90 miles inland. Although not traced in detail to northeastern South Carolina or southeastern North Carolina, they are in the trend and reconaissance of intervening areas points to a connection. It is questionable, however, if any of these linear features is subcontinental in dimensions.

There appears to be a low magnetic ridge, which may be interpreted as basement irregularity or lithologic difference, trending east-west near Savannah. This may mark the southern extension of the Beaufort basin of South Carolina.

Likewise, there may be a similar ridge southwest of the Savannah, northwestward from Sylvania, Georgia. It may mark the western boundary of the Beaufort basin.

Between these two elevations, the Beaufort basin appears to open southwestward into northeastern Georgia. Finances were insufficient to permit a continuation of the observations into this critical area.

References Cited

Alexander, S. A., and MacCarthy, G. R., (1934), What lies under the coastal plain? *Jour. Elisha Mitch. Sci. Soc.*, vol. 50, p. 50.

Berry, Willard, (1948), North Carolina coastal-plain floor, *Bull. G. S. A.*, vol. 59, pp. 87-89.

Johnson, W. R., Jr., (1938), Geomagnetic reconaissance of the coastal plain of northeastern North Carolina, *Bull. G. S. A.*, vol. 49, p. 1951.

———— & Straley, N. W. III, (1953), Geomagnetics of the North Carolina coastal plain; Article published in this bulletin.

MacCarthy, G. R., Prouty, W. F., and Alexander, S. A., (1933), Some magnetic observations in the coastal plain of South Carolina, *Jour. Elisha Mitch. Sci. Soc.*, vol. 49, p. 50.

MacCarthy, G. R., (1936), Magnetic anomalies and geologic structures, *Jour. Geol.*, vol. 44, pp. 396-406.

MacCarthy, G. R., and Straley, H. W., III, (1937), Magnetic anomalies near Wilmington, N. C., *Sci.*, vol. 85, pp. 362-364.

———— (1938), Geomagnetic reconaissance of the Carolina coastal plain, *Bull. G. S. A.*, vol. 49, p. 1953.

Prouty, W. F., (1946), Atlantic coastal plain floor and continental slope in North Carolina, *Bull. A. A. P. G.*, vol. 30, pp. 1917-1920.

Richards, H. G., and Straley, H. W., III, (1948 - 1950), The Atlantic coastal plain, Int. Geol. Cong., *Rpt. 18th Session Ga. Brit., 1948*, part iv, pp. 86-91.

———— (1953), Some structural and stratigraphic features of the Atlantic coastal plain, article published in this bulletin.

Straley, H. W., III, (1948), The coastal plain of North Carolina, *Jour. Elisha Mitch. Sci. Soc.*, vol. 64, pp. 350-352.

———— (1948a), The South Carolina coastal plain, *S. C. Acad. Sci.*

GEOMAGNETICS OF SAVANNAH VALLEY

C. E. ROWLANDS, JR.
Carter Oil Co.

and

H. W. STRALEY, III
Georgia Institute of Technology

Introduction

During the 1930s, the University of North Carolina geological department made reconaissance geomagnetic traverses into the valley of the Savannah river. The primary purpose

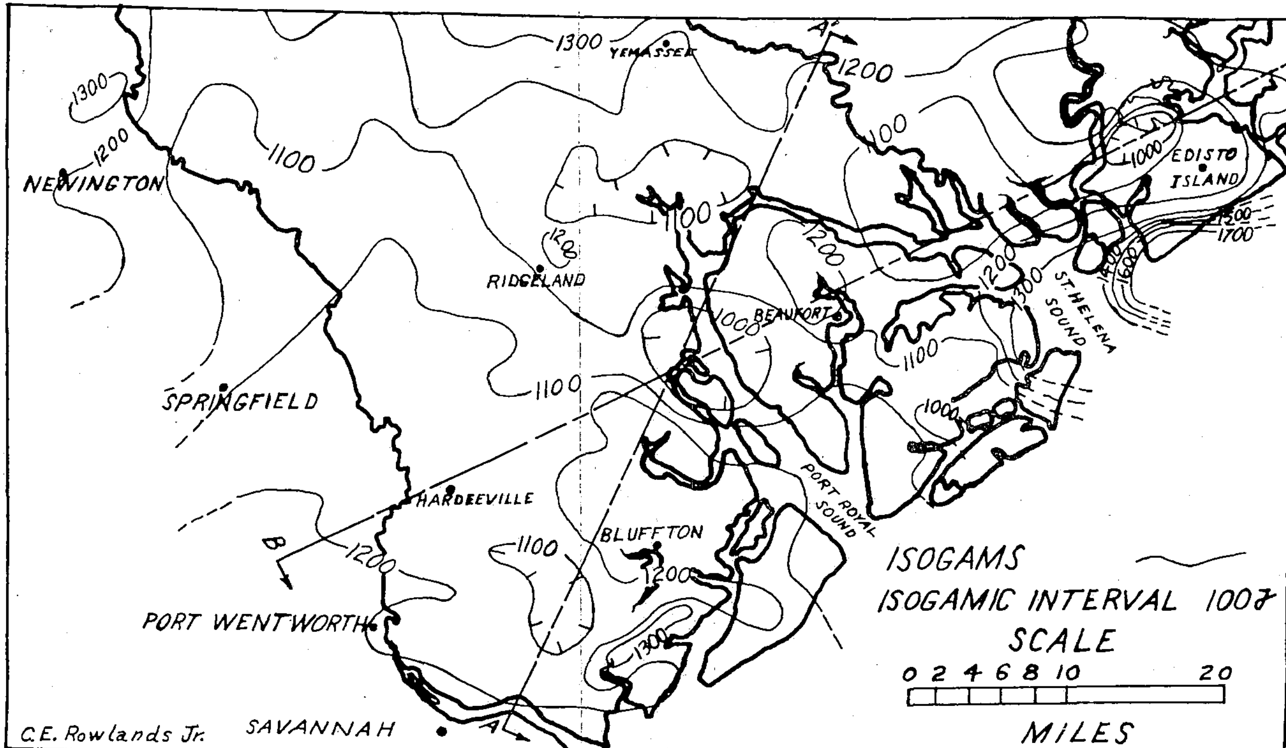


Figure 1. Beaufort Basin, S. C.

was to determine if there is a gradient change in the basement surface comparable to that found farther north in North Carolina, Virginia, and elsewhere. Secondarily, it was interested in extending the network of geomagnetism into the southern part of South Carolina and in discovering additional Carolina bays. (Alexander and MacCarthy; Alexander, MacCarthy, and Prouty; Johnson; Johnson and Straley; Johnson, Straley, and Straley; MacCarthy; MacCarthy and Straley; Prouty; Prouty and Straley; Richards and Straley; Straley).

In 1941, the American Association for the Advancement of Science supported connection of all previous Carolina surveys. The writers think that all non-commercial surveys, save those of the Georgia Department of Mines, Mining, and Geology and the United States Department of the Interior, that have been completed in the state of Georgia have been connected with those of the Carolinas, Virginias, and Pennsylvania.

In 1950, the American Association for the Advancement of Science, the Georgia Academy of Science, and the Society of Sigma Xi supplied funds to complete reconaissance of the Savannah valley southeast of Augusta. The Georgia Department of Mines, Mining, and Geology cooperated by furnishing part of the field expenses and plans to connect its own geomagnetic work to the network thus established. This should be completed during the field season of 1953.

ACKNOWLEDGMENTS. The writers wish to thank the sponsoring organizations, as well as Georgia Institute of Technology and all connected with the various Carolina parties.

Geomagnetics

Work was conducted as a typical geomagnetic road survey. A part of June 1951 was used in the field.

Figure 1 shows that Beaufort, Bluffton, Ridgeland, and other parts overlie rocks of low magnetic susceptibility. Discontinuously, in all directions from this low area are higher anomalies. To the north, Summerville and Walterboro are on the Summerville high (Straley, forthcoming). Southward, another high traverses Chatham County, Georgia, and the city of Savannah. It follows the Savannah river to Port Wentworth, Georgia, where it may open to the southward. On the western edge, higher anomalies trend northward through

Newington, Georgia. Northeast of Savannah the Beaufort depression opens seaward near Port Royal Sound, but from St. Helena Sound to Edisto Island is another elevation.

Within the depression lie smaller highs and lows. Beaufort is on the flank of a small elevation. North of Ridgeland, a small high and local low are situated. There are, altogether, four closed depressions within the larger one. A high projecting from the Atlantic has Blufton near its crest. The anomalies have a common east-west trend.

Both cross sections (Figure 2) pass over the landward extension of the Savannah-Port Royal Sound high. The dotted lines indicate the profile, if the effect of this basinward projection is removed.

Interpretation

The anomalies may be interpreted as: (1) folds of the basement; (2) topography on the basement surface buried beneath Cretaceous sedimentary rocks; (3) folds in an iron-rich sedimentary stratum; or (4) basement lithology and/or structure.

Some of the small highs may be associated with Carolina bays (MacCarthy; Prouty).

The floor on which the sedimentary rocks are deposited is deeper in this area than farther north. On the other hand,

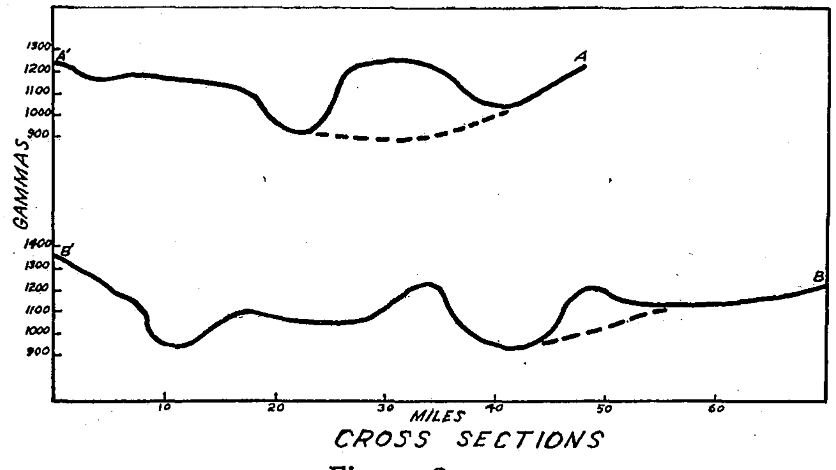


Figure 2.

the top of the Tuscaloosa is some 400 feet deeper in Chatham County, Georgia, than at Parris Island, indicating progressive deepening (Richards).

Folds in the basement would have affected superincumbent sedimentary rocks, as well as surface drainage. None of these effects have been noted on the surface or from well records.

Topographic irregularities of the basement surface have been noted elsewhere (Johnson; Johnson and Straley; Richards and Straley; Straley). On the contrary, the pattern is not that of normal topography. If it is topography, it must be controlled by lithology.

Aside from small limonitic concentrations, there is nothing in the stratigraphy to produce anomalies. The rocks are sands and clays, with a few impure marls. No iron-rich rocks, to produce postive anomalies, or dolomite or limestone, to produce negative anomalies, are known. It is, therefore, highly improbable that folds in the Cretaceous or Tertiary are responsible.

East-west, north-south, and northwest-southwest trending anomalies have been mapped farther north (Balsey, *et al;* Johnson; Johnson and Straley; MacCarthy and Straley; Richards and Straley; Skeels; Straley). Usually they have been interpreted as lithologically controlled. The probability is that the depression is, likewise, a lithological-structural feature within the preCretaceous rocks.

References Cited

Alexander, S. A., and MacCarthy, G. R. (1934) What lies under the coastal plain? *Jour. E. Mitch. Sci. Soc.*, 50, 50.

Balsey, J. R. *et al* (1946) Magnetic maps of Worchester County and part of Wicomico County, Maryland, U.S.G.S. *Oil and Gas Prelim. Map*, 46.

Ewing, W. M., Crary, A. P., and Rutherford, H. M. (1937) Geophysical investigations in the emerged and submerged Atlantic coastal plain, part i, geophysical studies, *Bull. G. S. A.* 48, 753-802

Hamm, S. I., and Heck, S. T., (1941) A gravity profile across the central Appalachians, Bauhannon, W. Va., to Swift Run Gap, Va. *A.G.U. Trans.*, 22, 353-362.

Johnson, W. R., Jr. (1938) Geomagnetic reconaissance of the coastal plain plain of northeastern North Carolina, *Bull. G. S. A.*, 49, 1961.

Johnson, W. R., Jr., MacCarthy, G. R., McCampbell, J. C., and Straley, H. W. III (1937) Tracing a basic dike, near Chapel Hill, N. C., by geoelectrical and geomagnetic methods. A.I.M.E., *Cont.* 106.

———————— (1940) Tracing a basic dike, near Chapel Hill, N. C., by geoelectric and geomagnetic methods. A.I.M.E., *Trans.*, 138, 160.

Johnson, W. R., Jr., and Straley, H. W., III (1934) Magnetic work in the Durham basin, *Jour. E. Mitch. Sci. Soc.*, 42, 156-163.

——————— (1935) An attempt to locate the boundaries of the Durham Triassic basin with a magnetometer. *Trans A. G. U.*, 16, 176-181.

——————— (1938) Geophysical work in Franklin County, North Carolina, *Jour. E. Mitch. Sci. Soc.*, 54, 197.

——————— (1938a) Tracing pegmatite dikes geophysically, *Bull. G. S. A.*, 49, 1951.

——————— (1941) Geophysical tracing of pegmatite dikes, *Pan. Amer. Geol.*, 25, 161-165.

——————— (1953) Geomagnetics of the North Carolina coastal plain, Article published in this Bulletin.

Johnson, W. R. Jr., and Straley, H. W., III and IV (1953) Estimated depth of anomaly source of Carolina Bays, Article published in this Bulletin.

Lee, F. W., and Swartz, J. H. (1940) Magnetic studies of the Florida peninsula, *A.G.U. Trans.*, 21, 297-301.

——————— and Hamberger, H. J. (1945) Magnetic survey of the Florida peninsula, U.S.U.M., *Rpt. Inv.*, 3810.

MacCarthy, G. R. (1936) Magnetic anomalies and geologic structures, *Jour. Geol.*, 44, 296-306.

———————, Prouty, W. F., and Alexander, S. A., (1933) Some magnetic observations in the coastal plain area of South Carolina, *Jour. E. Mitch. Sci. Soc.*, 49, 20-21.

——————— and Straley, H. W., III (1937) Magnetic anomalies near Wilmington, North Carolina, *Science*, 85, 362-364.

——————— (1938) Geomagnetic reconaissance of the Carolina coastal plain, *Bull. G. S. A.*, 49, 1953.

McCampbell, J. C., (1945) Meteorites and the Carolina bays, *Popular Astronomy*, liii, 1-4.

Nettleton, L. L. (1941) Relation of gravity to structure in the northern Appalachian area, *Geophysics*, vi, 270-286.

Prouty, W. F. (1946) The Atlantic coastal plain floor and continental slope of North Carolina, *A.A.P.G. Bull.*, 3, 1917-1920.

——————— (1952) Carolina bays and their origin, *Bull. G.S.A.* 63, 167-224 (Summarizes 20 years research with bibliography).

Prouty, W. F., and Straley, H. W., III (1937) Further studies of Carolina bays, *Proc. G. S. A.*, 104.

Richards, H. G., and Straley, H. W., III (1950) Atlantic coastal plain, *Int. Geol. Cong.*, *Rpt. 18th Ses.*, Gt. Brit., part vi, 86-91.

Skeels, D. C. (1950) Geophysical data on the North Carolina coastal plain, *Geophysics*, 15, 400-425.

Straley, H. W., III (1938) Geomagnetic reconaissance in the Appalachian mountains, *Bull. G. S. A.*, 49, 1962.

——————— (1948) Coastal plain of North Carolina, *Jour. E. Mitch. Sci. Soc.*, 64, 250-252.

——————— (1949) How deep are Appalachian anticlines, *Trans. W. Va. Acad. Sci.*

——————— (1950) Is the basement involved in Appalachian folding? *Int. Geol. Cong.*, *Rpt. 18th Ses.*, Gt. Brit., v. 121.

Straley, H. W. III and IV (1953) Some Georgia Carolina bays. Article published in this bulletin.

Swick, C. K. (1937) Gravity in southeastern Virginia, *Bull. A. A. P. G.*, 21, 333-337.

White, W. A. (1946) Blue Ridge, a fault-scarp, *G.S.A. Bull.* 57, 1242.

Woollard, G. P. (1941) A comparison of magnetic, seismic, and gravitational profiles across the Atlantic coastal plain, *Trans. A. G. U.*, 21, part i, 301-309.

——————(1941a) The surface and subsurface exploration of continental borders. *Trans. A. G. U.*, 21, part iiia, 805-815.

—————— (1940) Transcontinental gravitational and magnetic profile of North America and its relation to geologic structure, *Bull. G. S. A.*, 51, 1954.

—————— (1943) Geophysical methods of exploration and their application to geological problems in New Jersey, *N. J. Dpt. Cons.*, Geol. Ser. Bull., 54, 88p.

DEPTH TO ANOMALY SOURCE FOR CAROLINA BAYS*

W. R. JOHNSON, JR. (deceased)

H. W. STRALEY, III

and

H. W. STRALEY, IV

Georgia Institute of Technology

Introduction

Probably the entire scientific and half the lay world knows of a suggestion that a meteorite fragmented against the Carolina coastal plain (Melton, 1933). Proponents of this hypothesis have brought forward convincing arguments, among them the association of a magnetic high with each bay. Opponents have presented data to show the impossibility of such a collision, but have failed to explain magnetic anomalies.

There are several reasons why proponents of meteoritic hypotheses should select magnetic methods for exploration. They were searching for supposedly magnetic iron. If it survived impact, it must have left traces below the surface. What better method of search than the vertical-field balance? Gravitational residuals were not available. The seismograph

*Read at the Southeastern Mineral Symposium, Geology Department, Emory University, March 29-31, 1951.

was as useless as radon analysis of soil gas. Electrical methods were unreliable. It was a wise choice.

Although the elder Straley has done the lion's share of geophysical work on Carolina bays, the writers lay no claim to being authorities and have no favorite hypothesis. The present contribution deals solely with estimating depth to source of anomalies associated with bays, using a modified meteoritic hypothesis (MacCarthy, 1937) where method necessitated genetic assumption. No effort has been made to determine mode of emplacement.

ACKNOWLEDGMENTS. The writers are endebted to many persons, not all of whom it is possible to name. Free use has been made of published data, crediting where possible. During the course of field work, American Association for the Advancement of Science, Geological Society of America, Rockefeller Foundation, Smith Fund, and University of North Carolina contributed.

In the field, a number of persons were engaged. Time has, unfortunately, obliterated the name of a carnival balloonist, who did his utmost to make the areal experiment a success. Likewise, the ingenious carpenter, who made a portable observation tower, must remain anonymous. Observations were made by J. A. Alexander, Charles Hunter, T. D. Lance, H. E. Le Grande, G. R. MacCarthy, J. C. McCampbell, Grover Murray, W. F. Prouty, H. E. Vitz, W. A. White, and George Yoder, all staff and students at the University of North Carolina, Chapel Hill, and probably others whose names cannot be recalled.

Commercial establishments placed facilities at the disposal of the project. Observations were made under the auspices of Eastern Exploration Company, Worthington Consulting Service, and Research.

The writers wish to thank Captain Garland Peyton, director of the Georgia Department of Mines, Mining, and Geology, Mrs. Dorothy Crossland, librarian at Georgia Institute of Technology, and Mrs. Gaynell W. Barksdale, reference librarian at Atlanta University, for placing the facilities of their institutions at their disposal.

RESPONSIBILITY. Responsibility is divided clearly. Johnson did part of the field work, suggested procedure, and criticised interpretation. The junior Straley gathered physical data, computed, and prepared tables, in addition to suggesting interpretation. Straley senior conceived and led the project (not, however, any bay work), as he had much of the grandiose research that envisaged the department of geology, University of North Carolina, preparing geomagnetic maps from Florida to the St. Lawrence. To him, therefore, must go the onus for such errors as have crept into the study or its preparation.

FIELD WORK. Field work consisted of taking magnetic observations with Schmidt type (Askania Werke) vertical-field balances, at such intervals as appeared feasible. In some instances, control was by plane table and telescopic allidade; in others, pace and Brunton. Where possible, distances were measured by automobile odometer.

In some instances, observations at different elevations were made. A tower was constructed, from which observations could be made at an elevation of about 4 meters above the ground. In others, efforts were made to observe from a balloon, moored to a car on calm days and permitted to float at an elevation of 100 meters.

Angle of Approach

Depth of penetration of a projectile into the lithosphere is uncertain. Current research is under the utmost secrecy. Presumably, older formulae are being discarded or revamped.

There are inconsistances in older information. The National Academy of Science committee (Robertson, 1940) stated that the Poncelet (Poncelet, 1829) type of formula is most satisfactory. Others (Wessman) contend that shape has been neglected.

Although constants for Poncelet formula have been computed (Didion, 1837), the Petry (Petry, 1910) modification is more satisfactory for the problem under consideration.

$$x = k\,P \log_{10}\left(1 + \frac{v^2}{215{,}000}\right) \qquad (1)$$

where x is penetration in feet,
P is sectional pressure; W/A, in pounds/inches^2

v is velocity of impact, in feet/seconds
and k is a constant; a function of the material struck and including the acceleration of gravity; measured in feet inches^2/pounds.

Values of k are tabulated. The only uncertainty is P, for both weight of projectile and area of impact may be assumed.

Some limitations upon applicability are satisfied. Thickness of medium penetrated is greater than twice penetration and the body is supported continuously. Although formulae of this type are applied to projectiles impinging at low angles, the writers wish to stress inherent inaccuracies. Artillery formulae are not intended for velocity and mass hypothicated.

No reliable theoretical means of determining the diameter of a projectile from the size of its crater has been uncovered, when one considers the blast envisaged (MacCarthy, 1937). There are, however, empirical data. Shots were fired from weapons of known muzzle velocity, at angles comparable to those hypothicated and at known distances from the target (MacCarthy, unpub.). In no instance was projectile diameter/crater diameter as great as 1/10.

Furthermore, Meteor Crater, Arizona, offers possibilities for checking. It measures 4000 feet, or 0.8 mile across. The projectile has been found at a depth of 1340 feet. Drills penetrated 36 feet of it before freezing, which assures a minimum diameter of 1% of the width of the crater blown and gauged out of limestone, a rock less susceptible to removal by blast than unconsolidated coastal plain sediments (Watson, 1936).

In computing the weight of such an object, it has been assumed that it had, upon impact, a specific gravity of 5. Meteors strike the earth with speeds of between 7 and 40 miles/seconds.

Now, in equation (1), assume k to be 5 feet inches^2/pounds (Wessman, 1942), the specific gravity of the projectile 5, the velocity of impact 26 miles/seconds. Solve for x in terms of D (diameter of projectile in miles),

$$x = 190{,}666 \text{ D feet} \qquad (2)$$

and $d = xs$ in angle of approach $= x$ ratio of crater axes (3)
where d is depth to object.

Equation (3) has been solved for 10 or 12 bays (Table I)

Abscissa Distance

In Table I are depths determined by applying the Haanel and Tiberg rules (Jakosky, 1950), as well as another derived confidentially. These state that the depth to a spherical source is equal to the abscissa distance from the center of maximum vertical intensity, plotted on a cross section normal to the strike of the anomaly, to some fraction of the maximum.

Platform Method

If observations may be made at ground level and at some distance above, the depth may be found, if the difference in elevation is known. Results computed from observations made on a platform and in a balloon arreat in Table I.

TABLE I

Depth to Anomaly Sources (feet)

Bay	Geometrical Approach	GEOPHYSICS Tiberg	Haanel	Conf.	Plat.	Bal.	Reference
Big Bay, White Lake		2980	2330	2732			3
Little Dial	1470	2683	2610	3051	2650	2912	3
Little River	504	530	500	495	516	567	
Sessom	1570	3375	3784	3225			2
Shell Bluff (Georgia)	2365	1373	2367	1690			4
Singletary	1075	993	1066	1362			1, 3
Singletary (second)	1018	1986	1999	1862			1, 3
Syracuse	3120	1125	890	1151	1047	975	1
Unknown bay	890	1638	1598	3772			2
White Lake	1671	3905	3930	4120			1, 3
White Oak		1534	1948	1811			2
White Oak (second)		2482	2112	2540			2

References: 1 MacCarthy; 2 McCampbell;
3 Prouty; 4 Straley

Conclusions

Tables and development stand for themselves. With the exception of those dependent upon the modified hypothesis, they are standard and give acceptable results within their limits. Differences are due to exceeding the limits, the bodies not being spheres and platform distances far too small, and unreliability of assumed angles of approach.

References Cited

Didion, I. (1837) *Trait de balistique*, Leneveu, Paris.

Jakosky, J. J. (1950) *Exploration geophysics*, Trija, L. A. p. 186, 213

MacCarthy, G. R. (1937) The Carolina bays, *Bull. G. S. A.* 48, pp. 1211-1226.

MacCarthy, G. R., McCampbell, J. S., and Straley, H. W., III, (unpublished) Experiments on blast and blast craters.

McCampbell, J. S. (1945) A geomagnetic survey of some Bladen County, N. C., "Carolina bays", *Jour. Geol.* 44 pp.

Melton, F. A., and Schriever, William (1933) The Carolina bays—are they meteoritic scars? *Jour. Geol.*, 41, pp. 52-66.

Poncelet, J. V. (1829) Cours de mechanique industrielle and Rapport sur un memoire de Mm. Piobert et Morin, *Mem. Acad. Sci.*, 15, pp. 55-91.

Petry, J. (1910) *Monographies de systems d'artilleria*, Brussels.

Prouty, F. W. (1935) The Carolina bays and elliptical lake basins, *Jour. Geol.*, 43, pp. 200-207.

———— (1952) The Carolina bays and their origin, *Bull. G. S. A.*, 63, pp. 167-224.

Robertson, H. P. (1940) *Terminal ballistics;* tests at Rosedale.

Straley, H. W., III (1952) Some Georgia Carolina bays. Article published in this bulletin.

Watson, F. (1936) Meteor craters, *Pop.Astr.*, 44, pp. 2-17.

Wessman, H. E., and Rose, W. A., (1942) *Areal bombardment protection*, Wiley, pp. 60.

SOME GEORGIA CAROLINA BAYS*

H. W. STRALEY, III

Georgia Institute of Technology

Introduction

While in the field on another project, Captain Garland Peyton asked the writer to investigate a small, water-filled depression in Burke County (N33°8′, 81°55′W), Georgia,

*Read at the Meeting of the Georgia Academy of Science, University of Georgia, April 27, 1951.

which was suspected of having the characteristics attributed to Carolina bays. Accordingly, he went to Shell Bluff, on 10 February, 1951, to examine the pond.

Thanks are due to the Georgia Bureau of Mines, Mining and Geology for financing an interesting excursion, to the Georgia Academy of Science for furnishing accommodations, and to Research for the loan of instruments.

Topography

Burke County lies on the coastal plain side of the Fall Zone. It has gently rolling topography with one major tributary of the Savannah, Briar Creek. On the uplands, between 2 and 5 miles northwest of this stream, lie at least a dozen "wet-weather ponds".

They exhibit the characteristics of typical Carolina bays (Prouty), and attention was called to the Georgia occurrences by H. W. LeGrand remarkably elliptical with major axis strikingly subparallel northwest-southeast; sand rims at southeastern end; and no correlation between site and topography.

In contra distinction to most solution sinks, the Burke County bays are poorly drained. The absence of underground drainage offers an agricultural problem of some complexity, for much of the best land in the area is said to lie in them. The surficial stratigraphy is sand and clay, with only one indurated rock, a sandstone.

Magnetics

The area is covered with these depressions and in the short time allowed only two closed magnetic highs were mapped. Of these, the smaller appears to be associated with the bay indicated, although displaced slightly to the east from its position as estimated from Prouty's rule. The larger appears to be overlapping and due to a number of bays.

Normal field procedure was followed. Observations were made with an Askania, Schmidt type, vertical-field balance. All normal corrections were applied. The area examined in bay work is usually so small that latitude variation, in Burke County of the order of 10 gammas per mile, is usually neglected. For regional surveys in the Valley of the Savannah, longitude corrections may be considered useless.

Conclusions

Although the writer has done a deal of geomagnetic work for proponents of a prominent genetic hypothesis, he does not comment on the origin of these features. It may be noted that the depth to the projectile, if any, and source of the magnetic anomaly is of the order of 1400 or 2400 feet, which places it within the basement complex underlying the Cretaceous in this part of the state (Johnson).

References Cited

Johnson, W. R., Jr., Straley, H. W., III, and Straley, H. W., IV (1952) Depth to anomaly source for Carolina bays, Southeastern Symposium of 1951.

Prouty, W. R. (1935) Carolina bays and elliptical lake basins, *Jour. Geol.*, 43, pp. 200-207.

——————— (1952) Carolina bays and their origin, *Bull. G. S. A.*, 63, pp. 167-224.

GEOMAGNETICS OF NORTH CAROLINA PLAIN*

By

W. R. JOHNSON, JR. (deceased)

and

H. W. STRALEY, III

Georgia Institute of Technology

The late W. R. Johnson, Jr., conducted geophysical investigations on the North Carolina coastal plain during the mid 1930s (1938). The area lies between the Fall Zone and the present coast, beginning near the Virginia border and extending to Onslow County.

He used a Schmidt-type (Askania Werke), vertical-field balance, without temperature compensation. Corrections were made for temperature changes, geographical position, drift of instrument, and diurnal variation. The last was accomplished

*Read at the meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

by returning to a previously occupied station within three hours. Drift and misclosure were treated together by occupying a previously determined station as often as feasible. Geographical corrections were computed from U. S. Coast and Geodetic Survey data, to which organization thanks are due for information on magnetic disturbances.

All anomalies were computed on a base in the Arboritum of the University of North Carolina, Chapel Hill, to which work from Georgia to Pennsylvania was tied. Thus, results could be compared readily with those of Alexander, MacCarthy, and Prouty (1933, 1934, 1936, 1937, 1938), McCampbell (1945), and MacCarthy and Straley (1937, 1938, 1948) on the coastal plain; Johnson, MacCarthy, McCampbell, and Straley (1934, 1935, 1938, 1941) on the Piedmont; and Johnson (unpublished), Nettleton (1941), and Straley (1938, 1949, 1950) in the Appalachians. The investigations were, therefore, part of a regional program covering the Applachians, and Coastal Plain from the St. Lawrence to the Gulf of Mexico.

Johnson's part was closed in 1940, when he was stricken in the field while on commercial investigations. He had with him notes, computations, maps and typed manuscript for a North Carolina coastal plain contribution. Unfortunately, these papers were missing when he was returned home and have never been recovered. This summary has been prepared from fragmentary sources, including his Richmond (1938) notes, partially complete profiles, incomplete notes (Straley), and memory. In evaluating it, one must bear in mind that Johnson and Straley were partners in a number of ventures, including the research noted. The close association has made it possible to reconstruct the contribution. Errors must be attributed to Straley.

Results

Johnson noted five significant anomaly groups: (1) a linear positive zone along the Fall Zone; (2) a negative zone to the east; (3) another positive zone nearer the present coast; (4) a sharp increase in gradient, near the present shore line; and (5) a depression between the Dismal Swamp and the Carolina Ridge.

The first lies along and east of the Fall Zone. The anomalies are of the Piedmont order. He tentatively suggested an irregular upland topography for the basement. Toward the east, it slopes downward, in some places in dendritic patterns.

In Hereford and Martin counties, the highland gives place to uniformly lower anomalies, which he tentatively interpreted as a valley. Relief was thought to be of the order of 100 meters.

West of Edenton (Chowan County) and Plymouth (Washington County) rises another positive alignment, with anomalies slightly lower than the first. These, Johnson thought, represent the eastern flank of a valley.

That relief of the order cited is not unexpected is indicated at Fountain, Pitt County. In adjacent farmland, there are outcrops of granite that extend to the surface from a depth of some 60 meters below the fields.

Toward the coast from Edenton and Plymouth, the smoothed anomalies uniformly decrease. West of Fort Landing (Tyrrell County), Swanquarter (Hyde County), and Elizabeth City (Pasquotank County) the gradient becomes notably steeper. Johnson attributed this to a steepening of the basement surface, as noted by Alexander, MacCarthy, Miller, Prouty, Richards and Straley (1933, 1934, 1936, 1938, 1948, 1950) and Crary, Ewing, Miller, Rutherford and Swick (1937).

Johnson noted negative anomalies near the present coast, closing, if at all, off shore between Albemarle Sound and Onslow County. He suggested a basin attaining a depth of 2000 or 2500 meters.

He freely admitted the hypothetical nature of his conclusions. The change in gradient near the coastline, he considered most certain. Differences in basement lithology are the complicating factor and make interpretation difficult.

At no time did he feel confident of the discovery of petroleum or natural gas on the Carolina coastal plain.

References Cited

Alexander, S. A., and MacCarthy, G. R. (1934) What lies under the coastal plain? *Jour. E. Mitch. Sci. Soc.*, 50, 50.

Ewing, W. M., Crary, A. P., and Rutherford, H. M. (1937) Geophysical investigations in the emerged and submerged Atlantic coastal plain, part i, geophysical studies, *Bull. G. S. A.* 48,753—802.

Johnson, W. R., Jr. (1938) Geomagnetic reconaissance of the coastal plain of northeastern North Carolina, *Bull. G. S. A.*, 49, 1961.

———— and Straley, H. W., III (1934) Magnetic work in the Durham basin, *Jour. E. Mitch. Sci. Soc.*, 42, 156-163.

———— (1935) An attempt to locate the boundaries of the Durham Triassic basin with a magnetometer, *Trans. A. G. U.*, 16, 176-181.

———— (1938) Geophysical work in Franklin County, North Carolina, *Jour. E. Mitch. Sci. Soc.*, 54, 197.

———— (1938a) Tracing pegmatite dikes geophysically, *Bull. G. S. A.*, 49, 1951.

———— (1941) Geophysical tracing of pegmatite dikes, *Pan. Amer. Geol.*, 25, 161-165.

MacCarthy, G. R. (1936) Magnetic anomalies and geologic structures, *Jour. Geol.*, 44, 296-306.

————, Prouty, W. F., and Alexander, S. A., (1933) Some magnetic observations in the coastal plain area of South Carolina, *Jour. E. Mitch. Sci. Soc.*, 49, 20-21.

———— and Straley, H. W., III (1937) Magnetic anomalies near Wilmington, North Carolina, *Science*, 85, 362-364.

———— (1938) Geomagnetic reconaissance of the Carolina coastal plain, *Bull. G. S. A.*, 49, 1953.

McCampbell, J. C., (1945) Meteorites and the Carolina bays, *Popular Astronomy*, liii, 1-4.

Miller, B. J. (1937) Geophysical investigations in the emerged and submerged Atlantic coastal plain, part ii, geological significance of geophysical data, *Bull. G. S. A.*, 48, 803-812.

Nettleton, L. L., (1941) Relation of gravity to structure in the northern Appalachian area, *Geophysics*, vi, 270-286.

Richards, H. G., and Straley, H. W., III (1950) Atlantic coastal plain, *Int. Geol. Cong., Rpt. 18th Ses.*, Gt. Brit., part vi, 86-91.

———— (1953) Geophysical and stratigraphic investigations on the Atlantic coastal plain. Article published in this bulletin.

Straley, H. W., III (1938) Geomagnetic reconaissance in the Appalachian mountains, *Bull. G. S. A.*, 49, 1962.

———— (1948) Coastal plain of North Carolina, *Jour. E. Mitch. Sci. Soc.*, 64, 250-252.

———— (1949) How deep are Appalachian anticlines, *Trans W. Va. Acad. Sci.*

———— (1950) Is the basement involved in Appalachian folding? *Int. Geol. Cong., Rpt. 18th Ses.*, Gt. Brit., v, 121.

Swick, C. K. (1937) Gravity in southeastern Virginia, *Bull. A. A. P. G.*, 21, 333-337.

MAGNETIC RECONNAISSANCE, DAHLONEGA SPECIAL QUADRANGLE, LUMPKIN COUNTY, GEORGIA*

W. R. BROWN, D. W. GATES, C. E. ROWLANDS, JR., H. W. STRALEY, III

State Engineering Experiment Station and Georgia Institute of Technology

Introduction

The Dahlonega Special, Lumpkin County, lies in the heart of the Georgia gold belt. The quadrangle name comes from the county seat, Dahlonega, near the middle. Southward, one crosses Cane Creek, climbs low hills, follows a ridge top, and finally comes to the site of the former gold-mining camp of Auraria, called locally Nucklesville, which was long the center of eastern gold mining.

With decrease in gold mining, the U. S. Government mint was removed from Dahlonega and the area became somewhat deserted. Auraria developed into a veritable ghost town, only one street of which may be detected today and containing not more than a dozen families.

Iron mining, initiated before the Spanish-American War, has been sporadic, partially because of transportation. During the 1880's, three seams or veins were known in the southwestern quarter of the quadrangle. Failure to exploit them during and following the First World War discouraged industry, and natives have lost interest in the deposits.

Both transportation and paucity of resources contributed to the 1914-1920 failure at utilization. To remedy the latter, Captain Garland Peyton, director of the Georgia Division of Mines, Mining, and Geology conferred with the senior writer. It was concluded that geophysical exploration might uncover additional iron. A two or three week field investigation was decided upon, at that time, and initiated in July 1951.

Geology

The geology is complicated. To the east of Long Branch

*Read at the meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

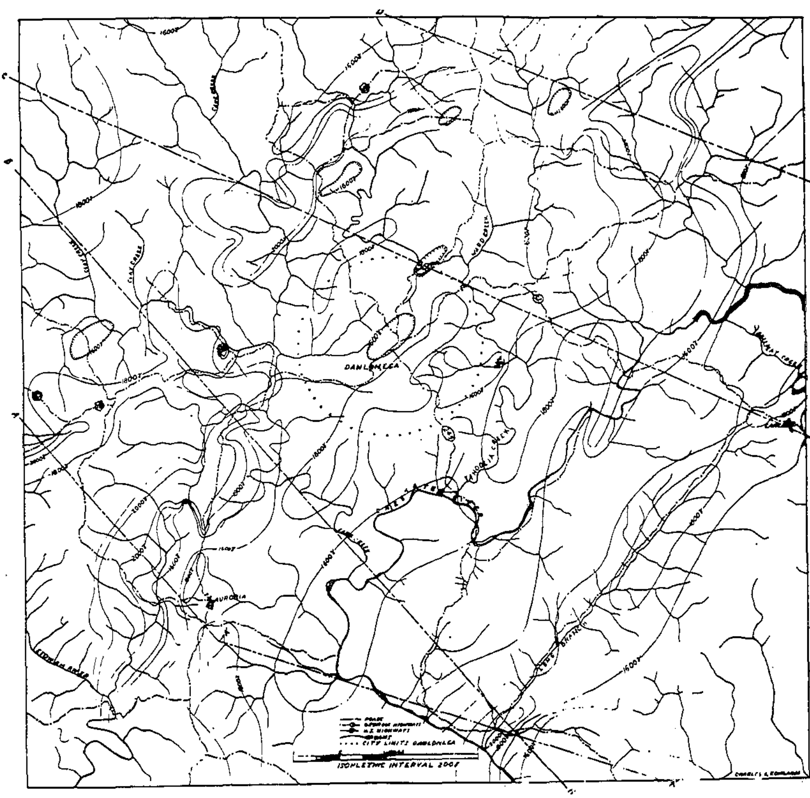


Figure 1. Geomagnetic map, Dahlonega Special Quadrangle, Georgia.

Creek (Figure 1) lie migmatites forming a low highland. The creek valley is cut along what is currently (1952) considered a fault. West of this fault, the Ashland forms strike valleys and ridges, across which the Etowah and Chestatee rivers pursue their courses. This formation is a biotite-hornblende schist, graphitic locally, containing hornblende gneiss, and dipping east or southeast.

West of Dahlonega and Auraria lies another schist, richer in muscovite and talcose in places. The structure of this belt is synclinal, complicated by northwest and northeast local structures. It is difficult to differentiate from Ashland, especially to distinguish one hornblende gneiss from another.

IRON. Dobson (1887) uncovered what he interpreted as three subparallel zones of iron ore, between five and nine feet thick. The westernmost is hematitic; the others, magnetitic, sometimes loadstone. He interpreted them as stratigraphic units, lying nearly flat, north of Cane Creek, and standing at high angles, south of Clay (Table I).

He does not report iron in certain parts along the trend of formations. North of land lot 829, near the intersection of the Cane Creek road with U. S. 19, they are high in sulphur (pyrite?). In that lot, he found only the two westernmost units represented. Between Cane and Clay Creeks, he left no record of their presence. Neither magnetitic body was actually traced far north of the Freetown road.

TABLE I
Analysis of Dahlonega Iron
(Percent)

	LAND LOTS			
	597	534	582	649
	Hematite		Magnetite	
Iron oxides	98.71	85.66	93.50	95.42
Metallic iron	68.10	—	67.69	69.08
Manganese oxide	—	1.46	0.016	—
Silica	1.01	1.67	6.24	4.25
Titanic acid	none	—	none	—
Phosphorous	none	—	none	—
Sulphur	none	—	none	—

Source: Dobson, *Report on iron fields of Dahlonega, Ga.*, 1887.

The easternmost, magnetiferous, crosses the Freetown road coincident with the magnetic high, herein styled Hedwig anticline. It forms a conspicuous outcrop along the road and extends northeastward from land lot 461, through 519, 518, 333, 534, to 566.

The westernmost, hematitic, is found in land lot 829 and northeastward. Along the strike, it appears in lots 648, 579, 341, 512, 466, 465, and 464. This course takes it from the western end of the Hedwig magnetic high, northwest of U. S. 19, to the Green-Acres road, and then roughly parallels the course of the Freetown road to the middle iron body at Hedwig.

From lot 329, the middle deposit is unreported until the western terminus of the Hedwig magnetic high. Here it occurs in land lots 683, 682, and 649, near the home of Oliver

Siebold, on U. S. 19. It reappears in lot 610; and again in lots 538, 513, 515, 466, 456, and 446, astride the Freetown road. In lot 465, the western magnetite is said to dip under the hematite, indicating anticlinal structure, as concluded from magnetic work.

The magnetitic iron deposits lie near the Ashland-muscovite schist contact. The bodies, between 5 and 16 feet thick, are largely granular, irregularly disseminated magnetite, although good crystals are often found toward the top, especially near the home of Siebold. They are, where observed south of Cane Creek, highly inclined, with varying strikes that may be interpreted at anticlinal between the Hightower Bridge, the Freetown road, Gibson's store where U. S. 19 crosses Cane Creek, and the Siebold home. This interpretation is based partially upon the geomagnetic work (Figure 1 and Figure 2) and partially upon the tentative conclusion

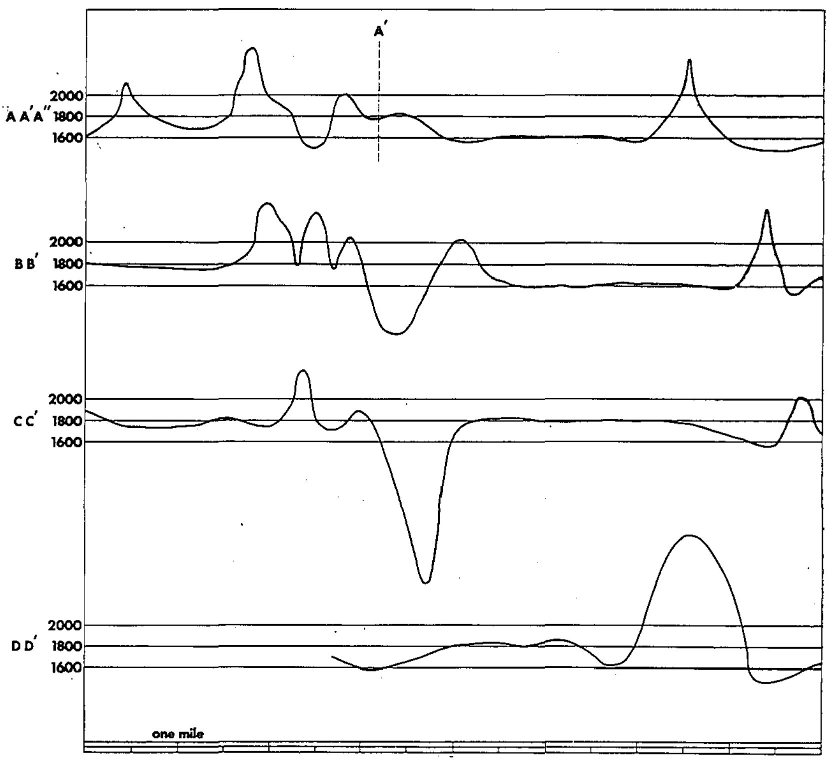


Figure 2. Magnetic cross-sections.

that schistocity closely parallels bedding, together with the hematite-magnetite relationship observed by Dobson.

Genesis. The origin of the iron deposits is undetermined, but it may be sedimentary as is indicated by the structures and conclusions summerized above. On the other hand, the western muscovite schist exhibits evidence of a basic core, which indicates possible igneous origin of hornblende gneiss exposed in the syncline. Perhaps, it may be connected with still intrusion prior to or simultaneous with deformation. That the magnetite is associated with hornblende gneiss, below which often lies quartzite, may be significant.

Geomagnetics

Insofar as possible, the writers followed the customary procedure for road surveys. The area is well served by roads and trails (Figure 1) over which an automobile may be driven. Observations were made at intervals of a quarter or a half mile. Along roads, distances were measured by odometer. Such data were supplemented, where necessary, by pace and Brunton surveys into key areas.

Vertical field balances, Schmidt type (Askania Werke) were used, with corrections for latitude and longitude, temperature, diurnal shift, drift of instrument, and misclosure.

HEDWIG ANTICLINE. Beginning just west of the Hightower Bridge, in the southern part, a belt of high anomalies extends for some four miles along the strike, N by NE, to Cane Creek. Near the home of Daniel Higgens, it bends sharply west and south to the residence of Oliver Siebold, on U. S. 19. Near the intersection of U. S. 19 with Georgia 52, one finds the same trend (?) leaving the map (Figure 1) toward the southeast. This pattern agrees moderately well with the outcrop pattern of hornblende gneiss, as shown on the manuscript geological map being prepared by Yoho.

The geological structure is tentatively interpreted as anticlinal. Along the eastern side, the schistocity dips toward the east or southeast. Cross sections AA'A" and BB' (Figure 2) may be interpreted as a possible fault, breaking a polarized member, on the eastern and southeastern side of the iron body, trending roughly with the Ashland outcrop. On the west, the body probably flattens into the generally synclinal muscovite schist.

CANE to YAHOOLIA. Along the same strike for more than two miles, is another area of high anomalies. They stretch from south of Cane Creek to north of Yahoolia, along and subparallel with U. S. 19 near its intersection with Yahoolia Creek. Cross sections (Figure 2) may be interpreted as the interruption of a polarized body terminated by a fault on the eastern or southeastern side.

CAVENDER CHURCH. Starting just southwest of Cavender Church and continuing to the northern edge of the map, lies another area of high anomalies. The shape of the anomaly (Figures 1 and 2) may be interpreted as a body lying a greater depth than the others, as well as probably polarized and broken on the east or southeast by a fault.

LONG BRANCH. The areas of high anomalies shown along Long Branch Creek (Figures 1 and 2) may be interpreted as reflections of the Nacoochee fault, along which the creek has carved its valley.

CONCLUSIONS

The writers are convinced that the bodies are sufficiently promising to warrant detailed investigation to permit determination of areal extent, thickness, and volume.

Reference Cited

C. M. Dobson, (1887) *Report on iron fields of Dahlonega, Ga.*

WATER PROBLEMS OF THE SOUTHEAST[1]*

By M. T. THOMSON

District Engineer, Atlanta, Ga.

The Southeastern part of the United States is noted for contrasts, changes, and problems. The water resources of the area have the same characteristics. Perhaps the story of the Southeast is more closely allied to her water resources than

[1]Publication authorized by the Director, United States Geological Survey.
*Read at the Southwestern Mineral Symposium, Geology Department, Emory University, March 29-31, 1951.

we would expect.

Water problems have always been a part of the history of the Southeast and today as the area is changing to diversified industry, water problems are assuming a complex and sometimes critical status.

Long before white men came to the Southeast the Indians had water problems. They knew that small streams would dry up for we have information that they poisoned fish left in the water holes. They avoided small stream sites for their villages, choosing instead major rivers where they always had water, and where they found most of their simple needs. On the major rivers they occasionally suffered from floods. There are records of floors during Indian times on many Southeastern rivers of the same magnitude as the maximum floods since white men developed the valleys. The Indians even referred to floods on the Alabama River near Montgomery in terms of frequencies not greatly different from the results of modern flood frequency analyses.

The Indian answer to floods was to move to a higher village site. Where we have built our cities, railroads and factories on land subject to flooding we have a more complex flood problem.

When Americans finally settled the interior of the continent, they raised more than they could consume but lacked adequate means of getting the surplus to market. This was at that time mostly a water problem. The Mississippi River provided ready transportation to the Gulf but coming upstream wasn't so good. The people seized upon the steamboat in answer to their need for upstream transportation. The ships for deep water traffic were unsatisfactory for the rivers, so Captain Shreve invented the shallow draft river steamboat with the boiler and engine mounted on the deck instead of in the hull. This solution to the problem built up the river navigation and created the great cities on the Mississippi River system.

The Atlantic seaboard cities were bypassed by the Mississippi and St. Lawrence River traffic. New York solved this water problem with the Erie Canal and New York City became America's largest city as a result.

Other seaboard cities had a tougher problem, for their canal routes proved impractical. They seized upon the railroad, and flung rails across the mountains. The railroads and, later, paved highways ended navigation on lesser rivers. The small rivers of the Southeast had too many meanders, too many snags, too many sand bars, and too long a period of low flow. Though there is little or no such river navigation at present, it may come back in the Southeast as a result of the overall river developments now authorized. Both the Ohio and Monongahela Rivers carry more tonnage than the Panama Canal, so we should not discount river navigation too hastily.

Manufacturing steel for the railroads grew into the country's greatest industry. Other manufacturing followed the North's steel industry to make that part of the country the greatest industrial area in the world. This was at a time of wild expansion when the resources of the country were ruthlessly exploited. In the process, northern rivers became grossly polluted.

While the North developed her industry the South concentrated on cotton which is peculiarly adapted to the heat, irregular rainfall, and dry autumn of the South's climate. "King" cotton prolonged slavery and brought in its wake secession and war. In the aftermath of war with its complete wrecking of the South's economy, the need for cash brought about the exploitation of cotton land and timber land. This made the already bad erosion problem critical. Soil conservation and reforestation is a vital water problem of the Southeast on which much progress is being made.

The textile industry developed in the South largely because of water assets. The South had abundant water power and soft river water. When Sam Slater started the cotton industry in America, he went to Providence, Rhode Island, where he found water power right at a deep sea harbor. Cotton textiles were being manufactured in South Carolina at the same time, but the South's water power was some distance from the coast on rivers that weren't too good for navigation. That was in 1790, before the steamboat. In the middle of the 18th century, cotton mills were built in the Southeast along the fall belt where there was water power and steamboat navigation. In the latter part of the century, the textile industry in the Southeast grew rapidly.

One reason for this growth was the perfection of the turbine that made it practical to develop high heads at waterfalls without the need for several canals with low heads adapted to water wheels. The steam engine was also improved making it practical to build mills somewhere else than on the river banks. Then came the transmission of high voltage alternating current that made it practical to build hydroelectric dams at isolated water power sites and to transmit the energy to factories close to cities and transportation.

Early water power developments utilized natural shoals by a low dam at the head of the shoals and a long canal to a power house at the foot of the shoals. Such developments were inexpensive and made good returns on the investments but they used only a fraction of the available power. As more power became necessary we learned how to build bigger dams and to use reservoirs to store water. With private capital alone such developments still could not fully develop the resource. As a result the Federal government took over regulation of water power on every stream in the country that affected navigable rivers. Private hydro-power development in the Southeast has practically ceased, but the Federal government with its great financial power is developing rivers in multipurpose projects of a magnitude scarcely dreamed of twenty years ago. These developments are not without new and perplexing water problems.

The timing of the South's textile and power developments had the effect of preserving a relatively clean condition in the rivers of the Southeast until the time when people understood the causes of typhoid and disentery, and objected to using polluted water.

Individual wells were impractical in crowded communities, so cities undertook the water supply function. Most cities have similar water supply stories. When they were small they used a well. Those fortunate enough to have adequate ground-water supplies continued to develop them but those which did not went to small streams until they were outgrown, then to reservoirs or large streams. As the cities of the Southeast have grown, and because they acquired industries that use water, the water supply problem has assumed critical proportions.

Unfortunately the problem is often obscured by the headline writers who scream "Water Shortage" when the real story is "City Growth". Our cities and their water supplies are like a little boy and his clothes. When the little boy outgrows his clothes his parents don't say, "How fast his clothes shrink". They are proud of his growth and set about getting some bigger clothes. So it should be in our cities. The water supply isn't going to grow with the city. When the water supply is outgrown, we need to get a bigger one. Where rivers supply the water, the shortage may not be generally recognized until a drought comes along which makes it easy to blame the trouble on the weather.

We have grown to the point where it is difficult and expensive to expand water supplies unless adequate groundwater supplies are available. Overpumping of ground water often leads to troublesome problems. Often when new surface sources are sought, it is found that they are polluted by upstream communities. The Southeast is fortunate in that the pollution problem is still subject to control by prevention, whereas in the older industrial sections of the country the pollution must be remedied—a very difficult water problem.

Water that is intended for municipal use must be potable and safe from water borne disease. Water consumers are also interested in the hardness of water and its content of certain dissolved minerals because of the effect on soap consumption, scaling or corrosion of boilers and hot water tanks, and the appearance and durability of fabrics in the laundry.

The need for comprehensive records of chemical quality for industrial use of water is continually increasing. In some cases the location of an industry depends almost wholly on an adequate supply of water of suitable quality. The Geological Survey makes comprehensive studies of the amount of dissolved minerals in surface and ground waters to provide the kind of data needed for industrial purposes. In addition, records are also obtained of the quantities of sediment in surface waters and the temperature of both surface and ground waters.

