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Abstract

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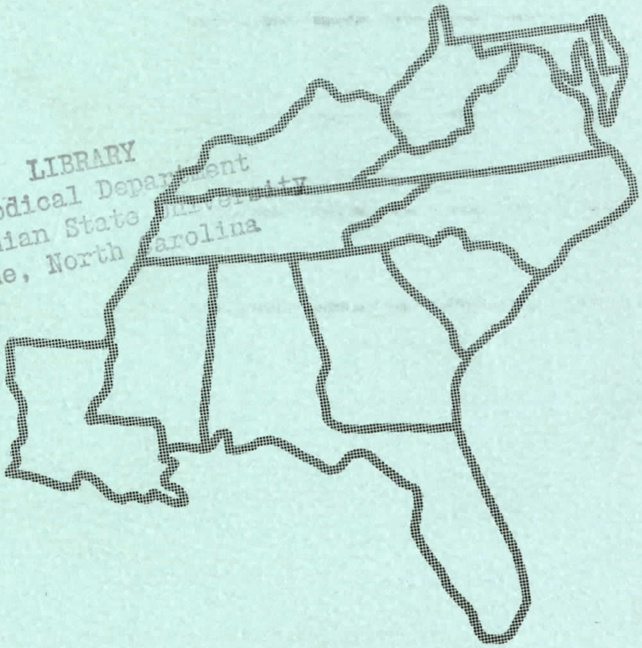
SOUTHEASTERN GEOLOGY



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SOUTHEASTERN GEOLOGY

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1975

PALEOENVIRONMENTAL SETTING OF CRASSOSTREA GIGANTISSIMA (FINCH) COMMUNITIES, COASTAL PLAIN OF NORTH CAROLINA

By

David R. Lawrence
Department of Geology
University of South Carolina
Columbia, South Carolina 29208

ABSTRACT

In North Carolina, Crassostrea gigantissima (Finch) lived along an arcuate belt extending from present-day Pollocksville through Jacksonville to the coast near New River Inlet. At Belgrade, the oysters overly late Oligocene carbonates with no evidence of an intervening, major stratigraphic gap; the oysters are also dated as late Oligocene in age. Local and regional evidences indicate regressive sedimentation during the oysters' span of existence. The oysters lived marginal to, and northeast of, a prograding Oligocene delta. This reconstructed paleoenvironment is very similar to that of present-day oysters in the East Mississippi Delta region.

INTRODUCTION

Background

Deposits containing the giant oyster, Crassostrea gigantissima (Finch), have been recognized in mid-Tertiary strata of Coastal Plain settings for over 150 years (Finch, 1824; Conrad, 1834). North Carolina occurrences of these oysters have played an important role in stratigraphic works for over 60 years (Clark *et al.*, 1912). Yet despite numerous studies, we still very poorly understand the details of the paleobiogeography, temporal occurrence, and paleoecology of these quite distinctive molluscs. This lack of understanding is primarily due to the scattered, small, and/or poor nature of the oyster-bearing exposures. Previously assigned ages of oyster-bearing strata and reconstructed paleoenvironments of these strata have been mainly based upon faunal determinations at isolated exposures without recognition of facies changes and successions, blending, or detailed stratigraphic associations. These problems have also hampered more general analyses of Coastal Plain strata (Brown, 1963).

It is obvious that both surface and subsurface geologic data must be integrated to provide a cohesive picture of the stratigraphic and environmental setting of these oyster deposits. Recently, Brown et al. (1972) have proffered such a unified and cohesive picture of the structural and stratigraphic framework of the Coastal Plain region including North Carolina. As such, this work is a noteworthy successor to the previous summaries of this area's Coastal Plain stratigraphy (including, Richards, 1945, 1948, 1950; Spangler, 1950; Spangler and Peterson, 1950; Murray, 1961; Maher, 1971). The general model developed by Brown et al. (1972) is extremely valuable in that it may (1) explain or elucidate local stratigraphic problems, (2) be further tested and refined through detailed studies of an area or areas, and (3) serve to pinpoint critical study areas in the Coastal Plain region. This paper has been written not only to document the setting of the oysters, but also to point out these potential uses of the temporal models of Brown et al. (1972). Their ideas have allowed a far better explanation of the age and setting of the oyster beds than was heretofore possible and the oysters, in turn, do add refinements to one small part of the general picture developed by Brown et al. (1972).

Previous North Carolina Oyster Studies

Serious and detailed stratigraphic work on North Carolina strata containing C. gigantissima began with Miller (1912). Numerous additional studies were made over the succeeding 40 years (e. g., Cooke, 1915; Harris, 1919; Loughlin et al., 1921; Kellum, 1925, 1926; Richards, 1943, 1950). By 1950, the giant oysters had been recognized from numerous localities south and southwest of New Bern in the state (see Figure 1 for all localities mentioned herein). The oysters were though to be part of two formations: the Castle Hayne Formation of the Jackson Eocene Stage and the lower Miocene Trent Formation (Richards, 1950). Brown (1955, 1963) suggested stratigraphic revisions in the eastern North Carolina area by recognizing the middle to upper Eocene Castle Hayne Limestone, unnamed Oligocene rocks, unnamed middle Miocene in the subsurface, and the upper Miocene Yorktown Formation. Lithic similarity makes separation of these stratal units difficult to impossible without faunal control, and this control is often lacking (see Brown, 1963). Thus a realistic lithostratigraphy, usable for surface exposures, is still lacking for this region.

These revisions and problems have affected the age and stratigraphic designations for the oyster deposits. Re-examination of collections has substantiated neither the Eocene age nor the Miocene age of individual oyster localities and, in the Belgrade example discussed later, strata associated with oyster deposits have been correlated with unnamed deposits of late Oligocene age (P. Brown, T. Gibson, and D. Wilson, personal communications, 1966). Arguments presented

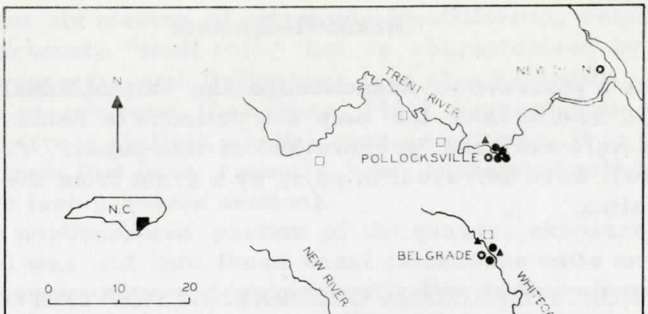

Figure 1. Map of southeastern North Carolina, showing occurrences of Crassostrea gigantissima (Finch) and their nature.

herein very strongly indicate that the oyster deposits, themselves, are of late Oligocene age.

Work on the paleoecology and paleoenvironments of the oyster deposits has not been numerous. Smith (1959) found one fragment of C. gigantissima at a new marl pit at Silverdale, and drew many paleoenvironmental inferences by analogy with modern ostreid ecology. Lawrence (1966) studied various aspects of the natural history of a C. gigantissima community at Belgrade, and parts of this work have already been published (Lawrence, 1968, 1969, 1971). This present paper is an attempt to tie together and expand upon these previously published parts of the story of the giant oysters in eastern North Carolina, and also to add information gathered since the field work associated with these previous publications.

Acknowledgments

It is a pleasure to acknowledge the help of Ronald A. Crowson during field studies and the help and patience of Ashley C. Lawrence during the field work and preparation of this paper. Travel expenses of this work were defrayed, in part, by a grant from the University of South Carolina.

NORTH CAROLINA OCCURRENCES OF THE OYSTERS

Life Sites

Over the past twelve years I have attempted, through field work, to verify all previously cited occurrences of C. gigantissima in North Carolina, and have searched for new localities. Numerous new localities have been found, and all but five of the localities cited by Miller (1912), Loughlin et al. (1921), or Richards (1950) have been re-established and verified. Because C. gigantissima has been confused with many other large fossil oysters (Howe, 1937), it is impossible to determine whether any or all of these latter localities (see Figure 1) do truly represent occurrences of C. gigantissima.

All of the older and new oyster localities are shown in Figure 1. The localities are divided into four categories: (1) in situ occurrences-- deposits containing densely packed and upright oysters that have obviously been preserved in their life positions, (2) near life sites-- outcrops lacking oysters preserved in their life positions, but with high shell densities and excellent shell preservation indicating that a life habitat of the oysters was very close to the exposure, (3) transported occurrences-- areas with few, scattered, fragmented oysters in outcrop or on beaches, and (4) unverified, previously cited occurrences.

As Figure 1 portrays, the geographic distribution of the oysters' life settings forms an arcuate belt, ranging from Pollocksville through Belgrade to Jacksonville, and thence south-southeastward, towards the coast, along the western margin of the New River Estuary. In addition, extensive in situ deposits occur in the present-day shallow sublittoral zone 5-10 km. south of New River Inlet (R. Crowson, personal communication, 1974). Because of relatively poor and small exposures and sampling difficulties, the small-scale details of the oysters' life settings have only been determined in the Belgrade area.

Oysters' Environment at Belgrade

Quarrying at Belgrade, along the banks of the Whiteoak River, has exposed a quite complete stratigraphic section for the area, including one exceptionally well-preserved oyster bed (Lawrence, op. cit.). The quarry strata are commercially exploited for stone aggregate and do include over six meters of extremely fossiliferous, relatively well-indurated, carbonate "shell rock" that is characterized by species of Anomia, Mercenaria, and Calyptraea (see also Richards, 1950). Numerous lines of evidence (Lawrence, 1966) suggest that these units document relatively shallow, shelfal, marine settings. It is these basal calcareous strata that have recently been correlated with beds of late Oligocene age (see previous section).

In the northwestern portion of the quarry, exposures indicated that a channel was cut into these basal calcareous units and that a C. gigantissima community did subsequently live in this channel setting. Paleontologic control for the age of the oyster community is lacking. However, the absence of well-developed hard grounds on the channel floor and nearby areas, and absence of other faunal elements preceding the oysters in the channel setting, do both indicate that a relatively short period of time intervened between the formation of the basal calcareous strata and the inhabitation of the subsequent channel by the oysters. The oysters are, therefore, also dated as late Oligocene in age.

Much of the channel's history can be deciphered from the complete cross-section shown in Figure 2A. The oyster-dominated community first settled in the central and deepest portion of the channel. The community migrated laterally, up the right or south side of the channel, as the channel was being filled with sandy sediments. These sediments included a sand unit devoid of megafossils, sand units characterized by gastropods encrusted by hydrozoans, and materials reworked from the surrounding calcareous strata (Figure 2A).

Two major lines of evidence indicate that this oyster deposit was formed during a regressive phase of sedimentation: (1) diversity changes within the oyster deposit, and (2) the very preservation and existence of this oyster exposure.

During their lifetimes, these oysters were associated with a large and diverse biota, of which some 16 to 18 megascopic animal species have been preserved (Lawrence, 1968). Oyster shells document the former presence of boring clionid sponges, encrusting byrozoans, boring bryozoans, polydorid bristleworms, a spirorbid worm, boring pelecypods, a low-spired gastropod, and a barnacle. Because the spirorbid worm and gastropod are each represented by a single occurrence it is the other oyster shell epibionts-- sponges, bryozoans, bristleworms, boring pelecypods, and barnacles-- that are most important in tracing diversity changes through the deposit. Using their distribution, in conjunction with analyses of the oysters' density, orientation, and enclosing matrix, it was possible to map three subunits of the channel oyster deposit (Figure 2B).

The lowermost subunit I contained mainly disarticulate, fragmented, and horizontal oysters. When upright and in situ individuals did occur, these oysters were scattered or loosely packed. Appreciable amounts of lime mud and fragmented oyster lamellae were present

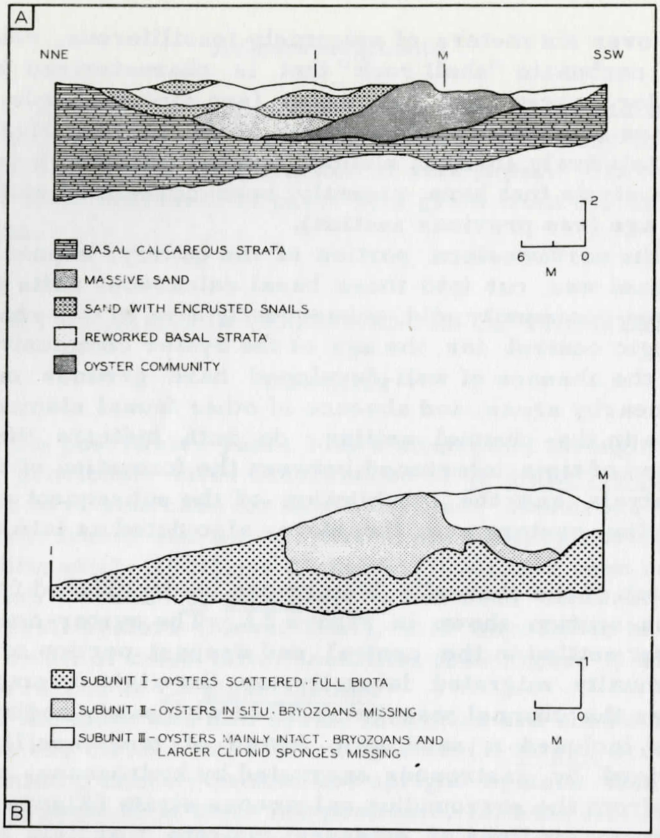

Figure 2. Channel setting of Crassostrea gigantissima (Finch) at the Belgrade quarry. A, channel cross-section. B, details of oyster bed, showing the three subunits mapped on the basis of oyster density, distribution, shell epibionts, and enclosing matrix.

between and within the preserved oysters, and this subunit contained all of the megascopic shell epibionts described above. The medial subunit II was characterized by densely clustered, in situ oysters that formed an intact framework of organisms in a quartz sand matrix. Shell epibionts of this subunit included the polydorid worms, clionid sponges, barnacles, and boring pelecypods. Encrusting or boring bryozoans were lacking. The uppermost subunit III contained both densely packed, upright oysters and disarticulate, fragmented oysters. The sediment matrix was largely a clean and friable quartz sand, although some areas contained significant amounts of lime mud and broken lamellae of oysters. In the main, disarticulate oysters and a finer-grained matrix occurred uppermost in the subunit. Throughout, however, this last subunit was characterized by the conspicuous lack of the large oyster shell perforations and massive internal galleries of the clionid sponge form group Cliona cf. C. celata Grant (Lawrence, 1969). The other shell epibionts of subunit II did remain in this final subunit.

In summary, the channel setting recorded an initial period of colonization by oysters, the subsequent expansion of the oyster community to form a clustered and intact framework of organisms in the channel, and the oyster community's demise in this local area, apparently due to the complete infilling of the channel. The taxonomic diversity of oyster associates decreased through these successive phases of the community's history. Thus in vertical sequence, this oyster bed displayed the well-known inshore or estuarine decrease in taxonomic diversity. This decrease has been documented for oyster communities (e. g. Wells, 1961) and for a wide spectrum of other coastal zone communities (Emery, Stevenson, and Hedgpeth, 1957). This vertical expression of diversity decrease can be most simplistically explained by regression, with the channel setting at Belgrade being brought into more and more inshore settings through time.

The exceptional and in situ preservation of this oyster community does also suggest sedimentary processes associated with regression. Coastal erosional or transgressive conditions are much more likely to obliterate the evidence of oyster communities than are coastal accretionary processes and settings. This process-to preservation relationship can be seen in many present-day settings of the southeastern United States. (For example, the uncovering and obliteration of earlier Holocene beds of Crassostrea virginica (Gmelin) can be observed along portions of the presently-eroding beaches of Edisto Island, South Carolina.) In addition, both of these general arguments for late Oligocene regression in the Belgrade area are strongly reinforced by the regional geologic picture developed by Brown et al., 1972.

Regional Setting and a Present-Day Analog

Brown, et al. (1972) have recognized other scattered deposits that directly overly their mapped units of Oligocene age in the Coastal Plain of eastern North Carolina. "In their areas of occurrence, these deposits occupy depressions, formed prior to their deposition, in underlying molluscan limestones of both Oligocene and Eocene age. The lithologic character, areal distribution, thickness, and possible early Miocene age of these deposits suggest regressive deposition that accompanied structural realinement. . . . " (Brown et al., 1972, p. 51). They included these scattered deposits with rocks of Oligocene age for mapping purposes (Brown et al., 1972, Pl. 19). This regional lithofacies mapping, when complemented with the present analysis of C. gigantissima life sites, does provide a general and harmonious model for the regional setting of the giant oysters.

Brown et al. (1972) recognized seven Coastal Plain lithofacies based upon textural and chemical criteria; four of these are present in

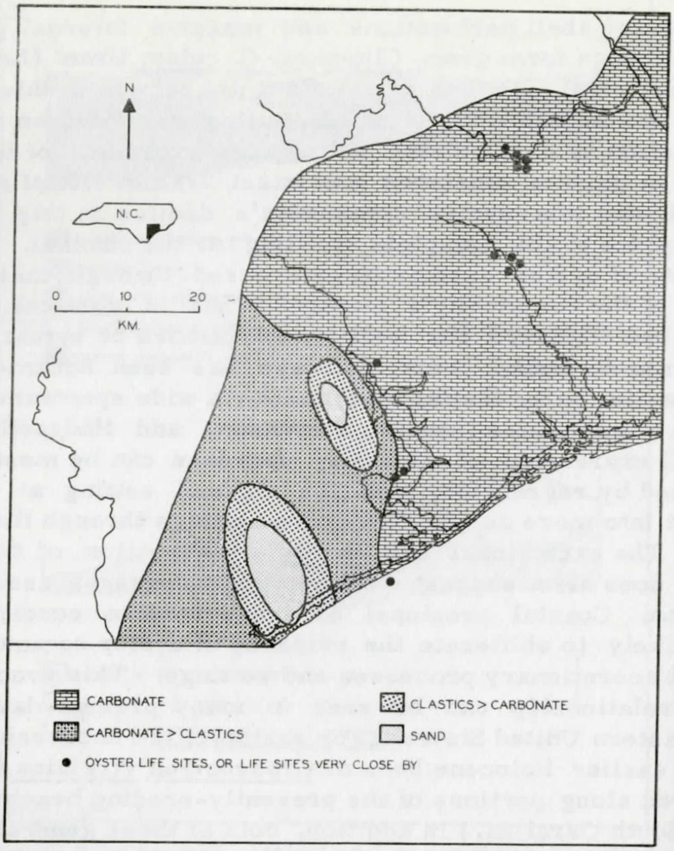

Figure 3. Oligocene lithofacies in southeastern North Carolina, and their relations to life sites of Crassostrea gigantissima (Finch). Lithofacies after Brown et al. (1972, Plate 19). Base map identical to Figure 1, which see for localities.

the Oligocene mapping units south and southwest of New Bern (Figure 3). The main of the Oligocene in this latter area consists of carbonates that are lithically similar to the basal calcareous strata at Belgrade. Southwest of Jacksonville, however, sandier units become more prominent in this portion of the stratigraphic column. The individual and sand-rich lithofacies units have long axes oriented NNW-SSE. This areal distribution, and individual unit geometries, are very suggestive of a prograding delta complex, perhaps related to antecedent drainage in the Cape Fear River system. Within this environmental reconstruction, C. gigantissima would have occurred along the margins of the delta plain and also in areas to the northeast (Figure 3).

This proposed paleoenvironmental setting shows many striking similarities to the present-day settings of the East Mississippi Delta

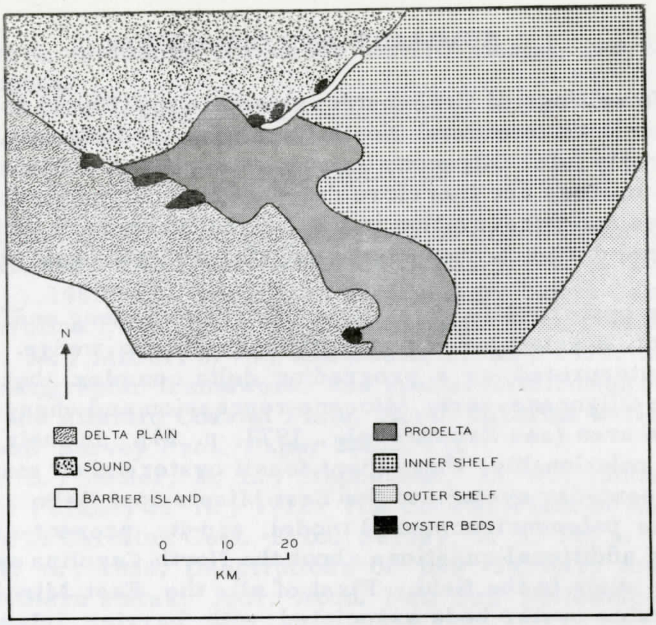

Figure 4. Model for general facies and oyster life sites on the eastern flank of a delta, based upon studies on the East Mississippi Delta region of Louisiana. Adapted and greatly simplified from Parker (1956) and Stanton and Evans (1971, 1972).

region. The macrofauna of this present-day setting was extensively studied by Parker (1956), and Stanton and Evans (1971, 1972) have more recently reanalyzed the assemblages or communities of shelled macrofauna occurring in the East Delta area. The present-day facies maps are not directly comparable to Figure 3, however, because significantly more control did exist in the analysis of the present-day setting. To make these two analyses more comparable, I have generalized and coarsened the fabric of the East Mississippi Delta biofacies (e.g., Stanton and Evans, 1972, Text-fig. 1) while retaining the charted oyster beds; the resultant map is shown in Figure 4. In the present-day East Mississippi Delta region, Crassostrea virginica (Gmelin) is the characteristic invertebrate of certain areas near the delta shores. Extensive live oyster reefs occur especially in the large indentations or bays of the Delta (Parker, 1956, p. 320). All in all, there are many similarities between this oyster distribution and that of C. gigantissima in the Coastal Plain of North Carolina (Figure 3). However, as the following discussion points out, additional tests of this analogy still need to be made in the North Carolina setting.

SUMMARY AND DISCUSSION

Life settings of Crassostrea gigantissima (Finch) do occur southwest of New Bern in coastal North Carolina. At Belgrade, the oysters directly overly late Oligocene carbonates with no evidence of a major hiatus; the oysters are therefore dated as late Oligocene in age. Diversity changes and preservation in the Belgrade exposure indicate that the oysters lived during a regressive-coastal accretionary phase of sedimentation.

The oysters' life sites are distributed along one flank of, and northeast of, a small but not insignificant clastic wedge. This wedge is herein interpreted as a prograding delta complex that was formed during late Oligocene-early Miocene regression and change in tectonic style in the area (see Brown et al., 1972, p. 51). In their distribution and facies relationship, these giant fossil oysters show many similarities to present-day oysters of the East Mississippi Delta region.

This paleoenvironmental model, and its present-day counterpart, raise additional questions about the North Carolina exposures that do warrant study in the field. First of all, the East Mississippi Delta model contains oyster beds associated with barrier islands, with the islands separating shelfal from sound environments (Figure 4). Were barrier islaands and extensive sound regions developed in the North Carolina Tertiary setting? If so, they might be preserved in the Pollocksville-Belgrade area. Continuing and detailed examination of the new quarry exposures at Belgrade should help to answer this question. Secondly, what is the exact temporal and environmental relationship between the oyster life settings and the classic pit exposures around Silverdale? C. gigantissima does occur in Silverdale float material. Although specimens are rare, fragmented, and obviously transported, one specimen in my collections was just as obviously transported in a fresh and articulate state. This suggests that the Silverdale beds were (at least in part) contemporaneous with the oyster deposits. Geographically, then, the Silverdale locale would represent an offshore, shelfal setting in the East Mississippi Delta model (Figures 1, 3, 4). Silverdale faunal lists (Kellum, 1926; Richards, 1943, 1950; Smith, 1959) contain taxa from a wide spectrum of the present-day deltaic settings yet the stratigraphic control for a realistic interpretation of this older Silverdale work is lacking. My own notes, made during two brief trips to Silverdale, indicate that distinctive outer shelfal taxa (Stanton and Evans, 1972, Table 1) may be numerically predominant at Silverdale. Here, again, integrated and detailed paleontologic-stratigraphic work at Silverdale will be necessary in order to resolve these paleoenvironmental undertainties.