The importance of water quality to industry might best be illustrated by the recent press releases about the atomic energy plant on the Savannah River. The plant, it is said, will cost $260,000,000. Out of over 100 sites considered, water treatment facilities on Savannah River were estimated to be as much as $165,000,000 less than at some others. In the final choice, a saving of $40,000,000 a year was made by selecting the soft Savannah River water.

The wise use of water resources of the Southeast, the avoidance of errors committed in other parts of the country and the resolving of conflicting claims to our not unlimited water, require thorough basic factual information and a thorough understanding of the nature of water as well as the purposes to be served by its use. We have heard much of the hydrologic cycle, but its essential elements do not get across to the public. Possibly this is because hydrologists have attempted oversimplification or perhaps they have gotten themselves too involved. Actually the hydrologic cycle is not one but many cycles all more or less interlocked in a complex pattern.

Most of the difficulty in the Southeast seems to come from what is the biggest item of water use, evaporation and plant transpiration of soil moisture. Two-thirds to three-fourths of our rainfall is absorbed by the ground and later returned to the air by evaporation and transpiration. This is neither ground water nor surface water as they are commonly understood. It is soil moisture in the root zone. In the dormant season, the ground in the root zone tends to remain well saturated so a large part of the rainfall runs off to become flood flow. Also surplus water percolating downward to replenish ground water causes the water table to rise. In the growing season, evapo-transpiration losses are high, thus the root zone loses its moisture rapidly. A lesser amount of rainfall is rejected to go into stream flow, and little is added to the water table. A few weeks without rain may result in drought.

Thus, if we retain water in the root zone during the growing season by improved land use practices we derive considerable benefit to vegetation but we do not tend to improve either stream flow nor ground water. In the dormant season it doesn't make much difference because the ground tends to be saturated in any case. I bring this out to show that we cannot have our cake and eat it too.

The supply of soil water in the root zone is a significant factor in both ground water, which is distinguished from soil water, and stream flow. In the Southeast there is an annual variation of the water table, rising in the dormant season and falling in the growing season. The rate and amount of change is variable depending on many factors. Such records as are available do not show any significant long range change such as the popular notion that the water table is falling. Falling water tables and artesian pressures are primarily local effects of overpumping.

Stream flow also varies depending on the water table condition which in turn depends on the vegetative season. Stream flow is further complicated by storm runoff and man-made regulation.

There are some regional variations in stream flow that in Georgia can be localized by geologic regions. The mountain area has more rainfall than the rest of the State, thus as expected, it has more runoff. The Piedmont and upper and lower Coastal Plain have about equal rainfall but the runoff of the upper Coastal Plain is roughly double that of the other two areas.

The proportion of the low-water flow to the mean flow in the mountains and Piedmont is almost a quarter of the mean. In the upper Coastal Plain it is more than half while in the lower Coastal Plain it is only two or three percent. Small streams in both the upper and lower Coastal Plain have poor dry-season flows.

These are facts that must be faced. The Indians recognized them and did not live in the greater part of the lower Coastal Plain. When DeSoto marched through Georgia he had to subsist on the food stored in Indian villages. His route therefore skirted the lower Coastal Plain. That area has always been a problem area because of its water problems. That is the part of the State where almost every year we hear of prayer meetings for rain. The region has excellent artesian water supplies but due to the protracted low river flows it has little water power, little water for industry, little water for irrigation. It even has trouble finding water for stock. I noticed the other day when flying to Montgomery that the Black Belt, a similar area, has turned to grass and cattle, a sweeping change which has taken place in the past few years. The landscape is covered with little ponds to supply stock water.

Right now industries are attempting to locate sites for paper mills in the lower Coastal Plain to use the pine forests. There just isn't any adequate water supply for a paper mill within large parts of the area, and a storage reservoir to provide it would be more expensive than shipping the logs to an adequate stream. The solution to this problem will come through the recapture of wastes—converting them into useful products instead of letting them pollute the streams.

One would think that there would be little object in surveying river resources in such a poor area. That would be true if we were concerned only with power or water supply. However, this area is about 17 per cent swamp or overflow land. These flood waters must be passed through the bridges thus here we find the most severe bridge problems in the State. There is a special project in Georgia between the State Highway Department and the Geological Survey to collect and analyze flood information to help in the design of complex bridge waterways. Nine out of ten such problems in Georgia are in this area. This is further evidence of the multitude of water problems that must be considered.

Curiously, flood flows are best described by the frequency with which they recur. Thus, anyone has a fair notion of what is meant by a 50-year flood though he would have difficulty in defining it in terms of stage, flow or damage. Popularly, we dislike floods because they do damage. We expect flood control works to prevent floods. Today, we are having a rather high flood in Rome, Georgia, though a flood control reservoir is in operation on one of the two rivers that meet at Rome.

The average citizen in Rome will wonder why he has a flood after the reservoir was built. It is because the reservoir controls only the water from about a quarter of the drainage area that contributes to the flood at Rome. The designers of the flood control project recognized this and knew that floods at Rome would still occur but not so often. In the long run the reservoir will prevent much damage but it cannot stop floods on the other river. Stream-flow records show that the Etowah River on which the dam is located runs off several days earlier than the Oostanaula River. The dam by withholding flash run-off, can aid materially in flood control of the Coosa River as a whole, but it has no power to relieve floods on the other river.

Flood control, in the intent of the Flood Control Act, means more than the relief of flood damage. It means the control of flood waters to reduce the damage that they might cause and to make them useful for power, navigation, water supply, and so on. The design and operation of these multipurpose projects are based on stream-flow records obtained by the Geological Survey in cooperation with the States and the Corps of Engineers and others. Records over a long period of years are needed for the planning and after it is built the operation is regulated by gaging station data.

Unfortunately, much of the difficulty of the water problems of the Southeast comes from the very human limited point of view of the people involved. Few people have the opportunity to see all sides of the complex water problems so it is difficult to reach compromises that please everybody. In fact, the average citizen has a difficult time learning anything about a water problem. Much information is available if he knows where to find it, but is apt to be so technical he can't understand it or if simplified, it may reflect a biased point of view. Our farmers have great government organizations to help them with their problems. Big industries, cities, and government agencies have staffs of experts. The great mass of little industries, suburban folks, small communities have no such assistance. Their water problems are just as real and just as vital but they also have to find the facts for themselves and attempt to understand them.

We have touched lightly on many water problems of the Southeast. Each problem would make material for a number of technical papers but as we consider in detail the precise nature of a single aspect we must never lose our perspective. Water problems are broad and complex, thus involve the affairs of all our people. There is no better keynote to a discussion of water problems than the familiar little prayer written by William Inge in "Come Home Little Sheba", "God grant me the serenity to accept those things that I cannot change, courage to change those things that I can, and wisdom always to know the difference".

LOW-WATER MINIMUM FLOWS IN SOUTHEAST GEORGIA[1]*

By A. C. LENDO

Hydraulic Engineer, Atlanta, Georgia
U. S. Geological Survey

In 1798 Benjamin Hawkins, in his Sketch of the Creek Country, wrote, "The land between Flint River, O-ke-fi-no-cao, A-la-ta-ma-ha—is poor pineland. In the rainy season, which commences after midsummer, the ponds fill, and the country, the greater part of it, covered with water, and in the dry season it is difficult to obtain water in any direction for many miles."

In the January 15, 1950, issue of the Atlanta Journal there was a news item in which County Agent Harold Brown reported that a water shortage on scores of farms in the Moultrie section was proving costly, directly and indirectly. Some farmers were having to haul water long distances for their livestock and for themselves. Even some of the so-called deep wells in the rural sections had failed and all but the largest streams had gone dry. Cabbage plants were dying in the field and there hadn't been enough moisture to cause seed to sprout in the tobacco-plant beds. Rainfall in Moultrie, since October 1, had totalled only 3.26 inches.

It is the intent of this paper to show that the dry seasons described by Hawkins and Brown are not phenomena occurring 152 years apart but are characteristic of this area.

During a dry season in November 1943, engineers of the United States Geological Survey observed that most of the streams were dry, including some streams having a drainage area of as much as 500 square miles, as described by Hawkins. For example, the streams draining into the Okefenokee Swamp were dry. Daily discharge records for Suwanee River at Fargo, with a drainage area of about 925 square miles, show zero flow on many days during this period.

The Willacoochee River above Valdosta, draining a large

---

[1]Publication authorized by the Director, U. S. Geological Survey.
*Read at the Meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

area, was dry. The flow of the Alapaha River near Alapaha, with a drainage area of 644 square miles, was 0.3 second-foot. Many streams in the Moultrie and Thomasville areas and streams in the area above the Altamaha as far north as the Ogeechee were dry.

The United States Geological Survey, in cooperation with the Georgia Department of Mines, Mining and Geology, has maintained stream-flow gaging stations at ten sites on streams in this area since 1937 and some of the records extend back to 1927. These daily discharge records show dry seasons in other years as intense as that observed in 1943 and more severe droughts are known to have occurred.

A perusal of these records shows that the flow of Satilla River at Atkinson, with a drainage area of 2,880 square miles, was as low as 4.5 second-feet in 1931, whereas in 1943 the minimum flow was 40 second-feet. Zero flow at Fargo has occurred in years other than 1943, as mentioned previously, and Alapaha River near Alapaha has had minimum flows of 0.2 to 0.6 second-foot each year in the period 1937-43.

These low-flow conditions exist for a considerable period during the year. Suwanee River at Fargo shows an average daily flow for a 30-day period as low as 0.04 second-foot, and an average of less than 1.0 second-foot for the same period has been known at other stations on that stream. Duration curves for gaging stations in this area, with drainage areas of 550 to 2,900 square miles, show that for 20 percent of the time the flow averages less than 0.05 second-foot per square mile, with a range from 0.02 to 0.08.

For comparison, these larger streams draining the area, the Satilla, Suwanee, Alapaha, Willacoochee, and Ochlocknee Rivers, show an average flow of 0.01 second-foot per square mile during the month of lowest flow, whereas rivers flowing through the area with sources in the northern part of the state, such as the Altamaha and Flint, show an average flow of 0.30 second-foot per square mile during the low-flow month.

Some of the factors involved in these low flows are intensity and distribution of rainfall, type of soil and bed on which the soil rests, topography, geologic structure, ground-water recharge, and evaporation and transpiration.

According to records of the United States Weather Bureau the average rainfall for the area is 50 inches, about the same as the State average. The average precipitation was below 40 inches in six years during the period 1892 to 1948. The distribution of the rainfall during the year was very aptly described by Hawkins, for water is all over the area during the wet season, and difficult to find in dry seasons. The dry seasons usually occur during the last three months of the year but have occurred as early as June. During these dry seasons rainfall is less than 1 inch a month.

Evapo-transpiration plays a major role in these oft-occurring dry seasons. Approximately 75 percent of the annual precipitation is returned to the air from water surface and soil, and the rate of loss is highest during the dry-season months.

The geology is important in causing the streams to go dry in the Lime Sink Region, which lies at the southern end of the area along the Florida line. Streams flowing into this area lose a part of their blow to subterranean channels in the limestone—in dry seasons all of it is so lost. During the dry seasons the flow of a stream is determined by the amount of water reaching the stream by seepage through the soil from the ground-water reservoir. As the water table declines below the stream bed in this area, owing to evapo-transpiration and to ground-water flow away from the area in the underlying limestone, the ground water stops contributing and the streams go dry.

This area was known as wire-grass country. History shows that it was mostly uninhabited by the Indians and it wasn't until the white man came along with fertilizer that the area became settled. However, even in the present time this lack of water is causing the farmers to worry, as reported by Brown.

The statements by Hawkins and Brown, and the description of the underlying factors causing these dry seasons, clearly show that these conditions have often occurred in the past and probably will recur often in the future.

FLOOD REGIME OF THE COOSA-ALABAMA RIVER[1]* HISTORICAL AND MODERN

By

R. W. CARTER

U. S. Geological Survey

Atlanta, Georgia

In the days before white man came to this continent, the Indians made their home along the banks of the large rivers. The rivers served as a source of food, water for drinking and bathing, and for transportation.

Because their lives centered around the rivers, the Indians were keen observers of the droughts and floods that occurred. They learned by experience how far back from the rivers to build their villages to be above ordinary flood stage. Streams that went dry during drought period were quickly abandoned. Had the Indians been able to record their observations, this information would be invaluable in evaluating the effect of white man's use or misuse of the land upon the flow regime of the streams. Many ideas on this subject have been advanced and popularly accepted, but owing to the paucity of the supporting data, they must be classified as purely conjectural.

The earliest source of information regarding our rivers prior to the introduction of agriculture is found in the writings of the explorers and Indian agents who traveled through the country. Many of these writings refer to floods but give no definite information regarding the height of the water, the volume of flow, or the frequency of such events. One notable exception is found in the writings of Benjamin Hawkins, who was a government agent to the Indians. Mr. Hawkins recorded the flood experience at one Indian village on the Alabama River during his travels in 1796. The record is contained in the following passages from "Letters of Benjamin Hawkins"**:

---

[1]Publication authorized by the Director, U. S. Geological Survey.

*Read at the Meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

**Georgia Historical Society Volume 9, 1916, pp. 41-43.

. . . "Continue on 2 miles X a small creek, at Mucclassau, continue on in all 18 miles X a creek 10 feet wide. 1½ miles further X another creek and in half a mile arrive at the house of Charles Weatherford.

. . . **"Tuesday, 20th of December, 1796**—The residence of this man is on a high bluff on the left bank of the Alabama one mile below the confluence of the Coosau and Tallapoosa, it is the first bluff below, here are to be seen near his house 5 conic mounds of earth, the largest 30 yards diameter, 17 feet high, the others all small, about 30 feet diameter and 5 feet high.

"It has for some time been a subject of enquiry when and for what purpose these mounds were raised but here it explains itself as to the purpose. **The Alabama is not more than 150 yards over at low water, the banks high, yet subject to be overflowed in the season of floods, which happen once in 20 to 25 years.**

"The last flood was in January last, the river rose at the house where I am 47 feet high, it spread itself over the adjoining country for many miles and the general width of the river was below junction 6 to 7 miles, everything within that scope was compelled to retire from it to the trees on rising grounds or were destroyed. The margin of the river is low swamp and canebrake, the uplands stiff level, pine and oak very open.

. . . "The flood rises the highest in the Coosau, and some times so sudden as to drive a rapid current up the Tallapoosa for 8 miles." . . .

It is believed that these observations are worthy of comparison with present-day records of river stage. With this in view, the site described by Hawkins was visited by the writer and L. B. Peirce of Montgomery. The large Indian mound and Indian burying ground was found on the plantation of John Greer, one mile below the junction of the Coosa and Tallapoosa Rivers and 11 miles upstream from Montgomery, Ala. The mound had not been disturbed and was 90 feet in diameter and 17 feet high.

Mr. Greer stated that the river overflowed his land only twice since he moved there in 1926, once in 1929 and again

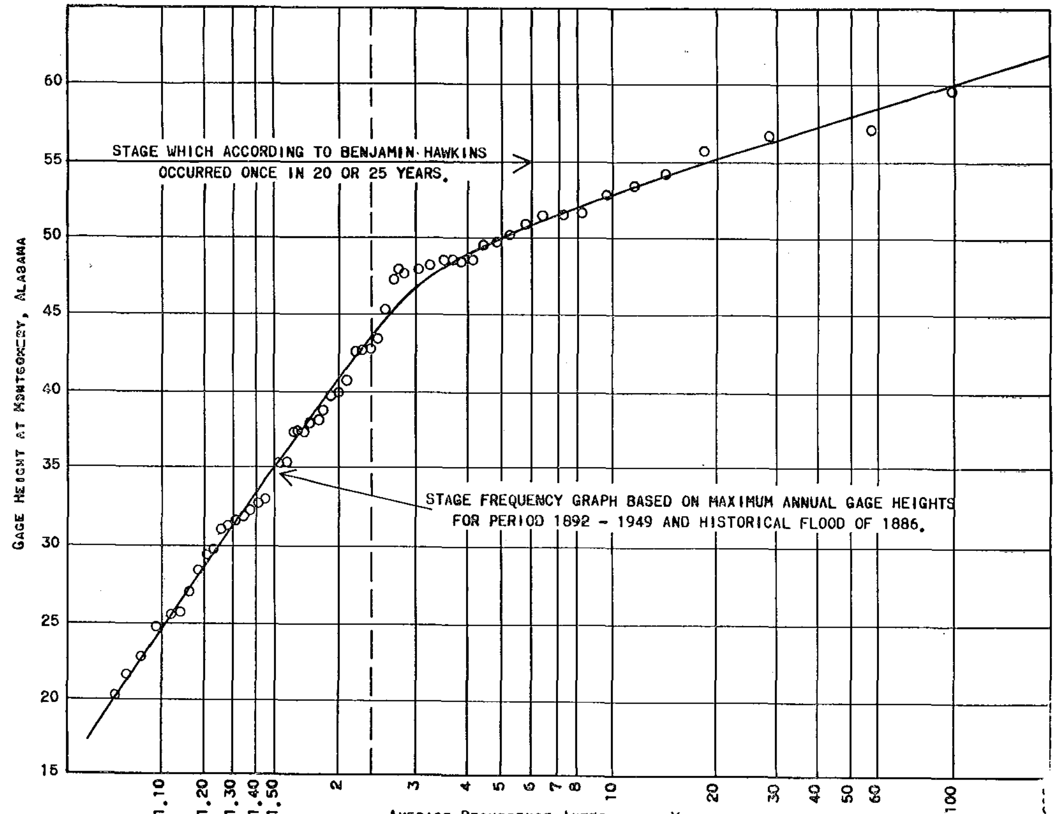


Figure 1. Flood Frequency Magnatude Relationship of Coosa River.

in 1948. He said that he had secured his stock on the old Indian mound during both floods. Mr. Greer referenced the height of the two large floods to the floor stringers of his home; the 1929 flood was 3 beet below the bottom of the stringer and the 1948 flood was 4 feet below the stringer. The mark of the 1948 flood was determined to be 46 feet above the river water surface at the same time the Montgomery gage read 8.3 feet.

Mr. Greer stated that the river almost overflowed one other year about ten years ago. This must have been the flood of April 1938, which reached a stage of 54.2 feet at Montgomery. This was the third highest flood at Montgomery during the period of Mr. Greer's residence, 1926-49.

As the river did not overflow the Greer plantation at stage of 54.2 feet in 1938 but did overflow at stage 55.8 feet in 1948, the overflow point is about 55 feet. According to Benjamin Hawkins' record, this is the stage above which the river rose once in 20 or 25 years.

Hawkins' description of the flood regime of the Alabama River is compared with present-day experience in Figure 1. The stage frequency graph shown is based on maximum annual river stages at Montgomery for period 1892-1949. The average recurrence interval of a stage of 55 feet during this period was 20 years.

This comparison suggests that if the Indians were nearly right in their frequency statement as reported by Hawkins, then the frequency of floods of that magnitude is practically unchanged. The small difference between the recurrence interval of this flood height as reported by Hawkins and that indicated by the present day data is well within the limits of the expected error of even modern data.

Far-reaching conclusions cannot be drawn from this one observation, but it should be considered, along with any other data available, in evaluating the effect of white man's civilization upon the flood regime of our streams.

DISCHARGE RECORDS AND THEIR VALUE IN DESIGN OF BRIDGE WATERWAYS[1]*

By

C. M. BUNCH

U. S. Geological Survey

Atlanta, Georgia

Fundamentally, a bridge is a grade separation structure, passing hydraulic traffic under vehicular traffic. Much attention has been given to the determination of volume, trend and frequency of peak vehicular traffic, but little has been done to estimate accurately the hydraulic traffic. From a study of volume and trend, highway traffic can be reliably predicted for the immediate future, but hydraulic traffic cannot be predicted in the same way, as next year's peak flow may be a minor event, or it may be a major catastrophe. The magnitude and frequency of the hydraulic traffic are important in design but they cannot be determined by the most thorough survey of the site made at one time or in a short period of time. A long-term record of this traffic is necessary for an adequate design of highway structures. An engineer is no more warranted in undertaking the design of such structures without attention to hydraulic requirements than he would be in undertaking to determine the size of members without first ascertaining the loads that may come upon them.

The discharge records collected by the Geological Survey furnish a logical basis for the design of structures that are to provide passage for what is here termed "hydraulic traffic". These records are published each year in the Survey's water-supply papers. In recent years, much information has been obtained and reports published giving the results of many special field investigations of outstanding floods. Compilations of flood peaks and computations of discharge frequencies are now being prepared in several Survey offices. This array of data, when properly analyzed, and in some cases, adjusted for special applications, can be especially useful

[1]Publication authorized by the Director, U. S. Geological Survey.
*Read at the Meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

and valuable to the highway engineer; the use of such data will enable the best design of highway bridges, from both an economic and a safety standpoint.

The Special Committee on Flood Protection Data of the American Society of Civil Engineers has stated that:

> "It is important to emphasize strongly that the soundest basis for the study of floods as a guide for protective works and measures is the available authentic information regarding floods that have occurred. This information may pertain either directly to the stream under investigation or to other streams having comparable physical characteristics. Though flood formulas have a definite and valuable place in the recording of experience and in the analysis and interpretation of flood flows, they have such limitations of use that the individual investigator is safest if he bases his analysis to the fullest degree possible on original flood data and related hydrologic information."

The selection of the size of the bridge opening is not a proper function of the Geological Survey, but it is a proper function of the Survey to assist the design engineer and the hydraulic engineer of the highway departments by presenting as great an array of pertinent information as can be assembled. The final selection should be governed by the policy controlling the design in respect to frequency, hydraulic requirements, factor of safety, and economic consideration. To calculate properly the size of a bridge opening requires a knowledge of the magnitude and frequency of recurrence of flood discharges, the relation of the elevation of the water surface, or stage, to the discharge, and the physical and hydraulic characteristics of the stream channel.

The highway departments of seven southeastern states, including Georgia, now have cooperative programs with the Geological Survey. The Georgia program was begun in the summer of 1947, and during the period 1947 to date, analyses of flood flow characteristics have been made at about forty proposed bridge sites. Studies of past floods and estimates of frequency of recurrence have resulted in designs that, in many instances, represented substantial savings over designs that probably would have been used prior to the time when hydrologic data was available.

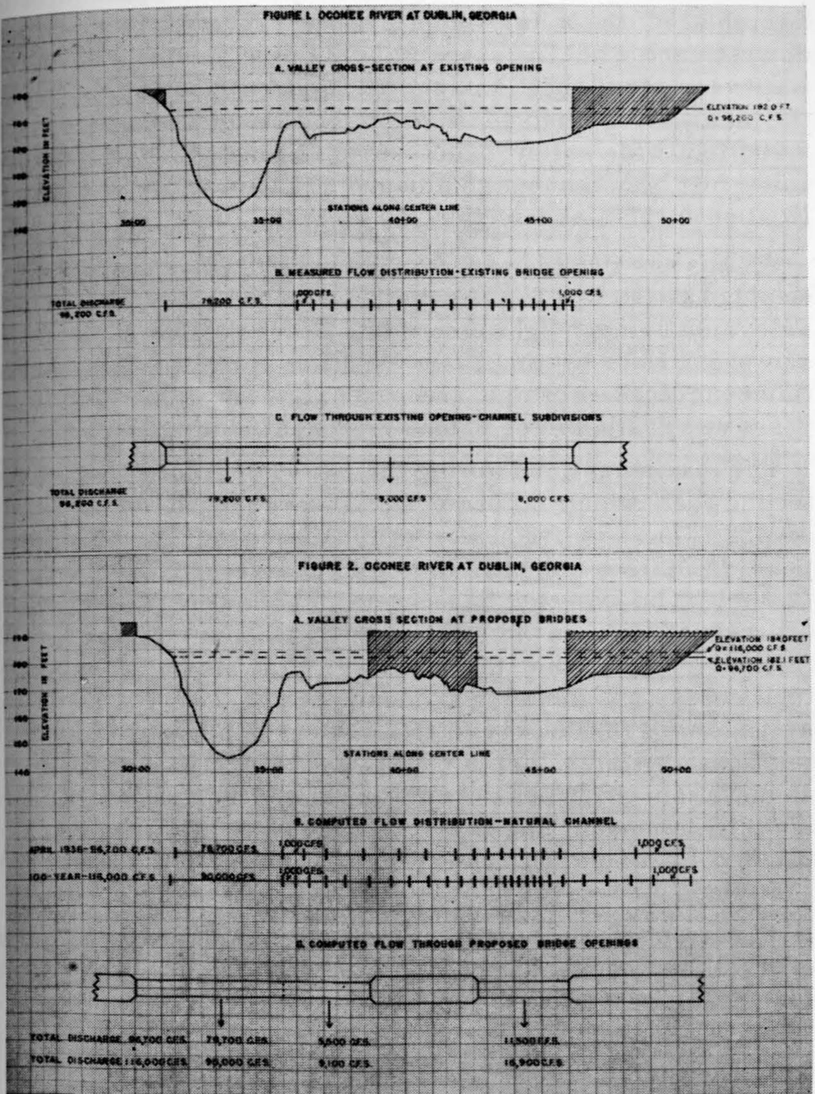


FIGURE I. OCONEE RIVER AT DUBLIN, GEORGIA
A. VALLEY CROSS-SECTION AT EXISTING OPENING
ELEVATION IN FEET
ELEVATION 192.0 FT.
Q=96,200 C.F.S.
STATIONS ALONG CENTER LINE
30+00
35+00
40+00
45+00
50+00
B. MEASURED FLOW DISTRIBUTION-EXISTING BRIDGE OPENING
TOTAL DISCHARGE 96,200 C.F.S.
79,200 C.F.S.
1,000 C.F.S.
1,000 C.F.S.
C. FLOW THROUGH EXISTING OPENING-CHANNEL SUBDIVISIONS
TOTAL DISCHARGE 96,200 C.F.S.
79,200 C.F.S.
9,000 C.F.S.
8,000 C.F.S.
FIGURE 2. OCONEE RIVER AT DUBLIN, GEORGIA
A. VALLEY CROSS SECTION AT PROPOSED BRIDGES
ELEVATION IN FEET
ELEVATION 184.0 FEET
Q=116,000 C.F.S.
ELEVATION 182.1 FEET
Q=96,700 C.F.S.
STATIONS ALONG CENTER LINE
30+00
35+00
40+00
45+00
50+00
B. COMPUTED FLOW DISTRIBUTION-NATURAL CHANNEL
APRIL 1936-96,700 C.F.S.
79,700 C.F.S.
1,000 C.F.S.
1,000 C.F.S.
100-YEAR-116,000 C.F.S.
90,000 C.F.S.
1,000 C.F.S.
1,000 C.F.S.
C. COMPUTED FLOW THROUGH PROPOSED BRIDGE OPENINGS
TOTAL DISCHARGE 96,700 C.F.S.
79,700 C.F.S.
5,500 C.F.S.
11,500 C.F.S.
TOTAL DISCHARGE 116,000 C.F.S.
90,000 C.F.S.
9,100 C.F.S.
16,900 C.F.S.

The design of a new crossing of the Oconee River at Dublin, Georgia, is a recent example of the use of discharge records resulting in a sizable saving in cost of the proposed structure. The existing bridge is a turn-span type and is to be replaced by a four-lane structure located immediately downstream with fixed spans built high enough above the water surface to meet navigation requirements. At this point the main river channel is on the extreme right side of a 2,000-foot-wide valley. The existing bridge, built in 1920, is 1,500 feet between end abutments. Figure 1 shows the bridge location in plan and section.

At this site records of discharge have been obtained by the Geological Survey for the periods 1898-1913 and 1931 to date, and a gage-height record has been collected at the same site since 1893 by the U. S. Weather Bureau—thus a continuous record of stage and discharge for a period of 56 years was available for a flood frequency study.

The maximum flood during the period of record was 96,700 second-feet, which occurred April 12, 1936, at an elevation of 182.1 feet. A frequency graph based on the 56 annual peak discharges indicates that a discharge of 96,700 second-feet might be expected to recur as an annual maximum on an average of once in 38 years. By extrapolating, the graph further indicates that the discharge that might be expected to occur as an annual maximum once in 100 years, on an average, is 116,000 second-feet. A curve of stage-discharge relationship shows that the 100-year discharge would occur at elevation 184.0 feet. As the proposed bridge is a link in a quite important highway, the highway department had decided to design a structure that would safely pass a 100-year flood.

A current-meter measurement was made near the crest of the 1936 flood by J. W. Kuhnel, operating out of the Ocala, Florida office of the Geological Survey, which handled the work that was done in Georgia before active participation in a stream-gaging program by the state. This measurement was invaluable in that it showed the actual distribution of flood discharge in the channel and substantially verified theoretical methods of computing distribution used when no current-meter measurement is available.

Figure 1B is a graphic presentation of the information provided by the discharge measurement. The concentration of flow in the main channel is to be expected. The graph shows a concentration of flow in the 300-foot section of the opening adjacent to the left-bank abutment, which is primarily due to greater relative depth and better flow conditions. It also indicates that the next 400 feet of opening is not carrying its proportionate part of the flow and, as the mean velocity through the entire flood plain section was far below the maximum allowable, suggests that the inefficient section of the opening might safely be eliminated.

Figure 2B shows the computed distribution across the natural or unobstructed channel of the 38-year and 100-year flood discharges. The same concentration of flow, between stations 42+00 and 45+00, is indicated and suggests the proper locations for openings. As a result, openings were designed by the highway engineers as shown in Figures 2A and 2C. When the discharge is routed through them on the basis of their relative capacities, the resulting mean velocities are within allowable limits as set by the highway department.

The substitution of earth fill for bridge opening in the section of least concentration of flow will represent a saving of approximately $200,000 in the total cost of the proposed crossing.

EFFECT OF BUFORD RESERVOIR ON FLOW OF CHATTAHOOCHEE RIVER AT ATLANTA[1]*

by

R. W. CARTER

Hydraulic Engineer

Atlanta District U. S. Geological Survey

Buford Dam, now under construction on the Chattahoochee River 40 miles above Atlanta, is a unit of an integrated overall plan for the development of the river. The principal purposes of the project are: to provide an increased flow for navigation in the lower river below Columbus, Georgia, during low-

---

[1]Approved by The Director, U. S. Geological Survey.
*Read at the Meeting of the Georgia Academy of Science, University of Georgia, April 27, 1951.

flow seasons; to provide flood protection in the valley below the Dam; to produce hydroelectric power; and to assure adequate water supply for municipal and industrial uses of metropolitan Atlanta.

Buford Reservoir will provide 377,000 acre-feet of storage capacity for flood control purposes, 935,000 acre-feet of usable storage for power and water supply purposes, besides a minimum lake containing 765,000 acre-feet. Economic, engineering, and stream flow factors have entered into the determination of these amounts. The minimum lake will be maintained to provide head for hydroelectric power development at the dam. The storage reserved for flood control, equivalent to about 7 inches of run-off from the drainage area above the dam, may not be used for power and water-supply purposes for fear of losing some of the flood-control benefits in flood emergencies.

The usable storage will be the most valuable function of the reservoir because it will provide the water to benefit navigation and for Atlanta's supply, and for hydroelectric power which is by far the greatest benefit from the project. The amount of this storage, its use and the effect on the river flow downstream are determined from stream flow records at gaging stations.

There are four gaging stations in the Chattahoochee River Basin above the dam site, one at the dam site and eight downstream from it. The gaging stations are operated by the United States Geological Survey in cooperation with the Georgia Department of Mines, Mining and Geology, the Corps of Engineers, and the Georgia Power Company. All of the gaging stations pertain to the overall river development projects, but two in particular show the effect of Buford Dam. These are the station at the site and the Vinings station just above Atlanta's waterworks intakes.

The gaging station records provide systematic information of river stages, the relation between stage and flow, usually termed gage height and discharge, and the daily flow, or discharge, over a long period. When needed, discharge records at a site that does not have a gage may be computed from those of a nearby gaging station. The daily record of discharge when plotted graphically is termed the hydrograph.

Figure 1 is the hydrograph of the Chattahoochee River at Buford Dam for the year 1925. This has been computed from the records of the Norcross gaging station which was in operation that year. It shows the effects of rain storms in causing increases of flow that last for a few days, and the sustained flow between freshets. In 1925 there were few rain storms so the flow declined to unusual low levels by September. Fortunately heavy rains in October and November relieved the drought but not before it had set all time records of low flow in Georgia.

If storage were not provided the minimum flow in 1925 would be all that could be depended on. Development of the river on this basis would obviously fail to use most of its potential water resources.

The average flow of the river at Buford as shown by long records of the flow at gaging stations is 2,010 second-feet. This amount could be made available all the time if sufficient reservoir storage capacity were provided. It is not economically feasible to do so at this time, however, as the plans for Buford Reservoir call for a regulated flow of 1,600 second-feet. This flow is shown on the hydrograph. It is the effect of STORAGE at a reservoir. STORAGE tends to make the flow uniform by utilizing the otherwise wasted, sometimes destructive, flood waters to increase the dry season flows. Thus, flood control becomes more than just the alleviation of

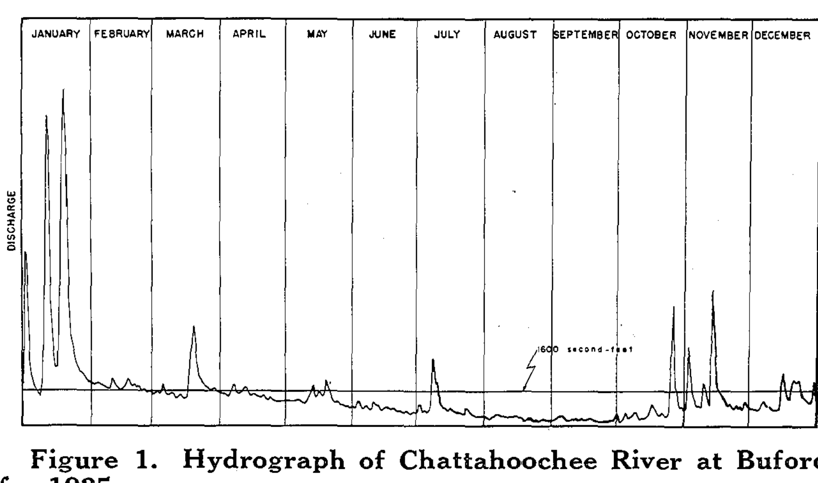


Figure 1. Hydrograph of Chattahoochee River at Buford for 1925.

flood damage. Floods become a resource instead of a liability.

A regulated flow of 1,600 second-feet at the net head of 136 feet would product 19,800 horsepower at normal efficiency, or 14,800 kilowatts of continuous hydroelectric power. Because of the great cost of the dam and reservoir this amount and type of energy would not be economical. In this region it is better to use steam energy for continuous power loads. Steam energy, however, is not well adapted for peak power. Hydroelectric power is most valuable for peak power, the sudden increases of power loads that take place in any power system.

As peak power loads usually occur during the day, the hydroelectric energy will be developed mostly during the day, and even then only at certain brief periods. At night the power will come from steam plants so the hydroelectric plant can be closed down. This allows water to be stored for use the next day. This practice, which is common even at small grist-mills, is called PONDAGE. The effect of pondage is opposite to that of storage. Pondage tends to make the flow from the power house irregular but in a calculated useful manner controlled by man, instead of by nature, for man's best interests.

Pondage is used not only on a daily but also on a weekly pattern. The five-day week is now well established so there is more use of electric energy on Mondays through Fridays than on Saturdays, and much more than on Sundays. Because peak power demand varies during the week, the operation of the hydroelectric power plant varies in the same manner, using weekly pondage in the reservoir to store water when the turbines are idle.

By use of pondage much more water for generation of power is available during peak hours, so larger turbines and generators are need than for a uniform power rate. At Buford Dam the total generator capacity will be 86,000 kilowatts, or 118,400 horsepower. At the head of 136 feet, 8,000 second-feet of water would be passed through the turbine to generate this amount of power. As the regulated flow is only 1,600 second-feet it would be possible to run the power plant at full load only 20 percent of the time. If the plant were operated on this basis only, the flow from the turbines could be 8,000 second-feet for about 7 hours each day Mondays through Fridays, and nothing for the rest of the time.

To regulate the flow at Buford Dam so completely for power purposes would be detrimental to the other purposes to be served by the project. The flow in the river below the dam would be a series of daily floods interrupted by short periods of extraordinary drought conditions. Navigation in the lower river would be handicapped without Bartletts Ferry Dam and Reservoir above Columbus, which would greatly modify the "wave" effect. Most severe would be the water shortages that would occur at Atlanta. To avoid this problem Buford Dam will have a small 6,000 kilowatt generator which will operate efficiently with a flow of 600 second-feet. This small generator will run continuously between peak periods and will provide a minimum flow of 600 second-feet at Atlanta at all times.

Actual operation will vary to some extent, as much of the time somewhat more power will be available from flood waters that can be stored below the maximum conservation pool level, and because the drainage area between the dam and Atlanta will contribute part of the 600 second-feet guaranteed to Atlanta.

The irregular flow from the powerhouse will be modified as it passes down river, with the peaks tending to decrease and the waves tending to last longer. The low flows will not be quite so low during the week, but over the week-end they will remain at the low figure of 600 second-feet for about 54 hours. On the basis of operations at Allatoona Dam on the Etowah River and the gaging-station records between the Dam and Rome, the Corps of Engineers has computed the probable hydrograph for a typical dry season week for the Chattahoochee River at the Vinings gaging station at Atlanta. This hydrograph is shown in figure 2.

The highest flow as shown by this hydrograph will be about 5,500 second-feet instead of 8,000 second-feet as at the Dam. The low flow of 600 second-feet is substantially greater than that in the drought of 1925. The most notable feature of the hydrograph is that the time required for the power waves to pass downstream, some 15 to 18 hours, causes most of the water to pass Atlanta at night.' Moreover, the Monday release

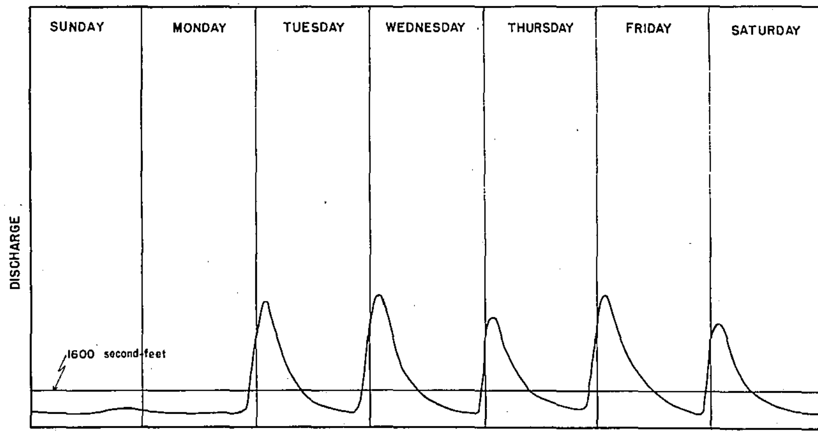


Figure 2. Probable hydrograph of Chattahoochee River at Atlanta for a typical low week with Buford Dam in operation.

does not reach Atlanta at all on Monday so that for one normal work day a week the City will have only the minimum flow available.

Metropolitan Atlanta's water-supply system has a present capacity of 94 million gallons a day, or 145 second-feet. About 80 percent of that is returned to the Chattahoochee River through the sewer systems. The steam power plant requires 670 second-feet, which, with the 20 percent of the municipal supply not returned above the plant, makes a total demand in Atlanta of 700 second-feet, somewhat more than that available under the tentative operating plan for Buford Dam. Atlanta's requirements are destined to increase.

The pollution problem is a further complication. The City of Atlanta does not have complete treatment at its largest sewage treatment plant. A large tract along the river has recently been zoned for industrial development, which will add industrial wastes to the pollution load. The steam power plant increases the temperature of the water several degrees, which has some effect on the pollution condition. It is apparent that the guaranteed flow of only 600 second-feet makes the maintenance of sanitary conditions in the river a severe problem. The situation will be especially difficult on Sundays and Mondays when the sewage loads are only a small amount less than the average. It will be difficult on other days, also, because the peak sewage load comes in the early afternoon when the river flow will be approaching a daily low level.

This problem, or rather group of problems, is being studied by the several agencies involved. These include the Corps of Engineers, the Federal Power Commission, the Southeastern Power Authority, the Georgia Power Company, the Georgia Department of Public Health, the counties, and the City of Atlanta. Other agencies, planning organizations, and industries are also concerned.

The number of agencies involved in this problem adds to the difficulty of reaching a solution because each one has its own special point of view. Such a complex problem is particularly suited to a Valley Authority that is interested in all aspects of the problem. It will be interesting to see how well the several agencies concerned with the Chattahoochee River can work out a satisfactory solution.

At this time it is not apparent what solutions will be proposed nor what would be most appropriate. Many economic and engineering factors must be considered. It should be feasible to control the river flow for the best use at Atlanta just as storage and pondage at the Dam are manipulated to secure the optimum power benefits.

HISTORICAL COMMENTS ON FLOODS AND DROUGHTS IN THE SOUTH-EASTERN UNITED STATES[1]*

By

M. T. THOMSON

District Engineer, U. S. Geological Survey

Atlanta, Georgia

The concept that there were no floods prior to the cutting of the forests is commonly accepted with a firmness of conviction not unlike that pertinent to the tenets of religion, morals, and politics. Despite the known geologic fact that

[1]Publication authorized by the Director, United States Geological Survey.
*Read at the Meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

the entire Coastal Plain and alluvial valley of the interior were built up by erosional processes through the ages, and the evidence of pronounced deltas at the mouths of major rivers, the idea persists that the Indians and early settlers of this country had no floods.

Examination of the writings of the early explorers, settlers, and travelers prior to the general introduction of agriculture in the southeastern states shows numerous references to floods and also to droughts.

The first such account from the interior of the southeastern states is found in the narratives of the DeSoto expedition in the several years following 1539. On entering what is now Georgia, the army found the river at Capachequi (Flint River) high with a swift current. A few days later, they crossed the River Toa (Ichawaynochaway Creek) which they also found high. These crossings were in March 1540, the month when the rivers are characteristically high. The chroniclers complained that they were "drenched with continual rain, the rivers always rising and narrowing the land" (Swanton, p. 44). This was in the upper Coastal Plain of Georgia where 11 percent of the land is swamp or subject to flooding. In August 1540 the army was compelled to wait six days to cross a river in flood (Mooney, p. 200), on one of the Piedmont rivers in northern Alabama. In December 1540 they came to the river of Chicaca (Tombigbee River), which they found overflowing its bed (Swanton, p. 44).

That floods were not unknown to the Indians is borne out by the fact that nearly every tribe (Mooney, p. 445) had legends of a great flood similar to the biblical story of Noah's flood, in that all the land was covered. Swanton traces one of these legends to a tribe which unquestionably had suffered flood experiences on the Mississippi near Natchez (Swanton, p. 23).

West of the Mississippi, DeSoto found tribes suffering as a result of a drought which was relieved by rain after a Spanish religious ceremony, whereby the Indians attributed supernatural powers to the white man. Similar fortuitous demonstrations aided the Spanish settlements along the coast of Georgia a few years later. In April 1566, Menendez and an expedition of Jesuits held religious services in the Indian towns at Santa Catalina, San Pedro, and Utina. At each place a devastating drought was broken by a shower, which convinced the Indians that the white man's Christian God was all powerful (Lanning, p. 39). A drought in April in this climate is rather unusual according to modern records.

A few years later, in September 1570, some Jesuits landed in Chesapeake Bay on a mission, probably on the Rappahannock River, in what was called the province of Axacan, where they found that a drought of six years' duration followed by a famine had decimated the inhabitants. This expedition was massacred by the Indians, ending the northward penetration by the Spanish (Swanton, p. 70).

Many of the early maps of the southeastern United States showed scattered lakes. Whether the lakes were inserted by the cartographer to fill up blank spaces or whether they were vague interpretations of references to the Great Lakes is not known. However, the theory has been advanced that some of the early explorers came upon rivers while they were in flood, covering miles of bottom lands. Some of the Coastal Plain flood plains are virtually lakes in extreme floods, thus with an explorer coming suddenly upon a tremendous body of water in the dense woods, he might have described it as a lake rather than a river in flood. Unquestionably there was much less silt in the rivers prior to the clearing of the forests for agricultural purposes, thus the flooded bottoms may well have been relatively clear.

In 1670 an explorer, John Lederer, travelled through the Piedmont and Coastal Plain regions of Georgia and the Carolinas. In his description of his trips he states, "The valleys they call Savanae being marsh grounds at the foot of the Apalataci and yearly laid under water in the beginning of summer by floods of melting snow falling down from the mountains." (Lederer, p. 2).

Mooney quotes Lederer as describing the Catawba River in flood as a lake. (Mooney, p. 200). He also states that in the year 1700, Lawson reported the Santee River thirty-six feet above normal (Mooney, p. 200).

A more particular reference may be found in James Adair, who stated in 1765 that the rivers of the Cherokee, generally the mountain and upper Piedmont region of the Carolinas and

Tennessee, seldom overflow except when rain falls on snow. (Adair).

That this could amount to a serious flood-producing potentiality is shown in a report by Ramsey that in 1775 a party of hunters led by one Mansco returning from the Cumberland settlements to the New River settlements in Virginia were delayed four weeks by snow that was waist deep. (Ramsey).

Adair, who was an Indian trader, also described a portable canoe made of leather similar to the bull boats of the prairie tribes, which could be assembled on a frame of saplings to cross flooded streams. He states, "When we expect high rivers, each company of traders carry a canoe." (Adair).

In 1773 a party of pioneers coming from South Carolina to the newly Ceded Lands of Georgia in the valley of Savannah River north of Augusta, crossed the Tugaloo River when it was swollen out of its banks because of recent rains. (Hays).

About the time of the American revolution, William Bartram, a naturalist from Philadelphia, made a series of tours in the southeastern states to collect botanical specimens, one of which was the famous Gordonia Altamaha, which has never since been discovered growing wild. He usually described the rivers as being beautiful, lucid streams, so clear that the fish and pebbles on the bottom could easily be seen. However, when crossing the Ocmulgee River in January 1778 in the vicinity of Macon, Georgia, he found the river in flood and out of its banks, and described the passage by the same type of skin boat described by Adair.

In 1796, a flood was recorded on Savannah River at Augusta, Georgia, which the Corps of Engineers (Savannah River Report) listed at 40.0 feet at the Augusta gage, some 6 feet lower than the record 1929 flood height, but with a discharge of 360,000 second-feet, slightly more than the discharge of the 1929 flood, probably because the latter was confined by levees.

A few years later, Benjamin Hawkins, Indian agent to the four southeastern tribes, described a flood of January 1796 at the site of the old French Fort Toulouse in the forks of the Coosa and Tallapoosa Rivers, a short distance from Montgomery, as having risen 47 feet and spread for 3 miles, the normal width of the river being only 350 yards. He remarked on the Indian claim that floods overflowed the banks for 5 miles or more every 15 or 16 years; also, that the flood rise in the Coosa River was so sudden as to drive a current up the Tallapoosa River, a distance of 8 miles. He also observed that the Alabama River overflowed flat, swampy margins annually, generally in the month of March, but seldom in the summer. He stated that at one Indian town, river floods spread nearly 8 miles from bank to bank and were very destructive to game and stock (Hawkins, p. 38).

Hawkins also described a characteristic condition in the lower Coastal Plain of Georgia, stating that in the rainy season, which commences after midsummer, the ponds fill and the greater part of the country becomes covered with water, but that in the dry season, it is difficult to obtain water in any direction for many miles, and that the springs dry up.

The characteristic stream flows of the region are very apparent from modern stream flow records; the high-water season is almost always in the spring months, and only rarely in midsummer, but also every fall, between September and November, all but the very largest rivers drop to mere trickles or dry up altogether.

In 1828 a Captain Hall, a retired English naval officer, and his family made a tour of the United States, travelling through Georgia in a carriage at a time when the interior roads of Georgia and Alabama were merely forest trails marked by blazes on the trees. He described the journey as toilsome! He could not go directly across Georgia from Savannah because recent high floods had swept away most of the bridges over the creeks, rendering the roads impassable. By a detour, he arrived at the Oconee River in March and described it as a "dirty" stream. In April he reached Montgomery, Alabama, and took a steamboat to Mobile. He quoted a local resident on the Alabama River who had measured a 64-foot perpendicular rise during a recent high flood which had been general over the southern states (Hall).

The above observations were all made before any material change could have been effected by white men. They are clear evidence that floods and droughts were by no means unknown, though unfortunately few of the floods can be evaluated as to magnitude and none with respect to their frequency. Probably there is no way to ever evaluate the magnitude-frequency relationship between floods prior to the cutting of the forests and those of the present day.

The record of recurring floods and droughts prior to and since the introduction of white man's agriculture in the southeast seems to offer evidence that precludes the inference that such activity has greatly altered the behavior of the rivers of the region, or has seriously diminished their usefulness as dependable sources of water supply.

Bibliography

Adair, James, "History of the North American Indians", 1765.

Corps of Engineers, Savannah River Report, (74th Congress, 1st Session, House Document 64, 1935.

Hall, Captain Basil, "Travels in North America in the Years 1827-28", 1829.

Hawkins, Benjamin, "A Sketch of the Creek Country in 1798 and 1799", (Georgia Historical Society Coll. Vol. 3, Part 1), 1948.

Hays, Louise Frederick, "Hero of Hornet's Nest", 1946.

Lanning, John Tate, "The Spanish Missions of Georgia", 1935.

Lederer, John, "The Discoveries of John Lederer", 1672.

Mooney, James, "Myth of the Cherokee", (U. S. Bureau of American Ethnology, 19th Annual Report, Part 1), 1900.

Ramsey, J. G. M., "The Annals of Tennessee", 1853.

Swanton, John R., "The Indians of the Southeastern United States", (U. S. Bureau of American Ethnology, Bulletin 137), 1946.

THE ENGINEERING PROPERTIES OF GEORGIA SOILS*

GEORGE F. SOWERS

Georgia Institute of Technology

In the early spring of 1951 a Georgia contractor began leveling an area on which to build a block of stores. The site was a long hillside that sloped downward toward the street, and it was necessary to cut down 30 ft. at the rear of the lot.

*Read at the Meeting of the Georgia Academy of Science, University of Georgia, April 27, 1951.

Shortly after the excavation was complete the 30 ft.-high bank at the rear of the site began to slide, endangering not only the new building but also a home on the property above the site. It cost almost $30,000 to correct this failure and in addition the construction work was delayed several months.

Failures involving soil are by no means uncommon, and they emphasize the need for careful consideration of soil conditions before commencing construction projects. In the past, the availability of good building sites coupled with the use of relatively light structures made it possible to complete many projects successfully without paying much attention to soils. However, today's high buildings, huge bridges, massive dams, and heavily loaded highways make it necessary to determine the properties of the soils and rocks underlying each site and to design the structures accordingly.

The civil engineer is primarily concerned with two aspects of soils: first, the characteristics of the undisturbed soil deposit; and second, the properties of the soils affecting their uses as materials of construction. The undisturbed soil is important when designing foundations of bridges, buildings, and dams, when planning for cuts and excavations, and when correcting landslides and similar movements. Specifically, the soils' **strength** must be determined in order that the structure will be safe against any movement or failure in the soil mass; and the soil's **compressibility** must be determined in order to compute the probable settlement of the structure.

Soil as a construction material is used for highway and railroad fills, to support floors in buildings, and as subgrades (foundations) for pavements of highways and airports. A good construction soil should be **easily compacted, incompressible** and **strong** after compaction, and **insensitive to excessive moisture.**

Unfortunately only limited data on the engineering properties of soils are available. The soil (or mantle) of importance to the engineer consists of weathered rock and unconsolidated sediments that have received only superficial attention from geologists. Furthermore, only the uppermost few feet of the soil have been studied by agriculturists. Engineers, therefore, have had to secure their data by extensive investigations in the field and in the laboratory. These data, correlated with the records of past failures and successes, form the basis for design of our modern structures.

From the engineering point of view the soils of Georgia fall into five groups:

1. Ridge and valley soils of Northwest Georgia.
2. Piedmont and Blue Ridge soils.
3. Coastal Plain soils.
4. Sea Shore soils.
5. Alluvial valley soils.

By studying typical soils in each group it has been found possible to estimate the particular soil problems involved and to plan a program of field and laboratory investigation for each project that will secure the most data for the least money.

The ridge and valley soils of Northwest Georgia consist of silts, silty sands, and sandy clays produced by the weathering of the underlying shales, sandstones, and limestones. The deposits are relatively thin (a depth of 15 or 20 ft. is typical), and they are not stratified. The virgin soils are relatively dense, strong, and incompressible which means they provide high bearing capacity with little settlement. In the areas underlain by thick limestone strata, there is always the possibility that the collapse of underground cavities will cause damage to a building. Such occurrences in this area are infrequent and can be prevented by drilling to determine the presence of caverns before construction. Dams built on limestone in this area require extensive foundation grouting to prevent leakage and consequent structural damage.

The soils of this region are easily compacted into a strong, incompressible mass which makes them well suited to fill construction. The silty soils and some of the clays are very sensitive to excessive moisture which makes them troublesome when used as subgrades beneath pavements in areas of poor drainage.

The Piedmont and Blue Ridge soils are micaceous sandy silts and silty sands derived from the decomposition of the underlying schists and gneisses. The deposits are extremely erratic depending on the variations in the composition of the parent rocks and on the faults and cracks whose presence accelerates the weathering processes. The virgin soils are peculiar in that they resemble sands in having high internal friction and also resemble clays in having moderate cohesion. They are, therefore, strong soils and will support heavy foundation loads without shear failures. Furthermore, deep excavations can be made in many places without any side supports. Unfortunately, the soils tend to lose their strength upon exposure to air and free water, and so there have been frequent accidents due to the collapse of unbraced excavations. The high mica content of some of the soils causes them to be rather compressible; and the erratic structure of the soil deposits often consists of masses of highly compressible soils only a very short distance away from incompressible soils and rock. Consequently, it is not unusual for one end of a building to settle due to soil compression and the other end, on incompressible soil, to remain put. The result is cracking that can both disfigure and damage the structure. In many cases it is necessary to use pile foundations to prevent unequal settlement even though the soils are capable of supporting the load with adequate safety against shear failure.

These same micaceous sandy silts and silty sands are far from ideal materials for fill and subgrade construction. They do not compact very well because of their high mica content, and they tend to be rubbery or spongey when compacted. Worst of all, they are very sensitive to excessive moisture. Many roads in the Piedmont region have disintegrated because moisture, which accumulated in the subgrade, softened the soil until it became soft and mushy and incapable of supporting the pavement.