Coastal Plain geologic studies have suffered because too much fossil collecting and too little paleontology have been done in the past. Fossils only become the handmaidens of increased geologic knowledge when they are put into a detailed and comprehensive local framework--

a framework including temporal, environmental, and biogeographic considerations.

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GEOPHYSICAL INVESTIGATION OF A DIABASE DIKE SWARM IN WEST-CENTRAL GEORGIA

By

George H. Rothe*
and
L. Timothy Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

ABSTRACT

Ground level gravity and magnetic data across what was previously considered to be a single large diabase dike in Meriwether County, Georgia has revealed an injection zone (swarm) approximately 750m wide, consisting of a main dike 30 to 40 meters wide with one or more narrower dikes to either side. A simple Bouguer gravity map has shown the dike swarm to be responsible for an anomaly in the regional gravity trend of about two milligals. Four detailed gravity traverses of the swarm suggest that the component dikes dip slightly to the east. The mean of the observed ground level total field magnetic anomalies for three traverses of the swarm was a 1000γ positive anomaly. The magnetic traverses suggest that the dikes dip to the west and only by consideration of Natural Remanent Magnetization (NRM) can the dip be found consistent with the gravity data, i. e. to the east. The shape of the observed magnetic anomaly, in combination with consideration of the gravity data, indicated a Koenigsberger ratio, Q, of 1. 0 for an average measured orientation of NRM of 28° East declination of 30° inclination.

INTRODUCTION

Diabase dike swarms outcrop throughout eastern North America from Alabama to Nova Scotia (Cohee, 1962), (Stockwell, 1969). King (1961) commented that the pattern of diabase dikes in eastern North America is probably the result of deep-seated stresses, but that the cause of the stresses is not apparent. May (1971) noted that the pattern

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*Currently at Geophysics Program, University of Washington, Seattle, Washington 98195 of the diabase dikes in eastern North America is actually part of a larger, radial, pattern of diabase dikes surrounding the North Atlantic and suggested that this pattern is a result of stresses associated with the onset of North Atlantic sea-floor spreading in Late Triassic or Early Jurassic time.

The geologic investigation of diabase dikes has been inhibited in most areas of Southeastern North America by chemical weathering and vegetation cover. However, on the basis of linear trends in the occurrence of magnetic highs in north-central Virginia, Johnson and Watkins (1963) inferred the extension of diabase dikes into areas where no outcrops were previously known. The success of Johnson and Watkins (1963) suggests that geophysical methods could yield structural information as well as outcrop patterns. The purpose of this study was to apply ground-level magnetic and gravity data to a study of a diabase dike. The dike, which was later determined to be a swarm of dikes, selected for study is located in central Meriwether County in west-central Georgia and hereinafter is referred to as the Meriwether dike swarm. The known outcrop of the dike, according to the Geologic Map of Georgia (1939), extends southward from three kilometers northeast of Newnan in Coweta County, to five kilometers south of the Towaliga fault in southern Meriwether County (Figure 1).

Acknowledgments

Thanks to Robert Bentley for his helpful discussions concerning the geology of the Georgia Piedmont and for permission to use his map. Thanks to Doyle Watts of the Ohio State University for supplying the paleomagnetic data for the Meriwether dike prior to publication. The School of Geophysical Sciences at the Georgia Institute of Technology provided the computer time for the analysis of the data.

During this study, which represents the research for a Master of Science Degree, George Rothe, received support in part through a research assistantship made possible by grant #DA-ARO-D-31-124-71-G117 from the Army Research Office - Durham.

Special thanks to Donna Rothe and Roland Schenck who assisted in collecting the data.

GEOLOGIC SETTING

Bentley and Neathery (1970) renamed the metasedimentary rocks of the southeastern portion of the Inner Piedmont the Opelika Complex and divided them into two units, the Loachapoka Schist and the Auburn Gneiss-schist (Figure 1). These units which strike N40°E on the average, were interpreted (Bentley and Neathery, 1970) as metamorphosed sediments which are extensively intermingled with granites. The Meriwether dike swarm strikes about N20°W through the area and intersects the strike of the Opelike Complex at about 60°.

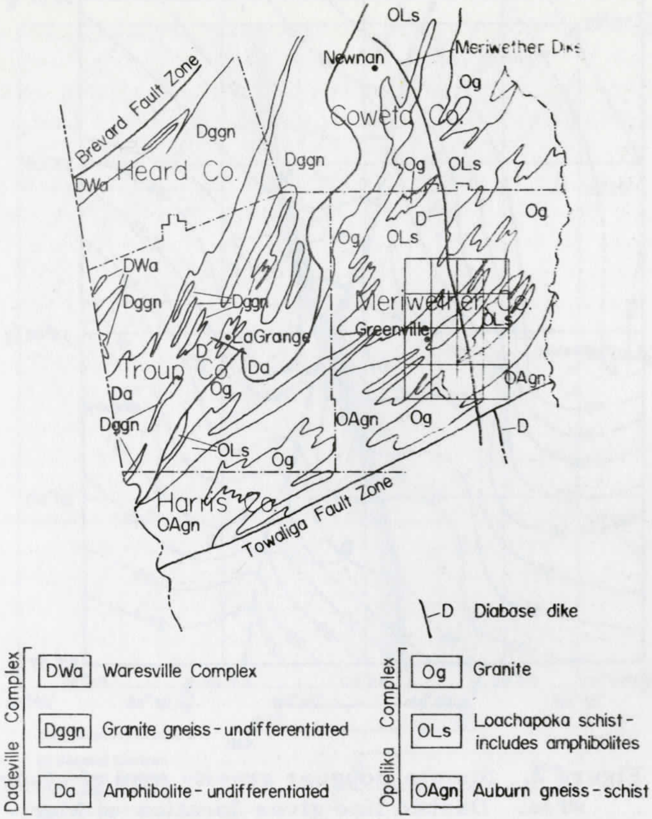

Figure 1. Geology of the Inner Piedmont of West Georgia (after Bentley and Nethery, 1970). Square grid shows area of study.

PHYSICAL PROPERTIES OF THE MERIWETHER DIKE SWARM

The density of field samples of diabase from the Meriwether dike is 3.0 ± 0.05 gm/cm^3. Watson (1902) determined the densities of the Loachapoka Schist and local granites to be 2.64 ± 0.01 and 2.70 ± 0.01 gm/cm^3 respectively. Thus, there is a 0.33 ± 0.07 gm/cm^3 contrast between the density of the diabase of the Meriwether dikes and the average density of the surrounding rocks.

Petrographic examination of the main Meriwether dike (Lee, 1971) showed that 2.3 to 4.3 percent of the diabase consisted of opaque grains which were assumed to be Fe-Ti oxides of spinel structure. The higher percentage occurred in the finer-grained zones near the dike's edges. Using the empirical formula of Balsey and Buddington (1958) and the range of percentages of opaques given by Lee (1971), the bulk magnetic susceptibility of the diabase composing the Meriwether dike swarm was estimated to be between 0.0066 and 0.0130 cgs.

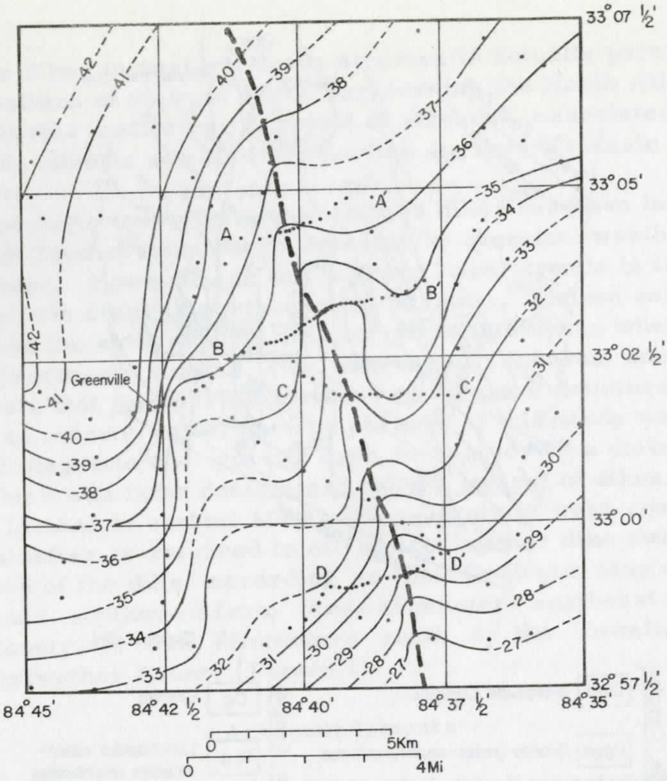

Figure 2. Simple Bouguer gravity map of study area. Dashed line gives location of Meriwether dikes. Letters designate beginning and end of gravity lines.

REGIONAL GEOPHYSICS

A simple Bouguer gravity map of the area of study (Figure 2) was constructed from measurements obtained at 195 stations. Standard procedures were used in the reduction of the data. The uncertainties in meter reading (±0.1 mgal for the Worden Educator, Model 113), meter drift (±0.05 mgal, as determined by reoccupation of base stations), and elevation determinations (±1 m, which, for the standard reduction density, corresponds to ±0.2 mgal) combined to give a precision of ±0.35 mgal for the regional data. Isogals trend approximately northeast-southwest, and the regional gradient is about -0.8 milligals/kilometer to the northwest. A steep gradient in the west-central portion of the study area is coincident with the contact between the Loachapoka Schist and granite west of Greenville (Figure 1). The Meriwether dike swarm is largely responsible for an anomaly in the regional trend of one to two milligals beginning in the southeastern part

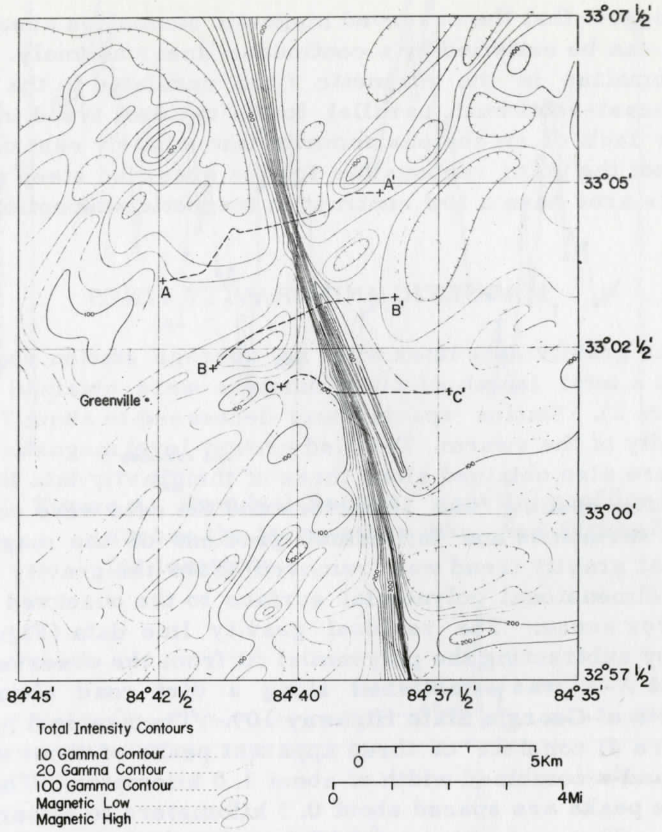

Figure 3. Total field aeromagnetic map of the study area contoured under the assumption that the Meriwether dike is a continuous magnetic feature. Anomalies are referenced to 55,000 gamma datum.

of the study area and continuing northward through the area.

The North-Central Georgia Aeromagnetic Map (open file report of the Georgia Geological Survey, 1973) includes the area of study. Large anomalies are shown where flight lines cross the swarm. Detailed ground-level magnetic traverses of the Meriwether dike swarm made at three locations between aeromagnetic flight lines (Figure 3) revealed prominent (1000γ) magnetic highs coinciding with observed outcroppings of the main dike.

Under the assumption that at least the main dike of the Meriwether dike swarm is continuous along strike, the magnetic data were recontoured in the region where the swarm outcrops. Although the extrapolation of data with 200 meter resolution between flight lines with 1.5 km separation is inherently uncertain, this interpretation does strongly suggest that the observed magnetic anomalies associated with the swarm can be satisfied by a continuous linear anomaly.

Anomalies in the magnetic field unrelated to the dike swarm trend northeast-southwest parallel to the regional trend in the gravity field. The lack of an obvious anomaly immediately east of Greenville suggests that the units responsible for the observed steep gravity gradient in this area have a low contrast in magnetic susceptibility.

MAGNETIC AND GRAVITY LINES

Four gravity data lines with an average station spacing of 150 meters and a total length of 20 kilometers were obtained in the study area (Figure 2). Station spacing was decreased to about 75 meters in the proximity of the swarm. Detailed ground-level magnetic (total field) profiles were also obtained along three of the gravity data lines (Figure 3). The data spacing was 16 meters and the data were corrected for the diurnal variations and latitudinal gradient of the magnetic field. The regional gravity trend was removed from the gravity line data by fitting a 2-dimensional polynomial surface to the observed values in a least squares sense. The residual gravity line data (Figure 4) were computed by subtracting the polynomial fit from the observed data.

Line A-A' was established along a dirt road about 3. 0 kilometers north of Georgia State Highway 109. The residual gravity anomaly (Figure 4) consists of three apparent peaks of about one milligal amplitude and a combined width of about 1. 0 kilometer. The less prominent side peaks are spaced about 0. 3 kilometers to either side of the main peak. The magnetic data (Figure 5) show four distinct peaks which correspond to the gravity peaks with two of the magnetic peaks associated with the west gravity peak. These data suggest that the dike swarm consists of as many as four distinct dikes.

Line B-B' was established along Georgia State Highway 109 between Greenville and Gay, Georgia. The residual gravity anomaly consists of a "noisy" asymmetric broad peak (Figure 4). Amphibolites were found outcropping to the west of the main dike and could be responsible for the observed scatter in the gravity and magnetic data west of the main dike. Diabase float was also found 1. 5 kilometers west of the main dike indicating that part of the observed scatter in the data may be a result of a side dike. The asymmetry of the residual gravity anomaly suggests that the dikes dip to the east (see Figure 6).

Line C-C' was established along the dirt road about 1. 5 kilometers south of Georgia State Highway 109. The residual gravity anomaly consists of three broad peaks. Dike outcrops were found coincident only with the central peak. Nevertheless the side peaks are probably associated with dikes which may not reach the surface or are obscured by weathering. The magnetic data were irregular indicating perhaps, numerous small dikes rather than a single side dike.

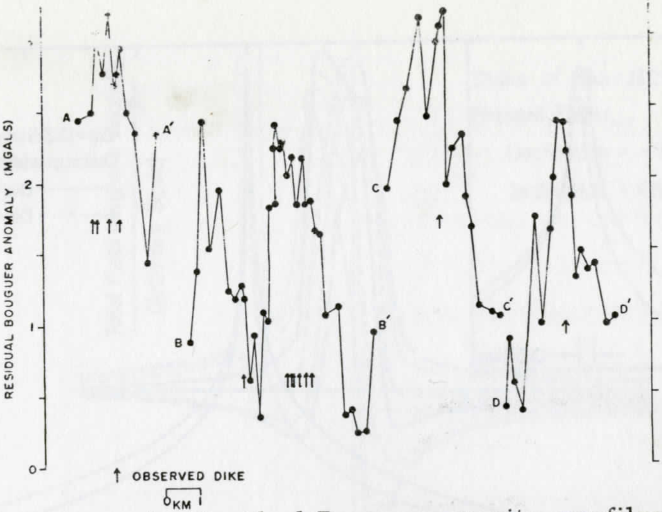

Figure 4. Residual Bouguer gravity profiles across the Meriwether dike. See Figure 2 for locations.

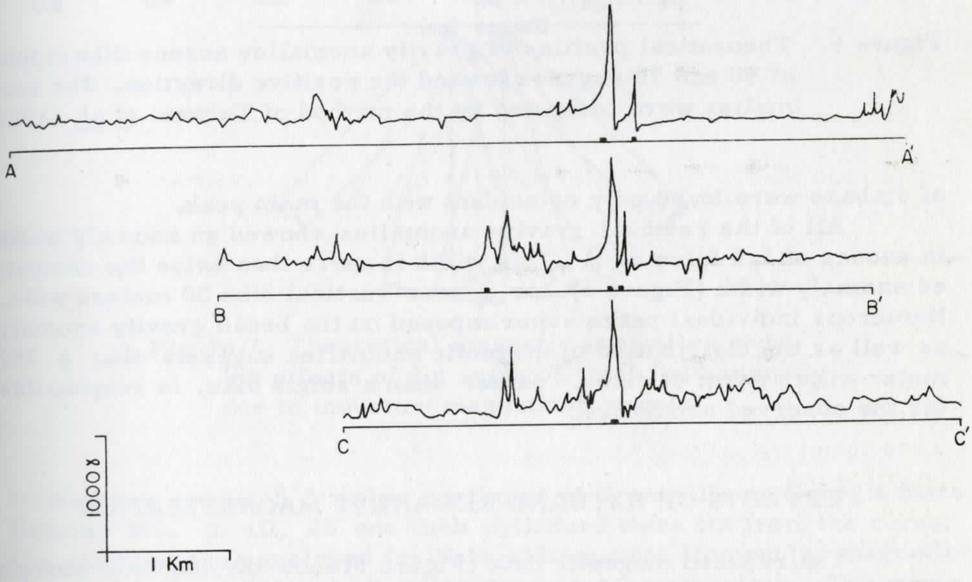

Figure 5. Ground-level total field magnetic profiles. Heavy bars below profile indicate diabase outcrops.

Line D-D' was established with gravity data along the paved county road about 8. 0 kilometers southeast of Greenville and 4. 5 kilometers south of line C-C'. The residual gravity anomaly again shows multiple peaks and asymmetry indicating a dip to the east. Outcrops

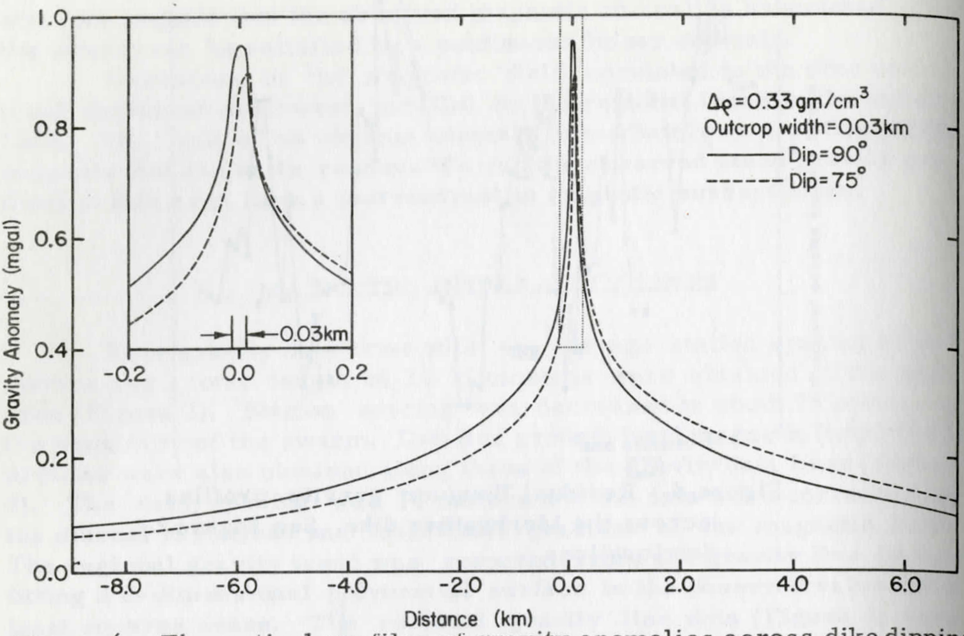

Figure 6. Theoretical profiles of gravity anomalies across dike dipping at 90 and 75 degrees toward the positive direction. The anomalies were computed by the method of Talwani et al. (1959).

of diabase were found only coincident with the main peak.

All of the residual gravity anomalies showed an anomaly width in excess of 1.0 kilometer. This width is more than twice the computed anomaly width (Figure 6) for a near vertical dike 30 meters wide. Numerous individual peaks superimposed on the broad gravity anomaly as well as the distribution of magnetic anomalies suggests that a 750 meter wide swarm of dikes, rather than a single dike, is responsible for the observed anomalies.

EFFECTS OF NATURAL REMANENT MAGNETIZATION

The reduced magnetic data (Figure 5) show the magnetic anomaly of the main dike to be asymmetric. However, the calculated anomaly due to induction magnetization for a dike dipping 75° toward N70°E is a symmetric positive peak (Figure 7). This suggests that induction magnetization is not the only cause for the observed anomaly and that natural remanent magnetization (NRM) must also be considered (Hood, 1963).

Samples from the main dike of the Meriwether swarm were collected and analyzed for NRM by Doyle Watts (Watts and Noltimier, 1974). Fourteen cores were obtained from a single outcrop of the

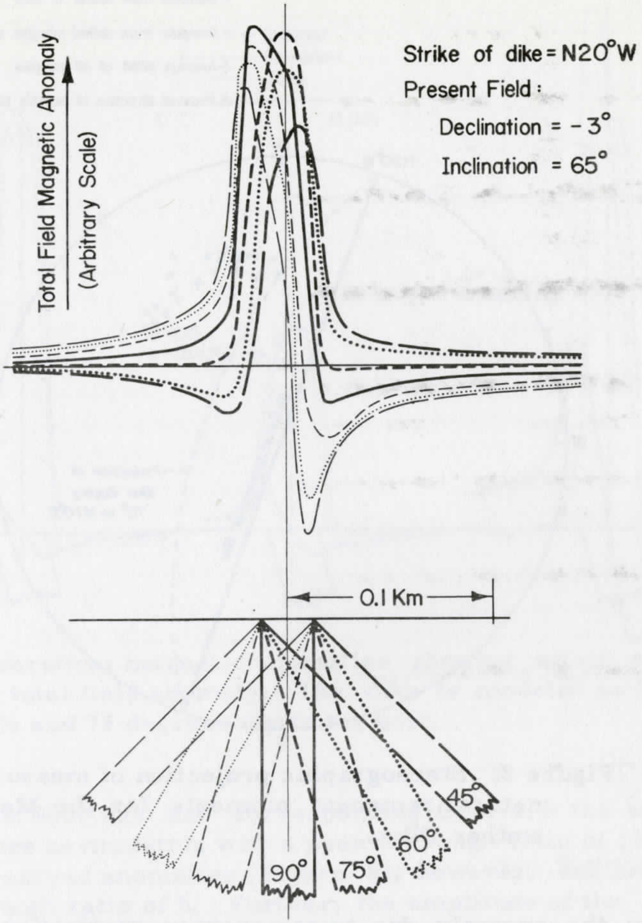

Figure 7. Theoretical magnetic anomalies showing effects of dip angle on total field anomaly due to induction magnetization only.