The Coastal Plain soils consist of strata of sand, sandy clays, and clays that were deposited in the shallow seas which ages ago bordered the Piedmont uplands. These strata have been well consolidated by the weight of the overlying sediments and by dessication which occurred when they were raised above sea level.

The undisturbed soils provide excellent foundation materials in most cases because of their high strength and incompressibility. The areas in which the soils are directly underlain by soluble Tertiary limestones may present problems because of irregular caverns and sink holes in the rock. In most cases the relatively thick soil deposit on top of the rock can bridge smaller cavities and prevent trouble, but there is always an element of risk when heavy structures are to be built in such areas.

A second difficulty sometimes encountered in the Coastal Plain is the occasional swamp. These are underlain by deposits of peat and peaty silt that are often as thick as 20 ft. and which provide little or no support for even light structures. In such areas it is necessary to use pile foundations or to remove the undesirable soils completely.

The Coastal Plain has abundant deposits of good soils for fill, subgrade, and road construction. The soils compact well, are incompressible when compacted, and the sands and some of the sandy clays are insensitive to excessive moisture.

The predominate soil deposits in the Sea Shore area consist of broad marshes underlain with from 20 to 50 ft. of soft rubbery clays. Beneath the soft clays are irregular strata of sands and firm clays to depths of several hundred feet. The soft clays are weak and highly compressible, having many of the physical properties of "Jello". Fills placed on top of the marsh soils have disappeared by breaking through the slightly harder crust that often forms on the soil surface. When the soil is strong enough to support loads without failure, considerable settlement occurs due to soil compression. Even light wood frame buildings may settle until their floors become wavey or sagging.

Scattered in irregular patterns thoughout the marshes are lenses and mounds of sands that represent former sand bars and similar deposits. Some of these "float" in the marsh clays while others rest on the underlying dense soils. The floating sands provide a fair foundation for light structures but may settle considerably under heavy structures. The thick sand deposits which rest on the underlying dense soils provide excellent foundations for heavy bridges and buildings.

The soft marsh clays are useless for fill and subgrade construction because of their very high water contents and high plasticities. The sands, however, are excellent for filling. They may be excavated, transported, and deposited hydraulically, because it is possible for hydraulic dredges to navigate many of the larger coastal channels and reach the sand deposits. This makes it possible to move large quantities of materials at a very low cost, and the long coastal highways are the direct result of such hydraulic dredging and filling.

The alluvial valley soils are found throughout the state along side the larger streams. These consist of alternate strata of sands, silts, and silty clays deposited during periods of high water. The deposits are rarely more than 20 or 30 ft. thick except on the largest streams. The soils are ordinarily unconsolidated and soft, and provide a poor foundation for all but the lightest structures.

The alluvial silts and clays are poor fill materials, but the river sands are excellent for fills and subgrades. Unfortunately, the sand deposits are somewhat limited so they are of most value in the smaller projects.

In assembling data on the soil conditions for any project the engineers have made extensive use of the data collected by geologists and agriculturalists. Geologic data are used to estimate the composition and structure of the soil deposits and to interpret the results of boring and sampling. The pedologic data from the agricultural engineers have been found useful in predicting the texture of the uppermost soil strata.

When it is necessary to have specific data on the depth, thickness, and composition of soils at a site and to determine the physical properties of the materials, a program of boring and sampling is required. The soil samples are tested in the laboratory and the test results form the basis for design. In Georgia, such programs for specific projects are carried out by agencies of the Federal Government, such as the Civil Aeronautics Administration, Corps of Engineers, and the Bureau of Public Roads; by the State Highway Department; and by private organizations who specialize in such work. The experience of these organizations, coupled with the available geologic and pedologic data, are the starting point for any investigation.

Selected References

1. Garland Peyton, "Publications on the Geology and Mineral Resources of Georgia," *Circular 1*, Department of Mines, Mining, and Geology,

Atlanta, 1947. (This publication lists many bulletins containing valuable information for engineers.)

2. D. S. Jenkins, D. J. Belcher, L. E. Gregg, and K. B. Woods, "The Origin, Distribution, and Airphoto Identification of United States Soils," *U. S. Dept. of Commerce CAA Technical Development Report No. 52*, 1946.
3. *Soils and Man*, U. S. Dept. of Agriculture Yearbook, 1938.
4. M. J. Hvorslev, *Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes*, U. S. Waterways Experiment Station, Vicksburg, 1949.

MEASURED SECTIONS OF KNOX DOLOMITE NEAR GRAYSVILLE, GEORGIA*

ARTHUR T. ALLEN

Emory University

Introduction

The Knox Dolomite comprises one of the most widespread of all the Appalachian Valley and Ridge Groups. Its outcrops are extensive in the eastern part of Tennessee, northwestern Georgia, and northeastern Alabama. Although areas underlain by Knox occupy a large part of the Paleozoic province of Georgia, outcrops are poor and normally when found represent only a small stratigraphic sequence.

Butts (1926) has made comprehensive studies of the Knox in Alabama and Oder (1934) in Tennessee. Heretofore, no attempt has been made to measure or study in detail this group in Georgia. Rarity of fossils within the group makes it necessary to depend entirely on lithology, characteristics of the weathered and unweathered chert, arenaceous zones, and topographic expression for correlation and subdivision.

The bluffs of Knox dolomite along the entrenched meanders of Chickamauga Creek (fig. 1) near Ringgold, Georgia have been noted previously by Butts (1948). Because of the steep dip of the formations, almost a complete Knox sequence is found and certainly represents the best and most complete exposures in the State.

The contact between the Copper Ridge dolomite and the Conasauga limestone is indefinite in this locality. Munyan

*Submitted for publication in 1952.

(1951) has chosen the top of the oolitic limestone in the uppermost Conasauga as the lower boundary. Here the oolitic limestone is absent and the base of the Copper Ridge has been selected on the basis of abundant chert in the Copper Ridge and the absence of chert in the top of the Conasauga formation.

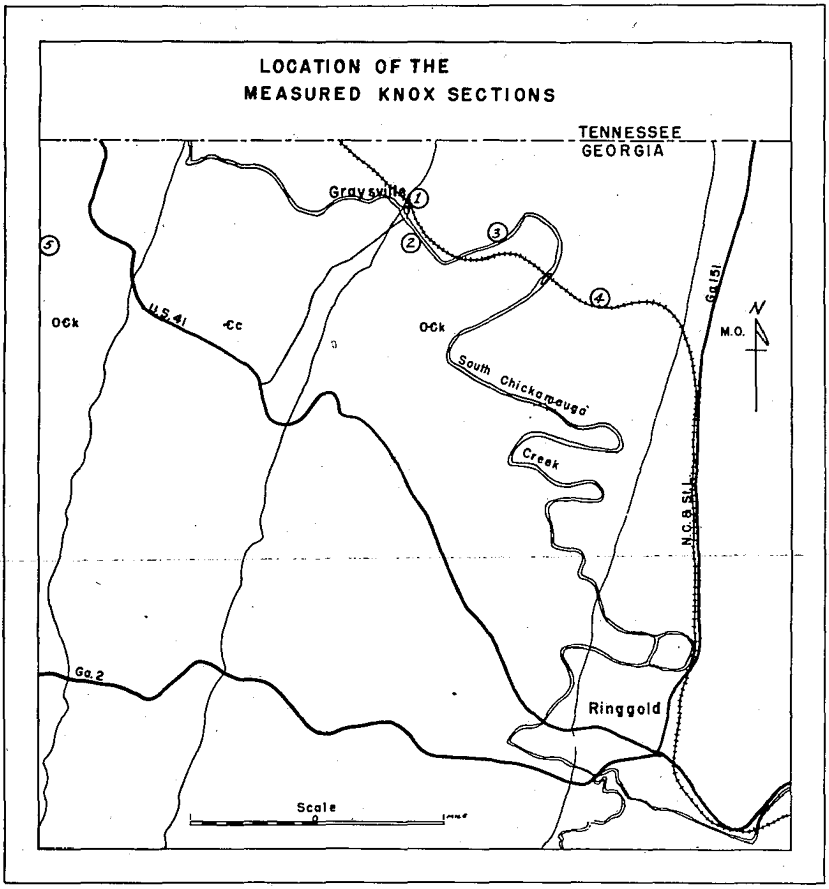
The top of the Knox is overlain by the Blackford formation (Munyan, 1951) which here is a thin, red, argillaceous limestone with a few scattered sand grains. The Copper Ridge, the Chepultepec, the Longview, and the Newala formations comprise the Knox and the total thickness is approximately 4500 feet, as indicated from the measurement of exposed sections and intervening unexposed portions.

The help given by students attending the Emory University Field Camp during the summers from 1947 to 1951 is gratefully acknowledged.

The sections at Graysville are presented as a beginning point for future detailed study of the Knox in Georgia localities.

COPPER RIDGE FORMATION

This formation is thickly bedded, dark gray to blue, fine- to coarse-grained dolomite with a low content of silica in fresh exposures. Only a few chert nodules or layers are present. There is a large amount of chert residuum developed in the soil of this formation. The thickness of the Copper Ridge, as indicated by the measurement of exposed sections and an estimate of the thickness of the intervening unexposed part, is about 2,380 feet.



LOCATION OF THE
MEASURED KNOX SECTIONS
TENNESSEE
GEORGIA
Graysville
1
2
3
4
5
OCk
U.S.41
Cc
OCk
South Chickamauga
Creek
Ga.151
N.C.&St.L.
N
M.O.
Ga.2
Ringgold
Scale

Figure 1.

Detailed Section No. 1. Measured in Graysville Quarry (Fig. 1).

	Thickness
Dolomite, medium gray; fine-grained; thinly bedded and shaly in middle	14′
Unexposed	16′
Dolomite, very light gray; concretionary at base	15′
Dolomite, light gray; fine-grained texture	14′
Dolomite, dark gray; 8″ chert zone at base	11′
Dolomite, very light gray; fine-grained texture	9′
Dolomite, dark gray; upper 6″ zone conglomeratic	3′
Dolomite, dark gray; alternate bands of chert nodules in lower 8″	10′
Dolomite, light gray; fine-grained texture; thinly bedded	2′
Dolomite, medium gray; fine-grained; massively bedded	6′
Dolomite, very dark gray; fine-grained; massively bedded	6′
Dolomite, very dark gray at base; upper part light gray	6′
Dolomite, upper 5′ light gray; lower 3′ dark gray	8′
Dolomite, medium gray; darker at base; massively bedded	6′
Unexposed	45′
Dolomite, medium gray; fine-grained texture	15′
Dolomite, dark gray; massively bedded; **Cryptozoan** present	61′
Dolomite, very dark gray; medium-grained	29′
Dolomite, upper zone dark gray; lower part light gray; fine-grained	37′
Dolomite, light gray; medium-grained	53′
Dolomite, medium gray; darker at base	30′
Dolomite, dark gray; weathers to dull gray with yellowish stains on surface; fluted	45′
Total	441′

Detailed Section No. 2. Measured along South Chickamauga Creek, southwest of Graysville, Georgia. (Fig. 1).

	Thickness
Dolomite, very dark gray; fine- to medium-grained texture; surface appears mottled on weathering	35′

	Thickness
Dolomite, very dark gray; fine-grained; even texture; black and white banded chert nodules near center	7′
Dolomite, very dark gray; coarsely crystalline	6′
Dolomite, upper 8′ very dark, medium-grained, heavy dark-blue chert zone, all oolitic; lower 1½′ is light gray, thinly bedded; slightly banded	10′
Dolomite, light to dark gray; dense; fine-grained; black and white banded chert nodules near center	8′
Dolomite, very dark gray; medium- to coarsely crystalline; weathers to light buff; chert layers at base with blue-black oolites	5′
Dolomite, medium dark gray; very cherty; all chert highly oolitic; oolites differ in characteristics from the Chepultepec in that they are longer and commonly black	5′
Dolomite, very dark gray; fine-grained	6′
Dolomite, very dark gray; dense; small bands of dark-blue chert at top	4′
Dolomite, dark gray; medium- to fine-grained	4′
Dolomite, very dark gray; brecciated; scattered bands of vein calcite; bands of chert about midway of bed; blue chert broken and recemented with white chert	5′
Dolomite, light to medium gray; dense to medium-crystalline; scattered chert nodules near the center of bed; small thin white nodules at base	3′
Dolomite, medium gray; medium-grained; even textured; brown chert band at base	7′
Dolomite, light gray; dense; fine-grained	4′
Dolomite, dark gray; coarsely crystalline texture; scattered large calcite "eyes"; small band irregular brown and white nodules at top	8′
Dolomite, light gray; fine-grained; dense; blue and white chert band at top; scattered nodules at base	3′
Dolomite, light gray; dense; fine-grained; black and white spotted chert at top	2′
Dolomite, dark brown; very coarsely crystalline; massively bedded; weathers buff to brown	6′
Dolomite, dark gray; dense; fine-grained; heavy bluish black chert at base	2′
Dolomite, dark gray; fine-grained	2′

	Thickness
Dolomite, dark to light gray; medium-grained; scattered blue chert nodules	4′
Dolomite, light gray; fine-grained; dense; massively bedded; thin shale bed at base	6′
Dolomite, light gray; fine-grained; saccharoidal texture	6′
Dolomite, light tan at top to light gray at base; heavy band of blue-gray chert at base	8′
Dolomite, medium brown; coarse- to fine-grained; dense; scattered white chert nodules	6′
Dolomite, very light gray; fine-grained; bluish-brown band of chert at base	4′
Dolomite, light tan; saccharoidal; weathers to buff color; scattered brownish-white chert nodules	7′
Dolomite, dark gray; coarse-grained; scattered blue to white nodules	8′
Dolomite, light gray; dense; fine-grained texture	8′
Dolomite, dark brown; coarse-grained; small amount of blue chert	7′
Dolomite, light gray; fine-grained; dense	3′
Dolomite, very light gray; fine-grained; dense	2′
Dolomite, medium dark gray; very coarse- to medium-grained	7′
Unexposed	40′
Dolomite, light tan; medium-grained; oolitic chert scattered throughout	6′
Unexposed	25′
Dolomite, medium to dark gray; medium- to coarse-grained bluish-brown oolitic chert at base	11′
Dolomite, very light gray; fine-grained; dense; thinly bedded; blocky on weathering	2′
Dolomite, medium light tan; fine-grained texture; light-blue chert nodules at middle of bed	8′
Dolomite, light tan; medium-grained; scattered oolitic chert nodules	10′
Unexposed	3′
Dolomite, very dark brown; almost entirely replaced by brown and white secondary chert, some of which is oolitic	7′
Dolomite, dark gray; coarse-grained; brownish-blue chert nodules near top	4′

	Thickness
Dolomite, light gray; coarse-grained; heavy blue chert nodules at base	3′
Dolomite, very dark gray; very coarse-grained; little chert	5′
Dolomite, dark gray; coarse-grained; band of blue-black and white chert nodules at base	5′
Unexposed	6′
Dolomite, dark to tan; coarse-grained; heavy white chert	6′
Unexposed	51′
Dolomite, dark brown; coarse-grained; massive white and blue chert layers; chert comprises 40% to 50%	5′
Unexposed	2′
Dolomite, dark gray; medium- to coarse-grained; calcite stringers	5′
Unexposed	3′
Dolomite, light tan; medium-grained; heavy oolitic chert scattered throughout; oolites are ovoid in shape	4′
Unexposed	9′
Dolomite, light gray to tan; dense	2′
Unexposed	12′
Dolomite, light gray; medium- to coarse-grained	4′
Dolomite, medium tan; coarse-grained; scattered brown oolitic chert nodules	2′
Dolomite, light gray; fine-grained texture; no appreciable chert	10′
Dolomite, dark gray at top to light gray at base; coarsely crystalline to fine-grained; scattered blue to brown oolitic chert nodules	10′
Unexposed	30′
Dolomite, light to medium gray; fine-grained; dense; scattered white chert nodules	6′
Dolomite, dark gray; coarse-grained; scattered light-gray to dark-gray chert nodules; heavy band of blue and white chert nodules at base	8′
Dolomite, medium to light gray; fine-grained; dense; blue chert bands near top and bottom	5′
Total	535′

Detailed Section No. 3. Measured in abandoned quarry east of Graysville, Georgia. (Fig. 1).

	Thickness
Dolomite, dark gray; thinly bedded; dark; oolitic, banded chert 6″ above base	4′
Dolomite, gray; medium-grained; scattered white chert nodules	6′
Dolomite, buff colored; thinly bedded; scattered chert nodules	2′
Dolomite, dark gray; medium-grained; crystalline texture; massively bedded; blue oolitic chert nodules at top	10′
Dolomote, gray; medium-grained; blue chert nodule layer containing angular chert fragments at top	1′
Dolomite, brownish gray; coarsely crystalline; massively bedded	6′
Dolomite, brown; fine-grained; 1′ layer of blue and white chert at the top	12′
Dolomite, dark brown, medium-grained; blue chert nodules scattered throughout	6′
Dolomite, medium dark gray; fine-grained; massively bedded; lower 2′ thinly bedded light gray	10′
Dolomite, medium gray; fine-textured; massively bedded	7′
Dolomite, dark brownish gray; coarse-grained	8′
Dolomite, medium brown; coarse-grained	10′
Total	82′

CHEPULTEPEC FORMATION

This formation is predominantly dolomite, medium to light gray in color, fine- to coarse-grained in texture, and massively bedded. Limestone beds which are light gray to tan in color, fine- to coarse-grained, thinly to massively bedded, are scattered throughout.

Bedded chert is one of the most distinctive features of the formation. Chert beds six to eight feet thick are not uncommon. The chert is light gray, blue, and white, often exhibiting a banded appearance. Some beds of white, opaque chert as thick as five feet are present, and numerous bright reddish chert bands occur in the upper part of the formation interbedded with a purplish to greenish dolomite.

The cavernous or "worm-eaten" appearance of the chert where weathered, and the presence of numerous limestone beds help in distinguishing the Chepultepec. The thickness is approximately 1400 feet of which only the upper-most 153 feet has been measured along the Nashville, Chattanooga, and St. Louis railroad.

Detailed Section No. 4. Measured along N. C. and St. L. Railroad, 3⅓ miles north of Ringgold, Georgia. (Fig. 1).

Chepultepec and Longview Contact

	Thickness
Dolomite, clayey; weathered	1′
Dolomite, light gray; with chert stringers	1′
Dolomite, light gray; medium-grained	1′
Chert, light to dark gray; banded; weathers to white	3′
Dolomite, light gray; fine-grained	1′
Dolomite, dark to light gray; coarse-grained	5′
Dolomite, dark gray with calcite "eyes"; chert stringers	12′
Dolomite, light gray; fine-grained; highly fractured	14′
Chert, dark gray; banded	1′
Dolomite, light gray; medium-grained	7′
Chert, light gray to dark gray	3″
Dolomite, light gray; green chert stringers	16′
Chert, dark gray	6″
Dolomite, light gray; fine-grained	12′
Chert, light gray to red	3″
Dolomite, light to dark gray; fine- to coarse-grained	25′
Chert, brown to dark gray; highly fractured	8′
Dolomite, light gray; coarse-grained	3′
Chert, light gray	2′
Dolomite, light gray; medium-grained	5′
Chert, light gray; banded	4″
Dolomite, light gray; medium-grained	6″
Chert, gray; banded	2″
Dolomite, light to dark gray; medium- to coarse-grained; massively bedded	28′
Chert, light gray to red; highly fractured	6′
Total	153′

LONGVIEW FORMATION

In Georgia, the Longview is approximately 560 feet thick, and is correlated with the Longview of Alabama. However, here it is predominantly dolomite with a small amount of limestone, whereas in Alabama it is predominantly limestone. The rock is light gray, fine-grained to coarsely crystalline, and thickly bedded. The chert is light to dark gray, occurring as nodules or thin beds, and is highly fractured. Limestone beds are present near the top of the formation; they are light gray, fine- to coarse-grained, massively bedded, and contain a few fossils.

The Longview, where it is composed essentially of limestone, has been noted as a valley-former. In this area, the percentage of chert is high in the soil residuum, and the formation forms low hills and ridges.

Detailed Section No. 4. Measured along the Nashville, Chattanooga, and St. Louis Railroad, 3½ miles north of Ringgold, Georgia.

Longview and Newala Contact

	Thickness	
Unexposed	20′	
Dolomite, dove gray; fine-grained	2′	
Unexposed	138′	
Dolomite, light gray; coarsely grained	2′	
Dolomite, light gray; fine-grained; reddish-brown chert nodules	3′	
Dolomite, light gray; fine-grained; reddish-brown chert nodules	1′	
Chert, thinly bedded		6″
Unexposed	373′	
Dolomite, light gray; medium-grained	4′	
Chert, brownish to red with white streaks	1′	
Dolomite, light gray; coarse- to fine-grained	11′	
Dolomite, gray with reddish tinge; coarse-grained, with banded grayish-white chert at top	5′	
Dolomite, light gray; fine-grained	1′	
Dolomite, medium gray; fine-grained; with dark-reddish chert at base	1′	
Total	563′	

NEWALA FORMATION

Butts (1926, p. 95) describes the lithology of the Newala as follows: "The Newala is composed of much limestone and proportionately little dolomite. Most of the limestone is thick-bedded, compact, non-crystalline or textureless, dark gray, pearl gray, and bluish gray. The pearl gray color perhaps predominates and is most characteristic." For such compact limestone the name Vaughanite has been proposed.

In the Ringgold locality, the Newala is a blue, bluish-gray, dove, red, or green mottled limestone with little dolomite. Its texture is fine-grained to vaughanitic. The Vaughanite is typically a thick-bedded, compact, brittle, bluish-gray or dove-colored limestone. On some weathered surfaces, small black flint and red chert nodules and stringers occur.

One of the most distinctive characteristics of the Newala is its variegated color on fresh exposures. It has a red and green mottled appearance in some beds; others have a pink and dove-colored inter-fingering pattern. This characteristic seems to be present only in this area and westward to Lookout Mountain. In the Rockmart area and in Alabama, the rock is predominantly blue.

Butts (1948) estimates the thickness as 250 to 300 feet. The maximum thickness of the Newala measured in this area was 167 feet, on Scruggs road.

Detailed Section No. 5. Measured at Scruggs Road Quarry. (Fig. 1).

	Thickness
Limestone, light gray; medium-grained; massively bedded; weathers from light to dark gray	2′
Unexposed	24′
Limestone, reddish gray; massively bedded; weathers to pink	4′
Limestone, grayish green; granular texture with dark, medium-grained "splotches"	2′
Limestone, purplish red, grayish green, mottled; fine-grained	4′
Unexposed	4′
Limestone, medium gray; medium-grained; top of bed is conglomeratic, containing angular to rounded chert fragments	3′

	Thickness
Limestone, brownish gray; fine-grained; thin layers of brown limestone, which weathers to light gray	1′
Limestone, purple and gray splotched; medium-grained	2′
Limestone, greenish gray; brownish splotched; medium-grained, fluted surface	2′
Limestone, red and green; mottled; fine-grained; weathers with pitted surface	2′
Limestone, medium gray; brown splotches; medium-grained; massively bedded	2′
Limestone, red and green alternating layers; fine-grained; massively bedded	6′
Unexposed	6′
Limestone, medium gray; fine-grained	1′
Limestone, red and green mottled; fine-grained; massively bedded	4′
Limestone, green; medium-grained; massively bedded	4′
Limestone, red and green; mottled; fine-grained; massively bedded; small amount of jasper present	10′
Limestone, green; medium-grained; massively bedded	4′
Limestone, medium gray; fine-grained; contact of brightly colored zone and dull gray zone	8′
Limestone, medium gray; fine-grained; massively bedded; weathers to light gray	19′
Limestone, medium gray; fine-grained; weathers to dark gray	54′
Total	167′

References

Butts, C. (1926) *Geology of Alabama, The Paleozoic Rocks,* Geol. Survey of Alabama, Spec. Rept. 14.

——————— (1948)— *Paleozoic Area of Northwest Georgia,* Georgia Div. of Mines, Min., and Geol. Bull. 54.

Munyan, A. C. (1951) *Geology and Mineral Resources of the Dalton Quadrangle, Georgia-Tennessee,* Georgia Div. of Mines, Min., and Geol. Bull. 57.

Oder, C. R. L. (1934) *Preliminary Subdivision of the Knox Dolomite in East Tennessee,* Jour. of Geol. Vol. 42.

ECOLOGICAL SIGNIFICANCE OF A MISSISSIPPIAN BLASTOID*

ARTHUR T. ALLEN and J. G. LESTER

Emory University

Introduction:

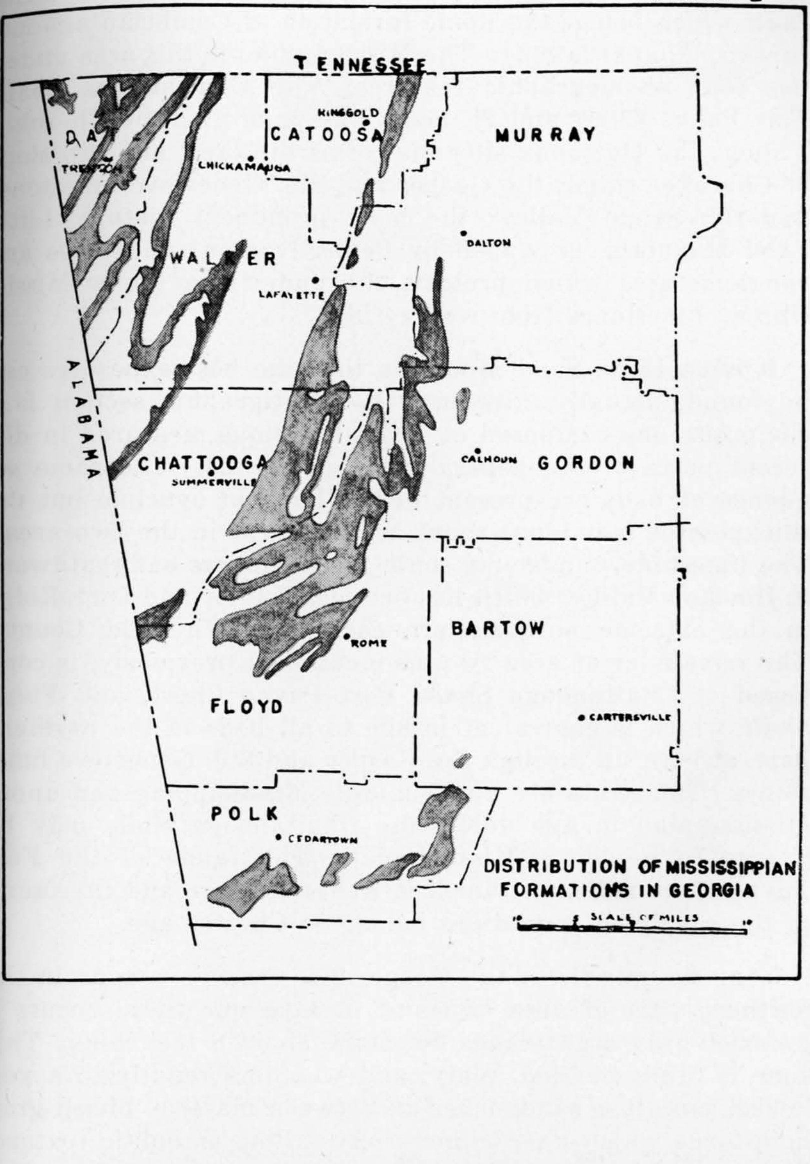
Examination of a map of Northwestern Georgia prepared by Butts and Gildersleeve in 1948 for the Georgia Department of Mines, Mining, and Geology shows the areal distribution of the Mississippian strata in Georgia. Plate 1 has been prepared by deleting all geology except the outcrops of the Mississippian so that its extent can be more easily shown. The areas underlain by strata of this age can be roughly divided into three parts. Part one in the extreme northwestern corner of the state, occupying parts of Dade, Walker, and Chattooga counties, may be better described as the Lookout Syncline Area in which the Mississippian rocks occur along the flanks of Sand, Lookout, and Pigeon Mountain and are protected from weathering by the overlying resistant sandstones and conglomerates of Pennsylvanian Age. Part two occupies portions of Catoosa, Murray, Walker, Chattooga, Gordon, and Floyd Counties. The linear arrangement of the outcrops parallel the strike and structures of Taylor Ridge, Armuchee syncline, and Lavendar Mountain. Part three is restricted to Polk County where the Mississippian is represented by the Rockmart Slate.

Stratigraphy:

The sediments in these areas are not all alike lithologically, but differ to a marked degree from one area to another. On Lookout Mountain, in area one, a stratigraphic column would show thick zones of limestone and some thin shales. This same sequence is also present in the northern part of area two (Plate 2). However, in the southern part of area two, the strata are predominantly shale. Area three is composed of shale and slate and has not been satisfactorily correlated with the horizons of the other two areas. This paper will be confined for the most part to a study of area two.

*Read at the meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

PLATE 1



DISTRIBUTION OF MISSISSIPPIAN FORMATIONS IN GEORGIA

The stratigraphic sequence of Mississippian formations in the Ringgold, Catoosa County Area are shown on Plate two. Along the eastern flank of White Oak Mountain, beds of Mississippian age dip about 15° to the east and strike in a northeast-southwest direction. They overly strata of Silurian age and are intersected farther to the east by a major thrust fault which brings the Rome formation of Cambrian age into juxtaposition (Plate 3). The Mississippian in this area underlies four physiographic features. The Chattanooga Shale, Fort Payne Chert and St. Louis limestone underlie Cherokee Valley; the Golconda siltstone forms the crest and dip slope of Cherokee ridge; the Gasper and Ste. Genevieve limestones underlie Salem Valley; the most prominent feature, Little Sand Mountain, is capped by Pennsylvanian sandstones and conglomerates which protects the underlying upper Mississippian limestones from weathering.

It is on Little Sand Mountain that the best exposures can be found, actually, however, the stratigraphic section is a composite one composed of several sections measured in different parts of the general area (Plate 2). The same sequence of beds are present in the Lookout syncline but the thickness of individual zones are different in the two areas. The limestone, sandstone, shale facies fingers out southward in Houston Valley, which lies between Taylor and Dick Ridge in the extreme northwestern corner of Whitfield County. The remainder of area two, as mentioned previously, is composed of Chattanooga Shale, Fort Payne Chert, and Floyd Shale which is equivalent in age to all beds in the northern part, at least up through the Gasper and Ste. Genevieve limestones. The strata are upper middle Mississippian and upper Mississippian in age unless the Chattanooga shale may be proved to be lower Mississippian. The fauna of the Fort Payne chert indicates that it is Keokuk in age and the fauna of the overlying formations belong to Chester age.

Near the middle of the Gasper-Ste. Genevieve zone in the northern part of area two and in area one there occurs a greenish-gray argillaceous limestone about 8 feet thick. This zone is thinly-bedded, platy, and weathers readily to a yellowish soil. It is sandwiched in between massive, bluish-gray limestones which have either a crystalline or oolitic texture. Because of the silty conditions prevailing in the sea during

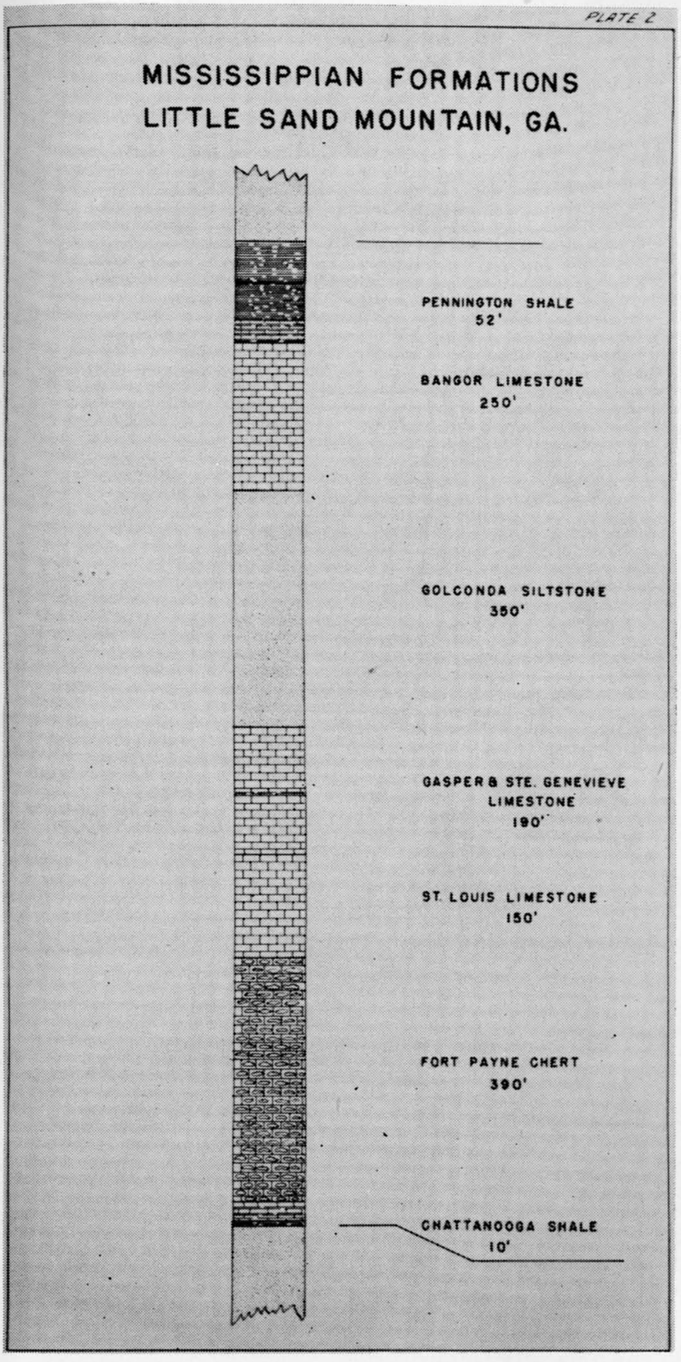
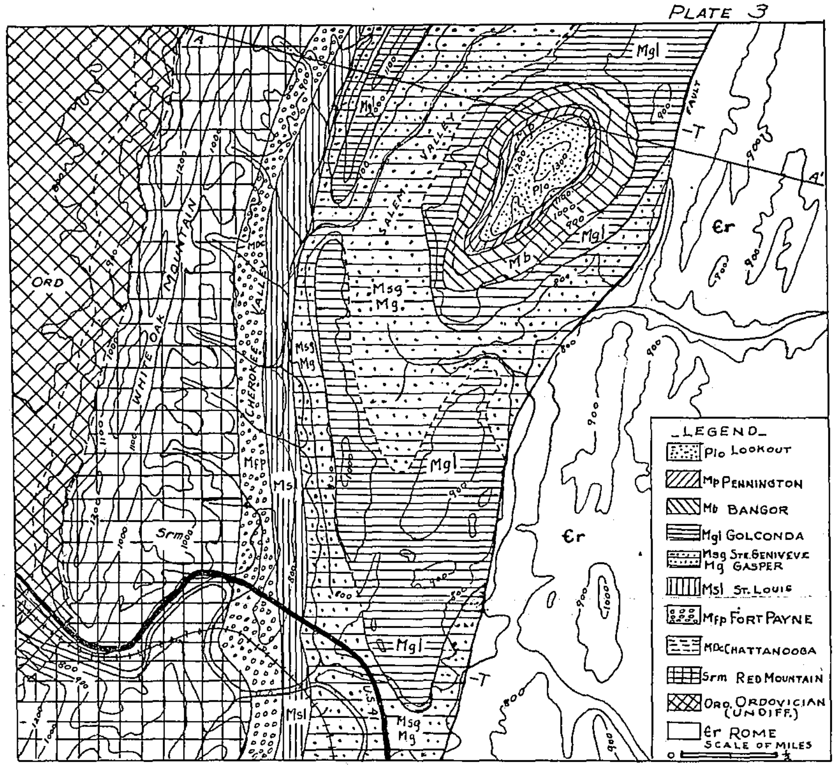
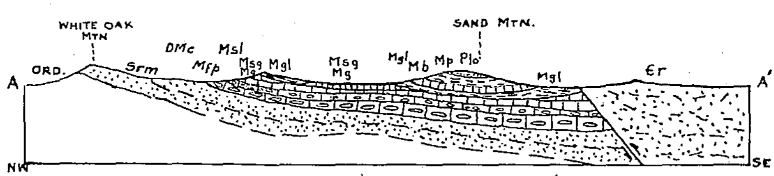


PLATE 2
MISSISSIPPIAN FORMATIONS
LITTLE SAND MOUNTAIN, GA.
PENNINGTON SHALE
52'
BANGOR LIMESTONE
250'
GOLCONDA SILTSTONE
350'
GASPER & STE. GENEVIEVE
LIMESTONE
190'
ST. LOUIS LIMESTONE
150'
FORT PAYNE CHERT
390'
CHATTANOOGA SHALE
10'

PLATE 3



GEOLOGIC MAP OF SAND MOUNTAIN AREA CATOOSA CO., GA.



STRUCTURE SECTION A-A'

the deposition of the impure limestone of this stratigraphic interval, organisms capable of combating such an environment are to be expected.

Fossils belonging to four classes are present. Bryozoa of the **Fenestrellina** and **Phyllopora** types are extremely abundant. Next in abundance are the large blastoids which belong to the genera **Pentremites** but which represent a new species not previously described. The name **Pentremites gianteus** is here given to this species because of its abnormal size. Specimens are shown in plates 4, and 6 where it can be seen how much larger they are than the normal blastoid represented by **Pentremites welleri**, an average size member of this group. The other two classes found are dwarfed corals and dwarfed brachiopods which are so rare that they do not form an important part of the faunal assemblage.

The blastoid calices found in the overlying and underlying members of the Gasper and Ste. Genevieve are about 1.5 cm. in height, symmetrical, and associated with an abundant normal coral and brachiopod fauna. These lived in warm, clear, silt-free, probably deep marine water in which large quantities of calcium carbonate was being precipitated. This is shown by the purity of the associated massive limestones. As the environment changed to a shallow, muddy sea, abrupt changes in the fossils had to take place in order for them to become acclimated to the new conditions. The numerous species of blastoids, brachiopods, and corals present in the pure limestones could not tolerate this new environment.

In their place are found abundant specialized bryozoa and blastoids. Because of the silty conditions of the water, larger amounts of it had to be sieved in order to secure adequate food. Hence the blastoids became greatly enlarged in order to increase their food gathering brachioles and ambulacral grooves. The ratio between the size of the calyx and the rather small stem should be noted. This development must have taken place rapidly because the plates of the calyx are poorly sutured and often become flattened and distorted during burial. Frequently the base plates break off with the columnal which also increases the chances of becoming flattened. This characteristic is seldom encountered in other blastoids (Plate 5).

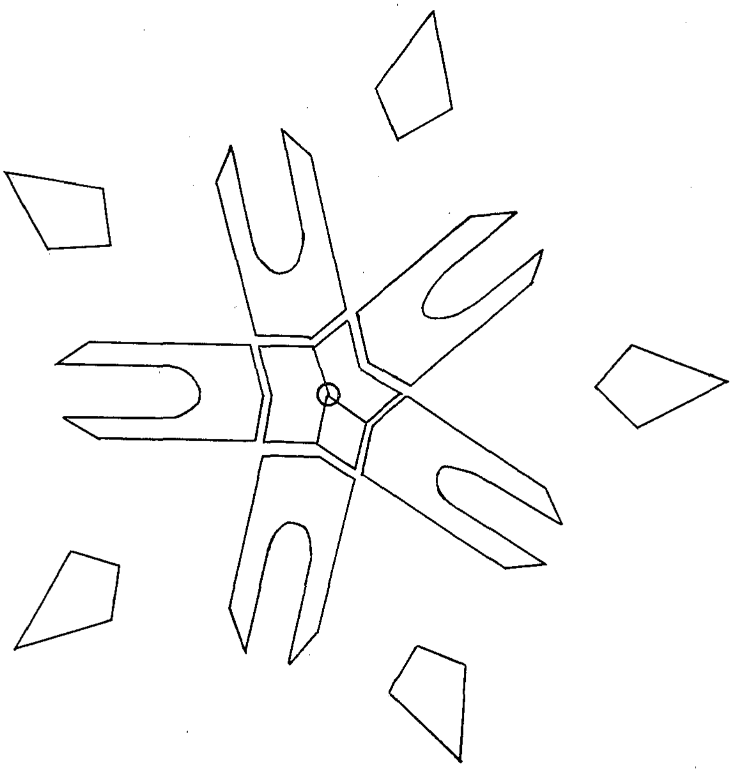
PLATE 4

1

2

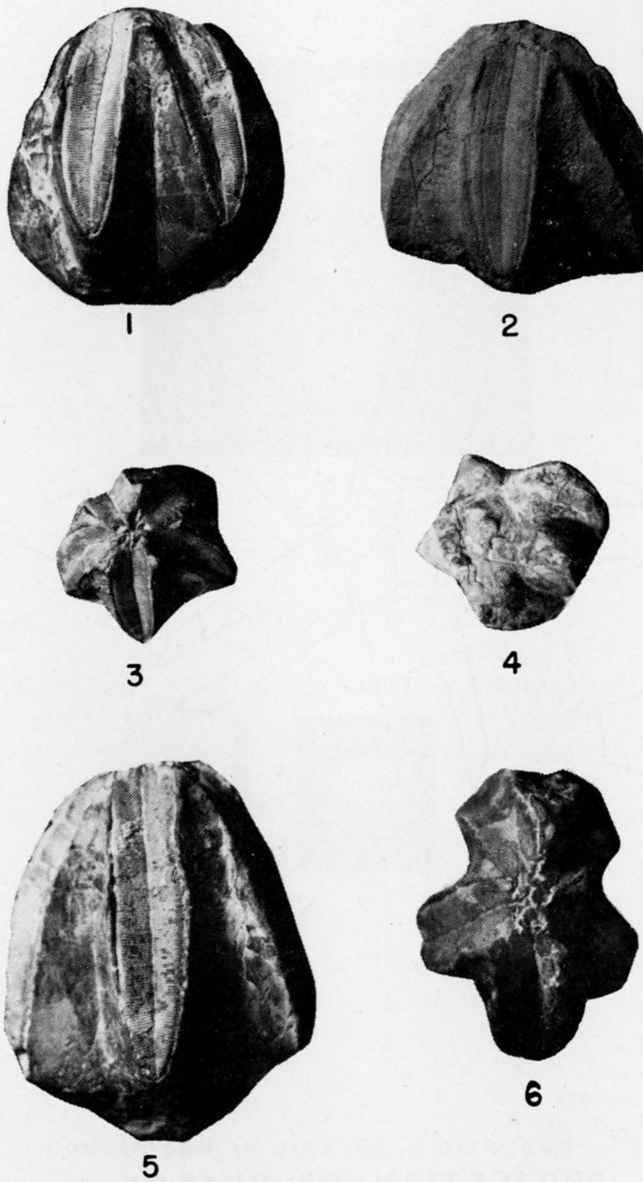
COMPARISON IN SIZE OF P. GIANTEUS AND P. GODONI

PLATE 5



PROJECTION OF PLATES

PLATE 6



VIEWS OF P. GIANTEUS

Pentremites gianteus disappeared as suddenly as it had appeared. As the sea encroached during Gasper time and conditions similar to those prevailing during St. Genevieve time returned, the normal fauna returned and the fossils are are the same as those of the preceding time. The large blastoids had become so specialized to combat a given set of conditions that they could not compete in the new environment and therefore because extinct.

If we add our knowledge of this zone to the overall picture of the Mississippian period in Georgia, some significant observations can be made. At the base of the Ft. Payne is a shaly zone which carries essentially the same byrozoa as those found associated with the large blastoids in the shale zone of the Gasper. Higher in the section, at the top of the Bangor, is another thin shale bed which has the same bryozoa and a comparable blastoid, P. **spicatus** which is not as large **as P. gianteus.** It would seem then that during the Mississippian at least three short intervals existed which were essentially the same in depositional characteristics and faunal environment.

When we consider the uppermost Silurian and basal Pennsylvanian with the Mississippian, we have evidence of transgression, regression, and later transgression of the sea. The uppermost Red Mountain, the Golconda, and the Lookout (all of which are near-shore or littoral deposits) alternating with limestones of the Fort Payne, the St. Louis, the Gasper and the Ste. Genevieve, and the Bangor and grading from one to the other through shale zones.

It seems probable that no great mountain making movement began at the close of the Silurian or at the close of the Mississippian in northwest Georgia. The Devonian is apparently absent because of non-deposition. The non-marine Pennsylvanian simply represents the withdrawal of the Mississippian sea. This was the final result of unrest which had been present throughout Mississippian time.

CENOZOIC FOSSILS IN A CONGLOMERATE INTERSTRATIFIED WITH PALEOZOIC ROCKS*

H. E. COFER

Emory University

Introduction and Location of the Area

Three quarters of a mile SSW of Van Wert, Polk County, Georgia, three beds of coarse conglomerate occur interstratified with dark-grey magnesium limestone stratigraphically below the Rockmart slate and presumably corresponding to the Newala Formation. The outcrop forms a small conical hill rising approximately fifty feet above the flood plain of a small creek. With the exception of a few blackjack oak and scattered low bushes, the knoll is barren of vegetation.

Description of the Occurrence

The limestone beds on the south slope of the hill dip 70° to the north, but the dip flattens rapidly northward and then reverses itself to create a shallow asymmetrical syncline approximately 100 yards in width. The conglomeratic beds are exposed on the southern slope of the knoll and are interstratified with the steep northerly dipping beds of limestone. The lower conglomerate is exposed in the cliffs, that form the western side of the hill, for about 40 feet down-dip where it disappears under residual soil.

Lithology

The conglomerate beds are separated by two to four feet of dark-gray limestone. The thickest and most strongly indurated conglomerate averages two feet in thickness and is the lower-most conglomerate exposed.

The pebbles consist principally of angular limestone and chert derived from the rocks which enclose the conglomerate. In addition, scattered sub-angular and angular fragments of phyllite, slate, and sandstone occur (Fig. 1). Well-rounded and frosted sand grains and clay make up the finer detrital materials. Calcium carbonate is the cementing agent and

*Read before Earth Science Section, Georgia Academy of Science, Mercer University, Macon, April 24, 1953.

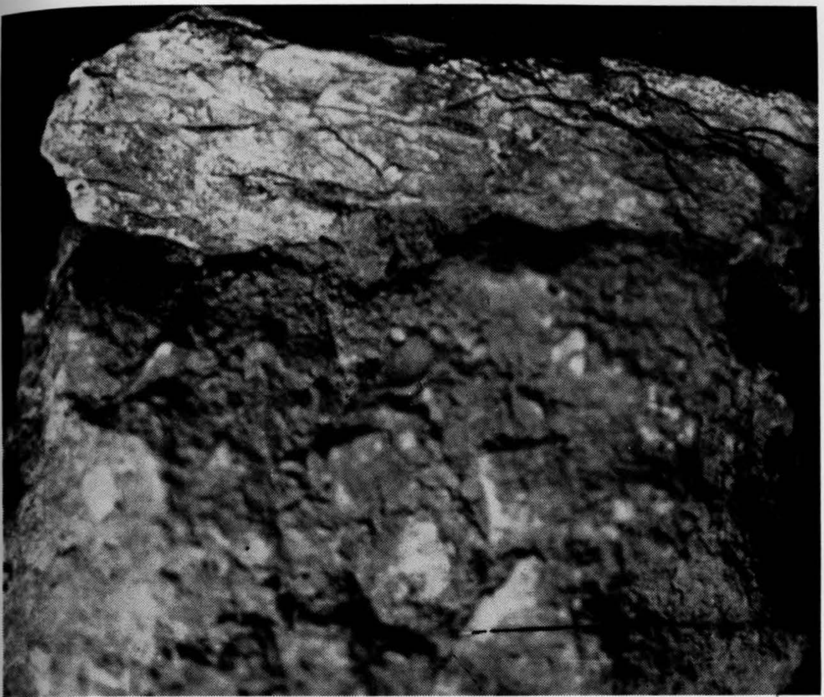


Figure 1. Hand sample of conglomerate showing the angularity and size variation of the incorporated fragments.

locally is as abundant as the detrital material (Fig. 2).

The calcium carbonate cement surrounds the least-weathered materials, but frequently penetrates and apparently replaces the slate and phyllite which show considerable weathering and oxidation of iron. Many concretionary and banded structures are present, usually surrounding an open space and rendering the rock vuggy and irregular. The inner surface of the cavities are characteristically lined with well-formed microscopic calcite crystals, oriented with the c-axis converging in the middle of the cavity. Occasional crystal growth completely fills the opening.

Although the limestone fragments show no evidence of solution or replacement the gastropod tests which occur sporadically throughout the matrix commonly show partial replacement by calcite. The replacement has apparently preceded from the interior outward and occasionally only the exterior

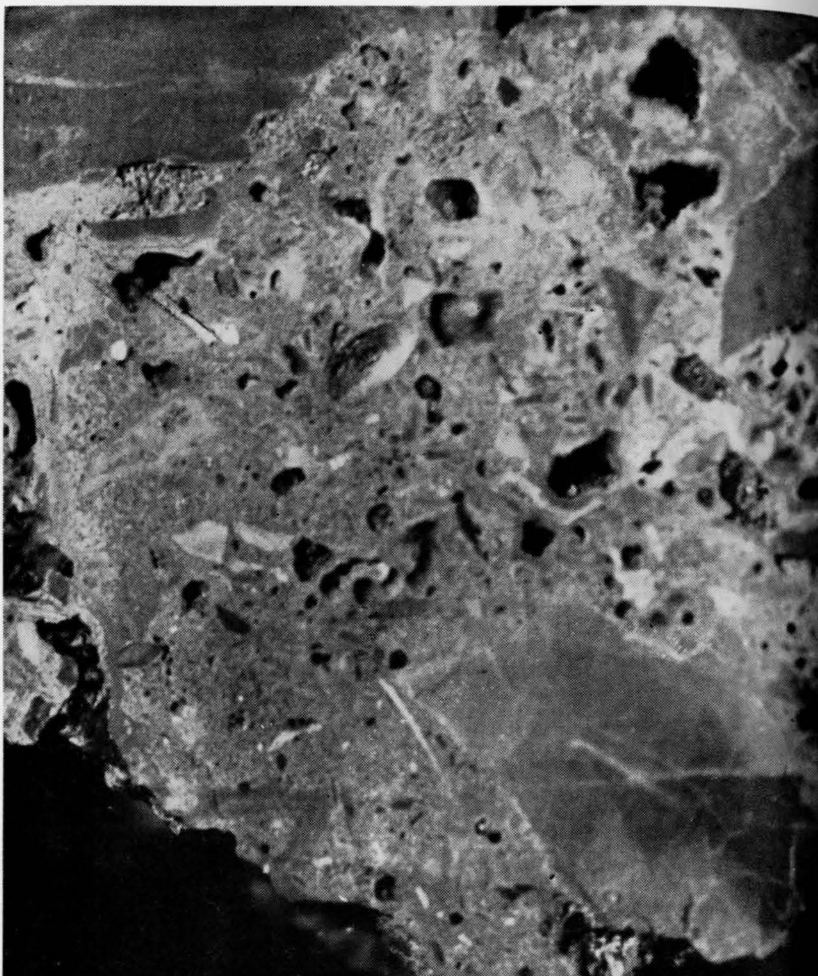


Figure 2. Sawed section of conglomerate: Fragments are limestone (light grey), slate (dark grey) and chert (white).

layer of the tri-layered test remains unreplaced. Partial or complete filling of the test is the rule. The filling is usually calcite, but in some instances may contain considerable clay.

Paleontology

At least two genera of gastropods, both belonging to the family Polygyridae, are present. No attempt was made to classify the forms as to species because structural modifica-

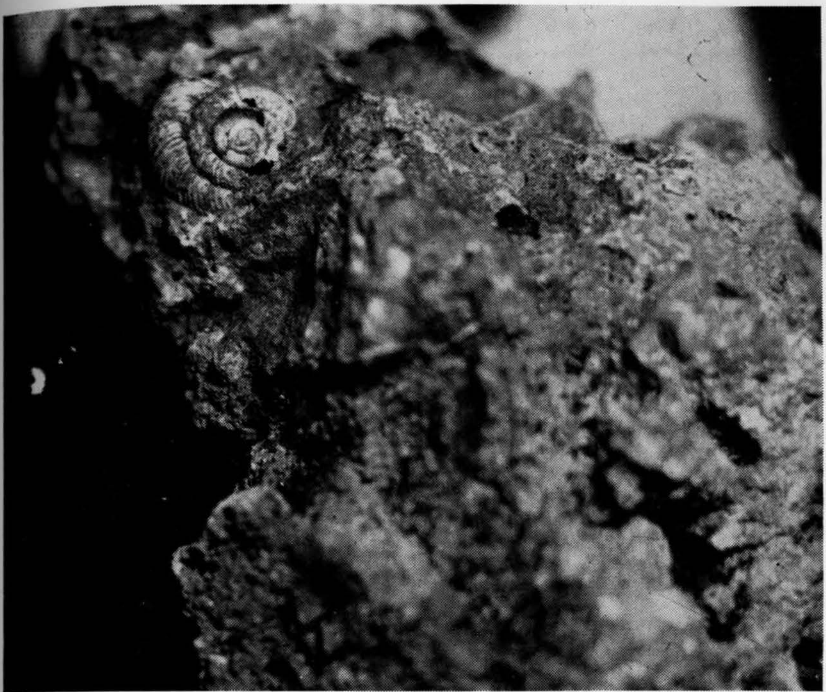


Figure 3. Partially filled and replaced land-snail test.

tion of the test within one species is frequently great. The two genera represented are Triodopsis and Mesodon, both of which have forms among the living land-snails, but range from Tertiary to Recent (Fig. 3).

Origin of the Conglomerate

The origin of the detrital material and the induration by the addition of calcium carbonate is an interesting problem. The limestone and probably the chert fragments are derived from the overlying limestone beds, which, on exposed under surfaces, spall rapidly producing many small, slab-like fragments.

Apparently solution took place along the inclined bedding plane for some distance down dip. Solution must have taken place largely at the expense of the underlying bed, whereas the overlying bed contributed the above described fragments. Fluting typical of solution beneath the water table was not observed and some of the clay appears to have been derived from the residuum of the underlying limestone.