Meriwether swarm 5.5 miles northeast of Greenville on Georgia State Highway 362. In all, 26 one inch cylinders were cut from the cores. The samples were analyzed for Natural Remanent Moment (no magnetic cleaning) using a Schonstedt SSM1 Spinner Magnetometer. The cores were taken from the center portion and from the chilled edges of the dike.

A Schmidt stereographic projection of the NRM directions (Figure 8) shows the NRM directions to be different from today's magnetic field. Samples taken from the center of the dike constitute one set of directions and those from the chilled margins another set. Because the variation of magnetization within the dike was unknown, an average of the directions (Figure 8) and magnitudes was used for

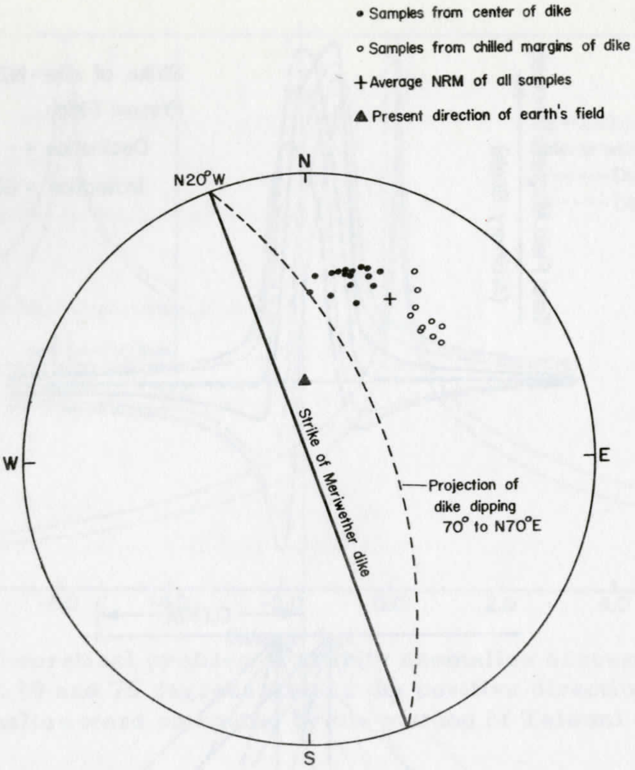

Figure 8. Stereographic projection of measured natural remanent moments for the Meriwether Dikes.

computing the anomaly due to remanent magnetization. The average direction has a declination of 28° East and an inclination of 30°. The average magnitude of the NRM is 0.00175 cgs.

The ratio of remanent magnetization to induced magnetization, the Koenigsberger ratio, Q, is commonly cited in paleomagnetic studies as an indication of whether or not samples have been subjected to lightning strikes. It has more recently been construed (Green, 1960) as a measure of the importance of remanent magnetization in the analysis of magnetic anomalies. Using the calculated bulk susceptibility for the diabase of the Meriwether dike swarm and the average intensity of NRM, the probable range of Q is 0.25 to 0.50. The range of Q is a result of the uncertainty in the bulk susceptibility.

To examine the effects of Q on the observed anomalies, several models were computed using the method of Talwani and Heirtzler (1965). For a Q of 0.25 and bulk susceptibility of 0.013 cgs, the remanent magnetization causes the anomaly to become slightly asymmetric (Figure 9) with a peak to trough ratio of about 15 to 1. For bulk

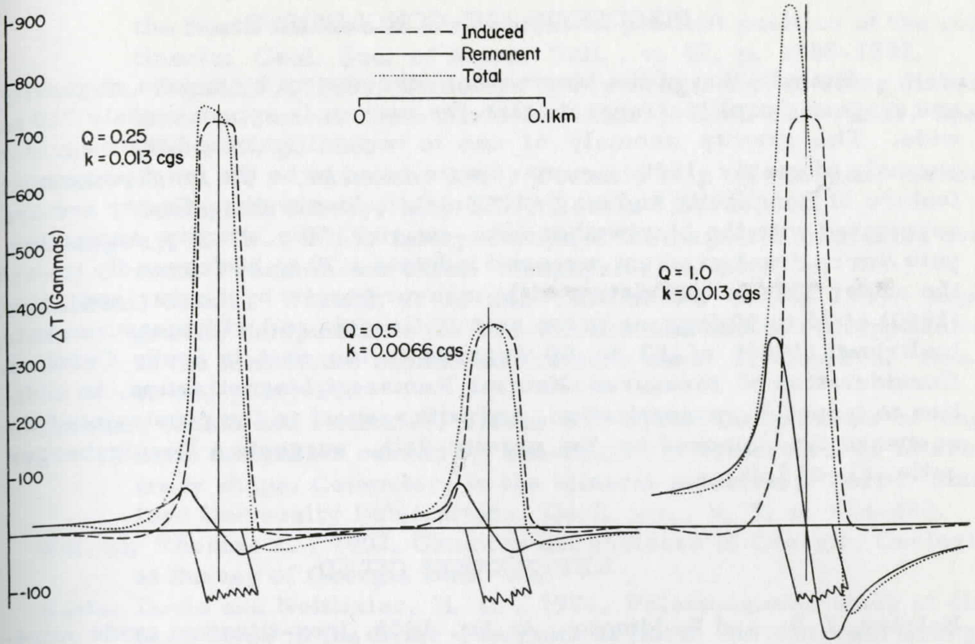

Figure 9. Theoretical magnetic anomalies showing effect of NRM on the total field anomaly. The dike is modeled as 30 meters wide and 75 degrees dip to the east.

susceptibility 0.0066 cgs and corresponding Q of 0.5 the anomaly is found to be more asymmetric with a peak to trough ratio of 10 to 1.

The observed anomalies (Figure 5), however, exhibit an average peak to trough ratio of 6. Further, the amplitude of the observed anomalies is greater than that calculated for the given range of susceptibilities and corresponding magnetizations. An increase in Q to 1.0 at a susceptibility of 0.013 cgs produced an asymmetric anomaly with a peak to trough ratio of about 6 to 1 (Figure 9) indicating that the bulk remanent magnetization was probably greater than that suggested by the surface samples.

Strangway (1965), who sampled a diabase dike at both the surface and at depth in a mine, found the ratio of remanent to induced magnetization to be greater for the underground samples. As a possible cause of this phenomenon Strangway (1965) suggests that temperature fluctuation at the surface, which was probably exposed for a considerable length of time, has accelerated the decay of the remanent magnetization. The same type of process may have occurred in the Meriwether dikes and hence, the effective Q, which includes the effect of subsurface portions of the dikes, is probably closer to 1.0.

DISCUSSION AND CONCLUSIONS

Examination of the Meriwether dike swarm by means of gravity and magnetic profiles suggests that the swarm is approximately 750 m wide. The gravity anomaly of one to two milligals and the magnetic anomaly of nearly 1000 gammas were found to be the most prominent feature of the gravity and magnetic fields in Meriwether County and are associated with the Meriwether dike swarm. The gravity anomalies with the regional gradient removed indicate a 70 to 80 degree dip toward the east. This is consistent with measurements by Lester and Allen (1950) of 75 to 90 degrees to the east in Georgia and with measurements by Privett (1966) of 80 to 90 degrees to the east in South Carolina. Consideration of measured Natural Remanent Magnetization, in addition to induction magnetization, and with respect to the constraint of the eastward dip imposed by the gravity data, suggests a Koenigsberger ratio, Q, of 1.0.

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A CRINOID LENTIL IN THE PENNINGTON FORMATION (CHESTERIAN), SLOANS VALLEY, KENTUCKY

By

Harrell L. Strimple
Department of Geology
The University of Iowa
Iowa City, Iowa 52242

and

Alan S. Horowitz
Department of Geology
Indiana University
Bloomington, Indiana 47401

ABSTRACT

An in situ collection from a 25 cm by 35 cm by 3 cm slab from a thin crinoid bearing unit in the basal Pennington Formation (=basal Tar Springs of the standard Chesterian section) near Sloans Valley, Pulaski County, Kentucky has yielded 21 crowns or partial crowns of 8 genera of crinoids (2 camerates and 6 inadunates). The blastoid genus Pentremites is uncommon in this material.

In the late 1800's many eminent North American paleontologists collected and/or described crinoids from the Sloan's Valley area of Pulaski County, Kentucky. Lists of echinoderms from this area are given in Bassler and Moodey (1943). Most of the material probably was obtained from debris excavated from the now abandoned railroad tunnel (Carter Coordinates E 1/2 NE 1/4 17-F-60, Burnside U. S. Geological Survey 7 1/2 minute Quadrangle) or from cuts in the approaches to the tunnel that are now overgrown or covered by slump.

Richard Q. Lewis of the U. S. Geological Survey, who has mapped the Mississippian rocks in this area, showed one of us (A. S. H.) an exposure on the old railroad right of way about a mile southeast of the tunnel (Carter Coordinates NW 1/4 NE 1/4 23-F-60, Burnside Quadrangle) in what is now regarded as the basal beds of the Pennington Formation (=basal Tar Springs Sandstone of the standard Illinois Basin section) on published geologic maps of adjacent quadrangles (for example, Smith, Pomerene and Ping, 1973). Preservation at this site is usually not as good as found in some of the original collections but an appreciable number of crinoids and a few blastoids have been obtained here. The exposure is a slope of thin limestones and shales capped by a massive limestone. The massive limestone is thought to be the same as that forming the roof of the abandoned tunnel and, on the basis of a more complete nearby section along U. S. Highway 27, lies about 4 meters above the base of the Pennington Formation. Most of the weathered specimens apparently came from near the top of the exposure because excavation in the interval about 30 cm below the massive limestone yielded slabs containing echinoderms.

In the spring of 1969 one of us (H. L. S.) visited this exposure in order to obtain an *in situ* block from individual crinoid bearing zone, which lies about 30 cm below the massive limestone capping the exposure. This crinoidal zone is about 3 cm thick and consists of two 1 to 1.5 cm thick limestones separated by a very thin shale parting. In some parts of the exposure crinoid crowns are present in the soft shale just above the top of the crinoid-bearing limestone unit but none were present above the slab excavated in 1969.

The excavated slab measured 25 cm by 35 cm by 3 cm and exhibited poorly preserved echinoderms. The lower limestone yielded remains of seven crinoid crowns, two blastoids and two *Pterotocrinus* wing plates, the thin shale parting contained nine poorly preserved cups or crowns and two blastoids, and the upper limestone exhibited five crinoid crowns (several of which were well preserved). Because all the upper limestone did not disaggregate when soaked in water, additional specimens may exist in the material although this is believed to be unlikely. Twenty-one crinoid crowns from so limited a volume of rock represents a prolific assemblage.

The following genera of crinoids were recognized:

Camerata		
	Pterotocrinus	2 blades
	Acrocrinus	2 fragments
Inadunata		
	Pentaramicrinus	1 crown
	Cymbiocrinus	1 crown
	Aphelecrinus	1 poorly preserved crown
	Dasciocrinus	2 crowns (one fragmentary)
	Tholocrinus	1 anal sac termination platform
	Phanocrinus	3 well preserved crowns; 11 cups and sets arms

The largest crown recovered was about 6 cm long and represents a *Phanocrinus formosus* (Worthen).

The preservation suggests relatively rapid burial by shale influxes. *Archimedes* axes are very abundant associates and this association suggests a rich filter feeding community but further conclusions must await additional collecting and analysis.

Material. - SUI 38950. Reposited Geology Department Repository, The University of Iowa, Iowa City, Iowa.