During exceptional high-flood stages of the stream which once flowed in the valley, thin wafer-like fragments of slate and sandstone, and sand and silt were introduced. Subsequently the slow movement of downward perculating groundwater dissolved calcium carbonate from overlying limestones and reprecipitated it as calcite in the highly permeable conglomeratic filling. The land-snails, the tests of which are preserved, apparently lived among the debris thus deposited and upon death became incorporated in the indurated rock.

The steam now flowing across the flood plain enters it from a youthful valley ¼ mile east of the area described and is actively downcutting in the present erosion cycle. Thus, it would appear that the conglomerate was formed in a previous cycle.

Implications

This conglomerate-forming process would take place only in restricted areas; hence, its significance is somewhat obscure. It may be pointed out, however, that local conglomerate zones occur in limestones of otherwise uniform lithology. That the process may occur in any geologic period seems undeniable.

In areas such as the folded Appalachians, where warping and erosion alternated with deposition, similar events may have taken place many times. Later burial or continued warping would promote partial recrystallization thus obliterating evidence of age differential. This, then, may constitute a satisfactory answer to the problem of certain local limestone conglomerates found at many horizons throughout the geologic column.

ANIMAL TRACKS IN AN ORDOVICIAN ROCK OF NORTHWEST GEORGIA*

A. T. ALLEN and J. G. LESTER

Emory University

Introduction:

The occurrence of animal trails and tracks has been reported in rocks of many ages but early paleozoic rocks are relatively free of such fossils. We believe that this is the first attempt to describe fossil spoor of early paleozoic time in Georgia.

The trails are found on the east side of Rabbit Valley about two miles north of Ringgold, Georgia (fig. 1) where they have been preserved in a green chert of Upper Middle Ordovician age. The chert exposure is slab-like, dipping 15° east and striking 20° northeast, and on the upper surface the trails are plainly seen.

Weathering of the chert has not affected the legibility of the tracks nor is it believed that it has destroyed any of the essential characteristics of them. Water flowing in the grooves may have modified the finer details of the bottom and sides of the grooves.

Description of trails and tracks:

The fossil spoor can be divided into three categories:

1. Fairly straight grooves ½″ wide x ⅛″ to 3/16″ deep and bordered on each side by a small ridge about ⅛″ high. The trails are often arcuate and in some cases loop back over themselves.

2. Regular grooves about ¾″ wide x ⅛″ to ¼″ deep, bordered on each side by a ridge ± ¼″ high. These are almost twice the size of the smaller grooves and at first glance give the impression of being two parallel small grooves but careful examination shows them to be distinctly different from the smaller ones.

It is possible, of course, that No. 2 was made by a larger

*Read before Earth Science Section, Georgia Academy of Science, Mercer University, Macon, April 24, 1953.

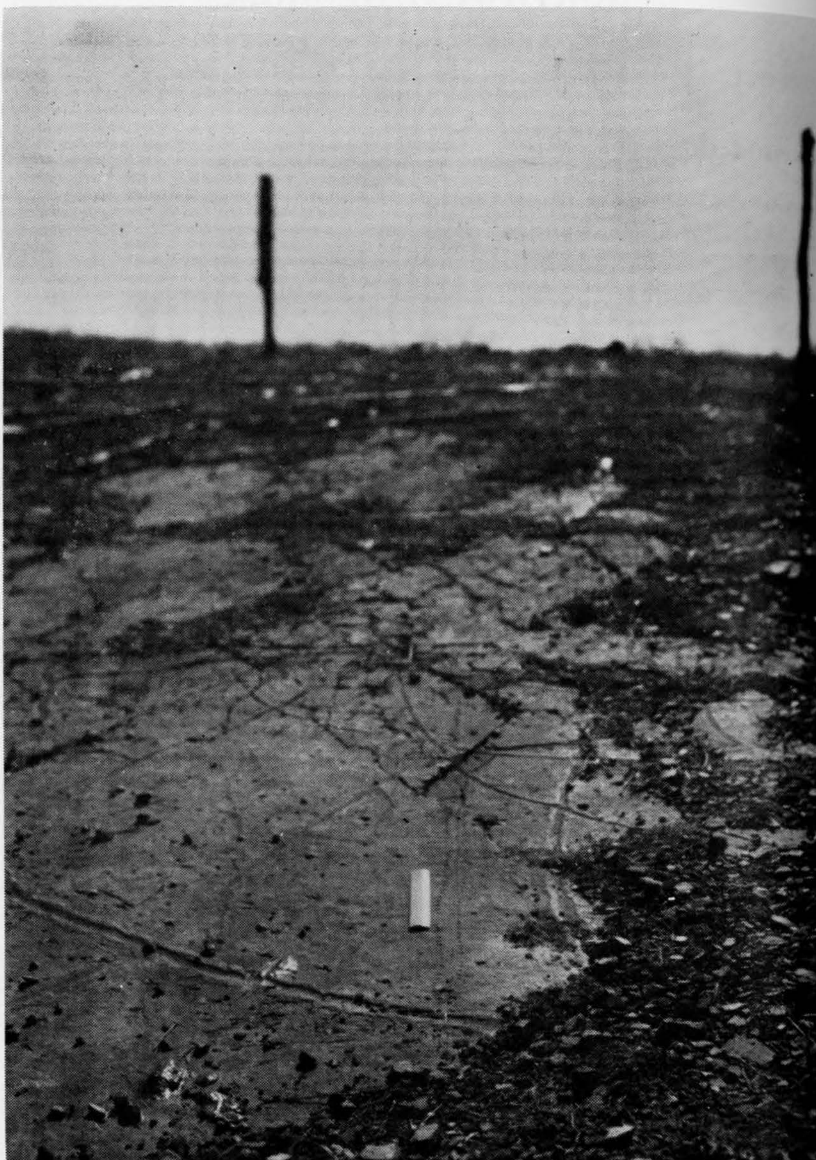


Fig. 1. Multitude of trails on exposed slab of chert.

organism than No. 1 but belonging to the same family.

3. This is a true track in that foot marks or appendage marks are plainly preserved. They are straighter in direction than the grooves and show less tendency to turn from a straight line.

The width of the track is about 1½″ outside to outside. A slight depression ½″ wide x 1/32″ deep forms the middle part. Separated from it by ¼″ - 5/16″ are parallel lines of crescentic impressions, one line on each side. The small crescents average ¼″ in diameter and are about ½″ - 9/16″ apart. The crescents on one side are very slightly staggered with respect to those on the other side.

The spacing of the crescents is uniform and their depth shows no appreciable variation. As the animal moved its legs backward in order to propel itself in a forward direction the feet piled up the ooze into asymmetrical mounds with the steeper side next to the foot and therefore pointing the direction of movement.

Origin of Green Chert:

The bed in which the fossil tracks are preserved is commonly referred to as the "Green Chert Layer" because it is a persistent marker in the Mohawkian limestones of northwest Georgia. In recent stratigraphic work this zone has been labeled Zone 18.

The chert in many places preserves casts of brachiopods and gastropods which are typical of the fauna above and below this zone. Since the organisms obviously had calcareous skeletons, which have been replaced in situ by silica, the chert is considered to be of secondary origin. Immediately above the chert is a layer of bentonite which correlates with zone B-3 of Fox and Grant (1944) and zone T-3 of Wilson (1949). It is thought that silica has been leached from the bentonite by downward percolating ground waters and has replaced the underlying limestone, at the same time preserving the structures and organic remains found in this zone. The layer is about 6 inches thick and grades into unaltered limestone at the base.

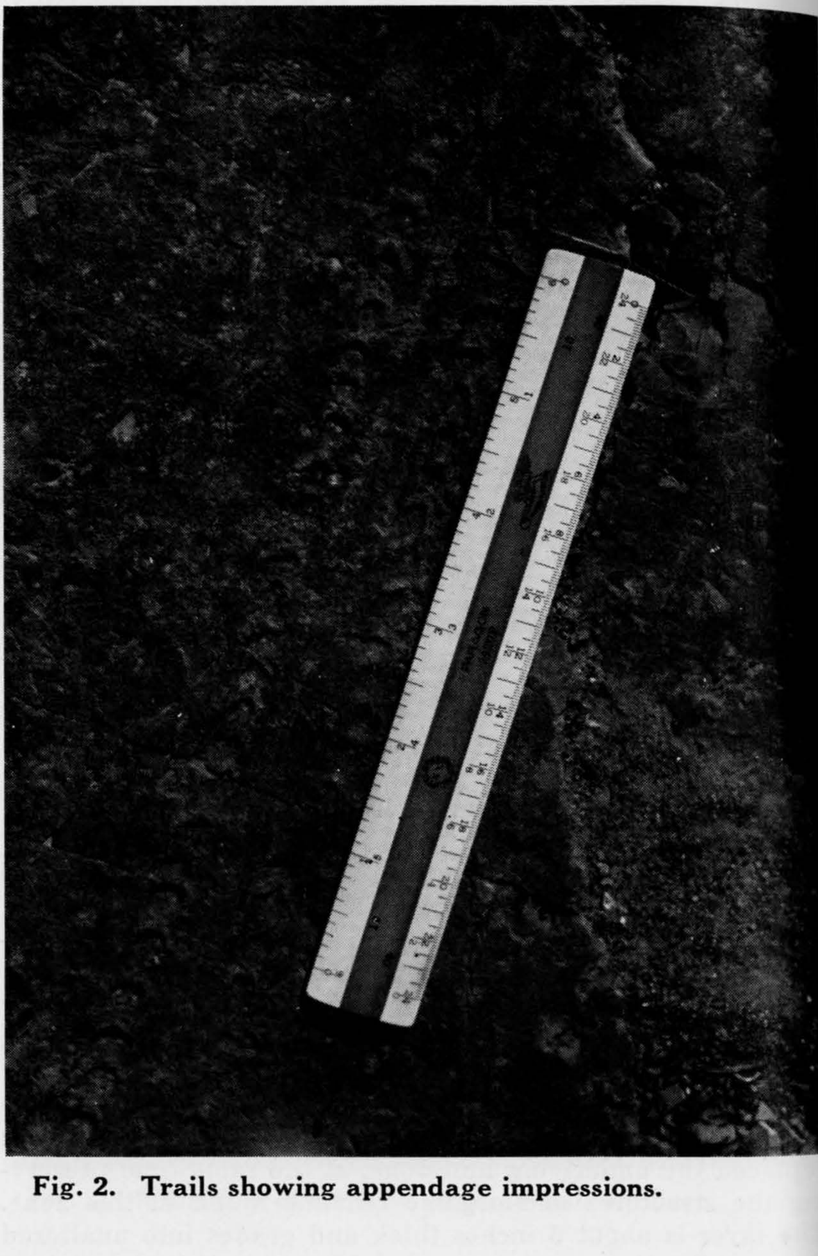


Fig. 2. Trails showing appendage impressions.

Possible origin of trails and tracks:

Hall (1887) described briefly some grooves similar to Numbers 1 and 2 and decided they were made by a mollusk; Vokes (1941) classed such grooves as being the trail of a gastropod. We believe that these are trails of a gastropod made in a limy ooze in not too shallow water for the following reasons:

1. The uniformity of the grooves and ridges indicate a very soft substance upon which the animal travelled and into which he sank slightly.

2. The animal or animals making trails illustrated in figure 1 possessed a relatively soft organ of locomotion, located beneath the center of gravity of the body and moved by muscular expansion and contraction in a gentle, flowing-like motion. This type of movement would produce just such an uninterrupted trail.

3. It obviously was some animal living during Ordovician time in the area or came into the area for feeding purposes or was migrating.

4. The absence of tentacle markings and operculum imprints is due to either weathering or to the silicification process which changed the limy material into chert.

5. The bulk of the animal making trails Number 2 would not necessarily be greater than that of such forms as Maclurites sp., which inhabited Ordovician seas.

6. The trail made by a modern water snail in red clay submerged beneath 6″ of water resembles very closely the fossil trails of Rabbit Valley (figure 3).

Because the grooves described above were made by organisms which evidently had no locomotor appendages, a search was begun to find an invertebrate which might be capable of leaving such spoor. In order to reproduce the conditions existing in nature as nearly as possible, a pan was filled with about 3 inches of water in which red clay was allowed to settle to a depth of an inch. Since the clay was saturated with water, it was soft enough to allow an organism to sink into it, yet firm enough to preserve any prints which might be made. Into the container was placed an ordi-

Fig. 3. Trail of modern water snail made in soft ooze.

nary water snail. The results are listed below and can be seen in figure 3.

1. Trail-like impressions left with faint tentacle markings along the sides.

2. An operculid-form snail leaves slight indentations within the groove because of the operculum.

3. The width of the trail is the same width as the diameter of the shell.

4. Trail may be widened locally by the turning from side to side of the snail or the reversal of direction.

A slime of marble dust was also used but the results were unsatisfactory.

Moore's **Historical Geology** (1933a) shows a picture after C. D. Walcott (1910) of trilobite tracks in the Upper Cambrian sandstones of New York which are very similar to track Number 3 in Rabbit Valley and approximately the same size. Ringueberg (1887) describes a trilobite track as, "In the form of a regular succeeding series of ten paired divergent indentations arranged in two diverging rows with the tail trail showing intermittently between".

In the tracks in Rabbit Valley, each individual appendage impression is so developed as to indicate the direction of movement. Gaps in the trail may be the result of a leaping motion or jumping. The persistence of the tail or body track between the appendage impressions seems to indicate that the animal was not able to support its weight by its legs and was a bottom crawler.

The shallowness of the impressions would indicate a relatively lightweight organism. Not as great, perhaps, as the gastropod which formed trail Number 2.

This track is thought to have been made by a form possessing strong, prominent, evenly-spaced appendages which were arranged in such a manner that the spacing between the individual appendages was essentially equal to the forward movement made at each step or the appendages were few in number. The tracks are so uniform in their spacing and so well-defined that such must have been the case or otherwise each succeeding appendage, where there were

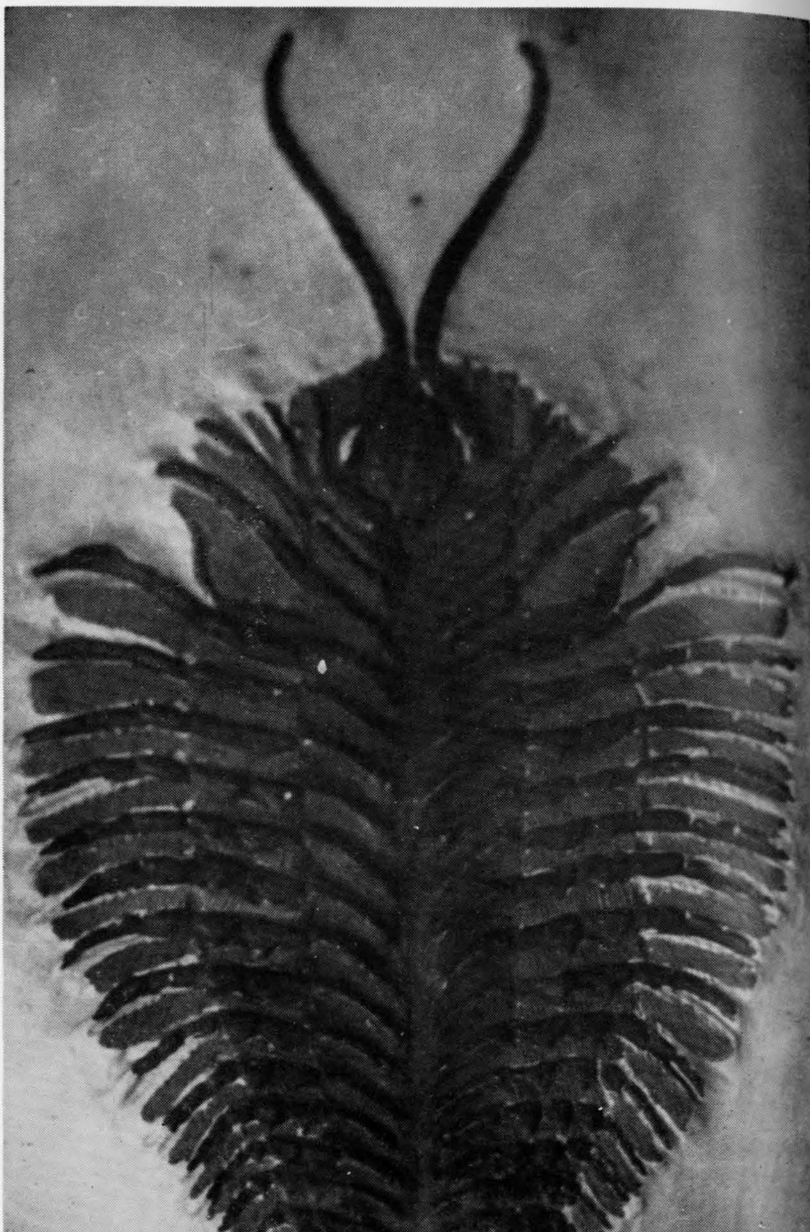


Fig 4. Cast of underside of a trilobite (Triarthis becki).

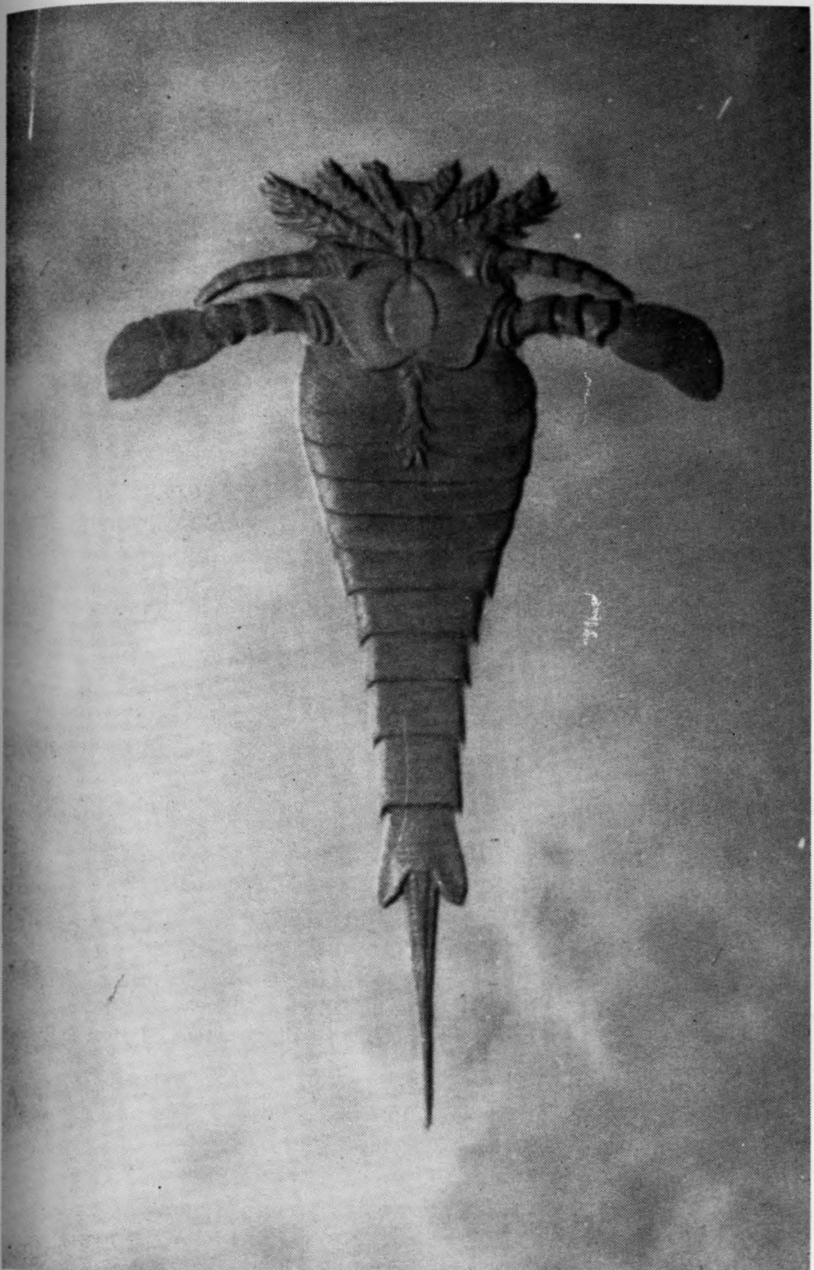


Fig. 5. Cast of eurypterid (Hughmilleria) showing appendages.

many of them, must have been placed in the print made by the ones in the forefront; this is hardly to be expected.

No fossil of the organism making the track has been found but Fig. 5 shows an eurypterid of Silurian age (Hughmilleria) which possesses paired appendages, body width and a bulk which could readily be responsible for such tracks. An appendage spread of 1½″ to 2¼″, width of body of 1″ and a smooth ventral surface on the body and tail.

We believe the track Number 3 to be the trails of a form of eurypterid or a form similar to it.

According to Moore (1933b) the eurypterids are marine forms, mostly mud crawlers, though some were excellent swimmers.

Six genera and 16 species have been reported from the Ordovician, but so far as we know, no fossil eurypterids have been reported from the Ordovician of Georgia.

No attempt was made to reproduce such tracks by experimenting with living animals.

Bibliography

Fox, P. P. and L. F. Grant, Ordovician bentonites in adjacent states. Jour. Geology, V. LII, 1944.

Hall, James, On trails and tracks in the sandstone of Clinton Group of New York, Amer. Assn. Adv. Sci. Proc. vol. 2, p. 256, 1850.

Moore, R. C., Historical Geology, p. 186, 1933.

——————, Historical Geology, p. 230.

Ringneberg, E. N. S., A trilobite track illustrating one mode of progression of the trilobites.

Schmidt, F., The Eurypterus beds of Osel as compared with those of North America, Geol. Soc. Amer. Bull., vol. 3, p. 59, 1892.

Vokes, H. E., Fossil (imprints of unknown origin, Amer. Jour. Sci. vol. 239, no. 6, p. 45, 1941.

Wilson, C. W., Pre-Chattanooga stratigraphy of the Central Basin of Tennessee, Tenn. Geol. Survey, Bull. 56, 1949.

CHERTIFICATION IN THE FORT PAYNE FORMATION, GEORGIA*

VERNON J. HURST

Emory University

ABSTRACT

Eight stratigraphic sections across the Mississippian Ft. Payne formation, seven in Georgia, and one in Tennessee, have been examined. The field work has been supplemented by a study of 48 thin-sections and seven chemical analyses. Evidence bearing on the origin of the chert in this formation is presented.

INTRODUCTION

Chert is known in all parts of the world and has attracted the attention of many investigators. A number of different theories of origin have been proposed. As early as 1888 Prestwich suggested that it originates as a primary deposit on the sea floor by the inorganic precipitation of the silica carried into the sea in solution by streams. An alternative theory was proposed at about the same time by Bowerman who believed that silica in the sea is not chemically precipitated but is segregated instead by silica-secreting organisms, such as radiolaria and sponges. Bowerman proposed that siliceous fossils in rocks are the immediate source of the silica in chert; and that chert is produced by action of ground water whereby siliceous fossils are dissolved and the silica redeposited, after more or less transportation in solution, about suitable nuclei or along bedding planes as replacements in the shape of the familiar chert nodules or chert beds. Bowerman's theory, supported by the researches of Sollas, Hinde[1], Jukes-Brown & Hill, Sorby, and others, was widely accepted. Textbooks used it for three or four decades as the best explanation for the origin of chert. Prestwich's views, although less generally accepted than Bowerman's, have nevertheless been advocated by many subsequent workers, among them: Hull & Hardman, M. A. Renard, C. A. White[2], E. O. Hovey, C. R. Van Hise & R. D. Irving[3], N. H. & H. W. Winchell, and A. C.

*Read at the Meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

Lawson[4]. Tarr[5] has been one of its strongest advocates of recent years.

Other theories for the origin of chert have been advanced. Griswold[6] proposed that the Arkansas novaculites may have originated as very fine-grained, clastic quartz. English[7] suggested a similar origin for siliceous rocks of the Monterey formation, California; however Bramlette[8] has since shown that the silica in these rocks came largely from diatom tests. For the chert in the Potosi group of southeastern Missouri, Ulrich[9] proposed the segregation of siliceous material during slow subaerial decomposition of limestone.

Van Tuyl[10], Dean[11], Ziegler[12], Twenhofel[13], and others have given strong support to the idea of secondary origin of chert by epigenetic replacement. Van Tuyl and Twenhofel have attempted to reconcile the conflicting evidences for primary and secondary origin by postulating the replacement of unconsolidated sediments on the sea floor by inorganically precipitated silica.

The origin of chert remains a debatable question, despite studies on the subject by more than thirty men. Most of the disagreement concerning origin has arisen between geologists because they have not investigated the same deposits, a fact which has lead some writers to point out that different chert deposits may have had various origins.

This paper is a first attempt to determine the origin of the chert in the Ft. Payne formation. The Ft. Payne is correlative with the Burlington and Keokuk of the standard Mississippian section of the Mississippi Valley (Butts, 1948). The chert in the Burlington was studied by Tarr who concluded that it is of primary origin.

FORT PAYNE FORMATION

The Ft. Payne formation in Georgia is less than 200 feet thick and is composed of stratified chert, calcareous shale, and argillaceous limestone. The distribution of the formation is shown by figure 1.

The bedded chert occurs at the base of the formation. The chert rests on, and is in places gradational to, the Devonian Chattanooga shale. In the sections where bedded chert is

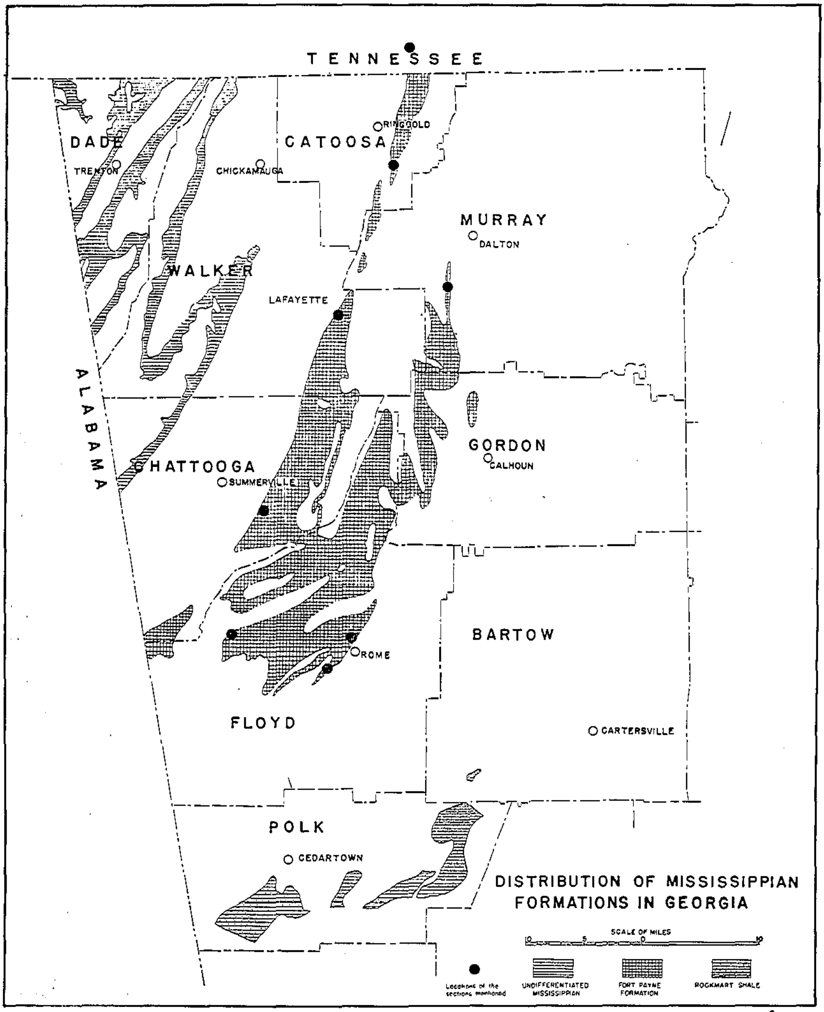

TENNESSEE
DADE
TRENTON
CHICKAMAUGA
RINGGOLD
CATOOSA
MURRAY
DALTON
WALKER
LAFAYETTE
ALABAMA
GORDON
CALHOUN
CHATTOOGA
SUMMERVILLE
BARTOW
ROME
FLOYD
CARTERSVILLE
POLK
CEDARTOWN
DISTRIBUTION OF MISSISSIPPIAN
FORMATIONS IN GEORGIA
SCALE OF MILES
10
5
0
10
Locations of the sections mentioned
UNDIFFERENTIATED MISSISSIPPIAN
FORT PAYNE FORMATION
ROCKMART SHALE

Figure 1.

absent, the base of the Ft. Payne is composed of a calcareous or argillaceous limestone, which Butts named the Lavender shale. The thickness of the Lavender member appears to be reciprocally related, at least in a rough way, to the thickness of the bedded chert. For example, one mile south of West Rome on the west slope of Mt. Alto, 30-50 feet of bedded chert is overlain by 80-100 feet of the Lavender member whereas fifteen miles to the north, along U. S. Highway 27, one mile west of Gore, about 150 feet of bedded chert is exposed, but the Lavender member is missing. The bedded chert is gradational to the Chattanooga shale at this locality (Fig. 4). Farther north, 1½ miles due east of Ringgold, the stratified chert is absent, and its normal position at the base of the Ft. Payne is occupied by less than 100 feet of Lavender shale, which is in conformable contact with the Chattanooga shale.

The calcareous shale in the Ft. Payne, i. e., the Lavender shale, is not readily separable from a dark-colored, siliceous, argillaceous limestone which occurs with and above it. The Lavender shale at its type locality ⅔ mile west of Lavender station in Floyd County is very near a limestone in both appearance and composition. Much of what Butts called Lavender shale is actually limestone. Sample 7 in Table 1 is an analysis of a composite sample of Lavender shale from the big quarry on the Southern railway one mile north of Rome; this sample contains more than 75% carbonate. It seems hardly appropriate to use the term shale in referring to a stratigraphic unit that is largely limestone. Accordingly, the dark-colored, siliceous, argillaceous limestone in the lower ⅔ of the Ft. Payne together with the associated calcareous shale is referred to in this report as the Lavender member.

The top of the Ft. Payne is not well exposed in the area studied. Fossiliferous, blue-gray, cherty limestone comprises the top of the formation at Parker's Gap, Tennessee, and grades upward into limy, residual soil. East of Taylor's Ridge in the Ringgold quadrangle, all the formation above the Lavender member is represented only by residual soil. The same is true of the upper part of the formation in Houston Valley, on the east side of Rocky Face Ridge 5 miles southwest of Dalton, and east of Lavender station in Floyd County. At the last-named locality and in Houston Valley the residual soil contains much thin blocky chert and irregularly-shaped nodular chert like that which weathers out of limestone. Because of the appearance of the residuum, the shape of the chert in it, and because of the evident increase in lime upward in the Ft. Payne, it is believed that the top of the formation consists of fossiliferous, siliceous, argillaceous limestone in which there are chert nodules and occasional thin chert beds.

The Ft. Payne fossils are silicified and have accumulated in great numbers in the soil, especially in soil derived from the upper member. Grinoid stems many of them a half inch or more in diameter, productid and spiriferoid brachiopods, horn corals and button corals are found. In the calcareous shale, fenestrellinid bryozoa are common. The following fossils have been assembled from the Ft. Payne by Dr. A. T. Allen and Dr. J. G. Lester of the Emory Geology Department, Emory University: **Hadrophylum ovale** Bassler, **Teleocrinus** sp., **Pentremites cava** Ulrich, **Philipsaster gigas** Billings, **Zaphrentis comicula, Z. Cliffordana, Favosites turbinatus** Billings, **Platyceras** sp., **Spirifer grimesi** Hall, **S. leidyi** Norwood & Pratten, **S. rostellatus, Athyris lamellosa** (L'Eveille), **Aviculopecten** sp., **Lingula carbonaria, Dielasma arkansanum** Weller, **D. illinoisensis** Weller, **Eumetria verneuiliana** Hall, **Goniatites kentuckiensis** Miller, **Penniretopora** sp., **Streblopteria cooperensi** (?).

In addition to the fossils listed above, Butts mentions the following: from the Lavender member, **Dictyonema** sp., **Cystodictya linearis, Hemitrypa** near **H. nodosa, Fenestrellina burlingtonensis, F.** near **funicula, F. multispinosa, F. regalis, F.** near **F. rudis, Brachythyris subcardiformis** (?), **Cleiothyridina glenparkensis, Dictyoclostus burlingtonensis, Phaethonides spinosus**; and from the rest of the Ft. Payne, **Zaphrentis compressa, Chonetes shumardanus, Linoproductus ovatus, Dictyoclostus** cf. **D. crawfordsvillensis, D.** cf. **D. inflatus, D.** cf. **D. viminalis.**

Bedded Chert

The bedded chert in the Ft. Payne is highly variable in thickness. It constitutes the bulk of the formation at some localities, but is absent from others; its maximum thickness is about 150 feet.

The bedded chert is dense, brittle, dark gray, and evenly bedded. Individual beds, which are mostly less than one foot thick, are separated by thin layers that differ in composition from the chert beds only by a higher content of clay and carbonate (Fig. 2). This difference is accentuated by weathering, which leaches the carbonate in these layers, causing the chert beds to be exposed in relief. Although the clay-carbonate layers are lumpy and the chert's bedding surfaces irregularly, furrowed, the individual chert beds are remarkably continuous and maintain a uniform average thickness. In road cuts along U. S. Highway 27 one mile west of Gore, thin chert beds can be traced laterally more than 250 feet without perceptible change in average thickness or appearance.

Two thin-sections each were made from samples collected

Figure 2. Bedded chert along U. S. Highway 27, one mile west of Gore, Georgia.

at 25 foot intervals across the bedded chert west of Gore in Floyd County and east of Lafayette in Walker County. All thin sections were cut perpendicular to the bedding planes; of the two sections from each sample, one was cut parallel to the strike of the beds, the other at right angles to the strike. Microscopically, (See Fig. 5) the chert beds consist of quartz and chalcedony, with possibly a small amount of amorphous silica; also conspicuously present, but usually constituting less than 10% of the rock, are carbonate rhombs, clay, black opaque matter, and occasional grains of glauconite and feldspar. The silica is mostly in very small crystalline grains of irregular shape and size, from 0.0008 to 0.02 mm. across. Contacts between grains are often intricately sutured. Many of the smaller

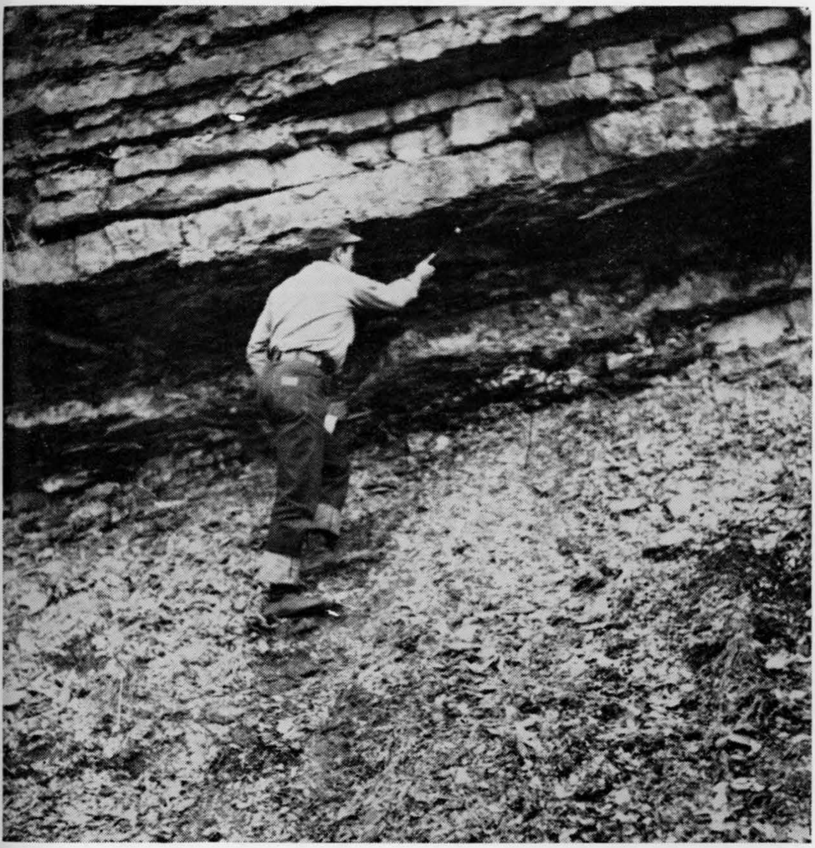


Figure 3. Contact between bedded chert and the underlying Devonian Chattanooga shale, one mile west of Gore.

grains are cryptocrystalline. A few small areas appear to be amorphous silica. Rhombs up to 0.09 mm. across are randomly scattered through the silica groundmass. Most of the rhombs, which were probably calcite originally, have been completely replaced by quartz. Instances were noted where the quartz replacing the calcite is in optical continuity with the enclosing quartz, the rhombic outlines of the replaced crystal being preserved only by faint lines of "dust." In other cases, the replacing quartz is in distinct crystals, optically unrelated to the enclosing quartz. Clay and probably ferric oxide are seen as a red-brown smudge throughout the thin-sections. The black, opaque matter occurs in irregularly-shaped grainy aggregates of tiny particles, in solid-appearing, irregularly-

Figure 4. A close-up of figure 3, showing the gradational nature of the contact. Note the phosphatic nodules in the Chattanooga shale extending upward into the Ft. Payne chert.

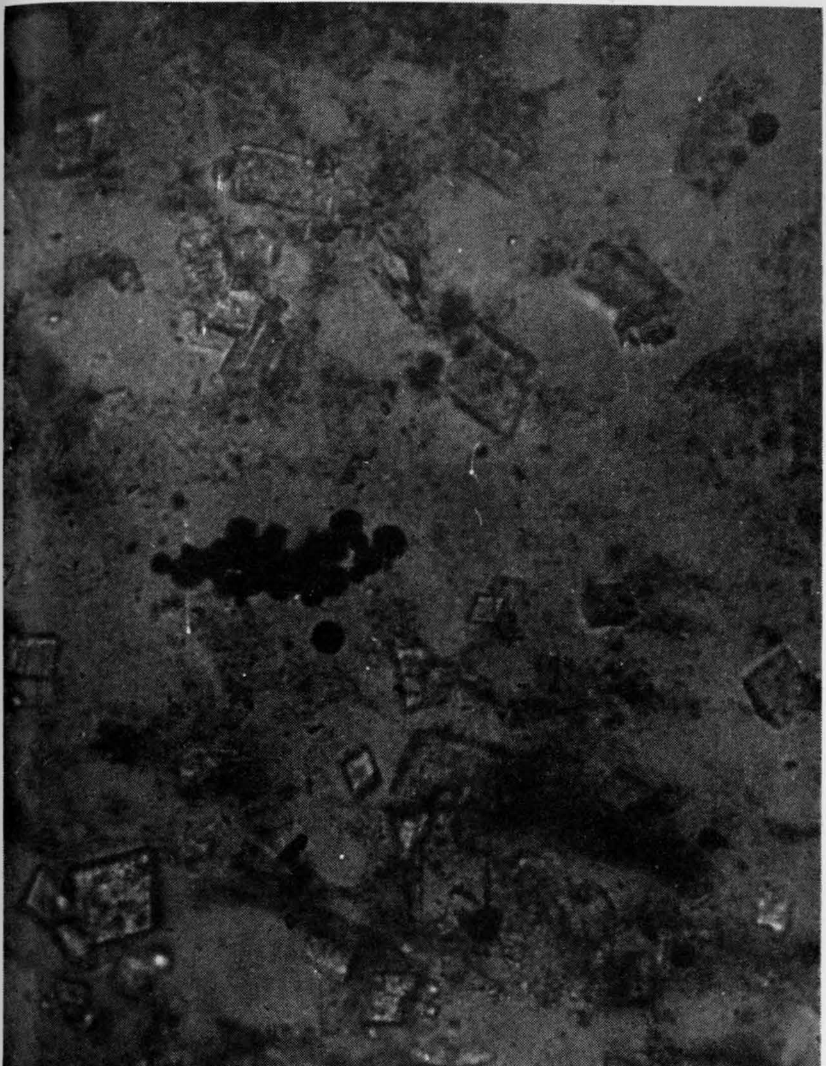


Figure 5. Photomicrograph of the bedded chert. The globular, opaque masses in the chert groundmass are believed to be marcasite. The rhombs are pseudomorphs of quartz after calcite. Plane polarized light x 440.

shaped flecks, and in trains or clusters of minute globular masses. The clay and opaque matter tend to be segregated in the intergranular spaces, as though partially expelled from the areas now occupied by the larger crystals during their growth or crystallization. Numerous instances were noted, however, in which the opaque matter, especially the larger particles, occurs entirely within carbonate rhombs or across their boundaries. In a few cases, opaque matter occupies most of the space within the rhomb but still terminated abruptly at its boundaries.

Few fossils were seen in the 20 thin-sections of chert, but bits of opaque matter which appear to be disrupted organic

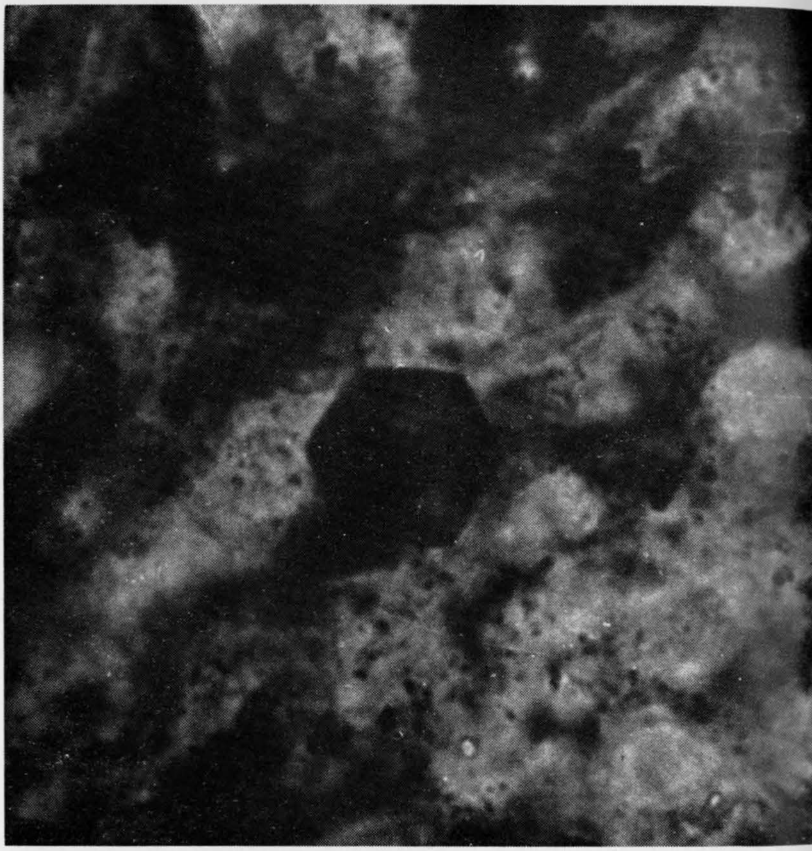


Figure 6. Minute, hexagonal plane or spine, probably an echinoderm part, in the chert. x 100.

structures are common. An occasional minute hexagonal plate or spine composed of silica, presumably an echinoderm part, was noted (Fig 6). Well-developed microstylolites in granular chert were observed in one thin-section (Fig. 7).

Four chemical analyses of chert (Samples 1, 2, 3, and 4 in Table 1) give an average of 87% silica. Carbonate is the next most abundant constituent, then alumina, and finally ferric oxide.

Lavender Member

The Lavender member consists of argillaceous limestone and calcareous shale, both dark-colored and siliceous (Analy-

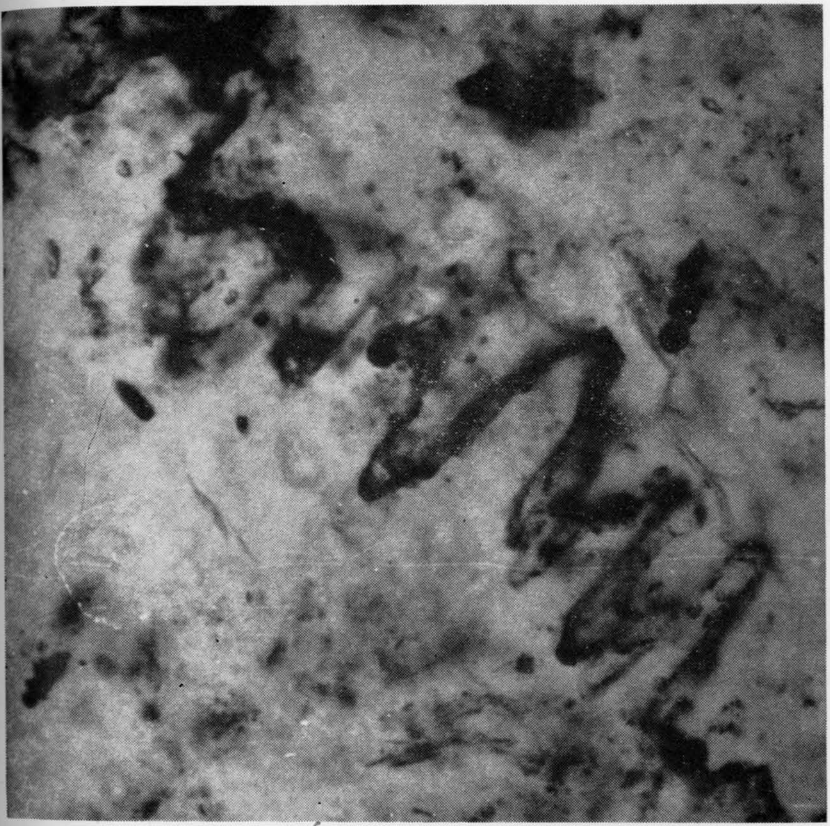


Figure 7. Photomicrograph. Microstylolite in chert. Plane polarized light. x 440.

ses 5 & 6, Table 1). The two rocks differ from each other mainly in the proportion of carbonate to silica.

During the time the Ft. Payne was accumulating, environmental conditions were changing from those which produced the Silurian-Devonian sandstones, silt-stones, and shales to the new conditions which produced the massive Mississippian limestones. The interfingered calcerous shales and siliceous limestones of the Lavender member represent the deposits that were being laid down during the change. These deposits are close enough in composition that each shift in the amount of silica being deposited, or—if the cheritification is secondary—each change in the degree of silification, was sufficient to cause the formation of one rock in place of the other.

The thickness of the Lavender member, as noted earlier, appears to be reciprocally related, in a rough way, to the

Figure 8. Siliceous, argillaceous limestone, the upper member of the Ft. Payne, at Parker's Gap, Tennessee.

thickness of the bedded chert. The Lavender member grades downward into bedded chert, when both are present, and upward into the limestone member. The combined thickness of Lavender member and bedded chert appears to become less in a northeast direction and to be replaced by a correspondingly greater thickness of the limestone member.

Four thin-sections, two of shale from the type locality west of Lavender station, and two of dark-colored limestone from the quarry on the Southern railway one mile north of Rome, show that the constituents in the Lavender member are the same as in the bedded chert, the only difference being in proportion. The two thin-sections of dark-colored limestone are identical, microscopically, with thin-sections of the limestone member at the top of the Ft. Payne except for the amount of opaque matter.

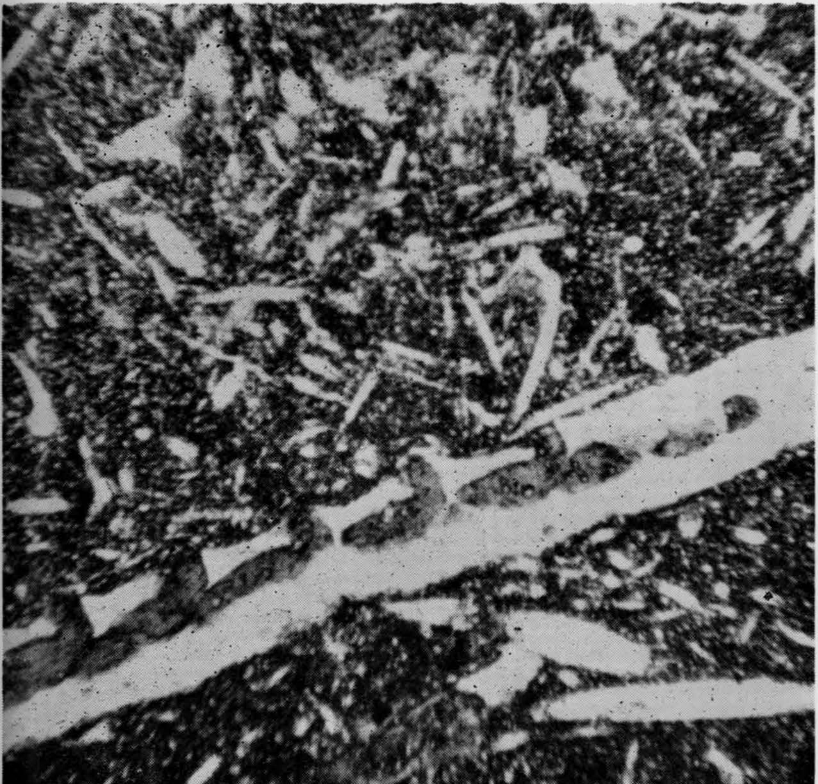


Figure 9. Fossils in the limestone member at the top of the Ft. Payne. Plane polarized light. x 40.

Figure 10. Asymmetrical spherulites in an elongate fossil fragment. x 440.

Siliceous, argillaceous limestone

At the top of the Ft. Payne is a siliceous, argillaceous limestone like that exposed at Parker's Gap, Tennessee (Fig. 8). This limestone member contains clay-rich lenses and even shaly layers, but it differs from the Lavender member by being predominantly limestone and by having a lighter color. It contains irregularly-shaped geodes, chert nodules, and occasional thin beds of light-colored chert. The geodes are up to four or five inches across and are lined with small quartz or calcite crystals. Stratification planes are warped about the geodes as though the rock underwent considerable compaction after the geodes formed.

Figure 11. Spherulitic silica in the bedded chert. x 100.

Twenty thin-sections were made from samples collected at regular intervals across the 60 feet of limestone in the Parker's Gap section, and four thin-sections from a single exposure of this member in Houston Valley, Whitfield County, Georgia.

Microscopically, the top of the limestone is indistinguishable from the bottom. The groundmass of the rock is crystalline calcite which is resolved into small, irregularly-shaped grains of varying size at a magnification of 400. Many of the small grains tend toward rhombic shape. Carbonate rhombs of larger size are liberally scattered through the groundmass without orientation. The larger rhombs vary in size but are mostly from 0.01 to 0.04 mm. across. Chemical

Figure 12. Calcareous fossil partly replaced by silica. The twinning lamellae are not present in the replaced portions; this might indicate that silicification occurred prior to crystallization of the calcite in the fossil. Crossed nicols. x 40.

analysis shows (Sample 7, Table 1) that some of the rhombs are probably dolomite. The largest grains present are grains of calcite up to 0.1 mm. across which have conspicuous twinning lamellae and frayed margins, and seem to have been enlarging themselves at the expense of smaller grains.

Microscopic fossils and fossil fragments are very abundant. (Fig. 9). Tiny spines that are circular and hollow in cross-section, and tubular in plan, are most common. A few spicules that are tetraxial in thin-section were noted, also remains of bryozoa, small brachiopods, and crinoids. A few of the larger

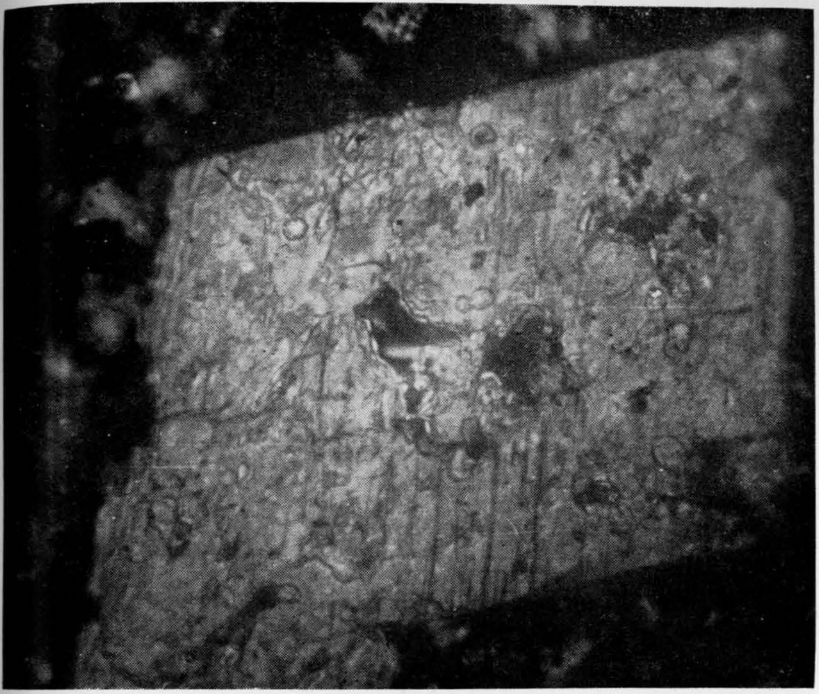


Figure 13. Carbonate rhomb partly replaced by, and enclosed in crystalline silica. Cross nicols. x 440.

fossils still consist of calcite or have been only partially replaced, but all the smaller fossils are composed of silica.

Spherulites are abundant in the smaller fossils (See Figures 10 & 11). The shape of the spherulites appears to be related to the place at which silification started in the fossil or to the point at which crystillization of the silica began. Circular spherulites with rays radiating from the center outward were formed when growth began in the center of the mass; asymmetrical spherulites resulted when growth or crystallization began along the margin. Very few of the spherulites are perfectly symmetrical. In the limestone thin-sections, only the silica in the large, partially replaced fossils and in the few small areas where silica is replacing the groundmass is nonspherulitic.

Finely-divided, red-brown, translucent to opaque matter that appears to be clay occurs in the groundmass along with slightly larger, black, opaque, irregularly-shaped particles that are possibly of organic origin. Also present are minute globular masses similar to those noted in the bedded chert (See Fig. 5). These opaque globular bodies vary in size, and slightly in shape, but are all very small at a magnification of 440. They occur singly, in trains, and in clusters. They are only slowly soluble in acid, yield good microchemical reactions for iron and manganese, and less satisfactory reactions for sulphur. The microchemical tests were performed on clusters of the globules carefully picked out of six uncovered thin-sections. Due to their small size, some of the enclosing rock was unavoidably included. The tests for sulphur were less satisfactory than the tests for manganese probably because the microchemical reactions for sulphur are less sensitive. These masses are believed to be mainly marcasite in view of their shape, composition, and mode of occurrence.

A chemical analysis of this member yielded 31% silica, at least 58% carbonate, about the same amount of alumina as in the other analyzed rocks, but less iron.

ORIGIN OF THE CHERT AND SOURCE OF THE SILICA

The various theories that have been proposed for the origin of chert and for the source of silica in siliceous formations have been arranged in a tentative genetic grouping by Bramlette[8]:

I. Inorganic source of silica

  A. Deposition of sediment unusually high in clastic silica.

  B. Inorganic precipitation from siliceous waters.

    1. Syngenetic

      a. Siliceous emanations from volcanic rocks.

      b. Silica in solutions and as colloids introduced by streams.

    2. Epigenetic

      a. Secondary introduction of silica by ground or surface waters.

  C. Chemical alteration and redistribution of silica of tuffaceous sediments.

1. Syngenetic
   a. Halmyrolysis or "submarine weatherings".
2. Epigenetic
   a. During compaction and lithification or later.

II. Organic source of silica.
   A. Organic precipitation and accumulation of siliceous organisms.
   B. Chemical alteration and redistribution of silica of organisms.
      1. Syngenetic
         a. Halmyrolysis or "submarine weathering".
      2. Epigenetic
         a. Diagenetic alteration during compaction and lithification.
         b. Metamorphic alteration during deformation and igneous intrusion.
         c. Alteration by ground or surface waters.

Each part of the list above may be regarded as a possible answer to the question of how chert originated in the Ft. Payne formation. Each is here briefly considered with regard to the information that has been gathered.

Possibility IA is ruled out for two reasons: first, because of the absence of a clastic texture—the silica grains in the Ft. Payne chert being very small and having sutured contacts; and secondly, because Grout[14] has demonstrated that in the finer-grained, clastic rocks the proportion of silica decreases.

IB1a and IC are eliminated because there is no field evidence that tuffaceous sediments were present or that volcanic emanations have affected the area.

Regarding IIB, siliceous spines are admittedly common in the upper member of the Ft. Payne, but it is not certain that they were originally siliceous. Further, the spines do not show corroded margins or partial removal as one would expect if they had supplied the silica for the chert below. The absence of radiolaria or even moderate numbers of other siliceous organisms in the chert is believed adequate to discount IIA.

Two possibilities remain: IB1b, "Inorganic precipitation of the silica introduced into the sea in solution or colloidal suspension by streams"; and IB2a, "Secondary introduction of the silica by ground or surface waters". The evidence that has been gathered conflicts and neither proves nor disproves either possibility. Accordingly, evidence for and against both is given.

ARGUMENTS FOR SECONDARY INTRODUCTION OF SILICA, i. e., EPIGENETIC REPLACEMENT

1. The chert occurs in synclines.
2. The chert is underlain by relatively impervious shale and overlain by a great thickness of siliceous limestone, a possible source of silica.
3. There is strong petrographic evidence for replacement. The following features were noted:
   a) Originally calcareous fossils now composed of silica.
   b) Pseudomorphs of quartz after calcite and dolomite.
   c) Microstylolites in the chert.
   d) Embayed residuals of calcite showing partial replacement by silica.
   e) Small globular masses of marcasite (?), thought to be of secondary origin enclosed in crystalline quartz.
   f) Marked tendency for clay and other impurities to lie outside the crystalline silica as thought expelled during its formation or crystallization.
   g) Finer details of organic structure in the fossils composed of calcite than in the fossils composed of silica.

   One feature possibly indicates syngentic replacement:

   h) A fossil composed of twinned calcite partially replaced by silica, but with the twinning lamellae not preserved, as though the replacement occurred prior to the crystallization of the calcite in the fossil.

4. The chert at the base of the Ft. Payne and the Lavender member associated with it are both dark-colored and contain the same impurities, glauconite, feldspar and clay, in about the same proportions. Thin chert beds and nodules in the upper, lighter-colored parts of the formation are mostly light-colored.

ARGUMENTS FOR INORGANIC PRECIPITATION OF SILICA INTRODUCED INTO THE SEA BY STREAMS OR AT LEAST FOR A PRIMARY ORIGIN OF THE SILICA

1. The bedded chert occurs always at the same horizon over a large area.

2. The distribution of the chert beds is unrelated to the present topographic surface, or to an imaginable older surface.

3. To refute argument 1 above, for the secondary introduction of silica, there are no anticlines in the area, and the chert occurs on the limbs of the synclines as often as in the troughs.

4. Persistent carbonate-rich layers are found between chert beds.

5. The layers of chert are continuous and evenly-bedded. The even bedding cannot be satisfactorily accounted for by assuming epigenetic replacement of a limestone in which there were shaly layers, because within the chert beds there are places which contain as much clay as the carbonate-clay partings.

6. Despite a strong tendency for fossils to be replaced by silica in preference to the enclosing limestone, noted during study of the limestone in the upper part of the Ft. Payne, the only calcite seen in the bedded chert is either in fossils or in distinct rhombic crystals.

7. Tabular bodies of chert lying parallel to the bedding planes and enclosed by thick limestones, like the thin chert beds in the upper member of the Ft. Payne, are most easily explained by postulating a primary origin for the silica.

8. In argument 4, for secondary introduction of the silica, it was pointed out that the bedded chert and the overlying Lavender member are both dark-colored, contain the same impurities, and thicken and thin in a reciprocal fashion, facts which suggest that the bedded chert was produced by epigenetic replacement of the lower parts of the Lavender member. In considering this possibility, it was noted that the areas within the Lavender member which contain the most clay also now contain the most silica, according to two chemical analyses and six insoluble residues. One would expect this to be true only (a) if the silica is largely primary and was deposited with the clay, or (b) if silicification has affected mainly the argillaceous layers or (c) if large quantities of carbonate were removed instead of replaced during the silicification, thus enriching the silicified portions in clay. The last two possibilities appear unlikely. Such reasoning is admittedly weak, but is nevertheless mentioned here as a tentative argument in favor of a primary origin for the silica in the Lavender member.

9. So much silica has been carried in solution and colloidal suspension by streams, and so little is present in sea water, that a very large amount must have been removed in some manner. According to Bramlette, "The silica content of 255 streams given by Clarke[15], when recalculated, shows an average of 16.4 parts per million. The usual silica content of sea water at the surface is only about one part per million". Clarke has estimated that streams contribute annually to the sea about 319,000,000 metric tons of silica, compared with 557,000,000 metric tons of calcium and 258,000,000 metric tons of sodium. A part of this silica has, of course, been removed by siliceous organisms, but there appears to be little reason for believing that it can be removed only in this manner. Tarr, Lovering[16], Gruner[17], Moore and Maynard[18], and others have conducted experiments on the inorganic precipitation of silica from dilute solution. Their results are not entirely in agreement but do demonstrate, nevertheless, that silica can be precipitated inorganically.

CONCLUSION AND SUMMARY

The information that has been gathered does not permit a conclusive statement about the origin of the chert in the Ft. Payne formation. Much of the evidence supports the view that the chert is mainly primary, and that it originated by inorganic precipitation of silica carried into the sea by streams. The even-bedding of the chert, the repeated alternation of carbonate and chert layers, the association of the chert with clay-rich sediments, and the virtual absence in the chert of remains of siliceous organisms or of any carbonate except that occurring in fossils and euhedral crystals are regarded as the main points supporting a primary origin. The evidence for secondary origin, on the other hand, is equally convincing. The presence in the chert of pseudomorphs of quartz after calcite, of replaced fossils, and microstylolites shows definitely that considerable replacement has occurred. These opposing arguments do not appear to be satisfactorily reconciled by postulating the replacement of unconsolidated limy sediments by precipitated primary silica mingled with them. Probably the origin of the chert involved the interplay of complex environmental conditions that cannot be properly appreciated in terms of the relatively simple processes considered as possible explanations here. A conclusive statement must await further study.

TABLE I

Sample No.	1	2	3	4	5	6	7
SiO_2	74.56	87.00	92.50	93.75	50.00	14.00	31.00
CaO	6.26	2.20	0.80	1.36	18.60	38.26	29.94
MgO	3.60	0.47	Trace	Trace	0.95	8.22	5.58
CO_2	5.85	0.50	Trace	1.00	17.65	33.62	26.40
Al_2O_3	3.23	6.27	3.51	2.63	8.82	1.77	6.27
Fe_2O_3	5.23	3.77	3.03	1.43	3.72	3.87	2.33
P_2O_5	0.00	0.04	0.00	0.00	0.00	0.05	0.02
SO_3	1.30	0.00	Trace	0.00	0.01	0.31	0.27
MnO	0.01	0.00	Trace	0.02	Trace	Trace	0.02
TiO_2	Trace	0.00	0.00	0.00	Trace	Trace	Trace
K_2O	Trace	0.00	0.00	0.00	Trace	Trace	Trace
Moisture	0.05	0.00	0.00	0.00	0.36	0.05	0.80
FeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Undetermined	0.00	0.00	0.16	0.00	0.00	0.00	0.00
Totals	100.09	100.25	100.00	100.19	100.11	100.15	102.63

Analyses of Fort Payne formation made by Laurie H. Turner, Chief Chemist, Georgia Geological Survey.

Sample 1—Bedded Chert, road cut U. S. Highway 27, 1 mile west of Gore. A complete chip sample from the middle of the Fort Payne.

Sample 2—Bedded Chert, same locality as sample 1, but from the base of Ft. Payne.

Sample 3—Bedded Chert, west slope of Mt. Alto, 1 mile south of West Rome. Composite chip sample from base of the Ft. Payne.

Sample 6—Bedded Chert, from Dug Gap in Taylor's Ridge, about 7 miles east of Lafayette.

Sample 5—Dark blue-gray, calcareous shale. From the type locality, a railroad cut 2/3 mile west of Lavender station in Floyd Co. Ga.

Sample 6—Dark blue-gray, argillaceous limestone, called Lavender shale by Butts. From big quarry on the Southern railway, 1 mile north of Rome.

Sample 7—Blue-gray, cherty limestone. Parker's Gap, Tennessee, a few miles north of Ringgold, Georgia.

BIBLIOGRAPHY

[1]Hinde, G. J., Geol. Mag. vol. iv, p. 435, 1887.

[2]White, C. A., Geol. Surv. Iowa, vol. i, p. 223, 1870.

[3]Van Hise, C. R. & Irving, R. D., 10th annual report, U.S.G.S., pt. 1, p. 397, 1890.

[4]Lawson, A. C., 15th annual report, U.S.G.S., pp. 420-426, 1895.

[5]Tarr, W. A., Amer. Jour. Sci., fourth series, vol. 44, pp. 410-452, 1917.

[6]Griswold, L. S., Annual report Geol. Surv. of Arkansas, vol. iii, p. 177, 1890.

[7]English, W. A., Geology and ore resources of the Puente Hills region, southern California; U.S.G.S. Bull. 768, p. 31, 1926.

[8]Bramlette, M. N., U.S.G.S. Professional Paper 212, 1946.

[9]Ulrich, E. O. & Bain, H. F., U.S.G.S. Bull. 267, pp. 27, 1905.

[10]Van Tuyl, Francis M., Amer. Jour. Sci., fourth series, vol. 45, pp. 449-456, 1918.

[11]Dean, Reginald S., Amer. Jour. Sci., fourth series, vol. 45, pp. 411-415, 1918.

[12]Ziegler, Victor, Amer. Jour. Sci., fourth series, vol. 34, p. 121, 1912.

[13]Twenhofel, W. H., Amer. Jour. Sci., fourth series, vol. 47, no. 282, pp. 407-429, 1919.

[14]Grout, F. F., Geol. Soc. Amer. Bull., vol. 36, no. 2, pp. 393-415, 1925.

[15]Clarke, F. W., U.S.G.S. Bull. 695, 1920.

[16]Lovering, T. S., Econ. Geol., vol. 18, no. 6, pp. 523-540, 1923.

[17]Gruner, J. W., Econ. Geol., vol. 17, no. 6, pp. 407-460, 1922.

[18]Moore, E. S. & Maynard, J. E., Econ. Geol., vol. 24, no. 3, pp. 273-303, 1929.

PROVENANCE STUDY OF THE HEAVY MINERALS IN THE STREAMS OF THE GOLD BELT PORTIONS OF LUMPKIN AND WHITE COUNTIES, GEORGIA

HERBERT YOHO*

University of Florida

Introduction

It is the intent of this discussion to describe the methods and techniques used in collecting and preparing samples for a provenance study of the heavy minerals of Lumpkin and White Counties, Georgia.

Heavy minerals generally are considered to be accessory minerals which are minor in amount in the parent rock and which survive destruction by weathering, abrasion, or intrastratal solution. They are the minerals that are seldom seen except for occasional grains in thin sections of the unweathered rock. In order to study these minerals, it is necessary that they be concentrated and isolated from the bulk of the light materials with which they are associated.

Since the heavy accessories are usually resistant to destruction, they become concentrated in the stream sands when the parent rock breaks down by weathering and is removed by erosion. Thus, it is easy to obtain a heavy mineral sample by panning the sands of a stream.

Three principal kinds of samples were collected for the study. These were the stream sand samples, the saprolites, and the unweathered rocks.

The flow sheet for the treatment of the three kinds of samples is shown in (Fig. 1).

Collection and Treatment of Unweathered Rock

In preparing the heavy mineral concentrate from the unweathered rocks, about ten pounds of rock material was collected in the field. The sample consisted of many small fragments broken from enough different places over the outcrop to make it representative. The sample was then crushed on

*Read at the Meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

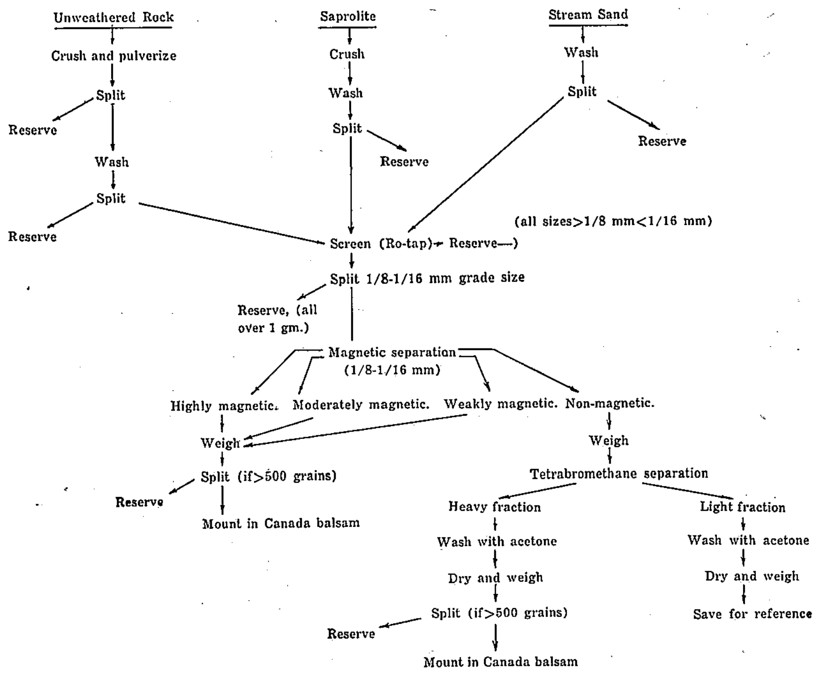


Figure 1—Flow sheet for sample treatment.

a laboratory-size jaw crusher and pulverized by a disc pulverizer.

Heavy mineral recovery from these rocks might have been higher if pulverizing had been sufficiently fine for all material to have passed through a #120 (¼-⅛ mm) screen. However, if all particles had been pulverized to pass through the #120 screen, too many of the crystal faces would have been broken or destroyed. The sample was pulverized to pass the #60 screen (½-¼ mm).

After the sample was pulverized, an ordinary large size prospector's pan was used and the sample was reduced to a few grams by the usual panning methods.

Saprolite Collection and Treatment

The minimum weight of each saprolite sample was eight pounds. Channel samples across the foliations were taken whenever possible. Road cuts were found to be the best places to obtain saprolite samples.

Some of the saprolites were highly weathered and needed no crushing. Others, a little less completely weathered, were run through the jaw crusher. Generally, the crusher broke them down sufficiently so that pulverizing was not necessary.

Stream Sand Sample Collection and Treatment

Samples from stream beds consisted generally of one large panfull of wet gravel and sand. Occasionally a second pan was necessary to obtain a sufficient amount of concentrate. On the other hand, in some localities the black sand, consisting mostly of ilmenite, was so abundant that as much as 200 grams of concentrate could be obtained from a single pan.

A sample was obtained from the stream bed by digging deeply into the bed. It was best to go to bedrock, if possible, for otherwise there was little chance of getting a representative amount of the minerals of higher specific gravity, such as gold.

Pan Concentration in General

In the concentration of heavy minerals by panning, whether from stream sands or crushed rocks, a sample is never washed to completion, but only until most of the quartz and other light grains are washed out. It is during the last stages of pan concentration that losses of minerals that it is desirable to retain, are highest.

The time involved in panning a sample averaged between 15 and 20 minutes. J. B. Mertie[1] of the U.S.G.S., in his monazite studies in Georgia and the Carolinas, stated that the washing time per sample for his materials ranged from 20 to 30 minutes; but the size of the samples he used for his studies averaged about 10 kilograms or about twice the size of the samples used in this study. Mertie also stated that losses of heavy minerals of specific gravity greater than 4.5 need be no higher than 20 per cent if the panner is careful. High recoveries require considerable practice, patience and time.

Screening

The entire pan concentrate was screened, using a Ro-Tap with automatic timing. Six minutes was found to be sufficient to make a clean grade-size separation. Seven screens and a pan were used for these samples on which a screen test was desirable. Screen tests were made on the stream sand samples. For the saprolite and unweathered rock samples, numbers 120 and 230 screens and the pan were used. All grains larger than 1/8 mm were retained on the #120 screen; the grains smaller than 1/16 mm went into the pan. The grade size for further treatment was retained on the #230 screen, the 1/8-1/16 mm grade size.

If the 1/8-1/16 mm grade size weighed more than a gram, it was split before being subjected to magnetic separation.

Magnetic Separation

For making the separations into fractions of varying magnetic susceptibility, a model G1 Electromagnetic Mineral Separator was used. The separator was equipped with a rheostat so that it was easy to make the various separations.

The mineral grains that were readily separated by the lowest intensity of the separator constituted the highly magnetic fraction. Those grains that were not affected under the highest intensity made up the non-magnetic fraction. The portion of the sample remaining after the highly magnetic and non-magnetic fractions were removed was separated by an intermediate setting on the rheostat into moderately and weakly magnetic fractions.

Tetrabromethane Separation

The non-magnetic portion was further separated into a heavy and a light fraction. For this separation tetrabromethane (acetylene tetrabromide, $C_2H_2Br_4$) was used. It is a slightly syrupy, very light, yellowish-colored liquid with maximum specific gravity of 2.96. Tetrabromethane was preferred over the more commonly used bromoform because it is less volatile, and has less odor. It is a little less expensive and because of its less volatility, evaporation losses are lower. Furthermore, tetrabromethane is just as easy to recover from acetone washings as is bromoform.

In making separations, the open Coors dish method was used. Generally six separations were made at a time. The

Coors dishes found most suitable had steep sides and were about 3 inches in diameter. Each dish was filled about one-third full of tetrabromethane and the sample was poured onto the surface of the liquid. Some of the heavy grains sank immediately, but for others a gentle rotary motion of the dish was required to break surface tension. After about six minutes of settling time, the liquid on which the light materials were floating was decanted onto a filter paper in a small glass funnel. The sample was washed once, or occasionally twice if the sample was large or the separation unusually difficult, with tetrabromethane. After the tetrabromethane washing, both the heavy and light fractions were washed twice with acetone.

Grain Counting and Calculation

When all the separations were made, the fractions were weighed and the percentage of highly, moderately, and weakly-magnetic and the heavy non-magnetic fractions were determined. From the samples permanent mounts were made in Canada balsam. Most of the separates were too large to mount in their entirety. Reserves were stored in gelatin capsules. If a sample was smaller than about 500 grains, the entire sample was mounted.

In counting, either a minimum of 300 grains or all on the slide were counted. A mechanical stage was used, traverses were run from front to back, and back to front, and all grains in the field were counted as they touched the E-W cross hair.

For relative abundance of the various minerals, the following scale was used: flood -greater than 75%, very abundant -50-74%, abundant -25-49%, very common -15-24%, common -5-14%, rare -1-4%, very rare -less than 1%, and present -1-3 grains.

Observations and Conclusion

One of the most notable observations about the heavy minerals of the Lumpkin-White area is the large proportion of euhedral grains. The greater proportion of all the highly magnetic grains, which are almost entirely made up of magnetite, are almost perfect octahedrons. Some are relatively fresh in appearance, but most of them are coated with hematite, or are partly altered to hematite. Many, however, have remarkably clean-cut crystal boundaries.

Many of the zircons are also euhedral crystals although their boundaries are generally not as sharp as the boundaries of the magnetite crystals. Many of the zircons show zoning. In some samples the zircons are predominantly clear and colorless with few inclusions; in others they are dusky with so many inclusions as to make them appear almost opaque. Some samples contain citrine-colored zircons. A few samples contain a small number of hyacinth zircons. In still a few other samples there are prismatic zircons with well-developed outgrowths. These outgrowths are apparently secondary and occur as pyramid-shaped growths on the crystal faces. Such outgrowths on zircons have been described by Milner[2] from Yorkshire and Northumberland but there is not much mention of them in American geological literature.

Varietal characteristics seem to offer the greatest possibilities of making correlations in the Lumpkin-White area.

References

[1]Mertie, John B., Jr., *Personal Communication*: March 24, 1950.

[2]Milner, H. B., *Sedimentary Petrography*: Thomas Murby & Co., London, 3d ed., p. 355, 1940.

HEAVY MINERALS IN SAPROLITE DIFFERENTIATION*

VERNON J. HURST

Emory University

Introduction

The purpose of this paper is two-fold: (1) to show that the saprolites in the Athens area can be distinguished by their heavy minerals, and (2) to suggest by a survey of crystalline rock types outside the Athens area that many other saprolites are distinguishable on this basis.

The use of heavy minerals for saprolite differentiation is

*Read at the Meeting of the Georgia Academy of Science, University of Georgia, April 27, 1951.

based on the fact that many of these minerals are little affected by weathering. Saprolite, rock decomposed **in place,** contains about the same heavy mineral assemblage that was present in the parent rock. The saprolites in a given area may therefore be identified by the heavy minerals they contain, once the different mineral assemblages have been related to their parent rock types and proved to be distinctive.

Field Work and Acknowledgment

The work on which this paper is based was begun in April, 1950, in conjunction with the preparation of a geologic map of Clarke County. Since the writer was regularly enrolled at the University of Georgia, only afternoons and week-ends were spent in the field. Work was interrupted four months during the summer and completed in March, 1951. It is estimated that altogether 15 days were spent in the field collecting and panning the samples described here, and that 25 days were spent in the laboratory identifying minerals, making statistical counts of mineral grains, and drafting the composition charts.

The Geography-Geology Department of the University of Georgia supplied the laboratory equipment used in the study.

Athens Area Saprolites

The saprolites in the Athens area, which is arbitrarily delimited by a 9-mile radius about Athens, have been derived from 6 main rock types: (1) Gneissoid biotite granite, (2) Migmatite, (3) Schist, (4) Hornblende injection gneiss, which varies in mineral composition from diorite to hornblendite, (5) Basic dikes, and (6) Pegmatites.

To determine which heavy minerals characterize these rock types 41 saprolite samples were gathered from selected outcrops. The weathered materials of the three last-named types can be readily distinguished by their shape and color. For this reason, the 41 samples were taken from only granite, migmatite, and schist. All collections were made from outcrops where saprolite could be traced directly into hardrock within a short vertical distance, and to each sample was assigned the identity of the rock from which it was obviously derived. The heavy minerals in the samples were concen-

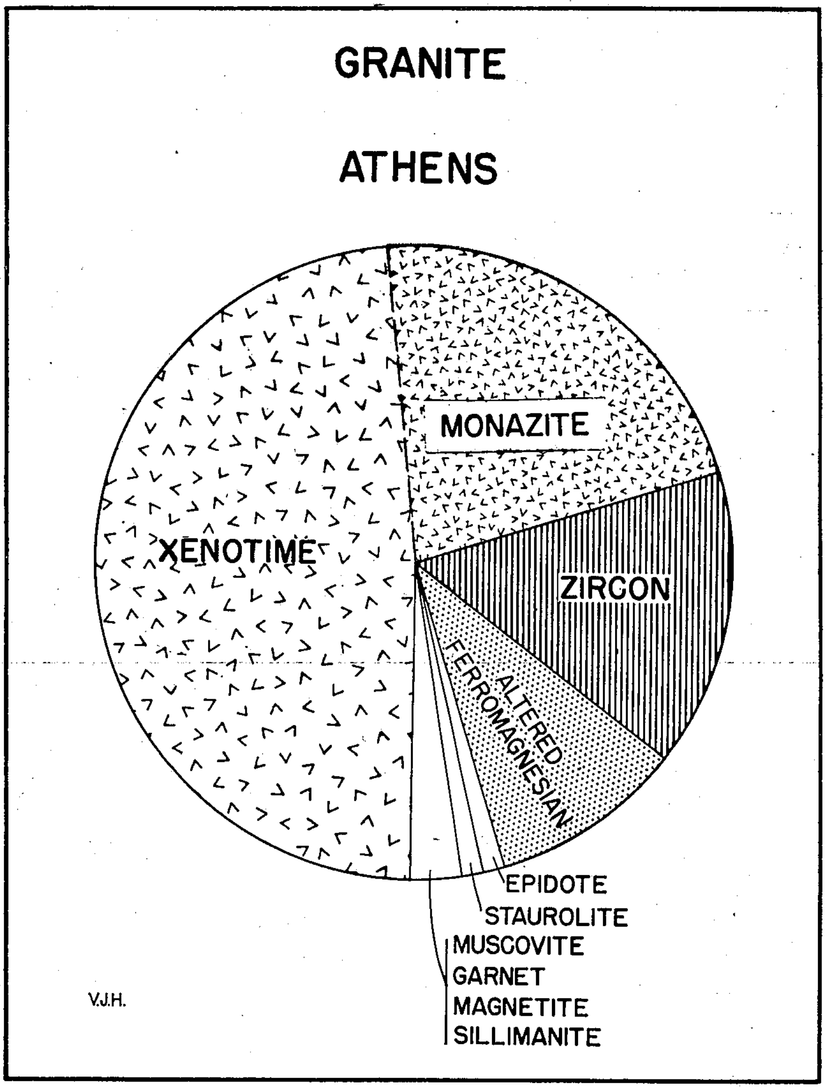

GRANITE
ATHENS
MONAZITE
XENOTIME
ZIRCON
ALTERED FERROMAGNESIAN
EPIDOTE
STAUROLITE
MUSCOVITE
GARNET
MAGNETITE
SILLIMANITE
V.J.H.

Fig. 1

trated by panning, passed through bromoform to eliminate all remaining light constituents, and identified with the petrographic microscope. The percentage composition of each sample was established by the statistical counting of mineral grains.

Figure 1 gives the heavy mineral composition of a typical granite saprolite in the Athens area. Xenotime, monazite, and zircon, the predominant minerals, were found only in granitic materials in this area.

The Xenotime occurs in yellow and yellow-brown tetragonal crystals resembling zircon in habit, the monazite in similar colors, also in olive-brown. The monazite may usually be distinguished by its monoclinic crystallization and greater susceptibility to weathering, but optical methods were necessary in some cases. A small percentage of the xenotime is in bright green crystals with prism faces suppressed so that the crystals appear like stubby, tetragonal dipyramids.

Zircon occurs in a wide variety of colors from white to brown, and locally in crystals more than 2 mm. long. The caption "Altered Ferromagnesian" includes weathered hornblende, biotite, and chlorite.

The sample represented by Figure 2 was also taken from granite, but near the contact between granite and schist. Xenotime, monazite, and zircon, which are characteristic of the Athens granite, are still dominant minerals, but the ferromagnesian content is greater than in Figure 1. A comparison of all the samples with respect to the place of collection revealed that ferromagnesian minerals, principally hornblende and biotite, are concentrated along the borders of the Athens granite. Whether this concentration results from assimilative contamination, contact metamorphic action, or from some other process is not at present known.

The sample represented by Figure 3 was collected still nearer the contact between granite and schist. All observed contacts in the Athens area are zones of variable width in which there is intricate interfingering of granitic and schist materials. Actually, this sample was taken from a granite lense in well-soaked schist, i.e., in the migmatite zone. The high ferromagnesian content, as noted in the paragraph above, is typical of the contact zone.

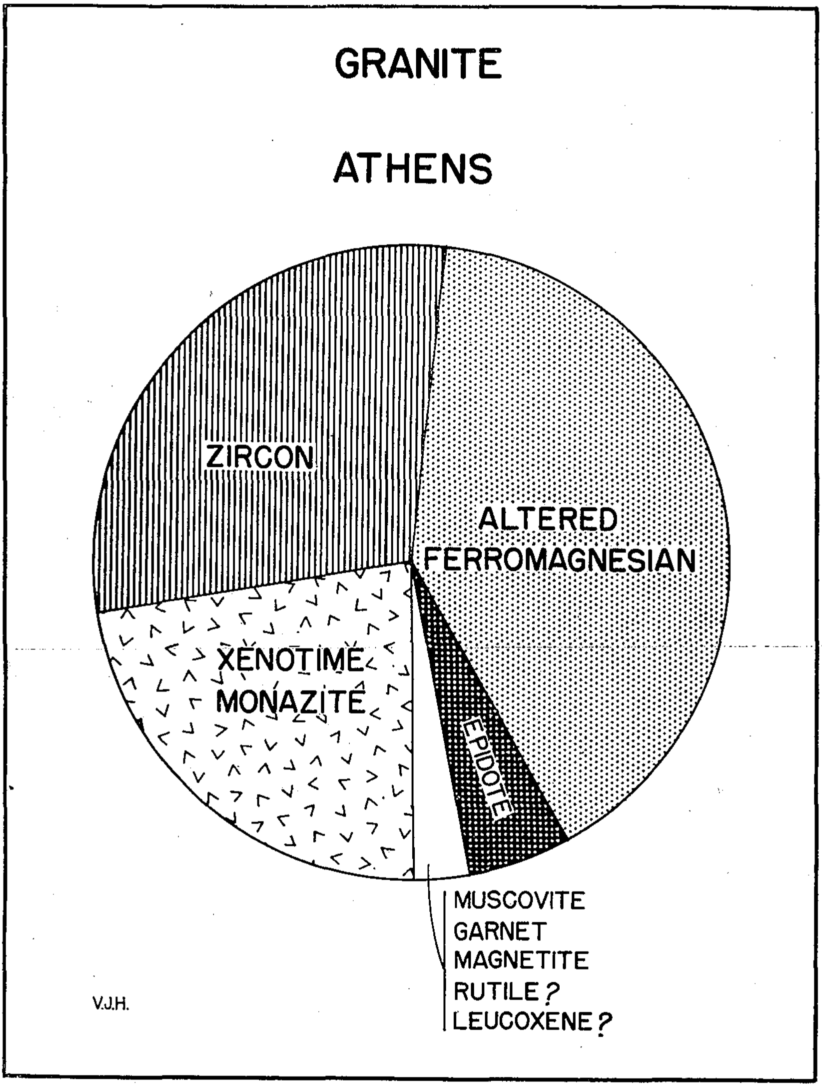

GRANITE
ATHENS
ZIRCON
ALTERED FERROMAGNESIAN
XENOTIME MONAZITE
EPIDOTE
MUSCOVITE
GARNET
MAGNETITE
RUTILE ?
LEUCOXENE ?
V.J.H.

Fig. 2

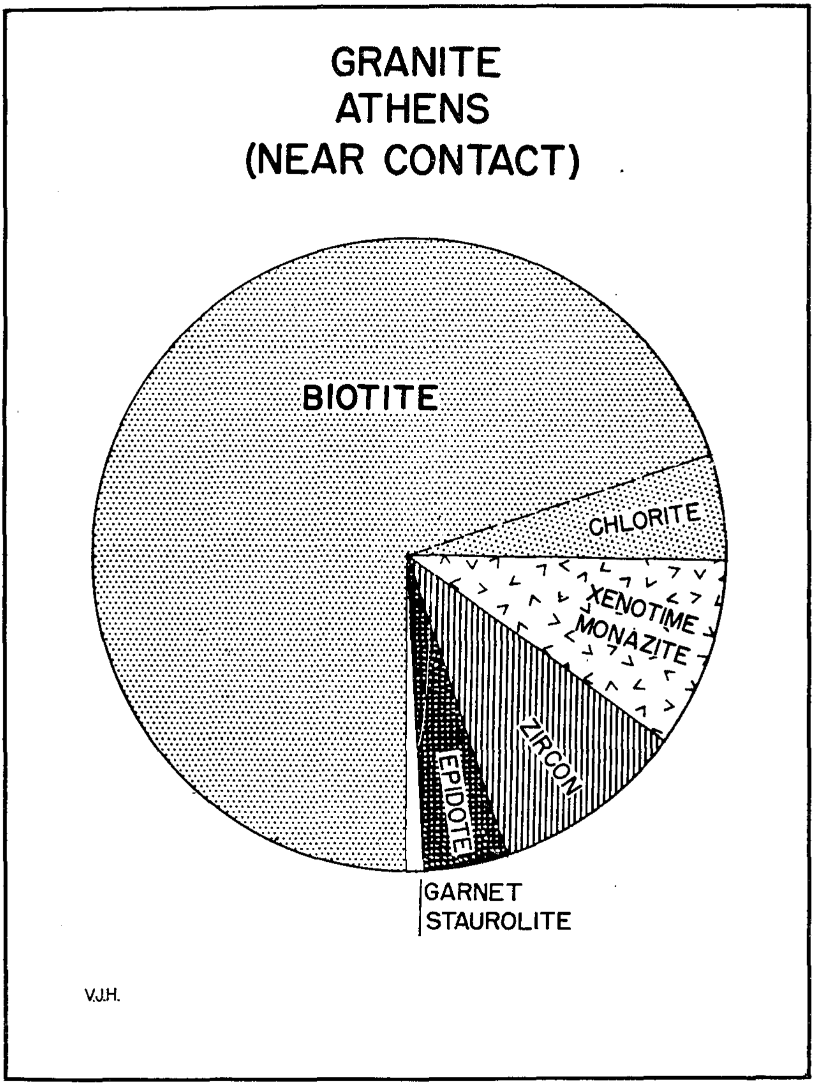

GRANITE
ATHENS
(NEAR CONTACT)
BIOTITE
CHLORITE
XENOTIME
MONAZITE
ZIRCON
EPIDOTE
GARNET
STAUROLITE
V.J.H.

Fig. 3

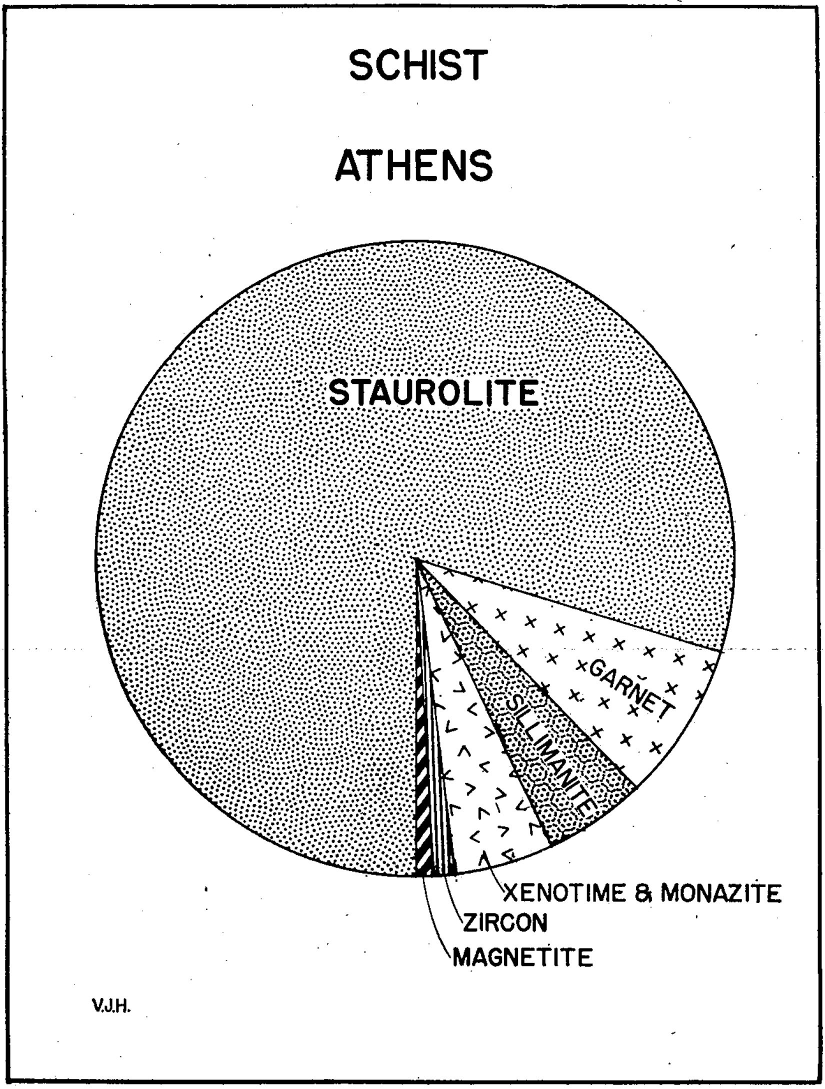

SCHIST
ATHENS
STAUROLITE
GARNET
SILLIMANITE
XENOTIME & MONAZITE
ZIRCON
MAGNETITE
V.J.H.

Fig. 4

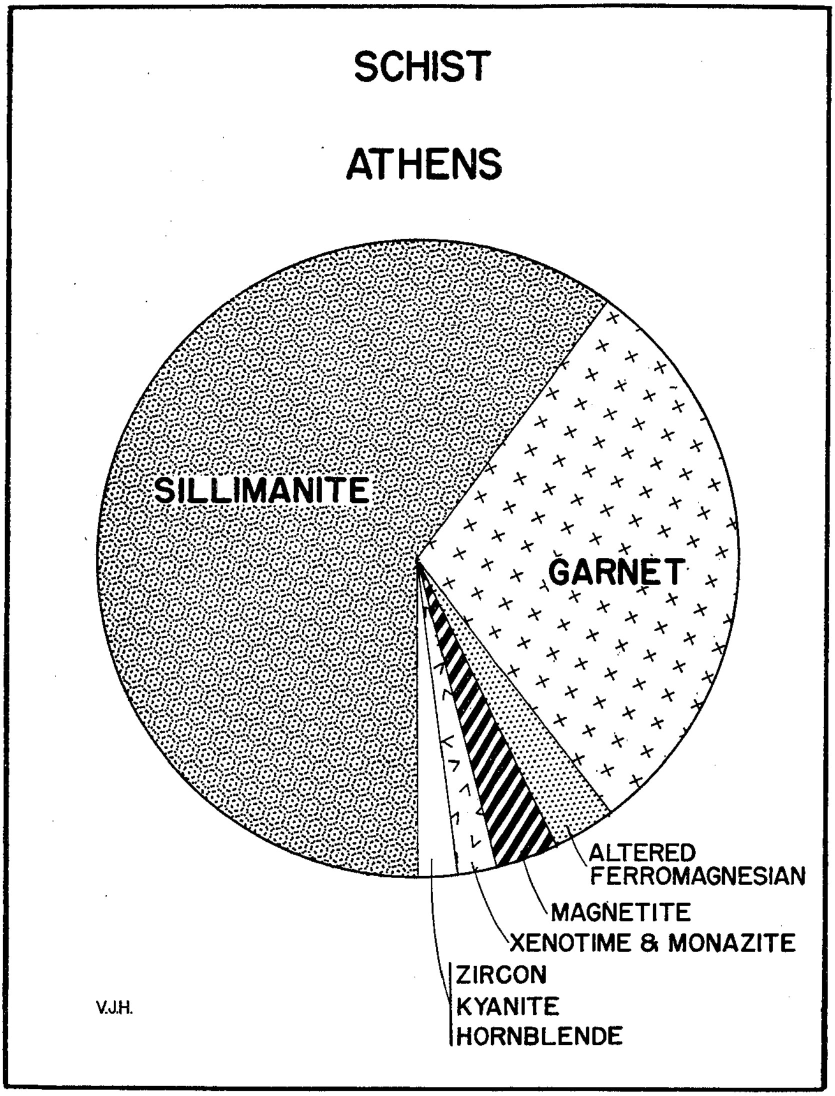

SCHIST
ATHENS
SILLIMANITE
GARNET
ALTERED FERROMAGNESIAN
MAGNETITE
XENOTIME & MONAZITE
ZIRCON
KYANITE
HORNBLENDE
V.J.H.

Fig. 5

The heavy minerals in the schists are the expected varieties; the dominant minerals are sillimanite, kyanite, staurolite, garnet, and anhedral magnetite. (Figures 4 and 5).

Sillimanite is both a dominant mineral in the schists and a common endomorphic constituent of the granite along the contact. It occurs in clear, striated, transversely-broken prisms, and also, at times, in fibrous masses. The staurolite is mostly crystals, commonly in multiple interpenetration twins. The garnet occurs mainly in fragments and in subhedral grains, rarely in euhedral crystals, except in the pegmatites. Garnet is strikingly common in the granite along the contact where, in view of its association with sillimanite, staurolite, and large volumes of biotite, and its abundance around zenoliths, it indicates assimilation.

In places, the order of distribution of heavy minerals about the border of the Athens granite suggests a metamorphic zoning. For example, in passing from granite to schist one can find, in succession: endomorphic sillimanite, sillimanite schist, and staurolite schist. The possibility of distinguishing

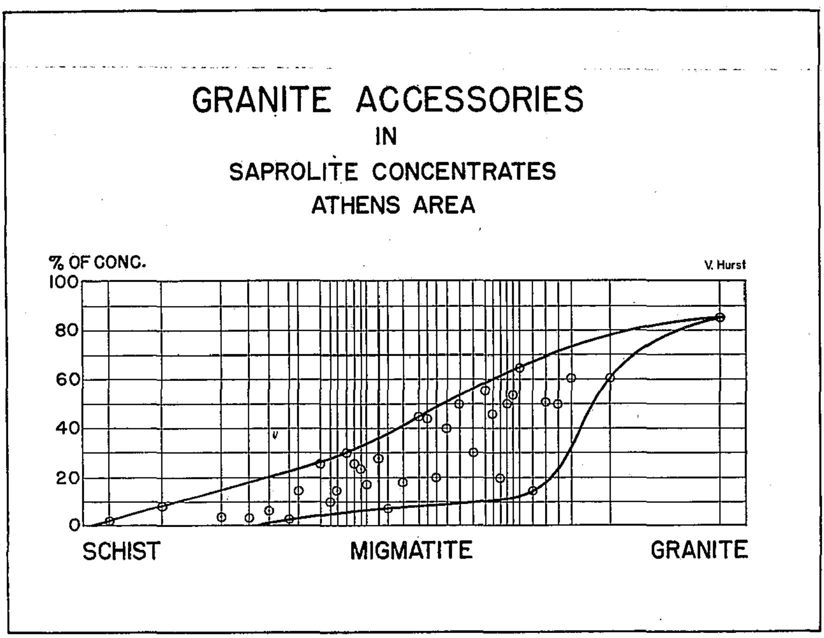


Fig. 6

well-defined, continuous zones, however, appears slight in view of the irregular nature of the contact.

Spherical grains of magnetite and rutile were found in 4 schist samples.

The distribution of the characteristic granite minerals, xenotime, monazite, and zircon, in all 41 samples is shown in Figure 6. Each vertical line represents a single saprolite sample. The position of the line gives the identity of the sample in relation to granite and schist. The vertical lines on the right represent granite saprolites, those on the left schist saprolites, and the lines in between represent migmatite, or rocks of transitional composition. The positions of these lines were plotted from field evidence after the samples were collected, but before their mineral composition was determined. A certain amount of arbitrariness is admitted, but the positions are essentially correct, as is proven by the fact that the percentage of granite minerals is at a maximum in the granite saprolites and decreases almost as a straight line toward the schist.

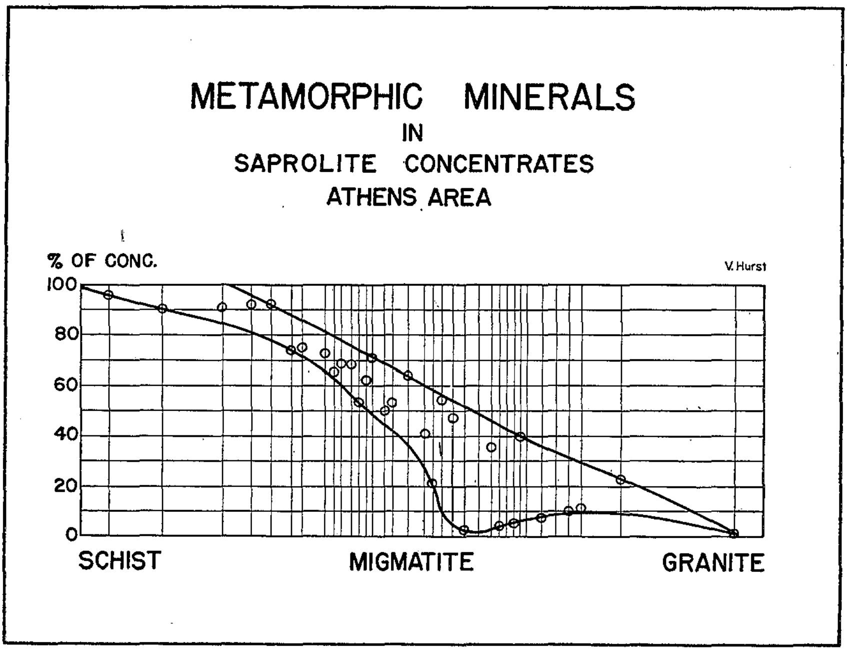


Fig. 7

Sillimanite, staurolite, garnet, kyanite, and anhedral magnetite were grouped together as the metamorphic minerals and plotted on the base explained above. (Figure 7) They show a maximum in the schist saprolites, as expected, and a gradual decrease toward the granite.

Each of these minerals, except kyanite, occurs also in the granite, but always in small quantities, and under such conditions as to suggest that in the granite they are endomorphic contaminants, not metamorphic in the regular sense.

The pronounced border concentration of ferromagnesian minerals is apparent in Figure 8. This concentration is made evident not only by the increased proportion of these minerals in the granite, as shown by Figure 8, but also by the occurrence in the field of a basic rock type restricted largely to the contact zone. This basic rock type, which has been called hornblende injection gneiss, is so typical of the borders of the Athens granite that a rough delineation of the body can be made by tracing basic exposures. Field relations suggest,

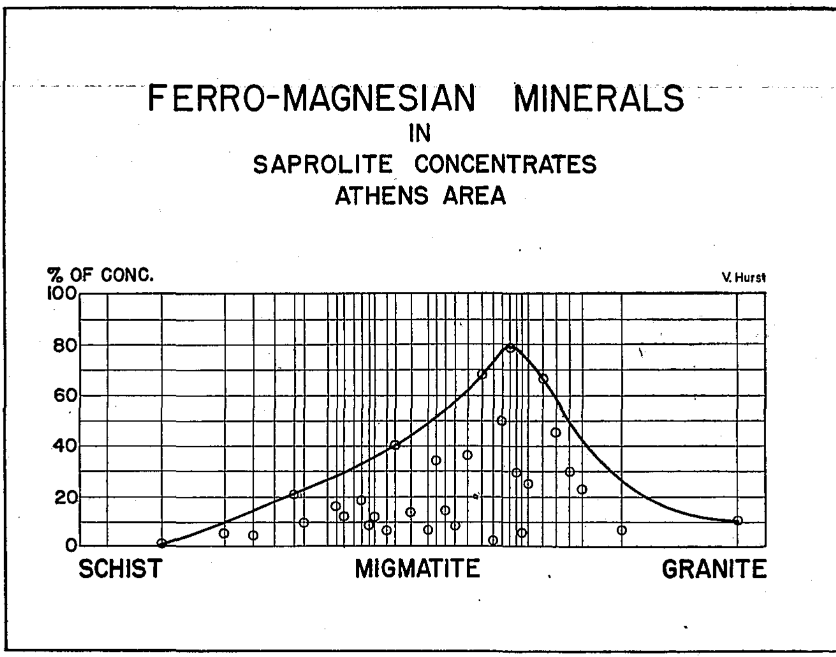


Fig. 8

though conclusive evidence was not observed, that this concentration is the result of not one process but of both processes mentioned earlier.

To summarize briefly: the Athens area saprolites that are indistinguishable by appearance belong to one of three major rock types, granite, migmatite, and schist. The granite saprolites characteristically contain high percentages of xenotime, monazite, and zircon; the schist saprolites contain high percentages of sillimanite, staurolite, garnet, and anhedral magnetite. An intermediate heavy mineral composition is characteristic of the saprolites derived from magmatite. Any given saprolite in the Athens area, which is not identifiable by its appearance, can be relegated to its proper rock type by comparing its heavy mineral content with the graphs which have been shown.

Saprolites Outside the Athens Area

To determine in a general way whether major rock types outside the Athens area, but within the Crystalline Belt in Georgia, also containing distinctive assemblages of heavy minerals, additional saprolite samples were collected.

COLLECTION POINT	ROCK TYPE
1 mile west of Crawford on U. S. Hgwy # 78, Oglethorpe County.	Elberton granite
5 miles east of Lexington on U. S. Hgwy #78, Oglethorpe County.	Elberton granite
½ mile east of Rayle on U. S. Hgwy #129, Wilkes County.	Elberton granite
On U. S. Hgwy #78, ½ mile southwest of the memorial on Stone Mountain.	Stone Mountain granite
On U. S. Hgwy #78, ½ mile northeast of the memorial on Stone Mountain.	Stone Mountain granite
½ mile south of Gray on U. S. Hgwy #129, Jones County.	Granite
About 2 miles due east of Gray along Commissioner Creek, Jones County.	Granite

A new quarry just southeast of Haddock, Jones Couty.	Granite
1 mile west of Milledgeville on U. S. Hgwy #441, Baldwin County.	Granite
Just east of the Lithonia-Klondike road, near a recently-operated quarry on the southern edge of Arabia Mountain, DeKalb County.	Lithonia granite
Along the Lithonia-Klondike road, about ½ mile south of Rockland Church, DeKalb County.	Lithonia granite
Along Stone Road between College Park and Ben Hill, Fulton County.	Palmetto type granite

The granites at Stone Mountain, Elberton, and Gray, of similar appearance, have heretofore been considered a common type. In heavy minerals, the Elberton granite and the granite at Gray are similar to each other but not to the Stone Mountain granite.

The dominant mineral in the Elberton granite (Figure 9) is magnetite which, with no exceptions noted, occurs in octahedra. The heavy mineral assemblage of this granite thus contrasts strikingly with that of the Athens granite which joins it on the west. If further investigation should prove that all adjoining rocks do not contain large quantities of octahedral magnetite, which appears likely, then the Elberton granite contact can be mapped in detail by using a common magnet.

The dominant mineral in the granite at Gray is also octahedral magnetite (Figure 10). A kinship between the granites at Elberton and Gray is suggested by two facts: (1) each heavy mineral observed in one was also observed in the other; and (2) the granite at Gray is on the strike of the Elberton granite body.

The heavy minerals at Stone Mountain are dissimilar to those at Elberton and Gray. The dominant minerals are garnet and tourmaline, the latter usually in brownish-black, transparent crystals. (Figure 11) Magnetite is not an important constituent and when found is mostly in anhedra. It is noted that xenotime and monazite, which are characteristic

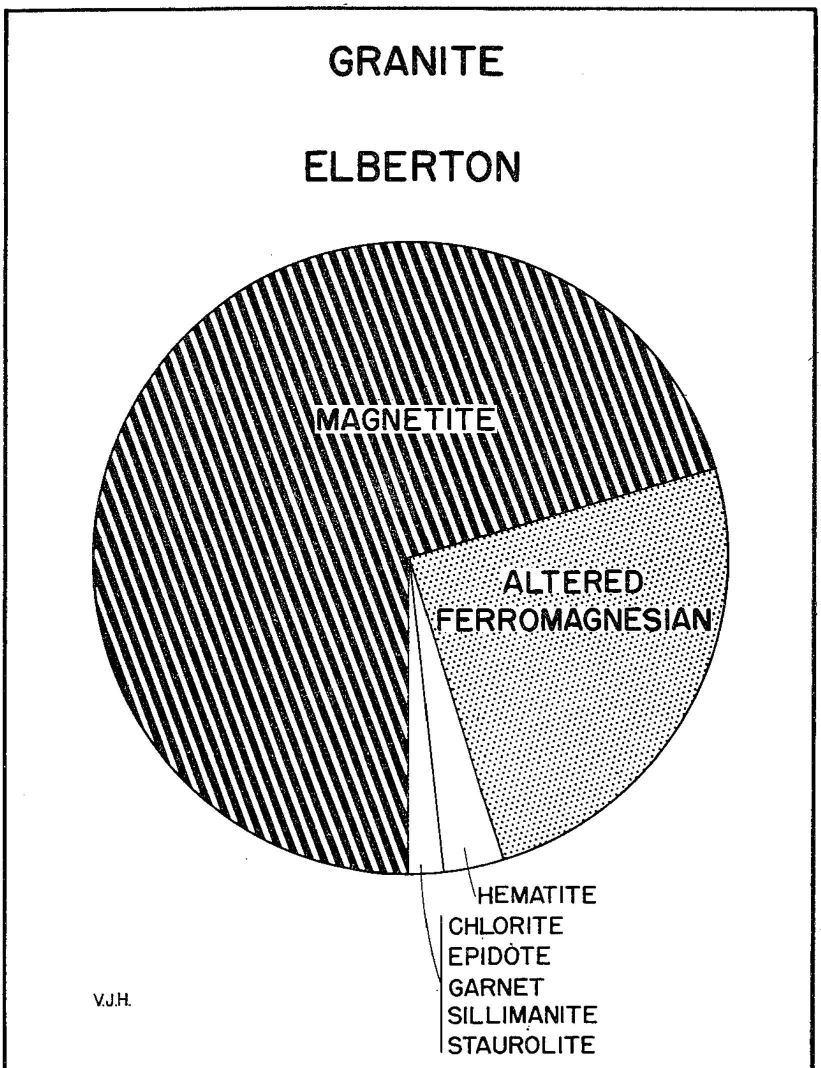

GRANITE
ELBERTON
MAGNETITE
ALTERED FERROMAGNESIAN
HEMATITE
CHLORITE
EPIDOTE
GARNET
SILLIMANITE
STAUROLITE
V.J.H.