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LOCAL CEMENTATION AND DEVELOPMENT OF POROSITY IN THE YORKTOWN FORMATION, NORTH CAROLINA

By

Richard H. Bailey
Department of Earth Sciences
Northeastern University
Boston, Massachusetts

ABSTRACT

At several localities in northeastern North Carolina the uppermost meter of fossiliferous, clayey sand of the Yorktown Formation is well cemented. Calcite cement occurs as microspar in a clayey, fine quartz sand matrix. Coarsely crystalline sparry calcite partially fills bivalve molds. Cement has been derived by the dissolution of bivalve shells within and above the cemented zone. Carbonate diagenesis is localized by the migration of groundwater along an unconformity. The nature of the calcite cement suggests that cementation and development of moldic porosity took place in the shallow meteoric phreatic zone. Carbonate diagenesis of Yorktown sediments is apparently proceeding slowly because a very clayey matrix prohibits the transmission of meteoric water through the Formation.

INTRODUCTION

Varying degrees of carbonate cementation can be observed in many rock units of the Coastal Plain of North Carolina. Cementation probably occurred when fossiliferous marine rocks of Upper Cretaceous and Cenozoic ages were subjected to diagenetic conditions related to changing sea and/or groundwater levels. Specifying the exact conditions and the precise time of carbonate cementation is very difficult. The Yorktown Formation, owing to a somewhat unique set of hydrologic and geologic conditions, is locally well indurated. The purpose of this paper is to examine the processes and products of carbonate cementation of Yorktown sediments at several localities in northeastern North Carolina. These localities are significant because the processes and conditions necessary for carbonate diagenesis are extant and we may therefore examine not only products but also processes.

The upper Miocene - lower Pliocene Yorktown Formation of North Carolina is a clayey and silty, very fine to medium sand containing abundant molluscan fossils. Yorktown sediments in North Carolina

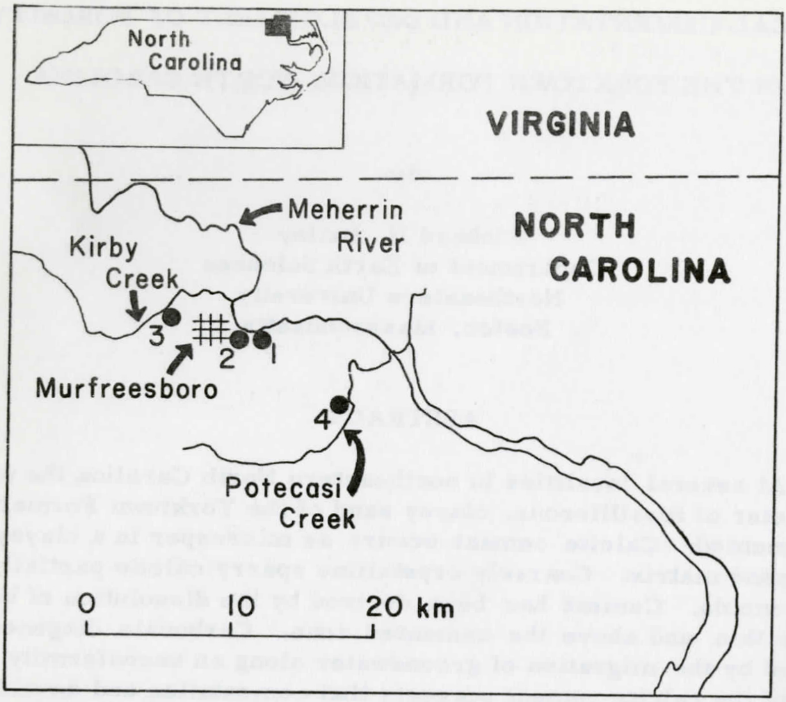

Figure 1. Yorktown localities in northeastern North Carolina where cemented intervals are present. Cemented units are at approximately similar stratigraphic positions at each locality.

are rarely well cemented even though the abundant shell material (50-60% in some samples) could provide upon dissolution, a large quantity of carbonate cement.

LOCATION AND STRATIGRAPHY

The Yorktown Formation is discontinuously exposed in an outcrop belt extending from the Rappahannock River in Virginia to the Neuse River in North Carolina. The formation crops out along the Meherrin River and in several tributary stream valleys in the vicinity of Murfreesboro (Figure 1). Yorktown strata thicken from 0 m at the western edge of the outcrop belt to approximately 150 m in the subsurface beneath Pamlico Sound (Brown, 1972, Pl. 21). In the area near Murfreesboro, Yorktown sediments are about 15 m thick (11. 8 m is the thickest section exposed in outcrop; fig. 2) and dip to the east about 0.1 m per km.

The most complete stratigraphic section in the area is exposed

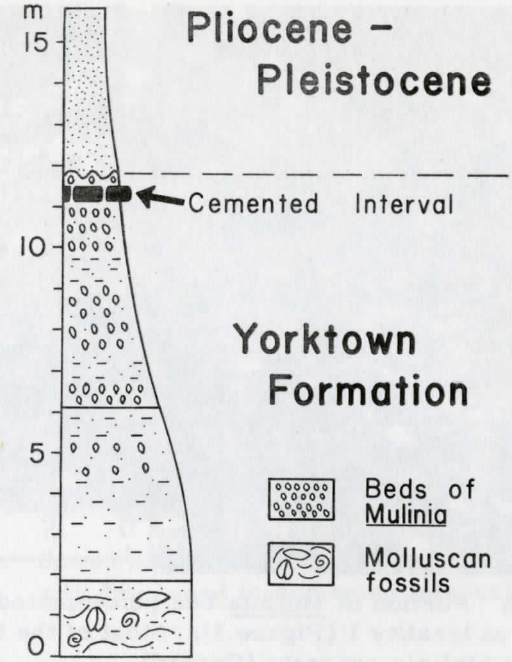

Figure 2. Stratigraphic section at locality 1 (Figure 1) showing position of cemented interval and its relationship to the unconformity separating the Pliocene-Pleistocene deposits from the Yorktown Formation. Base of section is at river level.

along the south bank of the Meherrin River about 1 km east of the town of Murfreesboro (Figure 2). The lower 2 m of this section are silty fine sands with abundant fossils; the upper 9 m are very clayey, thinly laminated silts and fine sands containing abundant shells of the small mactrid bivalve Mulinia congesta (Conrad) along with several less abundant species (Figure 3). The lower part of the section is interpreted to have been deposited in shallow shelf environments and the upper Mulinia-bearing beds seem to represent deposition in a lagoon, bay or protected shelf environment (Bailey, 1973, p. 54-55).

Yorktown sediments are usually unconsolidated; however, at several localities (Figure 1) the uppermost 20 to 80 cm of the formation are well indurated (Figure 2). The cemented portion stands out as a prominent ledge because of its relative resistance to weathering. Although the ledge is discontinuous, it can be traced for several tens of meters along the surface of the outcrop at locality 1. Elsewhere in the area, at approximately the same stratigraphic level, similar well

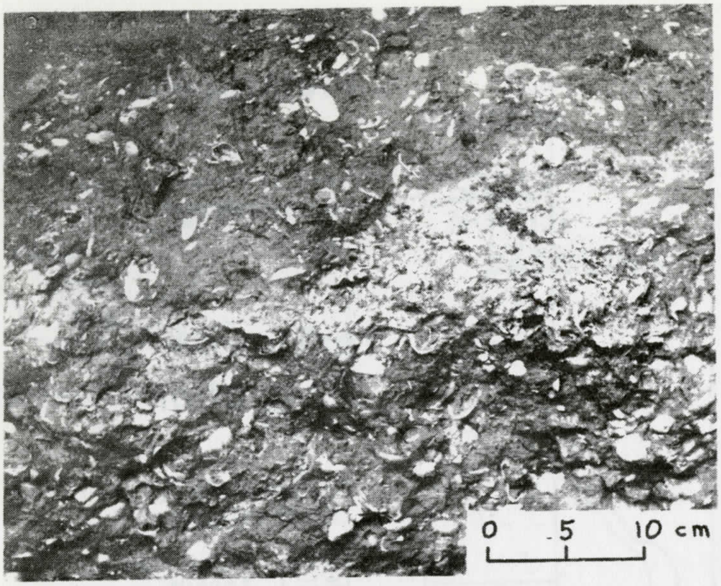

Figure 3. Portion of *Mulinia* bed (uncemented) exposed at locality 1 (Figure 1). Most of the bivalves are *Mulinia congesta* (Conrad).

cemented intervals occur (Figure 1). At 10 to 60 cm above the indurated interval a major stratigraphic break occurs, the unconformity which separates the marine, fossiliferous Yorktown Formation from the fluvial, non-fossiliferous, Pliocene?-Pleistocene deposits. These fluvial sediments are moderately sorted, very coarse to medium, micaceous, quartz sands with interbedded clay and gravel. The disconformity is very distinct as it is usually marked by a 0.2 to 1.5 cm thick ferricrete layer. The unconformable surface has low relief, generally much less than 0.5 m.

DESCRIPTION OF CEMENTED INTERVAL

The well-cemented layer has about 3 to 10 percent megamoldic porosity (Choquette and Pray, 1970, p. 224) due to partial or complete dissolution of *Mulinia* valves (Figure 4). In a few instances the moldic porosity has been secondarily reduced by solution-infill of coarsely crystalline sparry calcite. Thin section analysis reveals that the void-filling sparry calcite usually extends to the margins of the void without intervening finely crystalline calcite. Fine and very fine quartz sand grains are surrounded by a clayey matrix containing very finely crystalline sparry calcite and microspar cement. Very few molluscan shells show signs of recrystallization. Dissolution seems to have been the predominant mode of carbonate diagenesis.

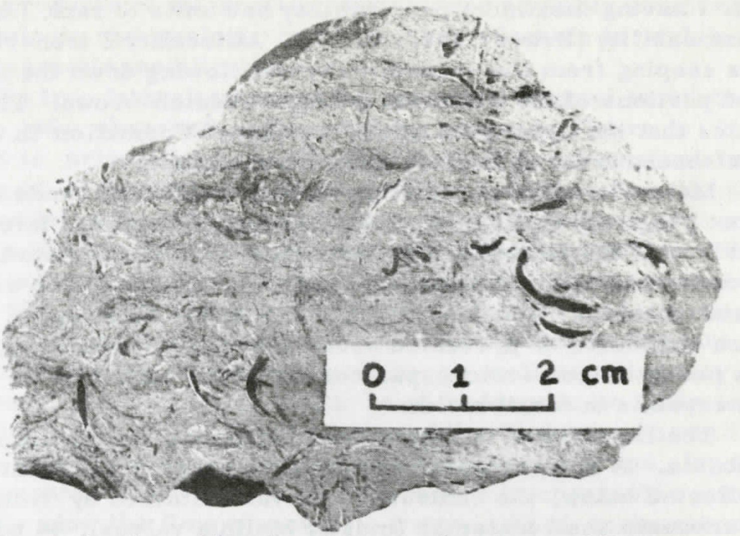

Figure 4. Sawed hand specimen showing moldic porosity developed in cemented interval.

Even though Mulinia valves and molluscan fragments are abundant, they do not consistently form a part of the framework of the rock. In most samples examined the bioclasts were matrix supported. There is no micrite in the silicate clay fraction of the matrix. The only primary carbonate grains are the molluscan skeletal remains.

ORIGIN OF CEMENT AND MOLDIC POROSITY

The Mulinia-bearing beds are only very slightly indurated except for the interval immediately beneath the unconformity. The concurrence of the unconformity and the cemented interval suggests a genetic relationship between the two.

Considerable seepage and spring activity were observed at the unconformity separating the Yorktown Formation and fluvial sands. The permeability of the two units varies greatly, with the fluvial sands and gravels having high permeability and the clayey Yorktown sands having little interparticle porosity and low permeability. The difference in permeability was especially notable after heavy rains when seepage runoff would emanate from the unconformity and flow down the surface of the clayey Mulinia beds. Brown (1972, Pl. 21) mapped the subsurface spatial distribution of permeability in an upper Miocene interval which closely coincides with the Yorktown Formation. His data (Brown, 1972, Pl. 21) show the area around Murfreesboro as a region of extremely low relative intrinsic permeability (rank 7). The permeability rankings he assigns are based on considerations of lithology with units of rank 1 having maximum permeability and units of rank 7 having lowest permeability (Brown, 1972, p. 71). At locality 2 iron-rich groundwaters seeping from the unconformity and flowing down the outcrop have stained portions of the Yorktown a bright reddish-brown. The evidence indicates that the upper part of the Yorktown Formation in the vicinity of Murfreesboro is, at least in part, an aquiclude.