Fig. 9

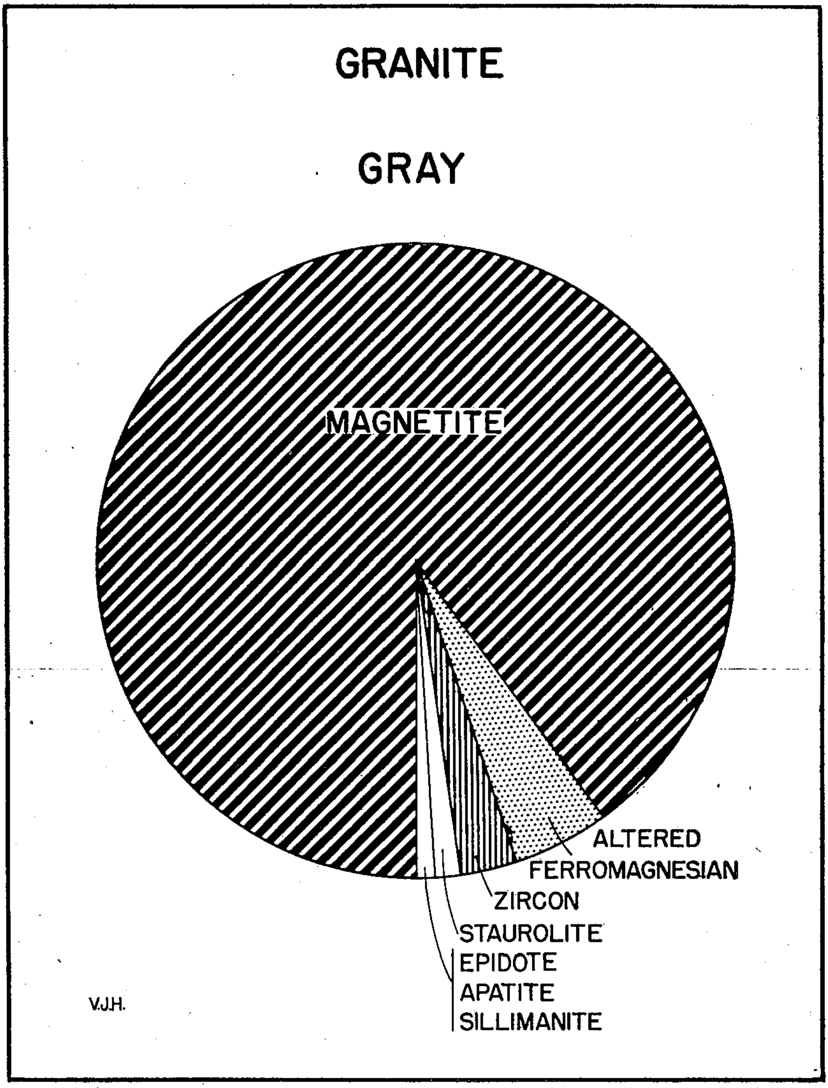

GRANITE
GRAY
MAGNETITE
ALTERED
FERROMAGNESIAN
ZIRCON
STAUROLITE
EPIDOTE
APATITE
SILLIMANITE
V.J.H.

Fig. 10

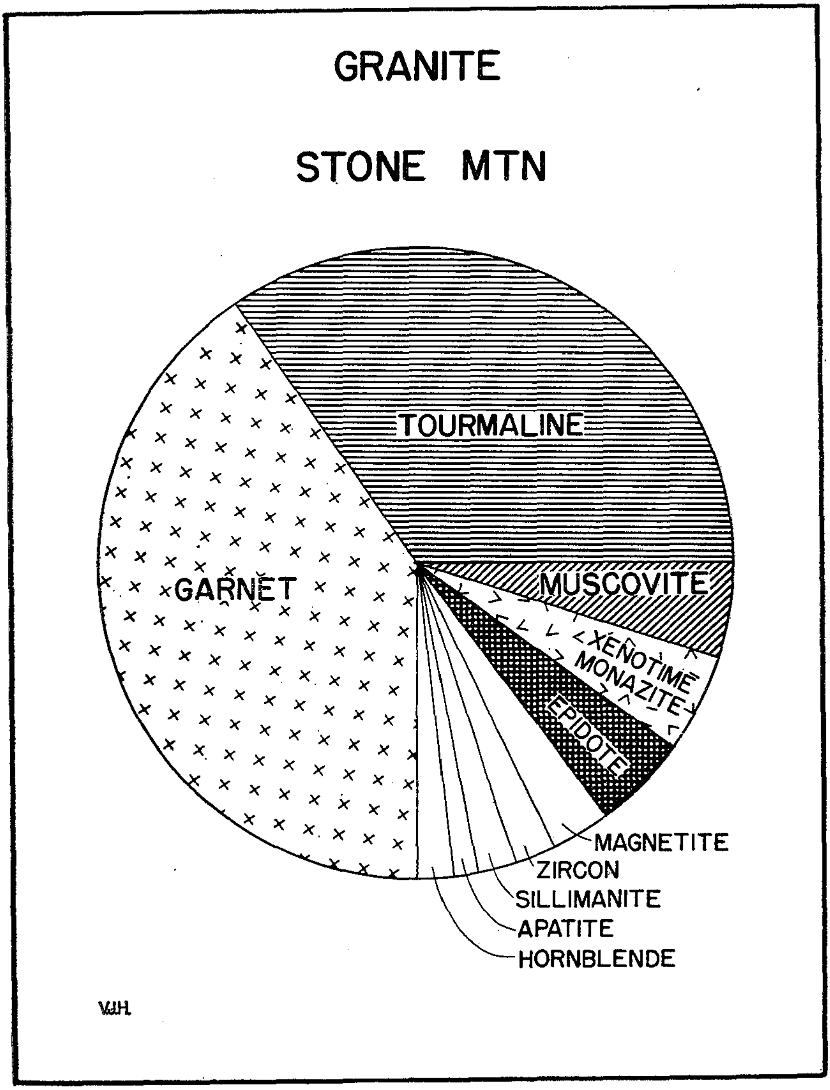

GRANITE
STONE MTN
TOURMALINE
MUSCOVITE
XENOTIME
MONAZITE
EPIDOTE
GARNET
MAGNETITE
ZIRCON
SILLIMANITE
APATITE
HORNBLENDE
W.H.

Fig. 11

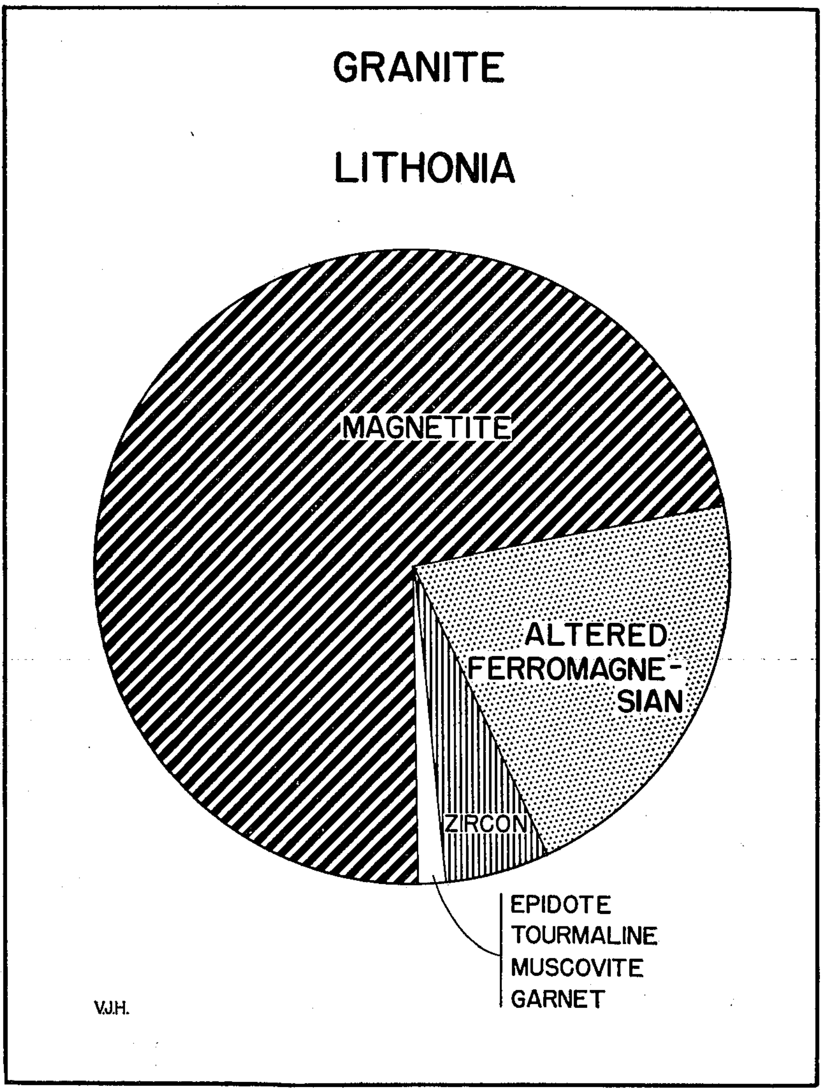

GRANITE
LITHONIA
MAGNETITE
ALTERED FERROMAGNE-SIAN
ZIRCON
EPIDOTE
TOURMALINE
MUSCOVITE
GARNET
V.J.H.

Fig. 12

of the Athens granite, also occur here, and that part of the xenotime is in bright green, bipyramidal crystals, as in the Athens area. Tourmaline and apatite, found here, were not encountered in the Athens granite, however, and the heavy mineral assemblage of the Stone Mountain granite is therefore still distinct.

The Lithonia granite, in appearance very similar to the Athens granite, was found to differ from it considerably in heavy mineral content. As seen in Figure 12, magnetite is, again, the dominant mineral, but the magnetite in this granite does not resemble that at Elberton and Gray. It occurs in imperfect octahedra, in irregular platy fragments and in cubes. The cubic magnetite is believed to have resulted from the alteration of pyrite, since altered pyrite that is only feebly- to non-magnetic also is found with the cubic magnetite.

The heavy mineral assemblages in the granites at Haddock, Milledgeville, and Stone Road in Fulton County were found in each case to be distinctive. The dominant minerals were, respectively, magnetite, dahllite (or apatite), and a ferromagnesian mineral of undetermined identity. The heavy minerals in the granites at Haddock and Milledgeville differ only in proportion from those in the granites at Elberton and Gray, a fact which suggests that these four granites are genetically related. (Compare Figures 9, 10, 13, and 14.) A very small percentage of apatite was found in the granite at Gray, about 1 percent in the granite at Haddock 9 miles to the northeast, 40 percent in the granite at Milledgeville farther northeast, and a very small percentage again in the Elberton granite. Octahedral magnetite is common to all four. It was noted that the granite at Haddock which closely resembles the Athens granite in appearance is very dissimilar in heavy mineral content.

In conclusion, three important, but tentative, inferences might be drawn from saprolite studies to date:

(1) Each rock type in the Crystalline Belt in Georgia contains a distinctive assemblage of heavy minerals.

(2) Saprolites derived from different rocks, regardless of appearance, may be distinguished by the differences in these assemblages.

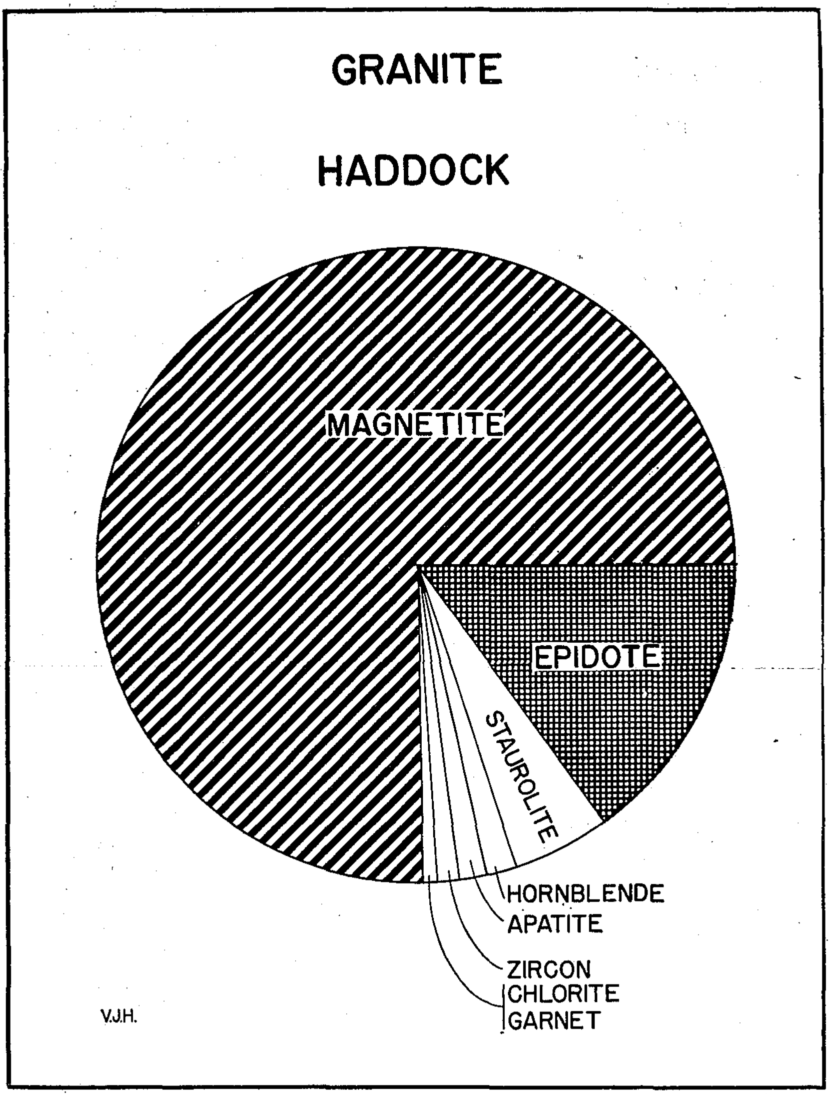

GRANITE
HADDOCK
MAGNETITE
EPIDOTE
STAUROLITE
HORNBLENDE
APATITE
ZIRCON
CHLORITE
GARNET
V.J.H.

Fig. 13

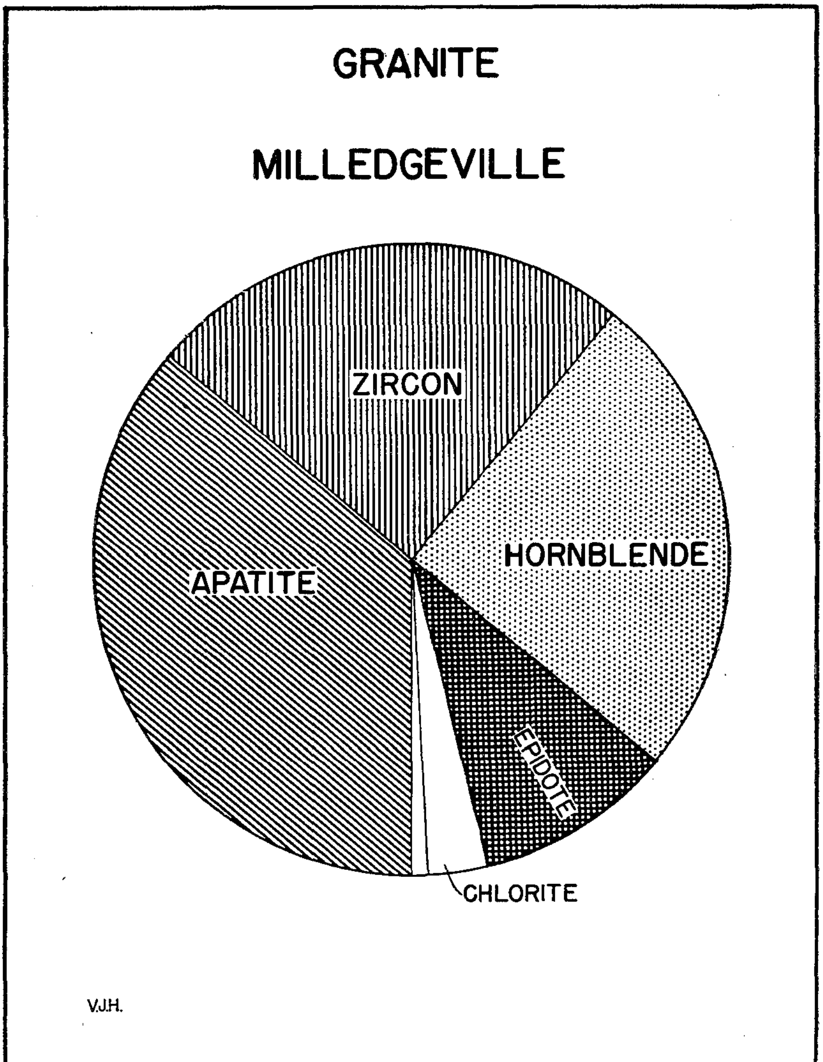

GRANITE
MILLEDGEVILLE
ZIRCON
HORNBLENDE
APATITE
EPIDOTE
CHLORITE
V.J.H.

Fig. 14

(3) Since emplacement of most Georgia granites appears to have involved a perceptible amount of country rock assimilation, as shown by the irregular contacts and endomorphic effects, it might be possible to determine relative ages, in some cases, by detailed heavy mineral distribution studies such as would reveal the presence of characteristic accessories for certain rocks as endomorphic contaminants in the invading rock.

OOLITES FROM THE ST. GENEVIEVE AND GASPER LIMESTONES OF NORTHWEST GEORGIA*

FRANK T. INGRAM

Emory University

INTRODUCTION

The St. Genevieve and Gasper limestones of Mississippian age that crop out in Northwest Georgia contain several oolitic zones. The Gasper conformably overlies the St. Genevieve and is separated from the St. Genevieve with difficulty as the lithologies of the two formations are essentially the same. For this reason the St. Genevieve and Gasper formations are considered in this paper as one lithologic unit.

Thin section examinations reveal that many of the nuclei of the oolites are formed by the tests of foraminifers. Previous to the writers investigation no foraminifers had been described from the Mississippian system of Georgia. Shrode (1947, p. 14), while working in the St. Genevieve in Illinois, noted that one zone contained oolites with nuclei of foraminifers. These oolites described by Shrode are strikingly similar to those found in the St. Genevieve and Gasper formations of Georgia. Oolites from both localities contain similar fossil fragments and the same genus of foraminifera.

These preliminary investigations indicate that oolites and their nuclei of foraminifers offer a possible basis of correlation for many Mississippian formations.

*Read before Earth Science Section, Georgia Academy of Science, Mercer University, Macon, April 24, 1953.

METHOD OF INVESTIGATION

The St. Genevieve and Gasper formations are part of a great thickness of Paleozoic rocks which form the Appalachian Ridge and Valley Province. Samples were collected at various places in Cherokee Valley near Ringgold, Georgia, and from the east flank of Lookout Mountain along Georgia Highway 2.

Depositional structures were studied in the field and thin sections were prepared in the laboratory. Also, polished sections were prepared and etched with dilute acid or treated with staining solutions. Thin sections proved to be the most useful for the study of microscopic features. In order to show more contrast sections were ground to a thickness of about .04 mm instead of the standard .03 mm.

DESCRIPTION

Oolites are defined as small spherical or subspherical accretionary bodies .25 to 2.00 mm in diameter (Pettijohn, 1949, p. 75). The average diameter of the oolites found in the St. Genevieve and Gasper formations is about .5 mm but a few have diameters up to 1.8 mm. Some of the more un-

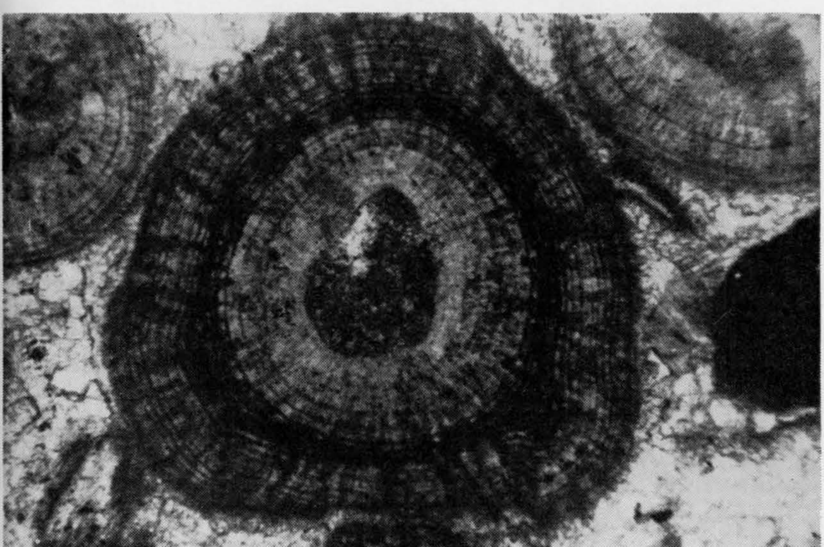


Figure 1. x 150

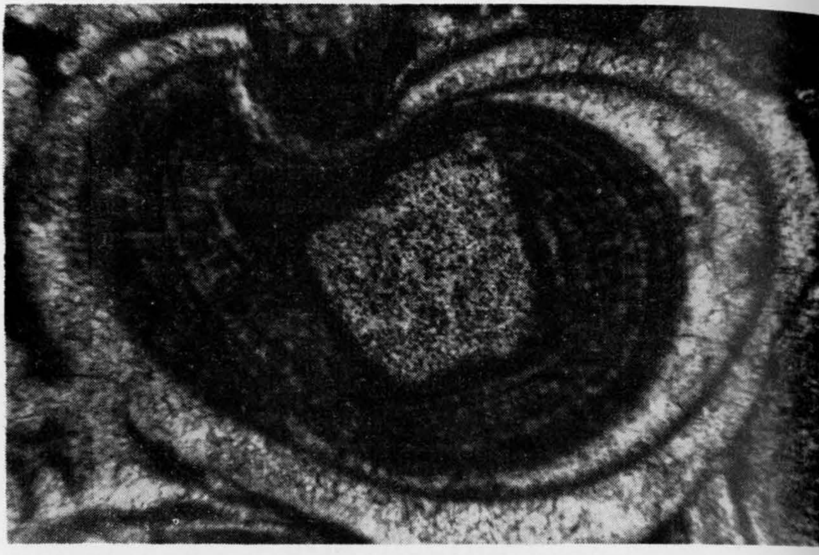


Figure 2. Oolite showing nucleus of calcite rhomb. At top oolite has been ruptured by a sharp fragment, x 150.

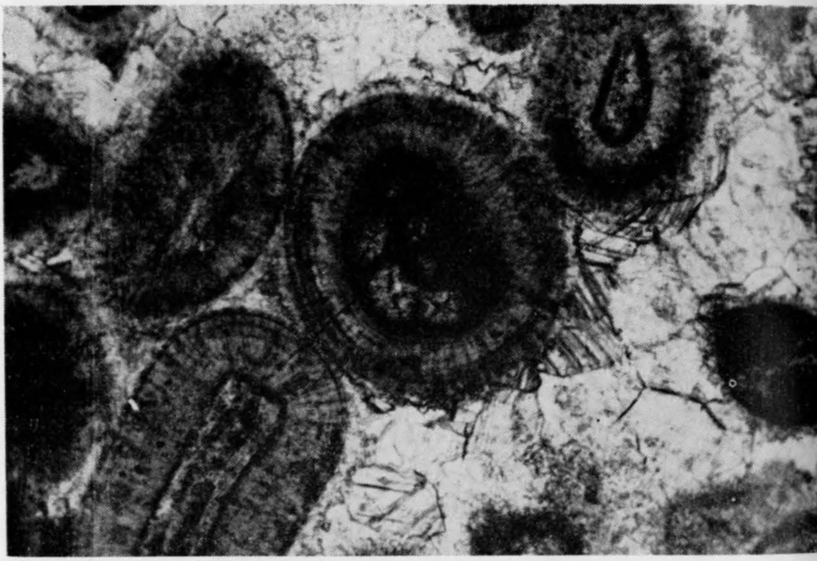


Figure 3. Oolite with foraminifera as nucleus, x 50.

Figure 4. Oolite with foraminifera as the nucleus, x 50.

Figure 5. Oolite with nucleus of crinoid arm plate, x 25.

common forms are heart shaped or rhombic. The typical oolite can be divided into three zones (fig. 1) ; the center or nucleus, the radiating crystals around the nucleus, and one or more concentric layers surrounding the radiating crystals.

The nucleus is the most variable of the three divisions, and the shape of the oolite is usually determined by the shape of the nucleus. Calcite is the most common nucleus, which may be in the form of a single rhombohedral crystal (fig. 2) or many extremely small crystals (fig. 1). The calcite rhombs are probably the result of recrystallization of the finer particles. Other mineral fragments rarely occur as nuclei. Many of the nuclei are formed by foraminifera and fragments of Bryozoa, crinoids, or brachiopods (fig. 3, 4, and 5). Of the several foraminifera observed only two genera could be identified—Endothyra and Hyperammina.

The crystals that radiate out from the nucleus are composed of calcite which are thought to be recrystallized aragonite (Eardley, 1938, p. 1367). This intermediate zone may be absent in many cases.

The outer zone of concentric layers is composed of calcite and a small amount of enmeshed clay particles. The clay particles are responsible for the darkness of the concentric layers that are seen in thin sections. The calcite crystals of the intermediate zone frequently pass through the concentric layers of the outer zone.

ORIGIN

At the present time, there is no consensus regarding the origin of oolites. Many theories have been advanced to explain their origin. One theory suggests that oolites form on mud flats when gas bubbles are present (Mathews, 1930, p. 635). Another theory explains their formation by the coalescence of colloidal particles (Bucher, 1918, p. 603; Bradley, 1929, p. 203). These theories may be applied to the growth of oolites in many cases, but chemical precipitation (Brown, 1914, p. 745) seem to be the process by which oolites were formed in the area investigated.

Observations indicating a shallow water origin are as follows:

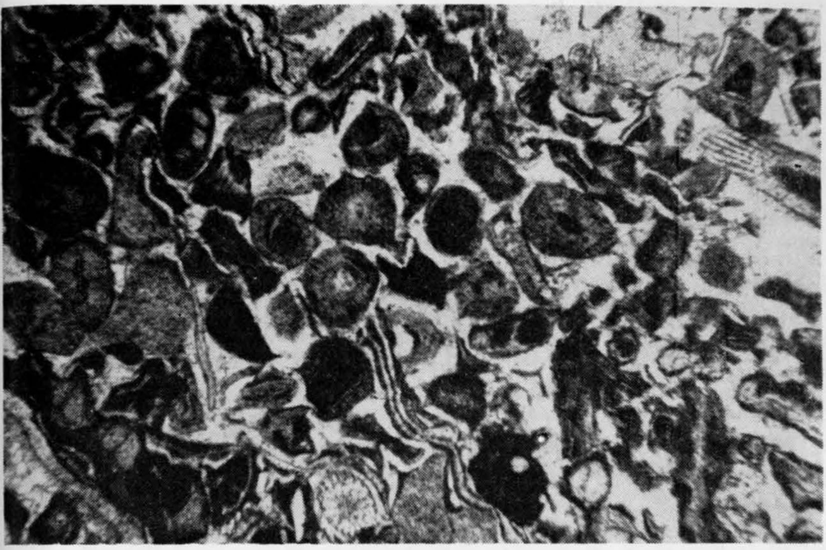


Figure 6. Section showing coquina-like nature of the limestone, x 25.

1. Crossbedding was observed at each sample locality.
2. Very few whole fossils are preserved in the limestone, but fragments are very abundant (fig. 6).
3. The oolites are usually well sorted.
4. Rarely do oolites come in direct contact with each other. If the oolites had grown in place, their surfaces would have come in sharp contact or merged with each other.

The Appalachian geosyncline, at the time of deposition of the St. Genevieve and Gasper limestones, must have been a broad, shallow basin. As small shells and shell fragments rolled about the sea floor due to wave agitation calcium carbonate molecules built onto their surfaces. Colloidal clay became enmeshed in the calcium carbonate at different intervals. The sharp boundaries between layers are probably the result of changes in concentration of calcium carbonate or colloidal clay.

In the Great Sale Lake in Utah, oolites are forming along the shorelines where constant wave action occurs (Eardley, 1938). Growth is accomplished by precipitation of calcium carbonate. Concentric layers are the result of seasonal variations in the concentration of calcium carbonate. The oolites in the St. Genevieve and Gasper formations of Georgia appear to have been formed by physical processes somewhat similar to those existing in Great Salt Lake today.

Bibliography

1. Bradley, W. H., Algae Reefs and Oolites of the Green River Formation, U. S. Geol. Survey, Prof. Paper 154-G, 1929, pp. 203-224.
2. Brown, T. C., Origin of Oolites and the Oolitic Texture in Rocks, Geol. Soc. Am. Bull., Vol. 25, 1914, pp. 745-780.
3. Bucher, W. H., On Oolites and Spherulites, Jour. Geol., Vol. 26, 1918, pp. 593-609.
4. Eardley, A. J., Sediments of Great Salt Lake, Utah, Am. Assoc. Pet. Geol., Bull., Vol. 22, 1938, pp. 75-81.
5. Mathews, A. A. L., Origin and Growth of Great Salt Lake Oolites, Jour. Geol., Vol. 38, 1930, pp. 633-642.
6. Pettijohn, F. J., Sedimentary Rocks, 1949, Harper and Brothers, New York, pp. 75-81.
7. Shrode, R. S., Unusual Oolites Grains from the St. Genevieve Limestone, Ill. State Geol. Sur., Circular No. 144, 1947.
8. Zeller, Eward J., Stratigraphic Significance of Mississippian Endothyroid Foraminifera, Univ. of Kansas Paleontological Contributions, Protozoa, Article 4, pp. 1-23, 1950.

SEDIMENTARY STUDY OF A COMMERCIAL SAND DEPOSIT IN NORTHWEST GREENE COUNTY, GEORGIA*

ELDON J. PARIZEK

University of Georgia

The L. C. Curtis farm in extreme northwest Greene County, Georgia, is the site of a commercial sand deposit currently being exploited. The deposit is located one-half mile south of the confluence of Rose Creek and the Oconee River, two streams that flow in a southerly direction. The true extent of the deposit has not been determined, but it is known to exceed the general limits shown on the accompanying map (Figure 1). It is likely that at least one hundred acres in the area can be worked satisfactorily. The surface of the land is fairly

*Read before Earth Science Section, Georgia Academy of Science, Mercer University, Macon, April 24, 1953.

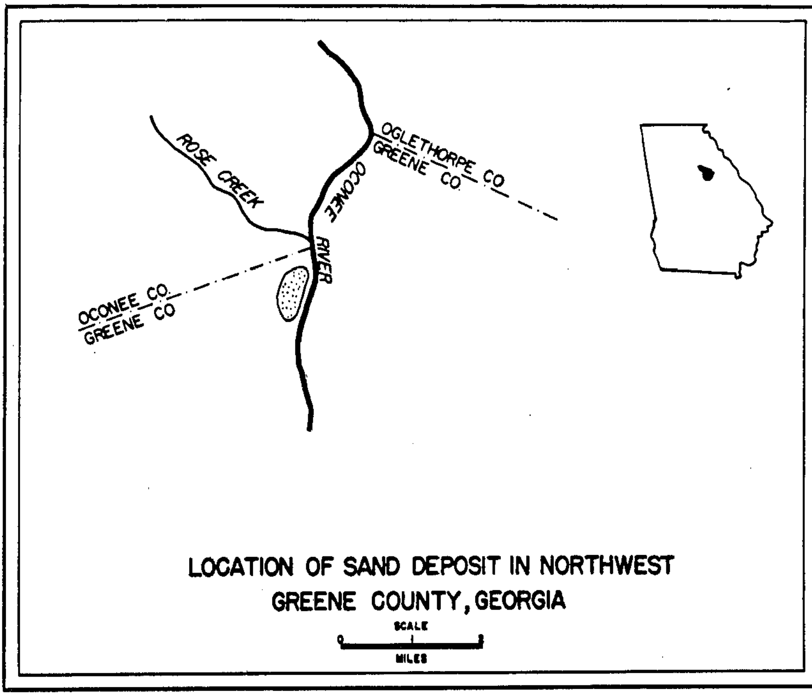


Figure 1. Generalized position of the sand deposit (stippled) in northwest Greene County, Georgia.

even in the immediate vicinity of the deposit, which is in contrast with surface characteristics a few miles to the north. Cores drilled in several places show that the sand thickness everywhere exceeds 30 feet. However, more than 60 feet of sand exist in places, indicating a rapid increase within a relatively small area. It has been determined that more than 750,000 sixty-ton carloads of commercial sand are present in the deposit. The composition and grain size are satisfactory for commercial purposes according to analytic reports from two grading firms in Georgia. For the past year the sand has been supplied to the M. P. Morris Cement Contractors, Athens, Georgia, for concrete, mortar and plaster work in Athens and nearby communities.

Sands of two colors are present. Red to buff colored sands with frequent incline-bedding form the upper 15 feet of the deposit. White to gray sands are subjacent to the colored beds and reach depths of 60 feet in places. Where observed they show little or no evidence of stratification and are free of incline-bedding. The two sands are separated by a spotty band of mostly weathered magnetite that is usually less than one inch thick.

A study of the deposit was made to determine possible conditions of sand accumulation. Location near the juncture of the Oconee River and Rose Creek suggests flood stream deposition; nevertheless, the location within reasonable distance of proven marine sands to the south suggests that a beach origin be considered.

Twenty-eight sand samples, averaging 200-250 grams each, were collected at random sites within the known extent of the deposit. The samples were taken at different stratigraphic levels, so that a vertical as well as lateral distribution was obtained. After drying, the sands were sieved for 15 minutes through Tyler Standard Screens, with diameters that range from 4mm to 1/16 mm. Following mechanical separation the percentage of grade-size distribution were computed. Histograms, frequency curves, and cumulative curves were constructed for each sample, and from them additional sedimentary data were derived. Mineralogy and roundness and sphericity of quartz and feldspar were determined by microscopic study.

Histograms of the twenty-eight samples are shown in Figure 2. The chief ingredient in each case is between ¼mm and 1mm. In eleven samples the chief ingredient is between ¼mm-½mm, in sixteen samples between ½mm-1mm, and in one sample the chief ingredient is between 1mm-2mm. The second high percentage always forms a proximate admixture. The maximum percentage in one size grade is in sample #15, where 60.4% of the grains range between ¼mm-½mm. The concentration of material between ¼mm and 1mm is significant, because it suggests the presence of a transporting fluid of similar competence during the period of sand accumulation. Modification in the size range of sieve screens would show histograms with a changed aspect; certainly the chief ingredients would possess higher percentages than those in Figure 2.

The number of size grades with more than one percent of sand may be significant. Tabulations of beach and fluvial

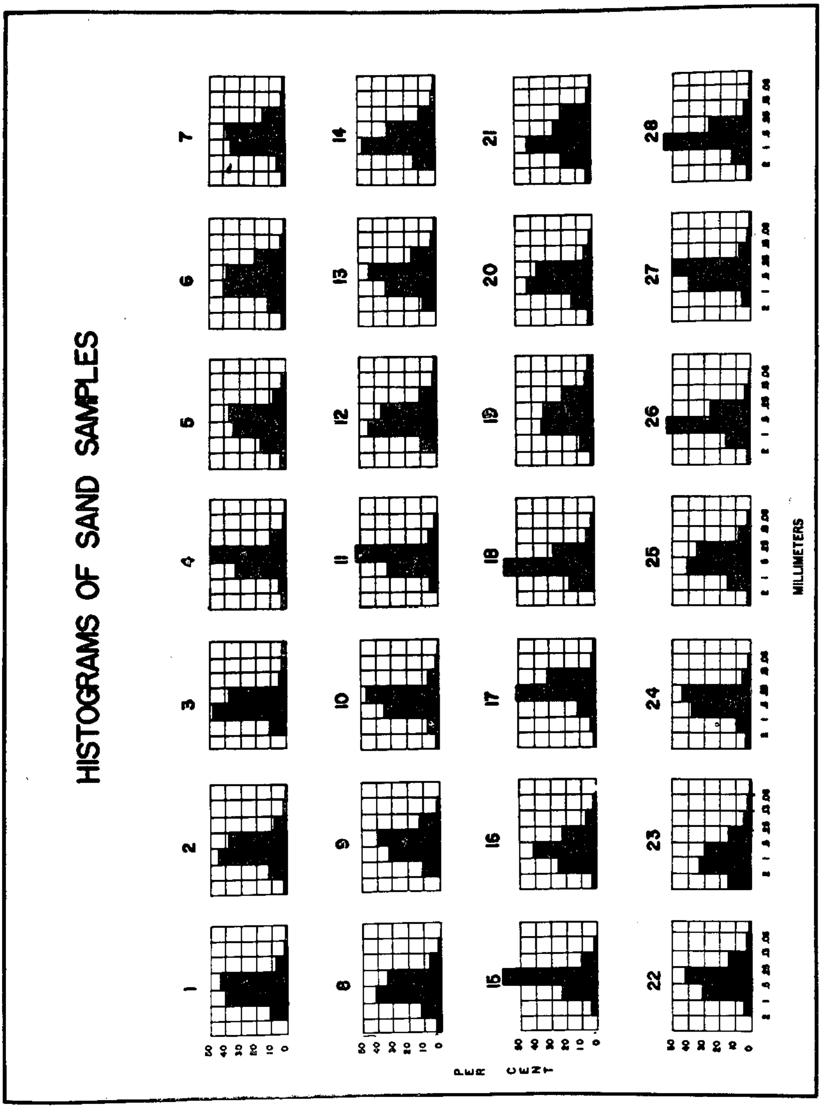


Figure 2. Twenty-eight histograms of sand samples. Note the concentration of sand between 1mm-¼mm, with the exception of Sample #23. Sample #15 shows the highest percentage in one grade, 60.4%.

deposits from many areas demonstrate that normally beach sands have three grades with more than one percent of material, and fluvial sands six or seven grades[1]. Of the twenty-eight samples studied from the Curtis farm, 3 have seven classes, 15 have six classes, and 10 have five classes with greater than one percent of sand. This summary is subject to limitations and may be unwarranted, but it does appear that this factor of the deposit suggests a similarity closer to fluvial deposition than to beach origin.

The sorting coefficient of each sample was determined. The values are shown in Figure 3. The So ranges from 1.245 to 1.742, with the average 1.452. This statistical measurement, developed by Trask as an index to the variation in conditions of a transporting fluid, proposes that the deposit is well-sorted. This assumes that Trask's value of 2.5 for the upper limit of well-sorted deposits is valid[2], a condition that has, however, been seriously doubted by several workers.

Composition of the sand is shown in Figure 4. Twenty-five minerals were identified, eleven of which form greater than 5% of at least one sample. In addition, a small percentage

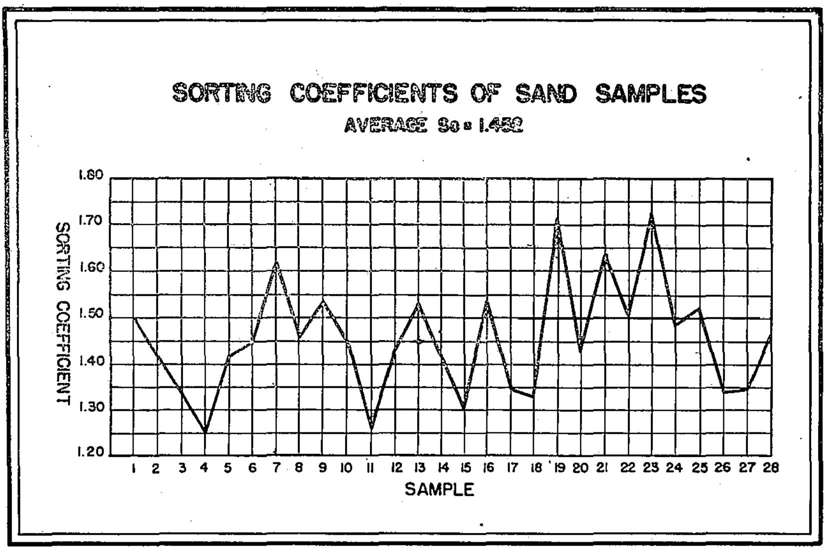


Figure 3. Range of sorting coefficients for the twenty-eight samples. The average is representative of a well-sorted deposit.

of schistose and granitic fragments form a portion of several samples. The mineral composition is generally representative of an arkosic sand that has been derived for the most part from granitic terranes to the north. Careful inspection of each sample was made for organic materials. If a part of this deposit is marine, then Foraminifera or similar small organisms might be expected. No marine or fresh water fauna was found in any sample.

Several tiny fibrous structures which possess openings along the major axis were observed. These are plant-like in appearance, and may well represent former algal material. Also a few small fragments of replaced woody material were isolated, in which growth rings are visible.

Quartz is the most common mineral and feldspars are second in abundance. In the larger grades the feldspars consistently are well-rounded and highly spherical. When schistose or granitic fragments occur they appear angular. In the smaller grades, ½mm or less, the feldspars are crushed fragments and the schists are more tabular.

Quartz grains are similarly better rounded and more spherical in the larger grades. Roundness values in the smaller grades of several samples are less than .3, but quartz sphericity is between .8 and .9[3]. A striking indication that quartz grains come from two sources can be seen in the grades less than ½mm. This is best observed in colored sands. Coated quartz grains with partially rounded edges and high sphericity exist in contrast to quartz grains that are clean and angular, and consequently less spherical and less rounded. The better rounded and more highly spherical quartz is probably carried by the Oconee River and mixed with deposits from Rose Creek whose distance of transport is considerably less. It is doubtful, however, that merely increased distance is in itself sufficient for the contrast in quartz abrasion. The deposits may well represent the mixing of first-cycle sands with sands that are in a second or even higher cycle.

Accessory minerals appear with increasing frequency in the smaller grades. They include apatite, hornblende, tourmaline, garnet, zircon, ilmenite, magnetite, and several others of minor importance.

In general the white sands have more feldspar and mica and less quartz than the overlying colored sands. In addition rounding and sphericity of grains average lower, and the contrast between quartz grains of different grades is not apparent. This suggests that the white sands may have had a common source closer to the site of deposition.

The absence of oxidized iron in the white sands is important. This may have resulted from rapid transport and deposition, and it may likewise suggest that the deposits were more or less continuously covered by water where oxidation of iron-bearing minerals would be restricted. A marine beach environment is the more likely situation if prolonged water-cover has prevented oxidation.

The colored sands suggest a flood-plain deposit, with oxidation occurring during the changing humid and dry periods. Incline-bedding in the colored deposits tends to dip consistently southward, in the direction of current flow, which may lend additional support to a proposed flood-plain origin.

Summarizing, well-sorted sands of commercial quality exist in northwest Greene County, Georgia. Superjacent beds are colored by oxidation of iron-bearing minerals, but the lower beds are not colored. The sands are of an arkosic type and show no microfauna. The number of sand grades in all the samples is more representative of fluvial deposition. Abrasion factors differ in both quartz and feldspar in the lower grades of colored sands, suggesting a greater distance of transport for some grains and/or considerable reworking.

The sands may be all of flood-plain origin or partly flood-plain and partly marine. If partly marine, the beds may have formed along a beach in a tongue of the sea that extended north of the Fall Line, which represents the current general inland boundary of marine coastal plain deposits in Georgia.

---

[1] F. J. Pettijohn, *Sedimentary Rocks,* Harper and Brothers, New York, 1949. pp. 234-235.

[2] P. D. Trask, *Origin and Environment of Source Sediments of Petroleum,* Gulf Publishing Co., Houston, Texas; 1932. pp. 71-72.

[3] W. C. Krumbein and L. L. Sloss, *Stratigraphy and Sedimentation,* W. H. Freeman and Company, San Francisco, California, 1951. p. 81.

MINERALOGY OF THE SAND DEPOSITS

MINERALS	ABUNDANCE
Quartz (Several Varieties)	1
Albite	1
Microcline	1
Orthoclase	1
Andesine	1
Biotite	1
Muscovite	1
Sericite	1
Chlorite	1
Hornblende	1
Actinolite	2
Black Tourmaline	2
Schlorite	3
Limonite	2
Hematite	2
Magnetite	1
Pyrite	2
Rutile	3
Ilmenite	2
Leucoxene	2
Garnet	2
Apatite	2
Zircon	2
Sillimanite	3
Kyanite	3

1—Greater than 5% in at least one sample
2—Less than 5% in each sample in which it appears
3—Only a trace in samples in which it appears

Figure 4. Twenty-five minerals determined in the sand samples. Of the minerals showing a #1 abundance, only quartz, albite, orthoclase, biotite and muscovite do so in more than one sample.

HEAVY ACCESSORY MINERAL STUDY IN THE DUCKTOWN BASIN*

by

OTIS GIBSON, Geologist

Tennessee Copper Company
Ducktown, Tennessee

Introduction

Study of heavy accessory minerals has proven useful in guiding exploration of the Ducktown Basin ore deposits. It is providing a greater knowledge of Basin stratigraphy and the relation of ore deposits to certain stratigraphic zones and, in addition, it has shed much light on the controversial subject of relation of the ore bodies to favorable beds.

The heavy mineral studies are a part of the geological program of the Tennessee Copper Company directed toward finding ore and determining its form and extent. Permission of the Tennessee Copper Company to publish the results of this study is gratefully acknowledged. The work was done under the supervision of Mr. W. W. Simmons, Chief Geologist of the Tennessee Copper Company, to whom thanks are due for aid given during the study and for critical reading of this paper. I am indebted to Dr. F. G. Snyder who made the initial studies of the heavy minerals and determined microscopically the local suite of accessory minerals, and also for aid in preparing this paper. Acknowledgments are due Mr. H. F. Kendall, Assistant Superintendent of Mines, and Mr. Owen Kingman, Geologist, for critical reading of this paper. Acknowledgment is due Mr. Edward Swanson who logged approximately 20,000 feet of drill core for zircon.

General Geology

Detailed geological mapping in the Ducktown Basin covers approximately fifteen square miles in Polk County in the southeast corner of Tennessee. The sedimentary series in the Basin is a part of the Great Smoky formation (1) of late pre-Cambrian age (2). A comprehensive description of the

*Read at the Southeastern Mineral Symposium, Geology Department, Emory University, March 29-31, 1951.

geology of the district is given by Emmons and Laney (1). Recent exploration, including a detailed map of the Ducktown Basin, has been described by Simmons (5).

Sedimentary rocks of the Basin consist of graywacke, graywacke- schist, graywacke-conglomerate, and schist. The graywackes vary from conglomeratic to fine grained; some contain pseudodiorite. Graywackes in general are composed of angular particles of quartz and feldspar set in a fine-grained micaceous matrix, some are calcareous. The term graywacke-schist is used to describe both micaceous graywacke and alternating thin schist and graywacke beds. The schist beds vary in texture from those with mica flakes ¼ in. in diameter to fine-grained, slaty rocks. Biotite, muscovite, chlorite, and sericite varities occur in the Basin. The schists and graywackes have been subjected to moderate metamorphism.

Gabbro of unknown age occurs in the Basin. It is metamorphosed, but not as much as the country rock. It probably came from the same magmatic mass as the ore solution but it is older than the ore.

There are numerous quartz veins throughout the Basin which range in thickness from five feet to microscopic dimensions. They are of at least two ages, one group being older than the major folding.

Structurally, the Ducktown Basin in Tennessee is an intricately folded area in which the main structural feature is a large drag fold composed of numerous closely folded anticlines and synclines; occasional domal and basin structures are found (5). Most fold axes plunge to the northeast, although some plunge to the southwest. The general strike of the beds is northeast with southeast dips predominating, although there are many variations from the general rule.

Three sets of faults have been described by Simmons (5); they strike northeast, northwest, and eastwest.

Ore minerals of the Ducktown Basin include pyrite, pyrrhotite, chalcopyrite, sphalerite, and magnetite. The most abundant gangue minerals are quartz, calcite, actinolite, and tremolite.

Stratigraphic Studies

Due to lithologic similarity of the beds, considerable difficulty was experienced in tracing individual beds from one section of the Basin to another, especially through covered areas and fault zones. Although the Ducktown Basin for the most part is devoid of vegetation, plant installations, débris, fault zones, wide creek bottoms, and complex structures precluded accurate correlation of beds by normal stratigraphic methods. In tracing beds from one side of the Basin to the other it was thought expedient to set up a stratigraphic section (5). The ore bodies are grouped in two producer zones. Efforts were made to extend the two producer zones throughout the Basin, but without success. Some distinctive beds were an aid for local correlations but did not persist throughout the Basin. They either lense out or lose their distinctive qualities. As a consequence it was considered necessary to develop some other criteria whereby a key bed or group of beds could be recognized.

The first attempt consisted of laying out ten surface cross section lines, each across a different part of the Basin. Six additional lines were later run over other key sections of the Basin, making a total of 40,000 feet of surface cross section lines. This work was done by Lacy (4) and Kingman (3). Each bed on each cross section was mapped, described megascopically, and sampled. Attempts were made at correlations between cross-section lines, but for the most part they were inconclusive and discouraging. No bed or group of beds was found which could be used as a marker. The samples were labeled and filed for possible future use.

Heavy Accessory Mineral Studies

After cross section correlations by megascopic rock identification failed, Dr. F. G. Snyder undertook a study of heavy accessory minerals as a basis for correlation. The area chosen for the study was a portion of the Coletown syncline, a major structural feature in the area mapped. Cross section lines on opposite limbs of the syncline were used since some of the beds may be followed in the field from one limb to the other. The continuity of beds between the cross section lines provided a basis for evaluating mineralogical similarities and differences between beds.

Heavy mineral separations were made on the surface samples and the minerals were identified with a petrographic

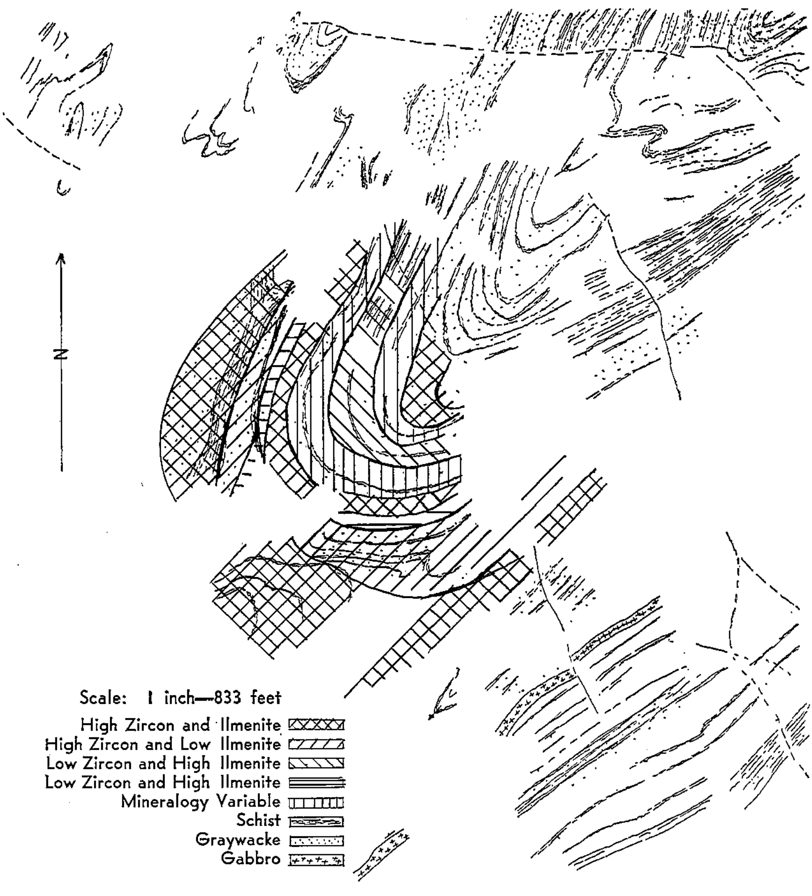


Figure 1
Geologic Map of A Portion of The Coletown Syncline

Figure 1

microscope. Zircon, ilmenite, and leucoxene were found to be the most useful minerals (6). One or all of these minerals were found to be more abundant in certain groups of beds than others, and that part of the stratigraphic section was broken down into groups of beds called zones. All beds in a zone were not uniform in terms of heavy mineral content because with a change in facies of an individual bed there was usually a change of heavy mineral content. Each group or zone was distinctly different from adjacent groups of beds in heavy mineral content and the zones were persistent. On these lines zircon was found to be more abundant in the youngest and oldest beds of the section studied and almost absent from the central zone. Ilmenite was found to be abundant in the oldest and youngest beds and central zone, as shown on the geologic map of a portion of the Coletown syncline.

The results were encouraging. Although no single bed stood out mineralogically, several groups of beds formed mineralogical zones that were quite different from other zones (6).

Ilmenite proved to be recognizable with a hand lens and hence very useful in surface mapping, because it is more resistant to weathering than the country rock. As a result after the preliminary study on the Coletown structure, Snyder was able to trace high ilmenite zones in the field in other portions of the Basin through covered areas and across fault zones. Zircon is too fine-grained to be useful in surface mapping with the hand lens. Leucoxene could not be used for field mapping due to its similarity in appearance to some of the weathered micas.

Drill Core Studies

In view of the success of using heavy accessory minerals for surface correlation an attempt was made to use ilmenite and zircon in logging diamond drill core to obtain correlations between drill holes in and adjacent to ore. To be economically feasible, the method must be rapid and easily applied. Heavy mineral separations, and detailed study of individual minerals was out of the question economically.

A binocular microscope is used to identify ilmenite in drill core. It was found that a 30 power magnification could be used speedily and still give accurate results. An operator can log ilmenite in approximately 60 feet of drill core per hour.

Most zircon in the Basin fluoresces a golden yellow (7). An operator can log zircon in approximately 100 feet of drill core per hour using a short wave mineral light; 2537 A. (Angstrom units). The filters deteriorate slowly. We found that after approximately 100 hours of use a filter will have deteriorated enough to cause the zircon to appear fainter and smaller. The best results are obtained by splitting the core and considerable more time is required to prepare the core than to log it for zircon or ilmenite.

Relative amounts of both ilmenite and zircon are estimated according to the following scale which proved adequate for our problem.

Table I—Heavy Mineral Scale

Abundance	**Size Approximate**		
0—None	A—Very large	.5	mm
1—Rare	B—Large	.3	mm
2—Sparse	C—Medium	.1	mm
3—Medium	D—Small	.05	mm
4—High			

Size of zircon grains has not been found useful as a correlative tool. After the core is logged, data are plotted on mine plans and cross sections, where correlations are made. The zonal arrangements of beds already recognized on surface is also recognizable in core. A study was made of drill core in the Calloway area, one of the operating mines. At that locality most schists were found to be low in zircon and most graywackes high; most of the ilmenite was found to be in schist. The ore and ore zone gangue minerals are low in zircon and ilmenite. A detailed examination of ore and ore zone with heavy mineral separation and study under the petrographic microscope was made by Snyder (7) to see if zircon and ilmenite were present but masked by ore. It was found that ilmenite is absent but that zircon does occur in ore as a very few minute crystals. Zircon in ore had not lost its fluorescent properties during the mineralization process (7). Although ilmenite was found in some schist beds, it is sparse in fresh drill core. An acceptable explanation for the difference in ilmenite content of fresh rock and weathered rock has not been found. Due to its scarcity in drill core the use of ilmenite in correlations of fresh rock was abandoned By dropping ilmenite in correlations, probably 60 per cent of logging time was saved. Zircon was found to be very useful for correlating rock beds in both fresh and weathered rock.

While using the ultra-violet light it was found that most of the calcite in the country rock, ore, and ore zone is fluorescent. The fluorescence varies from a dull red to a brilliant red. Non-fluorescent calcite is also found in country rock, ore and ore zone. No explanation for the difference between fluorescent and non-fluorescent calcite has yet been established.

Pseudodiorite is usually found to be high in zircon.

Calloway Ore Body

Calloway ore body is in the southeast section of the Ducktown Basin. It was first operated in 1853 and operated at various intervals until 1907. The mine was abandoned at this time due to excessive water and poor grade. The old workings extend down to the third level, 320 feet below surface. In 1940 a geophysical survey using methods which determined magnetic resistivity and self potential characteristics was run over the property. An anomaly was found southwest of the old workings. Exploration by diamond drill and underground development have outlined an ore body to a depth of 1600 feet below surface.

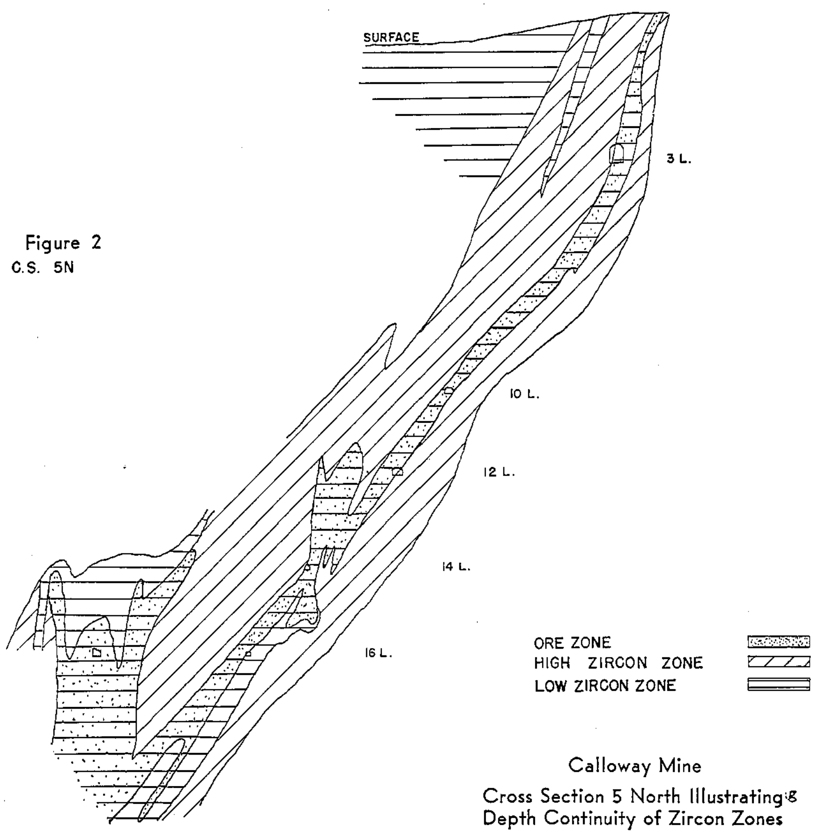
Twenty per cent of all diamond drill core from exploration of this ore body had been saved and it was split for zircon and ilmenite logging. Although all of the core was logged for ilmenite it was not found useful and will not be discussed further.

In most instances the zircon content was found to be low in the immediate hanging wall and footwall rock and in the ore. Since the ore is confined to the low zircon zone it is assumed it replaces a group of beds low in zircon. The group of beds includes alternating schists and graywackes and is probably more schistose than has been previously assumed. The favorable low zircon is sometimes wholly replaced by ore but most of the time it is only partially replaced. Where the favorable zone has been thickened by folding the ore is usually thick also. High zircon zones were found on both the hanging and footwall of the low zircon favorable zone. The high zircon zones were traced from 16 level to surface on mine cross section 5 north. See figure II.

The hanging wall zone is conglomeratic graywacke with occasional calcareous layers. The footwall zone is a graywacke with numerous pseudodiorites.

The heavy mineral or zircon correlations proved to be an aid in development. In some cases outlines of the ore body drawn after preliminary study were changed after heavy mineral correlations were made. The changes were later verified by diamond drill and drift exploration. On 16 level sub-level

Figure 2
C.S. 5N



Calloway Mine
Cross Section 5 North Illustrating
Depth Continuity of Zircon Zones

No. 1 on mine cross section 6 north, a drill hole verified a change in ore outline as shown in Figure III.

On 14 level a cross cut was driven in ore which verified a change in ore outline on cross section 1 north, as shown in Figure IV.

There is considerable lensing of beds in the Ducktown Basin. Some changes of lithology are gradual, while others are abrupt. The same conditions were found in the heavy mineral study of Calloway. In most cases in which a bed lenses out the heavy mineral content of the succeeding bed is different from that of the bed which lensed out. A part, at least, of the difficulty of correlating lenticular beds is overcome by use of the heavy mineral methods which permits grouping the beds into zones.

Conclusions

Study of heavy minerals has proven useful in interpreting the structure of Calloway ore body and in correlating beds over other parts of the Basin which have been tested. Ilmenite has been an aid in surface correlation, but not in drill core studies. Zircon correlations have proven successful in both fresh drill core and weathered surface rock and can be a

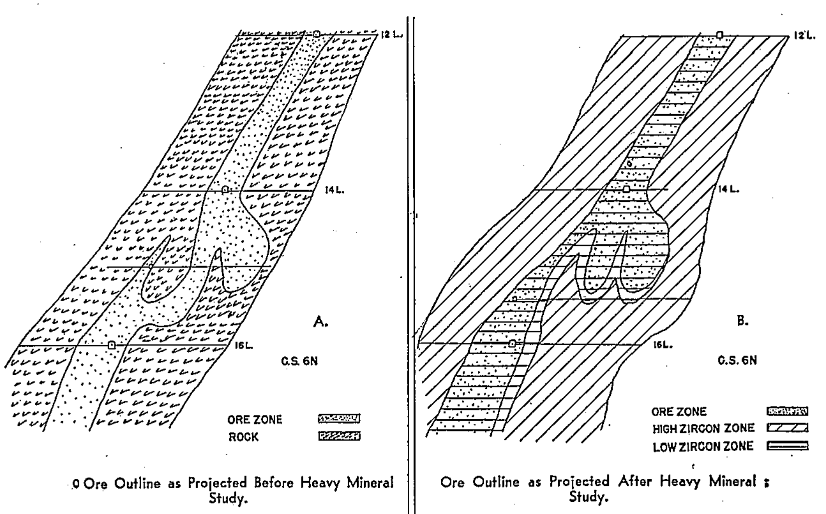


FIGURE 3
CALLOWAY MINE

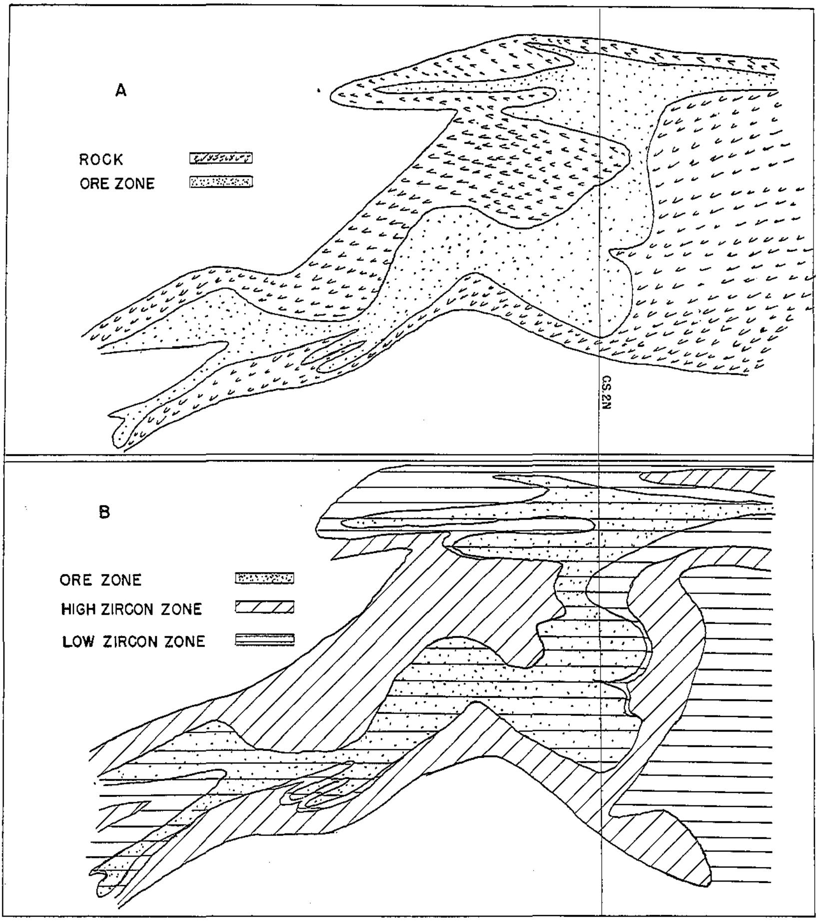


Figure 4
Calloway Mine 14 Level

A. Ore Outline as Projected Before Heavy Mineral Study.

B. Ore Outline as Projected After Heavy Mineral Study.

further aid on surface by use of the ultra-violet light on surface samples.

The Calloway study emphasized the importance of the lensing of beds and also the continuity of the heavy mineral zones. Though the heavy mineral zones may continue for great distances, individual beds in these zones may lense out or new beds may come in without serious consequence to the zone.

The heavy mineral study proved an aid to exploration by helping to determine the ore outline prior to development. Knowledge of the position of the favorable zone is very helpful in predicting the ore outline.

The relation of ore to favorable bed has been clarified by establishing the fact that the host rock is a zone low in heavy minerals. Although the ore is closely restricted to a certain group of beds and does not cross zones, locally it may transgress individual beds as shown by the fact that only a part of the zone has been replaced in most places.

References

(1) Emmons, W. H., and Laney, F. B., Geology and Ore Deposits of the Ducktown Mining District, Tennessee: U. S. Geol. Survey Prof. Paper 139, 1926.

(2) King, P. B., The Base of the Cambrian in the Southern Appalachians: Am. Jour. Sci., Vol. 247, pp. 513-530, 622-645, 1949.

(3) Kingman, Owen, Staff Report, Tennessee Copper Co., 1948.

(4) Lacy, R. J., Staff Report, Tennessee Copper Co., 1947.

(5) Simmons, W. W., Recent Geological Investigations in the Ducktown Mining District, Tennessee, in Proceedings, Symposium on Mineral Resources of The Southeastern United States, Knoxville, Tennessee, 1949.

(6) Snyder, F. G., Staff Report, Tennessee Copper Co., 1949.

(7) Snyder, F. G., Staff Report, Tennessee Copper Co., 1950.

STATISTICAL STUDIES OF THE SANDSTONES WITHIN THE LEE GROUP LOOKOUT MOUNTAIN, GEORGIA

ERNEST W. RENSHAW and ARTHUR T. ALLEN

Emory University

Introduction

The Pennsylvanian sediments in Georgia have been correlated with the Lee Group of Central Tennessee and Virginia. On Lookout Mountain this group is represented by five formations: the Lookout which consists of the Gizzard shale and the Sewanee conglomerate members, the Whitwell shale, the Bonair sandstone, the Vandever shale, and the Rockcastle sandstone. These formations have an aggregate thickness of 950-1000 feet.

Statistical studies were made of the Sewanee conglomerate, the Bonair sandstone, and the Rockcastle standstone. The Sewanee conglomerate is 165 to 175 feet thick and consists mainly of massive, highly crossbedded conglomeratic standstones, with at least two thin discontinuous coal zones, and occasional thin beds of dense conglomerate. This member of the Lookout can easily be recognized by the presence of white rounded quartz pebbles; it is the only conglomeratic formation on Lookout Mountain.

The Bonair sandstone is about 170 feet thick and consists of highly cross-bedded, well-sorted, thinly laminated sandstones. There is little or no shale in this formation on Lookout Mountain.

The Rockcastle sandstone is 350-380 feet thick and is made up of three thick sandstone members which are separated by shales and coals. These sandstones are lithologically similar to the Bonair sandstones and are highly crossbedded, thinly laminated, and well-sorted.

Sedimentary Analyses

Size analyses of composite samples, using U. S. Standard screens were made for each sandstone formation. The results were plotted graphically as histograms and the medium quartile, the first and third quartiles, the arithmetic quartile deviation, the coefficent of sorting and the skewness and kurtosis for each graph were calculated by the writers, using procedures as outlined by Krumbein and Pettijohn (1938, pp. 228-267).

Thin sections were examined with a petrographic microscope to determine the presence of detrital minerals, the types of contacts between grains, and the relations of grain size. Roundness determinations for the Sewanee conglomerate were made from projections of thin sections.

Heavy mineral separations were made to determine the relative amount and the types of detrital minerals present in each formation as an aid to correlation.

Roundness determinations for the Bonair sandstone and the Rockcastle sandstone were made by tracing grain outlines with a camera lucida. Roundness calculations were made by following the procedure as given by Krumbein and Pettijohn (1938, pp. 281-282) with a roundness factor of 1.0 used for a sphere.

Results of Analyses

Sewanee conglomerate: The sorting coefficient (So) calculated from these analyses is 1.79 which shows that the Sewanee conglomerate is well-sorted but not as well-sorted as the Bonair sandstone or the Rockcastle sandstone. The median quartile for the Sewanee conglomerate is .423 millimeters, with the first quartile (Qa_1) being .238 millimeters and the third quartile (Qa_3) .765 millimeters. The arithmetic quartile deviation (QDa) for this formation is .264. The skewness (SKa) foa the Sewanee conglomerate is .078, and the kurtosis (Kga) is .256. This latter figure shows that the curve for the Sewanee conglomerate is more nearly normal than the curves of the Bonair sandstone or the Rockcastle sandstone.

Thin sections of the Sewanee conglomerate used for petrographic analysis and for roundness determinations show the rock to be composed almost entirely of quartz, with an occasional grain of leached biotite and secondary hematite. The larger grains of quartz are normally rounded and show strain and fractures. Contacts between the larger grains are mutual and the contacts between the smaller grains are sutured. The distortion of grains by the impression of surrounding grains and the presence of secondary silica leaves almost no pore space. Megascopic examination of the Sewanee conglomerate shows it to be a dense medium- to coarse-grained conglomeratic sandstone. In outcrop iron stain on the surface gives the rock a light brown color; however, on a fresh surface it is white to light gray in color.

There is approximately .69 per cent heavy mineral content in this formation. Leached biotite is the most common detrital mineral with magnetite and hematite occurring in smaller amounts. The latter are probably secondary. Also, four fragments of microcline (?) were present in one sample. The average computed roundness is .85 for the Sewanee conglomerate, with the most nearly round grain having a factor of .96 and the most angular .62.

Bonair sandstone: Size analyses used for making histograms and statistical calculations of this formation were made from composite samples taken from exposures east of Johnson's Crook. The sorting coefficient for the Bonair sandstone is 1.135, showing it to be the best sorted of the three sandstone formations. The median quartile for the Bonair sandstone is .348 millimeters, with the first quartile being .320 millimeters and the third quartile being .408 millimeters. The arithmetic quartile deviation is .044, (the smallest value recorded in any sandstone formation) which also shows the excellent sorting of the Bonair sandstone. The skewness of the curves plotted for the Bonair sandstone is .015 and the kurtosis is .121.

Fig. 1. Statistical data on the three Sandstone formations

	S o	Median (mm)	Qa_1 (mm)	Qa_3 (mm)	Qda	Ska	Kga
Sewanee conglomerate	1.79	.423	.238	.765	.264	.078	.256
filled channel—1	1.61	.419	.298	.735	.225	.091	.177
filled channel—2	1.61	.419	.285	.775	.238	.117	.188
Bonair—1	1.135	.348	.320	.408	.044	.015	.140
Bonair—2	1.135	.348	.320	.408	.044	.015	.121
Rockcastle—1	1.29	.313	.227	.378	.075	.011	.204
Rockcastle—2	1.23	.360	.299	.451	.076	.015	.178

Thin sections made from samples taken in the Bear Creek Canyon exposure of the Bonair sandstone show that it is composed almost entirely of quartz with an occasional grain of leached biotite. The quartz grains show very little variation in size and have both sutured and mutual contacts.

Megascopically the Bonair sandstone is a fine-grained, thinly laminated sandstone. In outcrop the Bonair sandstone is white, but may have an iron stain coating giving it a light brown color.

Heavy mineral separations of the Bonair show only a trace of leached biotite.

The roundness coefficient of the Bonair was computed from 20 gains, selected at random from each of the 60, 80, and 100 mesh screens. These contained the majority of the total sample. The average computed roundness for the Bonair sandstone is .85, slightly less than the Sewanee conglomerate. The most angular grain recorded has a factor of .68 and the most round, .98.

Rockcastle: Size analyses were made on composite samples taken along the strike of three massive sandstone members within the Rockcastle sandstone. The sorting coefficient of the Rockcastle sandstone is 1.23 showing that this formation is better sorted than the Sewanee conglomerate but not as well sorted as the Bonair sandstone. The median quartile of the Rockcastle sandstone is .360 millimeters, the first quartile is .299 millimeters, and the third quartile is .451 millimeters. The arithmetic quartile deviation is .075, only slightly greater than the deviation in the Bonair sandstone. The skewness of curves plotted for the Rockcastle sandstone is .015 and the kurtosis is .178.

Thin sections show the Rockcastle sandstone to be composed almost entirely of quartz with an occasional grain of biotite. One grain of microcline was noted in thin section. The quartz grains show little variation in size and the majority of the contacts are mutual.

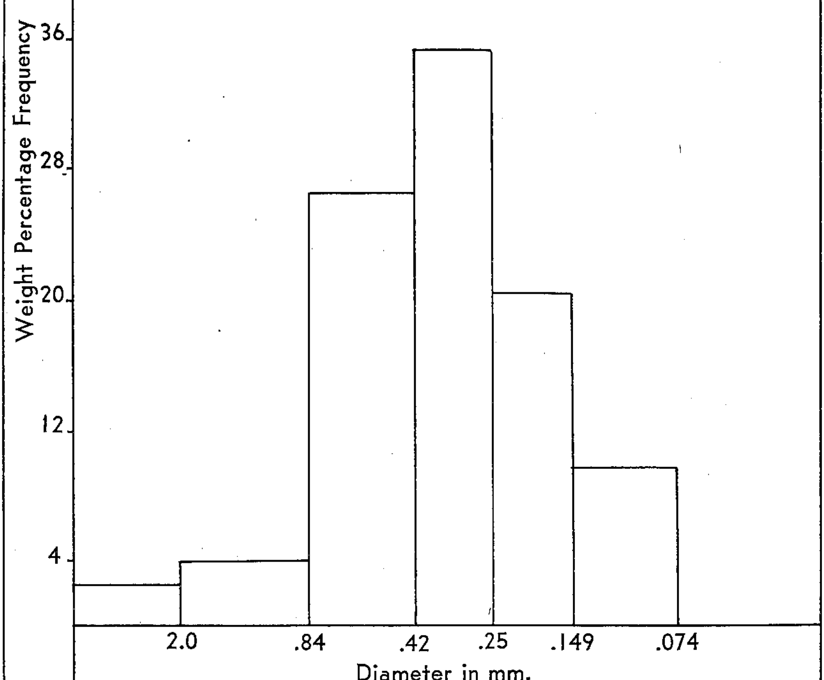
The Rockcastle sandstone is light brown in outcrop due to slight iron staining. On a fresh surface the Rockcastle sandstone is white or light gray. This formation weathers easily and occurs only in limited outcrops.

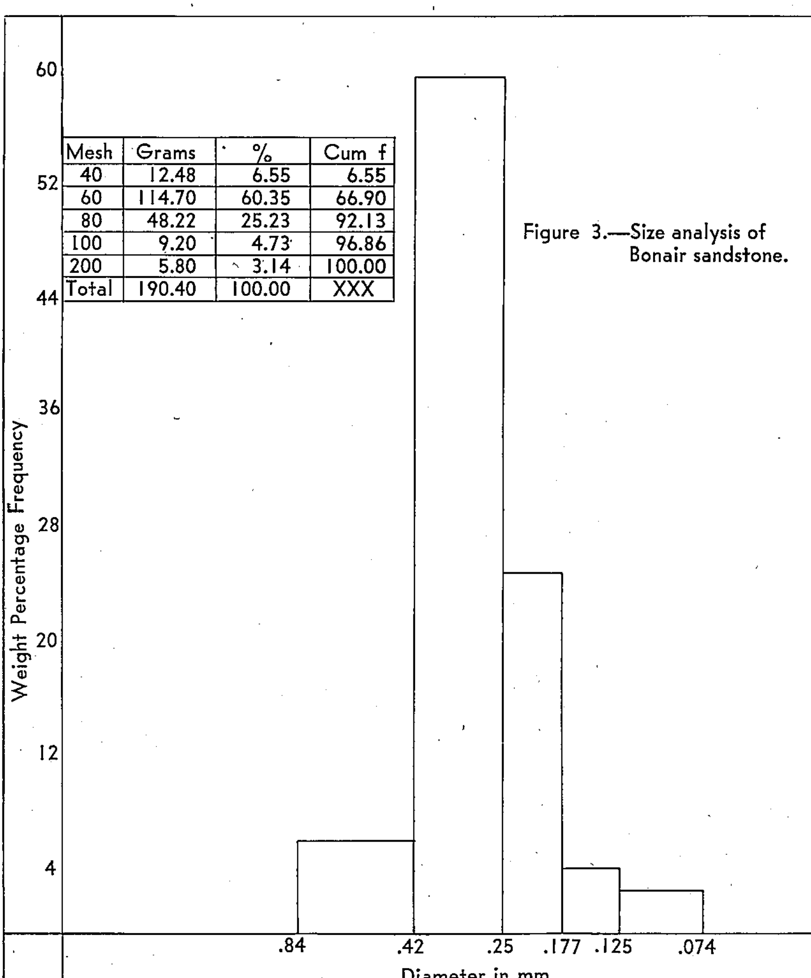
Heavy mineral separations in the Rockcastle sandstone show only a trace of leached biotite.

The average roundness factor in the Rockcastle sandstone is .79 with the most angular grain having a factor of .50 and the most rounded .94. This shows the Rockcastle sandstone to have the greatest average angularity of the three sandstone formations.

Mesh	Grams	%	Cum f
10	5.19	3.68	3.68
20	7.96	4.24	7.92
40	47.66	26.51	34.43
60	63.71	35.43	69.85
100	36.91	20.42	90.27
200	17.80	9.73	100.00
Total	179.23	100.00	XXXX

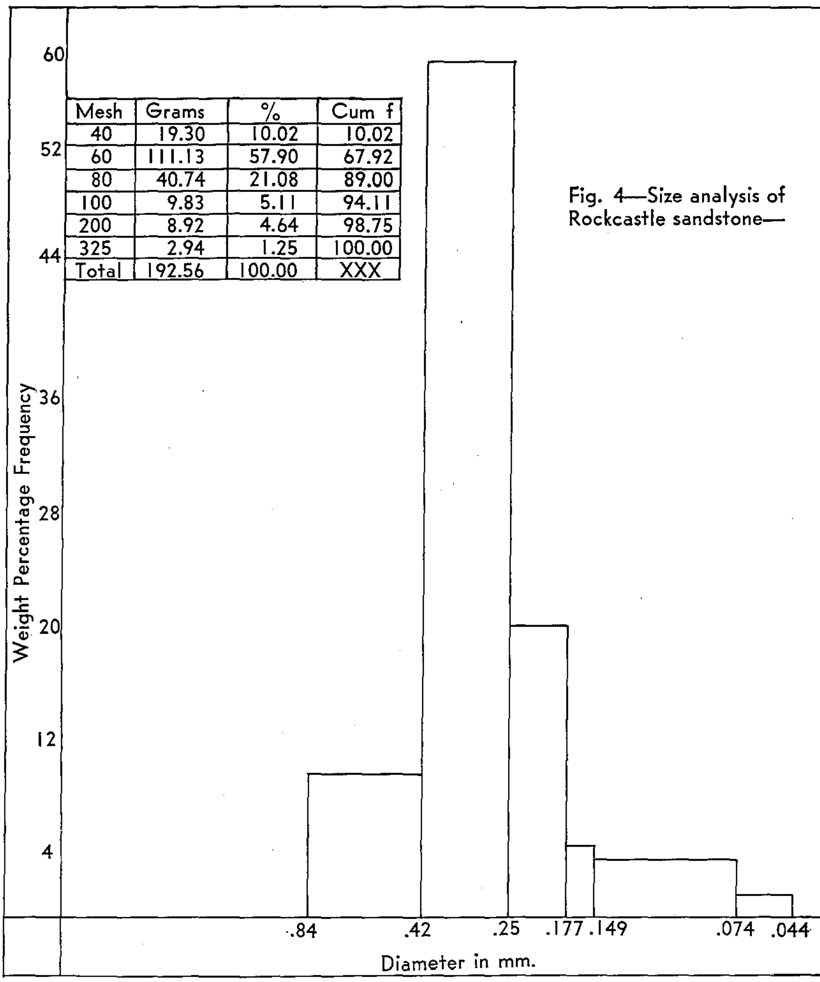
Figure 2—Size analysis of Sewanee conglomerate





Mesh	Grams	%	Cum f
40	12.48	6.55	6.55
60	114.70	60.35	66.90
80	48.22	25.23	92.13
100	9.20	4.73	96.86
200	5.80	3.14	100.00
Total	190.40	100.00	XXX

Figure 3.—Size analysis of Bonair sandstone.



Mesh	Grams	%	Cum f
40	19.30	10.02	10.02
60	111.13	57.90	67.92
80	40.74	21.08	89.00
100	9.83	5.11	94.11
200	8.92	4.64	98.75
325	2.94	1.25	100.00
Total	192.56	100.00	XXX

Fig. 4—Size analysis of Rockcastle sandstone—

References

Krumbein and Pettijohn, *Manual of Sedimentary Petrography*, Appleton, Century, Crofts (1938).

OBSERVATIONS ON THE TYPES AND DIRECTIONS OF LINEATION IN A PORTION OF THE EASTERN GEORGIA PIEDMONT*

ELDON J. PARIZEK

University of Georgia

Lineations result from the parallelism of directional properties within a rock. If this quality originates at the time of initial rock formation it is considered primary, but if it is later introduced or impressed upon a rock, the lineation is secondary. Lineations develop in many igneous and metamorphic terranes, and their accurate and careful study may make possible satisfactory determinations of movement directions. Moderate to well-formed lineations occur in the crystalline rocks of Georgia, and several types have been mapped in an area of several hundred square miles of the Eastern Piedmont (Figure 1). Observations on the kinds and trends of lineation in the area comprise the main objective of this paper, though the genetics of some lineation types are presented.

In this section of the Georgia Piedmont southwest plunging folds are the dominant structural elements. Subsequent erosion has destroyed the topographic evidence of these features, but their former appearance can be quite adequately restored from an analysis of subsidiary structural elements that are residual within the rocks. The fold axes strike northeast-southwest, parallel to the Appalachian system, and as in the case of the latter, show evidence of overturning to the northwest.

Both primary and secondary lineations are present. The igneous rocks, mostly granites or allied to granites in appearance and composition, possess a primary lineation due to magmatic flow. Igneous exposures frequently possess a strongly developed platy structure in one locality and elsewhere become massive and lack a platy appearance. Lineation is best seen in the platy granitic bodies and becomes fainter or practically indistinguishable in some of the mas-

*Read before Earth Science Section, Georgia Academy of Science, Mercer University, Macon, April 24, 1953.

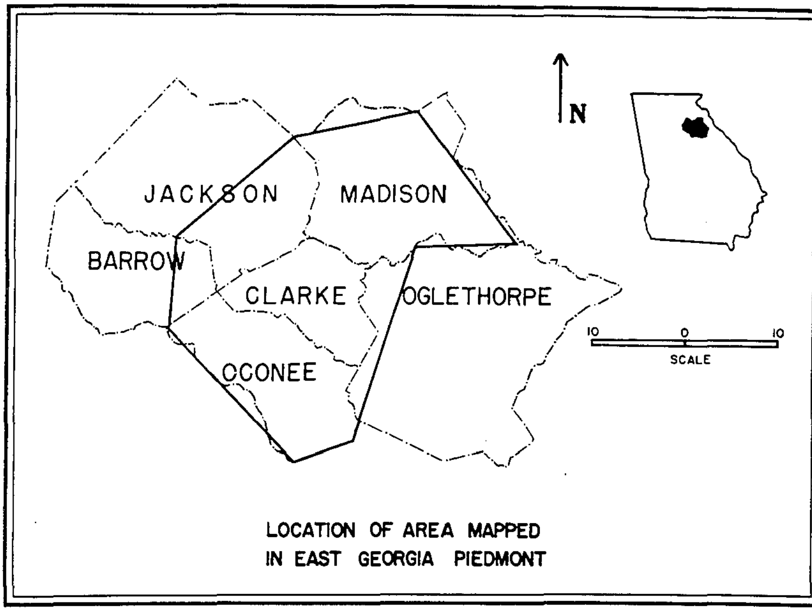


Figure 1. Generalized boundaries of area mapped in the east Georgia Piedmont.

sive exposures. Lineation developed from an alignment of prismatic and tabular minerals and inclusions at a time of magmatic flow. In limited igneous exposures the lineation displays a consistent strike, but a marked deviation or shift appears when the entire region is considered (Figure 2). Platy structures are best developed in the southeast, where a northeast-southwest lineation has been mapped. Dip of the lineation is variable in amount, but consistent in direction. It ranges between 10-15 degrees to the southwest.

In the central and south-central portion of the area under discussion linear properties within the granites trend regularly north-south (Figure 2), and maintain a southward dip of 10-20 degrees. In some places the linear strike changes sharply over a short distance from a north-south trend to one that strikes northwest-southeast. This agrees with the direction of both primary and secondary lineation farther to the northwest, in which region the strike averages N30-N50 degrees west.

It is convenient when referring to folds to adopt a coordi-

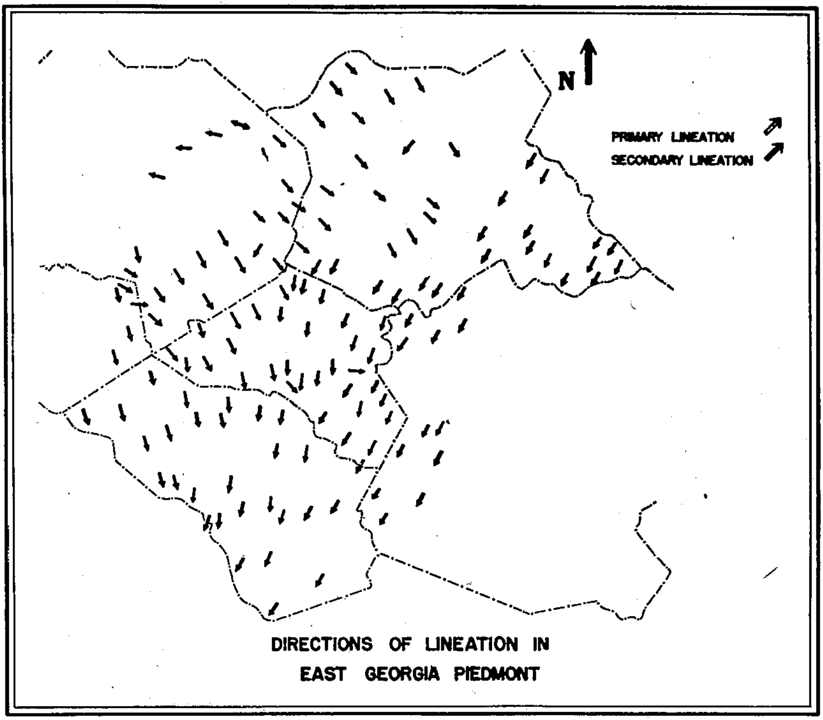


Figure 2. Linear directions in mapped area of east Georgia Piedmont. Note the similarity in trends between primary and secondary lineations.

nate system, to which system additional structural elements within the folds can likewise be referred (Figure 3). Commonly the coordinate **b** is placed parallel to the fold axis, an **a** coordinate is horizontal and normal to **b**, and the **c** coordinate is assigned the vertical position, normal to the **a** and **b**. Elements within a fold, including lineation, can then be referred to these coordinates. Using this system, the primary trends in the southeast of the area under discussion become for the most part lineations in **b**, while to the northwest, where some scattered exposures retain a primary flow structure, the lineation is predominantly in **a**.

The most widespread lineations in the crystallines of this area are those that developed following original consolidation of material. At present several kinds have been determined, but it is likely that additional types will be recognized.

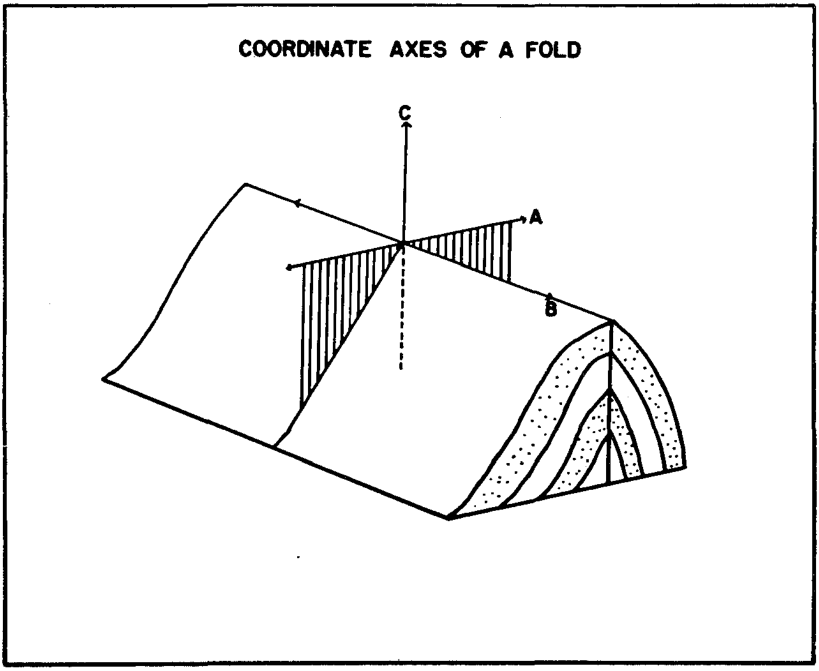


Figure 3. Sketch of a fold showing the assumed positions of the a, b, and c coordinates (after E. Cloos).

Noteworthy is the agreement in trends of many primary and secondary lineations, which would suggest a co-gensis in some places between the two (Figure 2). It must be stated, however, that this relation is not always true. Nevertheless, the similarity in trends between primary and secondary lineations is outstanding in the region.

Among the secondary lineations currently recognized are those caused by secondary flowage, slippage or slickensiding, rotation, and the intersection of planes.

Both meta-sedimentaries and meta-igneous rocks show evidence of lineation by secondary flowage. Statistical analyses have not been made, but other criteria verify its development; for example, the external shapes of grains, crushing, stretching and recrystallization of minerals, augen development in some granites, and the platy patterns of micaceous minerals. Figure 4, sketched from a thin section, illustrates the structures of a schist with secondary flowage. Micas have been

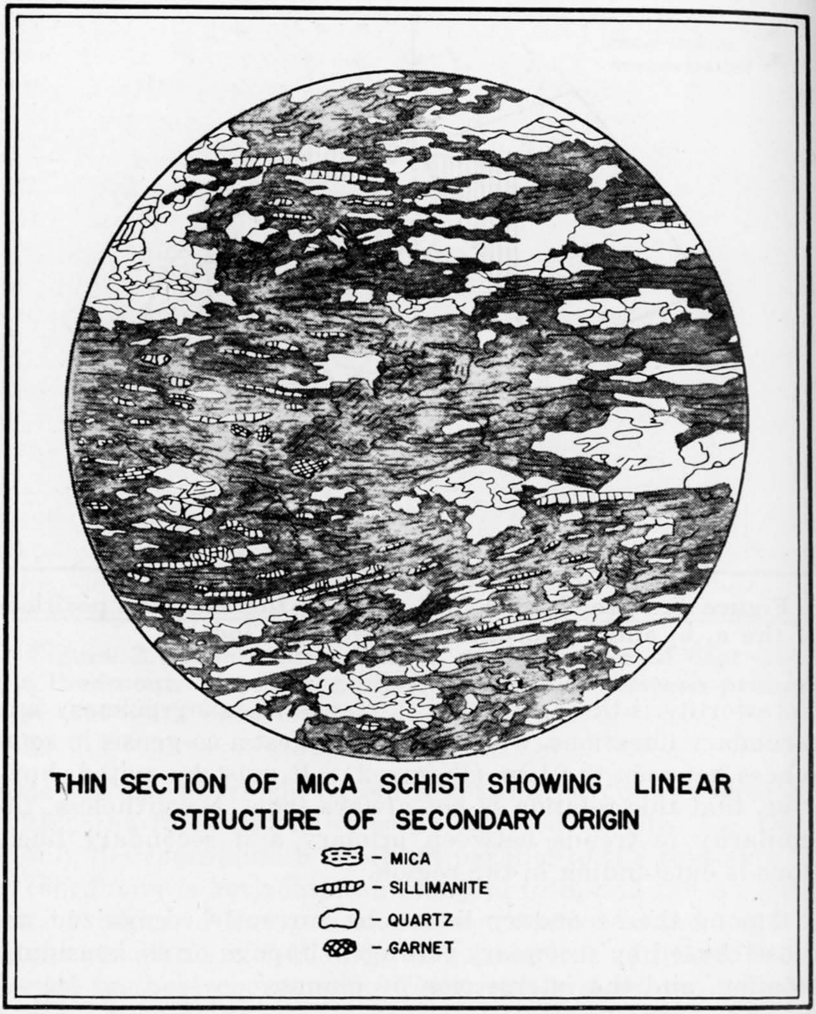


Figure 4. Sketch of a thin section of foliated schist. The cleavage direction is from left to right parallel with the sillimanite needles. Micas are shaded with different intensity in agreement with the colors of the grains in the section.

stretched and some recrystallization is present within the plane of shear. In addition sillimanite needles trend in the same direction. This feature is fairly characteristic of many schists within the area. Garnets often show deformation parallel to cleavage, with observed ratios of 2:1 to 4:1, compared with the original shape. Stretching or deformation has occurred parallel and normal to the major fold axes in the area. Lineation resulting from secondary flowage averages N25-N35 degrees east in the southeast, north-south in the central part of the region, and N30-N50 degrees west in the northwest. With few exceptions the dip of lineation is usually less than 20 degrees to the south, but in extreme cases it is as high as 70 degrees to the south.

Slippage will occur along planes when materials are folded, and this movement is usually most effective normal to the axis of folding. In highly metamorphosed areas like the Piedmont, original bedding of pelites and psammites cannot be determined, though slippage is pronounced. Movements during folding occurred along cleavage planes, which in some cases are likely to be in the original bedding planes. Slippage or slickensiding in this area is within the cleavage planes, most often in **a.** Exceptions to this are in the southwest section of Madison County, where slickensides within the cleavage trend parallel to the major fold axis, or in **b.** The exposed rocks are a part of the contact zone between underlying granite and intruded schistose layers. Migmatites were produced by penetration of granite juices into and along planes of foliated country rock. Pressures and drag from the invading magma were sufficient to cause sliding between planes of foliation in the direction of magmatic motion. Strike of primary flow trends in the area average N20 degrees east, and slippage is closely parallel to that direction.

Some rotational deformation accompanied the period of major folding in the Piedmont. Elongation developed parallel to the axis of rotation, associated in varying stages of formation, with small folds and wrinkles in the foliation planes. Lineation resulting from the common strike of these subsidiary fold axes is best developed in the southeast portion of the region, where the average strike is N20-N30 degrees east. The fold axes plunge consistently southwest in accordance with other linear elements. Many exposures possess strongly crenulated foliae that are cut by tension fractures formed at right angles to the direction of stretching. This has produced a "pencil structure" with rods commonly several inches in length and a fraction of an inch in diameter. The "pencils" are particularly well formed in northwest Clark County. There intersecting joints cut the "pencils" permitting them to weather easily and become dislodged from the exposures.

In the center and northwest of the area under discussion the lineation due to rotation is not clear and in some areas is totally absent. This may be the result of obliteration by a later and more strongly developed stretching to the northwest.

Lineation due to the intersection of planes can be frequently misleading when observed in highly metamorphosed rocks. Although directional properties are a consequence, their relation to the major structure may be questioned in the absence of definite bedding. The scarcity of exposures with positive bedding renders this type of lineation of less importance than those previously mentioned; nevertheless, it is common throughout the area, most frequently produced by the intersection of cleavage planes. In localities where flow cleavage and bedding intersect the trend is usually northeast-southwest, or parallel to the fold axis. Where only the junction of planes can be observed, it is usually due to the intersection of flow and fracture cleavage. Wrinkling of some foliae from minute displacements along the cleavages has formed small folds, whose axes parallel those of the major folds. Perhaps the most significant feature of this lineation is its general directional agreement with other linear types. This is best seen in the southeast of the area, and it would suggest that this type of lineation belongs to the same act of deformation as the others, or, at least a plan of deformation that is unchanged from the others.

It is not intended that this paper discuss in detail causes for the sharp reversal in linear trends between the southeastern and northwestern portions of the area. Nevertheless, two ideas are worthy of brief reference, both of which should merit further study. First, the shift in directions may represent two distinct periods of intense tectonic activity, occurring at separate intervals with stress directions essentially at right angles; or secondly, the linear trends may have formed from one major period of tectonic disturbance, in which case a major northeast-southwest fold was overturned to the northwest, accompanied perhaps by shearing and thrusting. Trends in the southeast would be for the most part caused by rotation and flowage parallel to the fold axis, while the trends to the northwest would represent for the most part stretching and slippage on the under limb of the fold, or perhaps along thrust planes now uncovered by erosion. Future investigations are necessary to support or deny the suggestions.

In conclusion, lineations in the crystallines of the east Georgia Piedmont are of primary and secondary origin. Several kinds have been mapped, including primary flow, secondary flowage, slippage, rotation and intersection of planes. In the southeast the trends of lineation average N20-N30 degrees east, in the center of the area they strike north-south, and in the northwest they trend northwest-southeast. The dip in practically all cases is to the south, in agreement with the plunge of folds remnants of which still remain in many exposures.

TITANITE NEAR KENNESAW MOUNTAIN, COBB COUNTY, GEORGIA*

WILEY S. ROGERS and J. G. LESTER

Emory University

Introduction

A new locality for the occurrence of titanite crystals was discovered when the four-lane highway from Marietta northward was being graded. Titanite has been collected from Kennesaw Mountain itself for many years where it occurs as random crystals in the pegmatitic phase of the rock. The new locality is genetically related to Kennesaw Mountain and the titanite occurs in the pegmatite dikes and along the borders of the dikes. Especially is this true where the dikes intrude the gneissic country rock. Collections may be made in those road cuts, immediately east and north of Kennesaw Mountain proper, which exhibit pegmatite dikes.

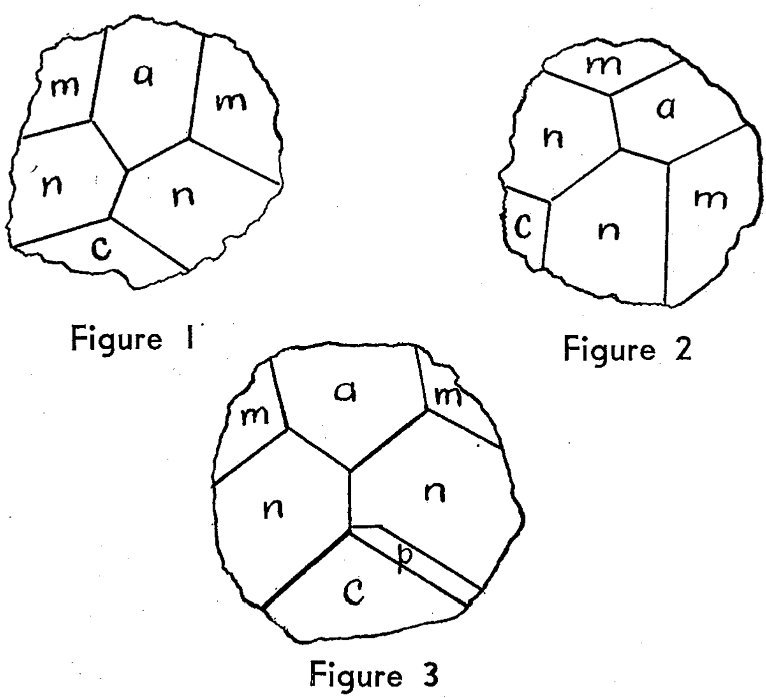
Chemistry of Titanium

The element titanium was discovered by William Gregor

*Read at the Meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

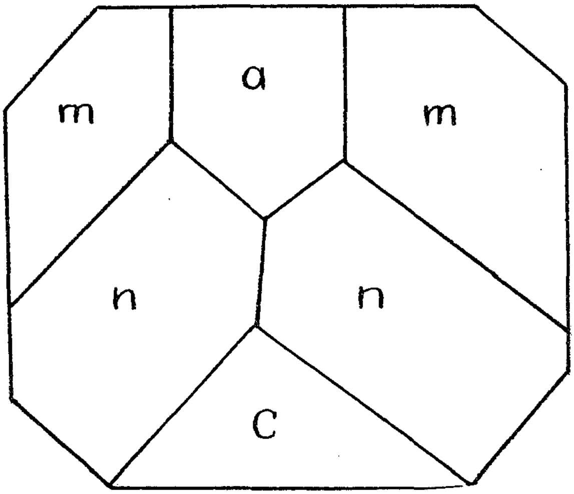
in 1790 while investigating a magnetic sand found near Menachan, Cornwall. He named the new element Menachanite. Seven years later Klaproth found that the Menachanite of Gregor was identical with an element he had isolated in a study of rutile and which he had named Titanium. Klaproth's Titanium thus replaced Gregor's Menachanite in chemical usage.

Titanium belongs to the silicon, zirconium, cerium, and thorium group. It is usually tetravalent but may have a lower valence. It is isomorphous with zirconium and silicon in some compounds. The atomic weight of titanium is 48.1. Elementary titanium has a bright metallic luster and a color which



Figures 1, 2—Sketches of titanite crystals from Kennesaw Mountain, Georgia

Figure 3 —Sketch showing development of second order pyramid p (122) on titanite crystal from Kennesaw Mountain, Georgia.



a —orthopinacoid (100)
m—unit prism (110)
r —pyramid (111)
c —basal pinacoid (001)

Figure 4. Idealized titanite crystal from Kennesaw Mountain, Georgia

resembles polished steel. It is hard and brittle when cold, malleable at a low, red heat and may be forged like iron. It is non-ductile. The specific gravity according to Moissan is 4.87 (Barksdale, J., 1949), and its melting point ranges from 1800° C. to 1850° C.

Physical Properties of Titanite

The crystals exhibit a reddish-brown color and upon casual examination resemble distorted andradite garnets.

The indices of refraction are very close to those given in standard reference books being: X = 1.900, B = 1.907 and C = 2.034.

Cleavage is distinct parallel to m (110). Parting is prominent parallel to n (111). Twinning is common with the twinning plane parallel to n (111) and the twinning is largely responsible for the parting.

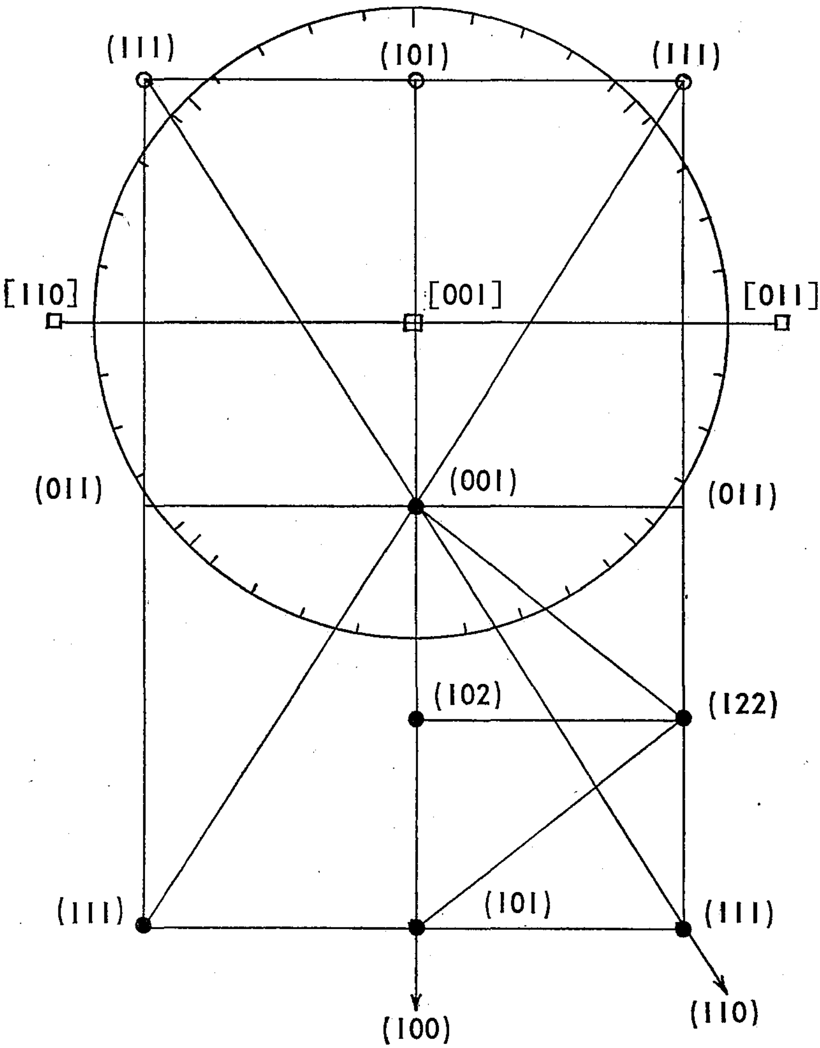


Figure 5. Gnomonic projection showing position of faces on a titanite crystal from Kennesaw Mountain, Georgia.

Specific gravity ranges from 3.4 to 3.6 depending upon the amount of iron present.

Natural etching is not common (Buckley, 1951) and all attempts to produce artificial etch patterns were unsuccessful. Various reagents were used including hydrofluoric, hydrochloric, acetic, nitric and sulfuric acids, and potassium hydroxide and ammonium hydroxide without results (Honess, A. P., 1927).

Upon heating the crystals to 1800°F. for a thirty minute interval a loss in color was noticed from dark brown to light brown. Keeping the crystal at 1800°F. for 12 hours did not cause a further lightening of color. No change in crystal form occurred and no change in chemical composition was detectable.

The color change brought about by heating is probably the result of a partial loss of water of crystallization.

Crystallography

Titanite crystallizes in the normal class of the Monoclinic system. In this class the b axis is the axis of binary symmetry, the a-c plane is the plane of symmetry and the crystal possesses a center of symmetry. Angle of B = 60° 17′.

The crystals from Kennesaw are normally distorted but interfacial angles remain true.

Crystal faces present are m (110) the unit prism; a (100) the orthopinacoid, n (111) the pyramid, c (001) the basal pinacoid and p (221) a second order prism.

Face pole angles derived by measurement on a one-circle reflection goniometer are as follows:

Face	**Angle**
N M	60° 26′
C A	60° 05′
A M	34° 46′
A N	35° 35′
C N	40° 58′
M N	27° 14′

Optical Properties

Relief is very high, n > balsam. Almost colorless to pale brown in thin sections. Slightly pleochoric, the pleochroism being manifested as an increase in relief. Birefringence is extreme ng — na = 0.092 to 0.141; interference colors are high-order white but are usually masked by total reflection. Rhombic sections exhibit symmetrical extinction but because of the strong dispersion other sections rarely show extinction.