Meteoric water percolating through the fluvial sands and gravels does not penetrate rapidly into the Yorktown, but moves laterally along the surface of the unconformity. Groundwater, undersaturated in calcium carbonate, slowly percolates into the upper surface of the Yorktown and dissolves shell material. Complete flushing of dissolved calcium carbonate is prevented because of low permeability, thus calcite is precipitated as microspar cement in the matrix or as sparry void filling crystals in fossil molds.

The lithology of the Mulinia bed suggests that such a mechanism is probable. A disaggregated sample of unlithified sediment similar to, but collected below, the cemented interval contained by weight 9 percent carbonate shell material (mostly Mulinia valves), 44 percent clay and silt, and 47 percent fine to very fine sand. The very clayey matrix would greatly inhibit the flow of interstitial fluids.

Alterations of carbonate mineralogy have been attributed to reactions with fresh and marine waters in both the vadose zone (above the water table) and the phreatic zone (below the water table). Land (1970, p. 184) noted that diagenesis of Pleistocene beach-dune calcarenites from Bermuda proceeded most rapidly in the meteoric phreatic zone and Steinen and Matthews (1973, p. 1013-1015) presented strong evidence that mineralogic alteration of Pleistocene carbonate sediments on Barbados was most rapid in the fresh water phreatic zone. Microspar cement in a clayey matrix and coarsely crystalline sparry calcite in voids are typical of cementation of carbonate-rich sediments in the meteoric phreatic zone. Folk (1974, p. 41) described similar crystals from the phreatic zone and attributed their formation to growth of calcite in meteoric groundwater with low Mg and Na concentrations.

CONCLUSIONS

Cementation of the upper part of the Yorktown is localized by meteoric groundwater flowing along the post-Yorktown unconformity. As meteoric water slowly penetrates the upper surface of the Yorktown Formation abundant calcite in the form of shell carbonate is dissolved, transported locally, and reprecipitated as cement in a clayey matrix.

The exact timing of carbonate diagenesis cannot be determined. The upper surface of the Yorktown was exposed to meteoric waters during the deposition of the unconformably overlying fluvial sediments. The degree to which cementation proceeded during this stage is unknown, but as the upper part of the Yorktown was subjected to significant erosion, products of diagenetic changes were probably removed. Present hydrologic and geologic conditions are adequate to explain the observed diagenetic modifications.

The true lateral extent of the cemented interval is indeterminate as it was only observed at the outcrops shown in Figure 1. If the cementation is primarily a surficial result of processes related to the discharge of groundwater saturated with calcium carbonate, the preceeding model will not have to be altered significantly. The primary revision might be that precipitation of calcium carbonate would occur rapidly due to CO_2 evasion or evaporation (Thorstenson and others, 1972, p. 164-165) as groundwater seeped from the unconformity.

This study is instructive in that it may help to indicate why the Yorktown Formation in North Carolina as well as other very clayey, fossiliferous Coastal Plain units have undergone so little carbonate cementation. Widespread cementation of the Yorktown Formation probably has been inhibited by the high percentage of silt and clay in Yorktown sediments. Very fine particles reduce intergranular pore space and greatly slow the flow of meteoric water. When meteoric water is prevented from interacting with carbonate grains, diagenesis will be greatly slowed.

The largely unconsolidated sediments of the Yorktown and of other middle and upper Miocene units contrast markedly with some thoroughly cemented Upper Cretaceous, Eocene, and lower Miocene sediments in southeastern North Carolina. Cunliffe and Textoris (1969, p. 428) studied the petrology of the Rocky Point Member of the Upper Cretaceous Peedee Formation and Eocene Castle Hayne Limestone. Portions of both of these units have undergone extensive and widespread carbonate cementation. Lower Miocene beds exposed in quarries around Silverdale, North Carolina are also well indurated as a result of carbonate cementation (Kellum, 1926, p. 12). One factor that these well cemented units have in common is that they originally were composed of fine to medium quartz sands and abundant amounts of carbonate, primarily in the form of molluscan skeletal remains. The cement which binds the matrix quartz grains was derived by dissolution of fossils (Cunliffe and Textoris, 1969, p. 428). Considerable moldic porosity is evidence of extensive fossil dissolution. A second factor that these rocks share is a basic similarity of depositional environments. They were deposited in shallow shelf settings during a tectonically quiescent period which extended from the latest Mesozoic to the middle Cenozoic. During this time the influx of clastic sediments was greatly reduced and rapidly accumulating calcium carbonate was mixed with texturally mature, well sorted shelf sands. During the Miocene renewed Appalachian and Piedmont uplift provided clastic sediments to shelf environments more rapidly than in the latest Mesozoic and early Cenozoic (Gibson, 1970, p. 1815-1817). Skeletal calcium carbonate was diluted with fine grained clastic sediment. The fine clayey snd silty sands, such as those composing the Yorktown Formation act as a buffer or retardant which prevents rapid cementation. Hence a low ratio of fossils to matrix combined with the fine grained nature of the matrix may account for the lack of Yorktown cementation.

Other factors such as local water table levels and the young geological age of the unit certainly have controlled to some degree the extent of carbonate diagenesis that has occurred. It is quite probable, that with greater age much more of the Yorktown Formation will be exposed to diagenetic conditions conducive to the development of calcium carbonate cement.

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EVALUATION OF POSSIBLE SOURCE REGIONS OF TRAIL RIDGE SANDS

By

Fredric L. Pirkle*
Department of Geology
University of Florida
Gainesville, Florida 32611

ABSTRACT

Trail Ridge is a prominent sand ridge spanning 130 miles of northern Florida and southern Georgia. Various hypotheses for the origin of Trail Ridge require different source areas for the sands comprising the ridge. The three most logical source areas consistent with the various hypotheses are areas of coarse sediments that crop out along the Altamaha River north of Trail Ridge, the Lake Wales Ridge area of Citronelle sediments south of Trail Ridge, and the area of high terrace sands west of Trail Ridge.

The heavy-mineral suites of the sediments in these three potential source areas were compared with the heavy-mineral suite of Trail Ridge sands. The sediments exposed along the Altamaha River were eliminated as immediate source sediments for Trail Ridge sands on the basis of the incompatibility of their heavy-mineral suite with that of Trail Ridge. Heavy-mineral suites of the sediments in the two remaining possible source areas are compatible with the heavy-mineral suite of Trail Ridge sands.

The sphericity of zircon in Trail Ridge sediments is identical with the sphericity of zircon in Citronelle sediments and in the high terrace sands. The sphericity of kyanite-sillimanite in Trail Ridge sands, however, is compatible only with the sphericity of kyanite-sillimanite in the high terrace sands. Therefore it is concluded that the area of high terrace sands to the west of Trail Ridge is the immediate source region for most of Trail Ridge sands and only those hypotheses on the origin of Trail Ridge consistent with this source region are viable.

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*Present address: Department of Geosciences, The Pennsylvania State University, University Park, Pennsylvania 16802

INTRODUCTION

Trail Ridge is a prominent sand ridge spanning 130 miles of northern Florida and southern Georgia (Figure 1). Its southern terminus is along the northern side of the Interlachen Karstic Highland near the junction of Bradford, Clay and Putnam counties in Florida. From this locality the ridge trends slightly west of north for 75 miles to the northern border of Charlton County, Georgia, southeast of Waycross, and then slightly east of north for another 55 miles to its northern terminus near the Altamaha River (Figure 1). The Georgia portion of the ridge ranges in elevation from approximately 140 to 170 feet above sea level. The ridge, in general, is higher in Florida, reaching an elevation of more than 240 feet in its southern parts.

Many concepts have been expressed on the origin of the ridge. The ideas and thoughts include the following:

1) The ridge is a spit or bar that built northward from Florida in an ancient sea (Cooke, 1925).
2) The ridge is a spit or bar that built southward from Georgia in an ancient sea (Doering, 1960, p. 198; Alt, 1974, p. 26).
3) The ridge formed along a shore line at the height of a marine transgression, the major source of the sands of the ridge being local land areas into which the seas eroded (White, 1970; Pirkle, W. A., 1972).
4) The ridge built across the mouth of an eastward-flowing Pliocene river (the ancestral Suwannee River) when transgressing seas encroaching from the east reached a height that now is approximately 120 feet above sea level (Brooks, 1966, p. 42-45).
5) The ridge formed initially as a beach ridge on the landward side of an ancient shore line that now is 95 to 100 feet above sea level in Georgia, and due to diastrophic uplift, is as high as 160 to 165 feet above sea level in northern Florida (Hoyt, 1967a, p. 1541; 1967b, p. 1130).

Despite extensive debate in the literature concerning Trail Ridge, nothing definitive has been established concerning its origin. One problem receiving only cursory attention in previous studies and debates is that of an immediate source region for the Trail Ridge sands. The zircon extracted from the very fine sand fraction (1/8 to 1/16 mm) of Trail Ridge sands has a mean axial ratio (sphericity) of 0.66; that of kyanite-sillimanite from this same sand fraction also is 0.66. The shape of zircon is very difficult to change or modify, and it is believed that sediments of the immediate source region for Trail Ridge sands should have contained, or should contain, zircons with the same mean axial ratio as that of the zircons of Trail Ridge. The axial ratio of kyanite-sillimanite is easier to change or modify than that of zircon, and it is believed that the immediate source region for Trail Ridge sands should have contained kyanite-sillimanite with a mean axial ratio

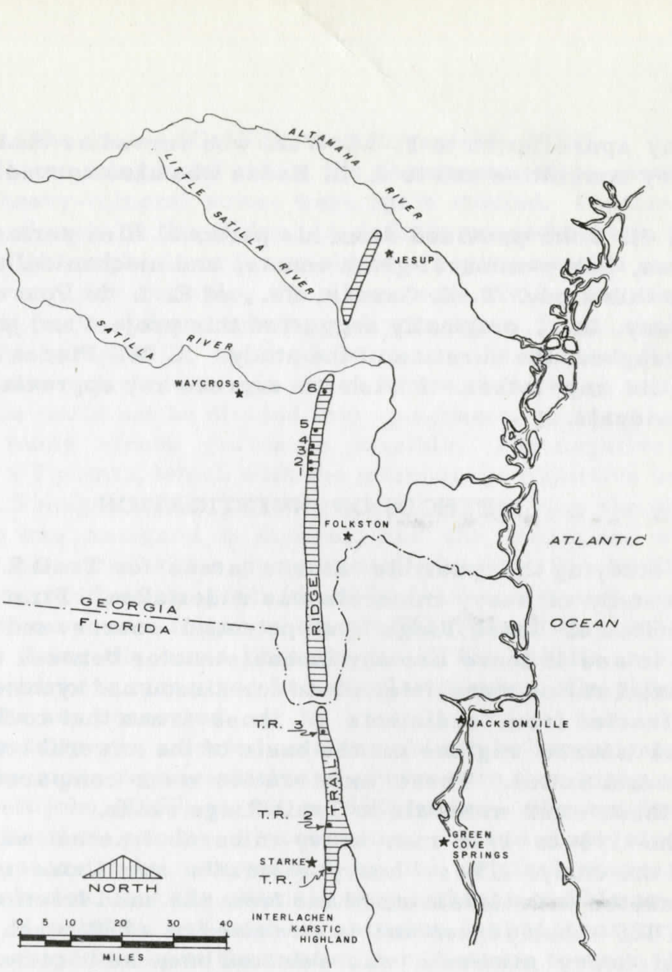

Figure 1. Location of Trail Ridge. The sites of Trail Ridge drill holes (T. R. 1, T. R. 2, and T. R. 3) and selected sample locations are shown.

either the same as that of Trail Ridge kyanite-sillimanite or perhaps slightly less. Zircon and kyanite-sillimanite were extracted from the sediments of regions which, according to the major hypotheses on the origin of Trail Ridge, could have been immediate source areas for Trail Ridge sands. A graphical evaluation of the sphericity of zircon and kyanite-sillimanite from the sediments of these possible source regions was undertaken to determine if such studies would indeed give insight into the problems of the source regions.