The interference figure is biaxial positive with the angle 2V varying from 23° to 50°. The acute bisectrix is almost normal to the (102) face. Dispersion r > V is strong.

Chemical Analysis

Laboratory analyses of the specimens followed the usual analytical methods and qualitative results obtained by chemical methods were checked with a Vreeland analytical spectroscope.

Element	Test
CaO	good
TiO_2	good
SiO_2	good
FeO and Fe_2O_3	fair
Al_2O_3	good

By spectrometer the following elements were determined: Ca, O, Ti, Fe, Si, Al.

Conclusions

1) Titanite near Kennesaw is typical titanite except for the distortion seen on crystal faces.

2) Alumina should be listed in the composition of the titanite.

3) All titanite crystals in the vicinity of Kennesaw Mountain have a common source.

References

1. Barksdale J., *Titanium, Its Occurrence, Chemistry, and Technology,* Roland Press Co., New York, 1949.
2. Buckley, H. E., *Crystal Growth,* Jno. Wiley and Sons, New York, 1951.
3. Honess, A. P., *The Nature, Origin and Interpretation of Figures on Crystals,* Jno. Wiley and Sons, New York, 1927.

GAHNITE OCCURRENCE AND ASSOCIATION AT MAGRUDER MINE, LINCOLN COUNTY, GEORGIA*

H. E. COFER

Emory University

Introduction

Gahnite is found in association with the sulfide ores of the Magruder Mine in extreme western Lincoln County. The ore deposit is a complex sulfide replacement in a silicified shear zone in the schistose rocks of the Little River Series. The mineralization was preceded and accompanied by silicification of the country rock which resulted in the alteration of most of the original minerals, and partial obliteration of the structure of the rock. The sulfides occur in stringers and small veinlets that follow the more highly silicified portions of the schist. Gahnite occurs along the borders of these small veinlets.

Historical Background

Gahnite is a rather uncommon zinc-bearing mineral of the spinel group. It was first described by Ekeberg and given the name "automolite," but a year later Von Moll renamed the mineral "ghanite", after its discoverer, J. G. Gahn, a Swedish chemist[1]. More recent work has shown the gahnite is not a single compound, $ZnAl_2O_4$, but rather a group of related compounds containing molecules $ZnAl_2O_4$, $FeAl_2O_4$, $MnAl_2O_4$, and $MgAl_2O_4$ in varying amounts. Winchell[2] has shown that the magnesium spinel, hercynite and gahnite (automolite) form a ternary homogeneous system. Dana[3] includes under gahnite all of those intermediate spinels that contain appreciable amounts of the molecule $ZnAl_2O_4$, including those with the galaxite molecule, $MnAl_2O_4$.

Gahnite of Lincoln County, Georgia

Gahnite was reported as occurring at Magruder Mine by Ross[4] in 1935. Other than this recognition of its occurrence,

*Read at the Meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

nothing appears in the literature concerning the gahnite of this locality.

Physical characteristics—Crystal habit octahedral, unmodified or slightly modified by a dodecahedron giving a slight flattening of the edge between octahedral faces. Cleavage, octahedral distinct. Fracture, subconchoidal to uneven. Brittle. Hardness 7.5. Sp. Gr., variable (due to included silica). Luster, greasy to vitreous. Color, leek-green to olive-green. Streak, grayish-green. Transparent to sub-transparent in thin fragments.

Optical properties—Index of refraction 1.77. Mineral is isotropic, but occasionally shows weak birefringence giving very low first order interference colors. In thin-section the megascopically homogeneous crystals show abundant inclusions of quartz.

Chemical properties—The mineral conforms approximately to the formula (Zn, Mg) Al_2O_4 with ferrous iron replacing up to 5% of the magnesium. The average specimen contains the molecule $ZnAl_2O_4$ and $MgAl_2O_4$ in approximately 60:40 ratio with ferrous iron replacing slightly more than 2% of the magnesium.

Occurrence and Association—The gahnite occurs in randomly oriented subhedral to euhedral crystals in a chlorite-sericite schist into which small sulfide-bearing quartz veins and stringers have been injected along the planes of schistosity. The gahnite is found only at or near the contact of the sulfide veins and the schist.

Occurring together and occasionally intergrown, are gahnite and euhedral, trapezohedral and dodecahedral spessartite crystals. These likewise are confined to the close proximity of the sulfide veins.

Chlorite is present as euhedral and subhedral pseudomorphs of amphibole (?) and pyroxene (?), and as scales and laths. In many thin-sections all stages of alteration from hornblende to chlorite, and actinolite to chlorite are observed. This, however, can best be seen in sections cut from rocks where the mineralization and silicification have not been so intense.

The sulfides present in the veinlets are pyrite, chalcopyrite, bornite, galena, and rarely, sphalerite. Pyrite also occurs as euhedral crystals scattered throughout the quartzose portions of the schist.

The quartz of the schist apparently was, for the most part, introduced prior to the main period of mineralization, but quartz of a still later period attacks and partially replaces spessartite and gahnite. Many euhedral and subhedral gahnite and garnet crystals contain upwards of 25% quartz.

Genesis of gahnite and spessartite—The close association of two such genetically dissimilar minerals is rather uncommon. Spessartite, especially that which conforms closely to the ideal formula $Mn_3Al_3Si_2O_{12}$, is generally accepted as an indication of low-grade metamorphism, whereas the spinel group, particularly magnesium spinel, is indicative of rather high-grade thermal metamorphism. The explanation of the nearly simultaneous formation of the two minerals seems to hinge on the almost complete immiscibility of the $Mn_3Al_2Si_3O_{12}$ and the $Mg_3Al_2Si_3O_{12}$ molecules which are the component molecules of spessartite and pyrope, respectively. Under conditions of an excess of Mn^{++} and Mg^{++} concentrations together with abundant Al^{+++}, the formation of spessartite would be favored. The excluded Mg^{++} would then combine with the excess Al^{+++} to form spinel. The presence of zinc could, perhaps, be accounted for by the introduction of sulfide solutions low in sulfur which would liberate the zinc to combine with magnesium and aluminum to form magnesium-rich gahnite rather than true spinel.

Conclusions

The gahnite and spessartite in the schist bordering mineralized zones is due largely to wall-rock alteration, produced early in the stages of mineralization of the schist by hot solutions arising from depth. The magnesium was supplied by the breakdown of magnesium silicates to form chlorite and sericite and the aluminum by original feldspathic minerals. The ascending solutions probably contributed the zinc and manganese.

References

[1]Dana, E. S., *The System of Mineralogy of James D. Dana*, sixth edition, John Wiley and Sons, N. Y., N. Y., pp. 224, 1920.

[2]Winchell, A. N., *The Spinel Group*, Amer. Min. Vol. 26, No. 7, pp. 422-428, 1941.

[3]Ford, W. E., *Dana's Textbook of Mineralogy*, fourth edition, John Wiley & Sons, N. Y., N. Y., pp. 490, 1932.

[4]Ross, C. S., *Origin of the Copper Deposits of the Ducktown Type in the Southern Appalachian Region*, U. S. G. S., Prof. Paper 179, pp. 28, 1935.

LUMINESCENT PROPERTIES OF SOME OF THE MINERALS OF ARABIA MOUNTAIN, DeKALB COUNTY, GEORGIA*

H. E. COFER and E. W. RENSHAW

Emory University

Introduction

Several minerals found in the granite gneiss and associated pegmatites of Arabia Mountain, DeKalb County, Georgia, exhibit interesting luminescent properties. They include a strontium-bearing fluor-apatite, fluorite, and certain microcline crystals found in a few of the larger pegmatites of the central and western domes of the Arabia Mountain exposure.

Acknowledgments

The writers wish to express their appreciation to Dr. L. H. Turner of the Department of Conservation for making a quantitative analysis of one of the minerals discussed. We also extend thanks to Dr. W. M. Spicer of the Georgia Institute of Technology for the spectrographic analyses of two of the minerals discussed.

Properties of the Minerals

Fluorapatite: This fluorescent variety of the mineral is found very rarely, only two small specimens have been found in one small pegmatite.

Physical Properties: The crystal structure was not observed but the mineral normally falls into the tri-pyramidal class of the Hexagonal System. Hardness—5. Brittle. Fracture, sub-concoidal. Specific gravity variable due to inter-growth

*Read at the Meeting of the Georgia Academy of Science, Oglethorpe University, April 21, 1950.

with feldspar. Color pale yellowish-green to colorless. Index of refraction 1.63±3.

Chemical Properties: The mineral was not analyzed quantitatively but reacted qualitatively for calcium, strontium, fluorine and phosphorous, and rare earths. A spectrographic analysis revealed iron, magnesium, manganese, titanium, molybdenum, boron, beryllium, yttrium, ytterbium, and cerium, in varying quantities.

Luminescent Properties: The mineral responds to ultraviolet light of both long and short wave-lengths. Using a Cooper-Hewett mercury-vapor tube adapted to pass light of 3480 A° as its most prominent band, the mineral fluoresces a pale reddish-orange. Using a M & R light producing shorter wave-lengths of 2536 A° and 2980 A° the intensity of fluorescence is increased and the mineral takes on a definite yellowish hue. The mineral also exhibits strong thermoluminescence which begins at approximately 100° C. and increases in intensity to a bright yellow-orange just before incandescence is reached. Repeated heat treatment destroys both fluorescence and phosphorescence. In addition, weak triboluminescence is produced when the mineral is ground to a powder or struck a hard blow.

Fluorite: The fluorite occurs relatively abundantly in several of the pegmatites where it is thought to be a product of hydrothermal solutions developed in the late stages of pegmatite formation. The characteristic crystal form has not been observed; the mineral occurs in irregular patches and in pseudomorphs after the plagioclase feldspars which it replaces.

Physical Properties: The crystal system is isometric, established optically. The mineral usually occurs in cleavable masses or in large triclinic pseudomorphs. Cleavage perfect in four directions. Hardness 4. Specific gravity 2.84. Color pale green, yellowish green, pale rose red, and colorless. Index of refraction 1.43.

Chemical Properties: The mineral is essentially a calcium fluoride. The following is the result of partial quantitative analysis:

Ca	48.77	percent
Al	1.80	"
Be	1.35	"
Na	0.05	"
F	38.53	"
Si	.08	"
Fe	1.40	"
Carbonate Trace		

A spectrographic analysis indicates, in addition, the presence of magnesium, cerium, yttrium, and titanium, in minor amounts.

Luminescent Properties: The mineral reacts to both the short and long wavelength ultra-violet light with about the same intensity. The color emitted is a soft yellowish-green which persists for some time after excitation has been removed. A two-minute exposure to long-wave ultra-violet light caused the mineral to phosphoresce for about four hours, while that exposed to the shorter wave length glowed slightly longer. The most striking property is the thermoluminescence. The mineral, when heated, emits a soft bluish-green light which is first visible at ± 60° C. and increases in intensity until the mineral begins to decrepitate at approximately 250° C. Repeated gentle heating does not appreciably diminish the effect. On the other hand, exposure to unfiltered copper x-radiation at 40 k. v. p. and 20 ma, for periods up to 20 minutes, failed to produce luminescence.

Microcline: Microcline crystals present in the pegmatites occasionally show pale pink fluorescence. Several euhedral crystals from two large pegmatites exhibited this phenomenon which could be traced to a microperthic inter-growth of microcline and calcite containing manganese.

Theoretical Discussion

It is well established that luminescence in substances is due to the absorption of energy, (quanta) by electrons, thus causing them to move to higher energy levels within the atom. If the energy absorbed is sufficient to drive the electron away from its parent atom it may wander about and eventually drop into its normal orbit in another atom or return to its parent atom. The return of its original energy level is accompanied by instantaneous release of the excess energy as light quanta which produces the luminescence. If the substance ceases to emit light when the excitant is removed, the property is known as 'fluorescence'. If, however, there is a continuation of light emission due to a prolonged return of electrons, the substance is said to be 'phosphorescent'.

The exact reason for this phenomena in some substances and not in others is not precisely known. In many instances the same substance or mineral from different localities may or may not be luminescent. In a few cases, such as zircon and calcite, it has been established that the presence of minor amounts of hafnium and manganese respectively will cause the mineral to be fluorescent. The presence of minute amounts of some uranium salts will produce fluorescence in many compounds. In addition, it is thought that a peculiar crystallinity or variable molecular structure may produce luminescent effects.

The luminescence produced in the fluorapatite described in this paper is thought to be due either to the presence of the elements yttrium and ytterbium, or to a peculiar crystallinity.

The luminescent properties of the fluorite may be caused by energy inequalities in the face-centered cubic space lattice due to the large variation in the effective ionic radii of the calcium, beryllium, and aluminum.

The fluorescence of the microcline is most surely due to the presence of managnese in the calcite with which it is intergrown.

ARCHAEOLOGY AND THE SCIENCES*

A. R. KELLY*

University of Georgia

The relationship of archaeology to other scientific disciplines must be distinguished on the basis of methods, interpretation, and philosophy. The purpose of archaeology, to re-

*Read at the meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

construct the past history of man, puts the science squarely within the broad scope of history. Anthropology finds man to be the only biological species capable of producing culture, as distinct from the communal organization and social activity of other forms in nature. Within the last twenty years of palaeontological discovery in the Old World, new finds of human fossils, including the famous Swanscombe Man in England ascribed to a second interglacial geological age and an early palaeolithic cultural provenance, have revolutionized current conceptions as to the antiquity of the Homo sapiens (neanthropic) type of man.[1] The Fontechevade skulls found in 1947 in southern France also tend toward neanthropic features and are placed in the third interglacial, precedent to typical Neandertal fossil remains long considered a distinct, now extinct, species of man. The implications of these new discoveries are that the essentially and relatively modern human type is probably 500,000 years old, and that man has been a culture-building species for approximately that span of time.

The methods and interpretative devices of field (exploratory) and laboratory analysis of collected materials definitely relate archaeology to the natural and biological sciences. The means by which archaeologists and the collaborating sciences date man's cultural past cover at some point almost the entire gamut of the natural and biological sciences. A list of the procedures employed in this connection is significant in indicating the protean nature of modern scientific inquiry.[2]

One might begin by referring to the combination of methods by which an absolute chronology has been established for the European Pleistocene, the backdrop against which both the biological and cultural development of Man can be traced in relation to time and area. Geochronology has worked independently from two distinct and methodologically unrelated fields of inquiry to produce remarkably consistent results: from astronomy, astro-physics, mathematics, and from sedimentary geology, glaciology, geomorphology, and paleoclimatology. The "relative chronology" of Penck and Bruckner's study of Alpine glaciation was based largely on sedimentation, age of sedimentary deposits, plus erosional history and

[1]M. F. Ashley-Montagu, Introduction to Physical Anthropology (Sec. Ed.), 1951.

[2]F. E. Zeuner, Dating the Past, Second Edition, 1951.

the calculated durations of age conditioning processes in Pleistocene soils. They arrived at a rough determination of approximately 600,000 years for the total Pleistocene by these methods. Mathematical calculations of age based on fluctuations in solar radiation as modified by a combination of factors explain the phenomena of four posited maximum glaciations with three interglacial phases, and minor oscillations of climate in both the glacial and interglacial intervals. By these means a total age of the Pleistocene, agreeing closely with that of Penck and Bruckner has been established. Human remains and artifacts found in glacial river gravels, river terraces, raised beaches, loess, solifluction deposits, sometimes associated with fossilized animal and plant remains, provided additional clues to chronological succession and indicated climate.[3]

A fruitful source of inter-disciplinary investigation has been the correlation of studies on raised beaches incident to the eustatic and isostatic oscillations in the Baltic region, with perceived stages of glacial retreat, the counting of varves of clay deposited seasonally in post-Pleistocene lakes and seas, the analysis of pollen samples to determine climatic successions as indicated by dominant forest phases, and the exploration of Mesolithic settlements along the beaches and shores of these remote land stages. In some instances, as in the case of the Ertebolle culture, the human occupation can be pen-pointed almost precisely by the conjunction of geochronological evidences; similarily with regard to the separation of England from the continent, the development of the English channel, which cut off the Anglian portion in late Maglemosian times as indicated by archaeological analysis. Thus the insular cultural attitude of the British, with regard to the Continent, began some 7000 years ago with the depression of the north European plain and has continued to the present.[4]

More recently chemical means of dating the past have been developed, but the adequacy is still in process of scientific testing. In this category might be mentioned the determination of the fluorine content of fossil bones relative to soil in which they are found. This method derives from the known

---

[3]Zeuner, op cit.
[4]Zeuner, op. cit., pp. 99-100.

fact that fluorine content of bone, relative to surrounding soil, increases with geological age. Hydroxyapatite, the chief inorganic salt from which bone is formed, acts as a trap for fluorine ions generally present in ground water. There follows a conversion into fluorapatite, tending to remain relatively stable where fixed in bone, resistant to erosion and weathering. Also, because of bone porosity, fluorine distribution is fairly uniform. Spectographic and microchemical analyses determine the fluorine present in such bone, thus when bones can be taken from the same soil provenience, an estimate of relative age can be arrived at on basis of fluorine content.[5] In contrast to the immense antiquity generally accredited to Swanscombe Man, the fluorine determinations run on bones of the highly controversial Galley Hill fossil, found in substantially the same Thames gravels and long regarded by Sir Arthur Keith and others as a possible contemporary, indicate a much more recent date, possibly only post-Pleistocene and late Palaeolithic. There is wide disagreement as to the validity and geochronological utility of this method.[6]

The Russians have made such absurd claims to priority in scientific discovery that they have discounted their real pioneer contributions in the field of soil science. Soil chemistry plays an important role in these determinations. In America, V. P. Sokoloff and George F. Carter of the Isaiah Bowman School of Geography at The Johns Hopkins University have teamed up in studying raised beaches, "senile soils", and geomorphology in relation to sites of early human occupancy. Sokoloff's methods are based on the determination of trace metals present in both natural and culture-bearing soils. Last summer in a visit to the University of Georgia's summer field school in archaeology, engaged in the exploration of limestone caves in Bartow county, Georgia, and in subsequent soil analysis of soil samples taken from a weathered midden profile exposed in the recently-cut shoulder of Highway 19 on the Kinchafoonee river near Albany, Georgia, Sokoloff found some startling results on the calculated age of the cultural deposits at the Kinchafoonee site. He made a preliminary

[5]Ashley-Montagu, op cit., pp. 190 et sequitur.

[6]G. F. Carter and V. P. Sokoloff, A Study of Soils and Land Forms of the Chesapeake Bay Margins, Johns Hopkins University, Isaiah Bowman School of Geography, 1951. Also, see "Time and Trace Metals in Archaeological Sites", *Science*, July 1952.

statement to the effect that the weathered midden layers at the Kinchafoonee site exhibited advanced stages of geochemical change, tending to approximate the conditions found in nearby "blank" or non-midden profiles on the Kinchafoonee. These authors originally ventured a conclusion that Kinchafoonee was older than could be determined by Carbon 14 methods at present, i.e. more than 17,000 years. They produce evidences and conclude that temperature is not the dominant factor in soil weathering in contexts studied all the way from Maine to Florida. They find typical A and B profiles markedly developed in southern latitudes, although truncation has partially obliterated and confused the picture over much of this region.

It is interesting to note that this Kinchafoonee site yield pre-pottery stemmed projectiles on the surface, of the type generally attributed to a widespread "Archaic Horizon" in the eastern United States. The profiled face of the highway cut shows highly altered or decomposed flint flakes to a depth of nearly three feet. The decomposed worked flint, scrap flint, and artifactual material, found at Lane Springs in northern Decatur county, Georgia, and at Macon, Georgia, have been reported by Kelly.[7] That such advanced alteration or decomposition of flint cortex may be an indication of great age is generally believed by most observers who have seen the Georgia flints in question, but probably most students would boggle at such expanded dates as that suggested by recent geochemical estimates at Kinchafoonee. If verified and accepted, this would make Kinchafoonee the oldest known human habitation site in the New World. The implications would be that we had Fourth Glacial, or even Third Interglacial Man in America, whereas present received views are to regard man's interception on this continent as late Glacial or early post-Glacial, with at most a mesolithic cultural equipment, rather than one assimilated to the Old World Palaeolithic cultures. It may be worthy of note, however, that the Georgia sites have produced some flint assemblages which do exhibit a generalized early palaeolithic facies. The significance of this "palaeolithicoid" aspect is yet to be guaged.

---

[7] A. R. Kelly, "An Early Flint Industry in Southwest Georgia", pp. 146-153, Short Contributions to the Geology, Geology and Archaeology of Georgia, Geological Survey Bulletin No. 56, 1950.

Dendrology, study of growth from annual rings of trees, afforded one of the first correlations of biological and natural science with archaeology. This was largely the pioneer work of Prof. A. E. Douglas of the University of Arizona. Tree ring dating combines coordinated studies of astronomy, meteorology, and botany. It has been widely applied to the dating of ruins and archaeological proveniences in the American Southwest, where dates go back to the Basket Maker sites at the beginning of the Christian era. In the American Southeast and in the Mississippi River drainage, application of dendrochronology so far is reliable only to around 1650 A.D.

Mostly highly publicized among recent methods of dating is the determination of the content of radioactive carbon, Carbon 14, present in palaeontological and archaeological materials. Radioactive carbon is stored metabolically in organic tissues during life and is dissipated at a constant rate after the death of the organism. W. F. Libby pioneered in early studies of radioactive carbon formed in the upper atmosphere by action of cosmic rays, and worked out the techniques for measuring Carbon 14, especially in enriched carbon in the heavy, stable Carbon 13 isotope, prepared for tracer studies. The value of the "half-life" of Carbon 14 was announced in 1949-50 and was described as follows: ". . . that one ounce of Carbon 14 will reduce by distintegration to ½ ounce in 5568 years, and one half of the remainder will decay during the next 5568 years, leaving a quarter of an ounce and so on."[8]

Radioactive Carbon 14 was hailed as a magical boon by many American archaeologists and publication of the first "dates" was eagerly awaited by investigators. The first authoritative announcements, list of Sept. 1, 1950, were greeted with mixed feelings, as there were both close agreements with archaeological expectations and some uncomfortable discrepancies. It has become evident from some of these discrepancies that there have been mistakes in methodology and procedure, and in some instances at least, the fault lies with the archaeologists in the matter of collecting samples in the field

[8]For a good summary of recent history relating to Carbon 14 dating see papers assembled under the editorship of Frederick Johnson in American ANTIQUITY, Vol. XVII, No. 1, Pt. 2, 63 pages with bibliography.

that are free from extraneous matter contaminated by more recent radioactivity. However, the techniques for testing apparatus in the nuclear laboratories have also undergone improvement. By 1952, after three years of experimentation, the prevailing archaeological judgment is yet to regard this new method hopefully as the most promising device yet developed to give reasonably precise indications of chronological interval. One drawback is that the method so far is approximately reliable or applicable only back to around 17,000 years, thus does not bear on Pleistocene materials except terminally. An enrichment technique is being developed which promises determinations extending back to about 30,000 years.

AGE MEASUREMENTS IN DECOMPOSED FLINT*

A. R. KELLY

University of Georgia

Recent development in the study of prehistoric flint tool assemblages in Georgia have suggested a possible method of determining the relative age of these specimens of the handiwork of early man. Methods of dating the past currently employed by archaeologists rely either upon geochronological evidences or upon conditions found in the particular archaeological context.[1] Association of flint tools and other artifacts with the remains of extinct fossilized species of animals and plants has not occurred in Georgia as have discoveries in the western United States where Folsom and pre-Folsom sites are fairly abundant. The occurrence of human remains with associated burial artifacts in Brown's Valley of Minnesota is still controversial or not completely accepted by all students of early man.[2] In the case of the Vero and Melbourne discoveries in Florida more recent pronouncements by the Smithsonian Institution have tended to reverse the position of the

---

*Read at the Meeting of the Georgia Academy of Science, University of Georgia, April 27, 1951.

[1]Zeuner, F. E., "Dating the Past." 1950 revised edition. This is the best general discussion of geochronology and archaeology, with particular respect to conditions in Europe and the Near East.

[2]Jenks, Albert Ernest, "Minnesota's Browns Valley Man and Associated Burial Artifacts," Memoirs of the American Anthropological Association, No. 49, 1937.

older school of commentators.[3] William Haag has reviewed the generally unsatisfactory and inadequate geochronological picture as it relates to the specific sites and occurrences in the southeastern region of the United States.[4]

There is a growing presentiment among southeastern investigators that there are some site indications of a still older occupation of the region than that indicated by the large number of pre-pottery, pre-agricultural, pre-mound building sites usually referred to as "Archaic". The highly specialized flint industry collected from weathered soils of the Macon Plateau at Macon, Georgia, and the Parrish site in Kentucky, exhibit vaguely "folsomoid" resemblances, with some specimens having a regional southeastern variant of the characteristic "fluted" points.[5] To these, with reference to Georgia, might be added the Lane Springs flint industry, recently discovered in connection with the archaeological survey of the Jim Woodruff basin of the lower Flint and Chattahoochee rivers of southwest Georgia.[6] Smithsonian Institution researches at the Buggs Island reservoir have revealed the presence of a heavy concentration of early flints assimilated to several western prototypes.[7] In all these instances, however, we are still plagued by the absence of specific and definitive geochronological conditions that might give evidence of relatively great antiquity. Typology alone is not considered adequate as native Australians, the inhabitants of central New Guinea, and other contemporaneous or only recently extinct peoples were still living in a Stone Age culture characterized by techniques and styles of working stone reminiscent of the Palaeolithic age of Europe and Asia.

[3]Stewart, T. Dale, "A Re-examination of the fossil human skeletal remains from Melbourne, Florida with further data on the Vero skull." Smithsonian Miscellaneous Collections, 1946. See also Rouse, Irving, "Vero and Melbourne Man: A Cultural and Chronological Interpretation.", Transactions of the New York Academy of Sciences, Ser. II, Vol. 12, No. 7, May, 1950.

[4]Haag, William G., "Early Horizons in the Southeast." American Antiquity, Vol. VII, No. 3, Jan. 1942.

[5]Webb, William S., The Parrish Site, Site 45 Hopkins County, Kentucky, Reports in Anthropology, Vol. VII, Number 6, 1951, Univ. of Ky.

[6]Kelly, A. R., "An Early Flint Industry in Southwest Georgia", in Short Contributions to the Geology, Geography, and Archaeology of Georgia, Geological Survey Bulletin No. 56, pp. 146-153, Atlanta, 1950.

[7]Miller, Carl F., "Early cultural manifestations exposed by the archaeological survey of the Buggs Island Reservoir in southern Virginia and North Carolina." Journal of the Washington Academy of Sciences, Vol. 38, No. 12, Dec. 1948.

This paper seeks to call attention to one potential geochronological index of age conditions in the flint materials gleaned from such sites as the Macon Plateau and the Lane Springs quarry. The Macon plateau flints, and those from Lane Springs, exhibit a marked alteration or decomposition of the worked flint surfaces. The tools are weathered to a marked extent, the chemical change in the cortex showing as a creamy white to yellowish brown or ochreous surface, in striking contrast to the natural color of the flint from which the tool was originally made. Cracking of the individual flints and examination in cross-section under low-power magnification reveals that the change in the outer surfaces of the flints penetrates to differential extent into or toward the "core" of the specimen. Some specimens are only slightly altered; others are modified throughout, and the flint tool appears as a nubbly, chalky mineral, softer and lighter, indicating a marked change in the physical characteristics. The significant point here is that this alteration or decomposition has very definitely taken place **since** the flint tools were manufactured by aboriginal Indians.

In previous studies of these decomposed worked flints from the Macon plateau, Macon, Georgia, the author collaborated with Dean Leon P. Smith of Wesleyan College in an attempt to make quantitative measurements of flint decomposition on flint collections taken from different archaeological sites or contexts of relatively known age. The hypothesis was that flint scrap or flint artifacts found in situ, indicating a definite archaeological provenience, i.e. deposits in a cooking pit or house floor debris or burial furniture, would constitute materials relatively fixed in the comparative chronological sequence of prehistoric cultures in Georgia, and would give a rough index of the measured degree or extent of cortical modification of the flint in these selected materials.

For example, flint collections from the late 17th century—early 18th century Trading Post site on the Ocmulgee river near Macon, Georgia, considered to have been destroyed at or about the time of the Yamassee Rebellion of 1717, would give some indication of whether any modification of the surfaces of worked flints had occurred during a 250 year period.[8]

[8]Kelly, A. R., "The Macon Trading Post; An Historical Foundling", in American Antiquity, Vol. IV, No. IV, 1939.

Dean Smith found only the faintest, incipient, or detectable modification of flints from this context. Glass objects obtained by the Indians as trade materials from Europeans were deeply etched and clouded, but the flints still showed the original color of the raw parent flint from which the tools had been manufactured. Subsequent studies by Dean Leon F. Smith on flint collections from the Lamar mound and village site, located on the Ocmulgee about two miles below the Macon mounds group, revealed only a barely measurable degree of flint alteration. Flint collections from the Swift Creek site nearer the Macon plateau, showed a tendency toward bimodality in the distribution curve; there seemed to be one mode of a high decomposition and another of only incipient change. It should be indicated here that the Swift Creek mound and village site is widely known in archaeological literature as the type site of one of the oldest stamped pottery groups in Georgia. Its relative chronological age in terms of generally accepted archaeological reconstructions is "Middle Woodland"; it equates approximately in age-area calculations with the Hopewellian cultures of the upper Mississippi and the lower Mississippi regions, and on the basis of the first geochronological age calculations by the Carbon 14 method on Hopewellian materials would be tentatively set as circa 500 A.D.[9] The Lamar mounds and village site before mentioned are a much more recent manifestation, assignable to almost certain occupation of the Ocmulgee area by the proto-historic Creek Indians at or just before the time of Hernando De Soto's journey through the Southeast in the mid-sixteenth century.

The method of studying and measuring flint decomposition in the above archaeological samples was to gather random collections of worked flint, tools or scrap of "reject specimens", and to break these transversely so as to permit of examination in cross-section, with measurements of the apparent extent of penetration from cortex to unmodified center or "core" portion. Dean Smith used a small hand lens which magnified the specimens about 6-8 times. This method had obvious imperfections and sources of error: the point of de-

[9] J. R. Arnold and W. F. Libby, "Radiocarbon Dates", Science, Vol. 113, No. 2927, Feb. 2, 1951. This article lists many dates obtained for archaeological specimens submitted to the laboratory of the Institute for Nuclear Studies at the University of Chicago. Those interested in the method and techniques of Carbon 14 dating in connection with archaeology will find a bibliography at the end of the article.

marcation between "altered" and "unmodified" flint is not always clear; the chalky cortex undoubtedly has worn away by attrition to some extent; the degree of change on different worked surfaces shows wide variation—a median measurement is taken in such cases. At least 100 individual flint specimens from selected context were considered to constitute a valid statistical population. Statistical means, standard deviations, were calculated for each series of flints. Dean Smith also gave his judgment as to the kind or variety of flint represented in each specimen, i.e. chert, chalcedony, jasper, onyx, etc. Admittedly, more complex and protracted study would be needed in many cases to determine mineralogical classification.[10]

The worked flints belonging to the Macon Plateau flint industry came largely from deeper provenience in the weathered loam of the plateau. This introduces a geochronological factor relating to the age changes in the soils. In the exposed profiles of the plateau in Macon, where the huge excavations for the Central of Georgia Railway have cut through, one sees parent red clay and a "calico clay" and an intermediate zone of orange loam intergrading into a top mantle of sandy loam. The sand has massed on the slopes and there is demonstrated to be simple sheet wash extension. In the central portions of this railway cut through the Ocmulgee bluffs, one is driven to the conclusion that this is a normal profile development, with all of the factors of soil eleutriation present. This view of the writer is supported by the inspection of the profiles by visiting scientists who were working with the soil conservation program of the U. S. Government, who were also impressed by the degree of flint decomposition exhibited by large collections of artifactual material catalogued from depths down to nearly four feet in the "weathered loam" of the bluffs. Professor Carl O. Sauer of the Department of Geography at the University of California was one of those who had occasion to visit Macon and to see both the soil conditions and the flint materials currently being excavated from this provenience. The consensus was then, and is now, that theoretically some correlations might be worked out between the age conditions in the soil and the flint materials currently

[10]Dean Leon P. Smith read a paper on his work of measuring decomposed flint of Macon before the Georgia Academy of Sciences just before his death in 1936. His contribution was never published.

being excavated from the weathered zone. No adequate explanation in terms of soil mechanics was available as to how these extremely weathered flints, and primitive tools considered typologically, occurred deep down in the sands of the bluffs overlooking the Ocmulgee river at this point. These old flints came out sporadically beneath the levels on which house floors, cooking pits, burials, and other features belonging to more recent chronological intervals in cultural development occurred. This was true on the open plateau section, where conditions were considerably obscured by the fact that the whole area had been cultivated continuously since the acquisition of the land from the Creek Indians in the first quarter of the 19th century. It was also true in the submound profiles, as under Mounds A, B, C, and D of the Macon Plateau mound group, where the original soil conditions and relations had been sealed up and preserved intact for an estimated period of six hundred years.[11]

This part of the report is posthumous. Dean Leon P. Smith died while the studies herein discussed were in progress. The author was soon transferred to an administrative post in Washington, D. C. The experimental studies above described had gone on for a period of about two years. No valid conclusions could be drawn from our data because of the many uncontrolled variables which even then were seen to be present, vitiating any assumptions of simple linearity in the progressive modifications of cultural flint catalogued from perceived time intervals in the very complex successive development of civilization uncovered in situ at the Macon excavations. But certain interesting facts and conditions were determined; some highly suggestive hypotheses could be advanced.

The seriations of flints from historic and proto-historic archaeological levels exhibited either no appreciable modification, or only barely measurable change, such as Dean Smith recorded in many instances simply as "trace". Measurements had been taken in 10ths of a millimeter. Let us say that the measured degree of cortical modification on a series of flints calculated to be 250 years old amounts to .1 millimeter. Actually, as stated it could not be measured by the device employed by Dean Smith. It is quite possible, even

[11]Kelly, A. R., "A Preliminary Report on Archaeological Exploration at Macon, Georgia" in Anthropological Papers, Bureau of American Ethnology, Bulletin 119, Washington: 1938.

probable, that the statistical expression of a measured degree of modification might well come from the chance inclusion of some flint specimens in the series which were obtruded and actually belonged to an earlier period of flint workmanship. Random sampling was an essential procedure in this study. And under the highly disturbed conditions of archaeological site and feature occurrences on the Macon Plateau, one could never be entirely sure of the absolute provenience of every single unit or specimen in a series. One could only hope that errors from this source would tend to balance one another.

Given then .1 millimeter of change in a 250 year old collection of worked flints. Given also approximately 1 **centimeter** or more change in a collection of flint artifacts and flint scrap assimilated typologically, and stratigraphically, to the "Macon Plateau flint industry", it was possible to contemplate in simple algebra an equation, in which x equals the age of the flint series from the weathered zone of the Macon Plateau. By these means, assuming simple linearity of progressive change or decomposition of the flint through time, one could arrive at a date around 8 to 10,000 years of age for the Macon Plateau flints!

But there were immediately perceived discrepancies in the measurements of decomposition of flint series by Dean Smith. One may state categorically that, within the period of archaeological time consideration in Georgia—whatever that might be—no changes took place in quartz materials. Similarly, certain bright-colored types of quartz, probably derived from quarry sources located in the north Georgia Piedmont section, were seen to exhibit relatively less modification than other lighter or flesh-colored specimens such as occurred locally in deposits that were of nodular marine origin. The Swift Creek site, older than the Macon Plateau mounds or the Lamar mound and village site, was characterized by the presence of numerous jaspers, bright red, rose-colored, yellow, purplish congeries not characteristically found on some of the sites determined to be later on purely archaeological grounds. If changes in flint modification were progressive and consistent through time, Swift Creek might be expected to show appreciable advancement over Lamar. Approximately 1000 years separated these two cultural horizons in middle Georgia. Not so! There were some markedly altered flints on the Swift Creek village site, but these on inspection were seen to represent types of artifacts which had already been found in abundance in the weathered loam of the Macon Plateau, not more than a mile away! It was evident on archaeological grounds that both the people responsible for the Macon Plateau flint industry (Early Archaic or "palaeo-Indian") and the group who made the Swift Creek mounds and village, had lived on the same site at different times.

Dean Leon Smith was cognizant of the fact that all of these flint categories in terms of chemistry were summed up in the simple formula: Si O^2. The physical changes in the appearance, the feel, and the weight of the weathered specimens were startling. There were individual cases of finished flint tools from the Macon Plateau, massive, crude, "turtle-back", end scrapers, which measured as much as 5 **centimeters** in thickness, which on breaking were seen to be completely modified throughout! In some cases a small core section of unmodified raw flint could be detected at the center of the broken specimen. Yet the chemical formulation of modification could hardly envisage more than a differential action of the water of hydration in these specimens. Perhaps, as Dean Smith suspected, a differential change as between flints of Piedmont types, and those derived from nodular marine flint (chert) from such quarries as occurred along the fall line of middle Georgia, or in south Georgia. The experimenters contemplated laboratory studies to attempt the control of some of the factors, but these were never carried out for reasons already given. I have discussed the problem with chemists more recently, noteably with Prof. G. E. Philbrook of the Department of Chemistry at the University of Georgia.[12]

For some years the experiments and their results, if any, languished until I had occasion again to return to Georgia and to renew archaeological explorations. I happened upon an old aboriginal quarry site at Lane Springs, on upper Spring Creek, northern Decatur county, in southwest Georgia, which exhibited many primitive stone tools reminiscent in some re-

[12] I have also been in recent correspondence with Prof. C. O. Sauer of the Department of Geography at the University of California, and Prof. George F. Carter, Department of Geography, Johns Hopkins University, concerning possible correlations between the age conditions in the soils and the altered flints.

spects to those previously found at Macon, Georgia, and which, likewise, showed an equal degree of extreme flint alteration or decomposition. The general typology of these flints corresponded closely with flint assemblages found in southern California.[13] Moreover, the Lane Springs flints had been washed out of a sand ridge by spring freshets, exposing an underlying hardpan of clay. The soil conditions were reminiscent of the situation already described for the Macon plateau finds.

Again, on another occasion, the University was collaborating with the Department of State Parks in the archaeological exploration of the mounds and village area at Kolomoki Mounds State Park, near Blakely, Georgia. On a sandy ridge running laterally through one part of the village area between two of the larger Kolomoki mounds, students of the University of Georgia in trenching found large numbers of weathered flint tools which typologically were "older" than those characteristic of the village levels assimilated to the mound cultures being studied in the park.

A new angle presented itself, however, in connection with these Kolomoki flint materials. The ridge on which the specimens were picked up was littered with potsherds and artifactual materials known to be characteristic of the Kolomoki people.[14] Numerous individual stone tools revealed on inspection that they had been reworked by later groups, perhaps by the Kolomoki folk themselves. An old tool had been refashioned at a later date. This gave worked surfaces or faces which were differentially altered. The older worked surfaces were heavily altered; the subsequent flint working exposed surfaces that were only moderately or incipiently altered! Theoretically, given a series of 100 specimens of this sort, with measurements of the degree of change taking place since the original first workmanship, with a check provided in the modification occurring since a relatively known later period, one could perhaps arrive at some closer approximation of elapsed time. For these specimens, according to

[13]Correspondence with Prof. George F. Carter, Johns Hopkins University.

[14]The culture represented at Kolomoki, to which the mounds and major village accumulations belong, is a localized variant in southwest Georgia of the Weeden Island Period, first recognized and described on ceramic and other traits for the northwest Florida coast. The age on relative chronological grounds as presently computed would be circa 1100 A.D.

archaeological indications, had first been worked up on the spot by the older group, then later reworked on the same ground by a much later group. Soil chemical conditions, climactic variations, differential reactions in different types of flint, seemed theoretically to be held in as nearly ideal laboratory controlled conditions as were possible! Throughout their history these specimens had rested in the same soil, been subjected to the same chemico-thermal factors, and the human interception had been produced upon the same flint materials!

It would still be true, however, granted the seeming stabilization of some of the variable factors which had stymied the original studies, that one could not arrive at reasonably precise age determinations, as long as one proceeded on the assumption of simple linearity of process. As the cortex of the flints became nubby and chalky, the surficial layers might act as a sort of buffer or insulation; the modifications theoretically would proceed at a slower rate after the first thousand years or so. The answer to this is that the dates arrived at by such methods could only be **minimal** dates. If and when any valid formulas for correction could be applied, these would have the effect of upping the age determined for any particular series. After the process of flint modification had reached a certain stage, thereafter the process would be slowed down. Linearity could not be assumed, but corrections for retardation in later phases must increase the time allowed for the measured degree of decomposition.

SOME GEOGRAPHIC ASPECTS OF ARTERIAL INDIAN PATHS ACROSS THE GEORGIA PIEDMONT*

by

JOHN H. GOFF

Emory University

The Piedmont Region of Georgia in Indian days was not a trackless wilderness as is sometimes assumed. There is sub-

---

*Read at the meeting of the Georgia Academy of Science, Agnes Scott College, April 18, 1952.

stantial documentary evidence and much tradition to show that the area was once well-threaded with aboriginal trails. This network was comparable to today's highway system in that it consisted of both local and arterial routes. The latter followed far-ranging courses that transcended the Piedmont by leading to the mountains, the Mississippi, and to the Gulf.

The most significant of these arterial thoroughfares for English-speaking whites were the noted trading paths that radiated from the area of present Augusta, Georgia, which early became the center of a thriving trade with the Indians.

Among the main trails leading from this section were[1]:

1. The Cherokee Trading Path, which led up the west side of the Savannah and Tugalo to Toccoa Falls where it branched to reach various Cherokee centers[2]. This trace clung so closely to the river that it had to cross every right-bank tributary of significance from Augusta to Toccoa Falls. This feature was unusual because ordinarily Indians selected routes which minimized fordings.

2. A Cherokee trading path that ran northwestward by way of Athens to Goddard's Ford now Brown's Bridge on the Chattahoochee in Hall County. Thence this trail led via Tate and Talking Rock to Cherokee settlements in northwest Georgia and southeast Tennessee. This way is of especial significance because following a treaty in 1805 with the Cherokees[3], a considerable segment of it became the Federal Road, northwest Georgia's first vehicular route[4].

3. The Upper Trading Road[5] or Oakfuskee Path.

4. The Lower Trading route which was sometimes referred to as the Lower Creek Trading Path.

The last two ways were the oldest, longest, and most important, economically speaking, of the noted wilderness thoroughfares that stemmed from Augusta[6]. Also, because of the manner in which they were affected by the Fall Line area, they are perhaps of especial interest to a group of earth scientists. This paper, therefore, will dwell on these routes.

The two trails were first used by white traders some 250 years ago[7] for reaching the important Creek Indian settlements on the Chattahoochee, Tallapoosa and Coosa Rivers of western Georgia and east central Alabama. At the last stream both ways connected with paths that led on to the Chickasaws and Choctaws in what is now Mississippi. Near the juncture of the Tallapoosa and the Coosa, to the east of today's Montgomery, Alabama, the lower trail also connected with a path to the Gulf.

The traces left Augusta on the same course, following almost identically the route of today's U. S. 78 or Georgia 12. At a point east of Harlem they forked[8] to pursue roughly paralleling westward courses which ranged up to 50-odd miles apart. Eventually, however, the paths came together again in Alabama at certain common destinations on the Tallapoosa and Coosa Rivers.

The upper way mounted to the Piedmont Uplands, whereas the lower trace skirted the southern fringe of the Fall Line Belt. Its fording spots on the Ogeechee, Oconee, Ocmulgee, Flint, and southward flowing intermediate tributaries of these rivers, were the shoally areas where the streams flowed over the lowest edges of the granitic formations of the Piedmont. Col. Benjamin Hawkins, in speaking of a ford used by this trail for crossing Flint River, referred to such a spot as "the first rockfalls."[9]

It might also be added that there were several crossovers from one path to the other. Interestingly enough these links usually sloped from the northeast to the southwest. Existence of these connections leaves the impression that travellers sometimes used a part of one trail and then a portion of the other. What the factors were which affected such a choice is a matter of conjecture. Probably weather and soil conditions were the influences. In dry weather the sandy course of the lower way was presumably very trying whereas the relatively firm soils of the Piedmont in such instances would have permitted easy travelling. In bad weather these conditions would have been reversed and the traveller might have shifted his route.

The upper path passed a little above Dearing along what is now called the Old Milledgeville Road. Just west of Sweetwater Creek it had a right fork that ran through Greensboro to a point immediately above the juncture of the Oconee and the Apalachee. After fording both streams[10] this way then veered northwestward through Buckhead and Madison to become the noted Hightower Trail[11], a route to the Cherokees of northwest Georgia and northeast Alabama.

The main upper path, however, continued through Warrenton and over the Ogeechee; presumably at the site of Latimore's Mill above Mayfield. It crossed the Oconee at some shoals above the mouth of Shoulderbone Creek and below Georgia 16, then passed westward via Eatonton[12], but below Monticello, to the mouth of Wise's Creek at the lowest of the Seven Islands of Ocmulgee. It led past Indian Springs and just east of Double Cabins in Spalding County it forked. Straight ahead toward Newnan went the McIntosh Trail[13], leading to the Chattahoochee, thence to the Coosa via Talladega, Albama. The main trail, as the Oakfuskee Path, veered left through Griffin to Flat Shoals on Flint River[14]. From there it touched Greenville and Odessadale, to pass south of LaGrange. In Troup County just east of Glass Bridge over the Chattahoochee on Georgia 238 it forked[15]. The right turn led into Alabama reaching eventually such points as Fort Williams, and Coosa Old Town, a noted Upper Creek settlement located on Coosa River about two miles above today's Childersburg, Alabama. There it rejoined a spur of the McIntosh Trail. Across the river and up a bit began the Chickasaw Path. The left turn at the Chattahoochee crossed that stream at some noted shoals called "Hell Gap," located below the mouth of Wehadke Creek. It continued into Chambers County, Alabama, passing Fredonia and Dadeville to Great Oakfuskee Town, a large Upper Creek center that was located west of Dadeville on the right bank of the Tallapoosa. The site is now flooded by a power reservoir. Here the trail connected with other paths that continued westward and southwestward to Coosa River Indian settlements, thence to the Choctaws of Mississippi.

The upper path in time became a pioneer's trace and some segments of it eventually grew into noted stage roads. Significant stretches of it are still in use as parts of present-day highways. Many portions of it, however, were completely abandoned, so much so that the old thoroughfare lost arterial significance over a century ago.

It is difficult in a limited time to trace the Lower Trading

Path since the route was not a single, precise trace. Rather it was a complexity of alternating trails that eventually reached the same general destinations.

The best-known strand, the Old Horse Path, veered left from the upper trail to the east of Harlem. It bore gently southwestward passing near Gibson and going over the Ogeechee at the lower end of the Shoals of Ogeechee. It crossed the Oconee at Rock Landing, located some four miles below Milledgeville, then led on to present-day Macon and from there to one of several Flint River fords to the west of Roberta[16]. Across this stream it forked with the right turn, as the Coweta Falls Trail, leading through Talbotton to today's Columbus. The main path bore left across the Fall Line Hills, passing through the center of the Fort Benning reservation to Cusseta Town a prominent Lower Creek settlement on the Chattahoochee, situated on the site of the main Fort Benning Airport. Here this trail fanned out to numbers of other important Indian communities located along this part of the Chattahoochee. Over the river the main thread continued to Creek settlements on the lower Tallapoosa and along the Coosa. As has been noted it also connected in the latter area with a trail to the Gulf.

The Lower Creek Path was one of the historic aboriginal routes of North America. And, pursuant to a treaty with the Creeks in 1805[17], a substantial part of its course became a Federal Road, the first white man's way of western Georgia and eastern Alabama[18]. Its tedious sandy course, however, proved too difficult for vehicular traffic. Relatively little of the route, therefore, survives as parts of present-day roads. Certain sections of it have been abandoned so long that it is impossible now to find traces of the early thoroughfare over spots which the first surveys unmistakably show it crossed.

It is difficult to retrace the courses of these early paths today without being impressed by the expertness with which the routes were layed out. The individuals who first chose these ways through the vast primeval forests showed great skill in taking advantage of physical features for securing the best passages to fit their needs. They favored gentle divides and south slopes, in preference to high ridges or low areas. The courses of these wilderness thoroughfares were reasonably direct, and would compare favorably in this respect with many modern roads. Providence seemingly connived to facilitate this directness by furnishing good fording spots at just the right sites on most of the streams that had to be crossed.

References and Comments

[1]The writer wishes to express his appreciation to the Research Committee of Emory University for a grant-in-aid which allowed him to retrace these routes and a number of other early thoroughfares of the Southeast.

[2]This trail is shown and named a number of times in the unpublished official land records of Georgia, Georgia Department of Archives and History. Cf, especially *Headrights Platbooks*, K, H, and R., *passim*.
The official land records of Georgia consist of platbooks, registers, surveyors' field notes, land district maps, early county maps, and other documents. The materials were mainly prepared by former Surveyors General of Georgia.
In addition to the early maps mentioned in fn. 6, *Infra*, these documents and the official land records of Alabama, Office of the Secretary of State, Montgomery, constitute the chief documentary sources of information on the routes of the paths which are being discussed.

[3]Treaty of Tellico, Tennessee, October 25, 1805, *U. S. Stat. L.*, VII, 93.

[4]The Federal Road across the Cherokee Nation was Y-shaped. It began on the Hall-Jackson County line, and forked (at today's Ramhurst in Murray County) toward Knoxville and Nashville. Much of it remains in use. People living along the leg and eastern prong still recall this route as the "Old Federal Road." The remains of the other fork are now remembered as the "Chattanooga or Georgia Road." Nearly all of the trace in Georgia is shown and named on *A Map of that part of Georgia Occupied by the Cherokee Indians*, John Bethune, Sur. Gen. of Georgia, Milledgeville, 1831.

[5]The term "road" was often used in connection with early wilderness thoroughfares. These passages, however, were in no sense *roads* in the modern view. At best they were no more than crude traces.

[6]These paths or parts of them are shown on numbers of early maps. Some representative examples consulted are: *Map of East and West Florida, South Carolina and Georgia*, transmitted by Col. Bull (President and Commander in Chief of South Carolina) . . . to the Board of Trade, 25 May 1738, photostat from the Library of Congress, original in the Library of the British Colonial Office; *A Map of the Sea Coast of Georgia*, etc., Henry Yonge and William de Brahm, 1763, photostat of the original in William L. Clements Library, Ann Arbor; *A Map of the Southern Indian District*, 1764 (no author), from a photostat in the Georgia Hist. Soc., Savannah, original in the Manuscript Collections of the British Museum; *Sketch* (Chart) *of the Boundary between the Province of Georgia and the Creek Nation*, 1769, Sam'l Savery, D. S., photostat of the original in the William L. Clements Library, Ann Arbor; *A Map of West Florida, part of E. Florida, Georgia*, etc. 1774, Barnard *(sic)* Romans, from a photostat in the Georgia Dep't. of Arch. and Hist., original in the Library of Congress; *A New and Accurate Map of the Province of Georgia* (no author), originally published in *Universal Magazine*, London, 1779, copy in Georgia Dep't. of Arch. and Hist.; *The State of Georgia*, John Dutton, 1814, photostat from the Library of Congress; *Map of Alabama*, John Melish, Phila., 1818; *Georgia and Alabama*, Phila., 1823, *A Map of the Creek Territory in Alabama*, John La Tourette, Mobile, 1833.

[7]The Bull map, *op. cit.*, shows the Upper Trading Path running from Charleston via Fort Moore (opposite present Augusta) to the Mississippi. He marks it "The Course Capt. Welch took in y.e year 1698, since followed by y.e Traders." Benjamin Hawkins, on the other hand, without giving any dates, says the "old horse path," (referring to the main Lower Trading Path) was the oldest way to the Creek Nation. Cf. *Letters of Benjamin Hawkins*, Coll. Ga. Hist. Soc., Vol. IX, p. 173.

[8]Yonge and De Brahm, *op. cit.*, show the two trails dividing to the east of Boggy Gut Creek, in what would be Columbia County today. The fork may have been at the little crossroads place now called Campania.

[9]Hawkins, *op. cit.*, p. 171.

[10]The trail crossed above the union of the rivers. This double fording was not common. Indian fords where streams united were usually below the juncture, presumably to gain the advantage of one crossing.

[11]The Hightower Trail is one of the best known Indian routes of Georgia. It did not, however, contrary to several published statements, cross the Apalachee at High Shoals. The early official surveys of Georgia show and name much of its course. At Social Circle instead of bearing northeastward to High Shoals it actually ran southeastward in the direction of the ford above the union of the Apalachee and Oconee. In the original survey of Walton County in 1819 it is shown and named not very far west of today's Rutledge, on the course of what is now Georgia Highway 12. Cf. *Platbook L L L*, lot 74, Dist. 1 of original Walton County, Georgia Dep't. Arch. and Hist.

[12]West of the Oconee to Murder Creek the trail takes on the name "Chattochuccohatchee path," Ga. land records, *Platbook E.E.*, Dist. 2, of original Baldwin County. "Chattochuccohatchee" was the Muscogee name for today's Murder Creek.

[13]Segments of the McIntosh Trail remain in daily use as little back country roads. Elderly people along its way remember the name and are quite familiar with its route in their respective communities.

[14]The trail along here was successively called The Oakfuskee Trail, Jordan or Jourdin Road, Ridge Road, Old Greenville Stage Road and the Old Plank Road. The last name is still remembered.

[15]This fork was on what is now the old Hudson Place, just above Ga. 238.

[16]Along the boundaries of southern Upson, northern Taylor and western Crawford Counties the Flint veers southeastward. The fords were in this stretch. Since the trails paralleled the river on each side, the traveller could cross at whatever ford he chose without losing distance. The three best known fords were the Buzzards Roost, several miles below the bridge on U. S. 80; the Island Ford, to the north of the present Wainwright place in Taylor County; and the Old Horse Path Ford, upstream from today's bridge at the site of the former Creek Agency, which was located some 7 miles west of Roberta.

[17]Treaty of Washington, D. C., Nov. 14, 1805, *U. S. Stat, L.*, VII, 96.

[18]This thoroughfare ran from the Ocmulgee at the present site of Macon to Mims Ferry, near tragic Fort Mims on the Alabama River, above Mobile. It is remembered as a former Federal Road by some people along the remaining parts of its course. On its eastern end it is also recalled as the "Old Wire Road" because the first telegraph line across Georgia into Alabama was strung along its course.