Acknowledgments

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W. H. Yoho provided from his personal files permanent-mount grain slides, heavy-mineral grain counts, and mechanical analyses required for this study. T. E. Garnar, Jr., of E. I. du Pont de Nemours and Company, Inc., originally suggested this project and gave valuable advice throughout the duration of the study. R. W. Pierce also offered advice as did my father. I wish to express my appreciation to all of these individuals.

METHODS OF INVESTIGATION

In studying the possible source areas for Trail Ridge sands a two-stage study of heavy minerals was undertaken. First, the heavy-mineral suites of Trail Ridge and potential source sediments were examined to see if there are any inconsistencies between these suites. Second, axial ratios were determined for zircon and kyanite-sillimanite grains extracted from sediments of those areas that could not be eliminated as source regions on the basis of the mineral composition of heavy-mineral suites. These axial ratios were compared to the axial ratios of these same minerals in Trail Ridge sands.

The 1/8 to 1/16 mm heavy-mineral fraction was used in all phases of the study. These heavy minerals are those minerals that were separated with tetrabromethane from the sand fraction that passed through a 120-mesh screen and was retained on a 230-mesh screen. This fraction of heavy minerals was selected because it contains all of the different types of heavy minerals in the sands, and because the axial ratio (sphericity) and grain size would be related. Pettijohn (1957, p. 60) states, "Actually in natural sediments not only are sphericity and roundness closely correlated with each other but each in turn is a function of size." A relationship between sphericity and size has been further substantiated by Lissiman and Oxenford (1973). Thus the same size fraction should be used in all investigations of this type in order to draw valid comparisons and conclusions.

In the first stage of this study, that of determining heavy-mineral suites, permanent slide mounts of the heavy minerals from Trail Ridge and from the sands of possible source regions were used. With the aid of a petrographic microscope a minimum of 300 heavy-mineral grains were identified on each slide.

The second stage of the investigation, the study of axial ratios, was applied to those potential source areas that could not be eliminated on the basis of the mineral components of the heavy-mineral suites. This portion of the investigation consisted of examining the axial ratio of zircon and of kyanite-sillimanite. The axial ratio is the width of the grain divided by its length. This biaxial value approximates the sphericity of the grains (Griffiths and Rosenfeld, 1950).

In determining axial ratios the permanent slide mounts used in examining heavy-mineral suites were again studied. Photomicrographs were made of each of the slides. A definite procedure was followed in taking the photographs in order to obtain a representative sampling. In studying zircon, for example, the slides were divided into four approximately equal parts and one photograph was taken from each quadrant. The field photographed in each quadrant was the one that displayed the greatest number of zircons. In cases where there were so few zircons that the slide could not be divided into quadrants, pictures were taken showing as many zircon grains as possible. The negatives were enlarged to 5 x 7 prints, which with the microscope objective used, resulted in an 87. 5 magnification of the grains. In studying the photographs each zircon was assigned a number, and the length and width of the grain were measured with a proportional divider. The width used was the maximum width of the grain (found by trail and error), and the length used was the maximum length of the grain perpendicular to the width measured. Using the same photographs all the kyanite and sillimanite grains present were measured in a similar manner. Graphical analyses of the results are presented.

Sphericity was selected as a variable to be investigated because it tends to be more representative of provenance than many other parameters. Pettijohn (1957, p. 66, p. 552) states, "Except for the slight shape modifications produced by abrasion, the end shape of a sand grain or pebble appears to be determined by its original shape... One may say, in conclusion, that the ultimate shape which a pebble or sand grain acquires is dependent not only on abrasion during transport, but also upon initial shape and upon the vectorial resistance to wear. In general, abrasive action during transport is not marked and the original shape seems not to be lost even by prolonged transport."

Zircon was selected for study because of its great resistance to abrasion; whereas, kyanite-sillimanite was chosen because of its relative ease in shape alteration. Hatch et al. (1952, p. 91) state, "...hard and stable minerals such as zircon, tourmaline, and rutile are almost indestructable, and are passed on from one sediment to another through many cycles of sedimentation. Such grains in time become smoothed and worn, but the process is very slow, and the well-rounded grains found in some sedimentary rocks indicate that the individuals in question are of very great geological age as detrital grains." In referring to shape studies Folk states (1968, p. 96), "...it is much more efficient to use soft heavy minerals like kyanite or amphiboles rather than hard quartz, as they are affected much more quickly."

CHARACTER OF TRAIL RIDGE SEDIMENTS

Sand Sizes

Trail Ridge sand is relatively coarse with more than 75 per cent of the sand particles falling into the medium (1/2 to 1/4 mm) and fine (1/4 to 1/8 mm) sand fractions (Pirkle, W. A., 1972). The grain-size distribution throughout the entire length and thickness of the ridge is remarkably uniform.

Heavy-Mineral Suite

The heavy-mineral suite of Trail Ridge sands consists of ilmenite, leucoxene, rutile, staurolite, zircon, kyanite, sillimanite, tourmaline, spinel, topaz, and corundum (Cannon, 1950; Garnar, 1972). Epidote and garnet are not present in the sediments. These two minerals are relatively easily weatherable in warm and humid climates (Sindowski, F. K. Heinz, 1949, p. 23; Folk, 1968, p. 98). Thus their absence in Trail Ridge sands is of much interest in evaluating source areas. If epidote and garnet were deposited in Trail Ridge sands and subsequently removed by weathering, the value of using these two minerals in drawing definitive conclusions relating to source regions would be minimal. If epidote and garnet, however, were never deposited in Trail Ridge sands, the use of the mineral composition of heavy-mineral suites in studying immediate source areas could be significant. Either the source area sediments would have lacked these two heavy minerals, or else any epidote or garnet eroded from the source regions was destroyed during transport from the source area to the site of Trail Ridge.

In the weathering environment to which the sands of northern Florida and southern Georgia have been subjected, high percentages of ilmenite alter to leucoxene before garnet and epidote are destroyed through weathering (Pirkle _et al._, 1974). Therefore, if garnet and epidote were original constituents of the sediments, they should still be present in the sediments if a substantial amount of ilmenite has not weathered to leucoxene.

A study of the existing relationships of ilmenite to leucoxene indicates that most of the leucoxene at Trail Ridge has resulted from the weathering _in situ_ of ilmenite. For example, the surface sands are relatively high in leucoxene and correspondingly low in ilmenite (Pirkle _et al._, Tables 3 and 6, 1970). Thus in the lower portion of the Trail Ridge sequence where ilmenite has not weathered to leucoxene, garnet and epidote should be present if originally deposited with the sediments. Epidote and garnet, however, are not present in these deeper Trail Ridge sands (Pirkle _et al._, Tables 3 and 6, 1970). Therefore it must be concluded that these minerals were not deposited in the sediments.

Furthermore it is not probable that epidote and garnet were removed during erosion and transport of sands from source areas to the site of Trail Ridge. During transport ilmenite did not alter to leucoxene. Therefore epidote and garnet should not have weathered during transport. Consequently it is believed that the immediate source area for Trail Ridge sands did not contain garnet and epidote.

POSSIBLE SOURCE REGIONS FOR TRAIL RIDGE SANDS

The major concepts that have been proposed for the origin of Trail Ridge require different sediment source areas. Coarse sands crop out along the valley walls of the Altamaha River just north of Trail Ridge. Because of their geographic position these sands must be considered as potential source sediments for Trail Ridge if the ridge built southward as a spit or bar in an ancient sea.

South of Trail Ridge there are vast areas underlain by sediments assigned to the Citronelle Formation by Cooke (1945). Cooke speaks of Trail Ridge as building northward as a spit or bar from islands in peninsular Florida and specifically mentions islands in the region of the southern part of Trail Ridge. These islands are composed of Citronelle sediments. Therefore the Citronelle sediments of peninsular Florida must be considered as potential source materials for Trail Ridge sands.

According to White (1970) and Pirkle, W. A. (1972), Trail Ridge formed as a beach ridge at the height of a marine transgression, the seas encroaching from the east and eroding into sediments of landforms to the west. The sources of sands accumulating along the shorelines were the sediments of the areas into which the seas were eroding. Therefore, according to this concept, the sediments of the high terraces west of Trail Ridge are major source materials for Trail Ridge sands.

In short, the most important possible source sediments for the building of Trail Ridge include (1) sediments north of Trail Ridge such as those that crop out along the Altamaha River, (2) sediments south of Trail Ridge such as the Citronelle sediments of peninsular Florida, and (3) sediments west of Trail Ridge such as the high terrace sands of the Northern Highlands. These are the potential source regions that were investigated in this study. The same principles and techniques utilized in the study could be applied to any other potential source sediments or source regions.

SEDIMENTS EXPOSED ALONG THE ALTAMAHA RIVER

W. A. Pirkle (1972) reports that at some sites along the Altamaha River near the northern end of Trail Ridge, coarse quartz sand almost identical in appearance to Citronelle sediments of the Lake Wales Ridge area of Florida are exposed in valley walls. A section was measured of these sands, and samples were collected and analyzed. More than 50 percent of the Altamaha sands fall into the coarse and medium

Table 1. Sediments from Exposure along West Side of Old Shrine Road at Altamaha River about 7 Miles North of Jesup, Georgia.

Percentages of Selected Heavy Minerals in 1/8 to 1/16 mm Fraction

Spl.*	Leucoxene in %	Ilmenite in %	Epidote in %	Garnet** in %	Hornblende in %
1	8.73	26.20	0.85	0.00	0.28
2	3.32	54.85	0.00	0.00	0.00
3	3.39	49.15	1.36	0.00	0.34
4	3.00	57.22	1.63	0.00	0.00

*Spl. 1 - Channel sample of sands from land surface to depth of 2 ft. 10 in.
Spl. 2 - Channel sample from 2 ft. 10 in. to 7 ft. 5 in.
Spl. 3 - Channel sample from 7 ft. 5 in. to 9 ft. 7 in.
Spl. 4 - Channel sample from 9 ft. 7 in. to 13 ft. 10 in.
**An ocassional grain of garnet was seen but none was positioned so as to be counted.

sand-size fractions (Pirkle, F., 1974). These sands, therefore, are sufficiently coarse to be the source sands for Trail Ridge.

The Altamaha materials, however, contain small quantities of epidote, hornblende, and occasional garnet grains (Table 1). These minerals are present within a few feet of the land surface. These same minerals were found in other samples of the coarse sands collected along the Altamaha River. The northern part of Trail Ridge begins only about 5 miles south of the Altamaha locality (Figure 1). Yet these Trail Ridge sands do not contain garnet, epidote, or hornblende, and leucoxene is abundant only in the upper few feet of Trail Ridge sands. The heavy-mineral suite of the Altamaha sediments, therefore, is not compatible with that of Trail Ridge, and the Altamaha sands must be eliminated as source sands for Trail Ridge.

Thus there remain two major regions to be considered as source areas for Trail Ridge sands. These two regions are the areas of Citronelle sediments underlying the Lake Wales Ridge south of Trail Ridge, and the area of high terrace sands to the west of Trail Ridge. The sands from both of these regions are sufficiently coarse to have been source sediments for Trail Ridge sands, and the sediments from both areas have heavy-mineral suites that are compatible with the heavy-mineral suite of Trail Ridge sands (Pirkle, F., 1974). Therefore the sediments of these areas require a more extensive treatment than that given for the sediments that crop out along the Altamaha River.

CITRONELLE FORMATION

The "Citronelle Formation" of peninsular Florida consists of

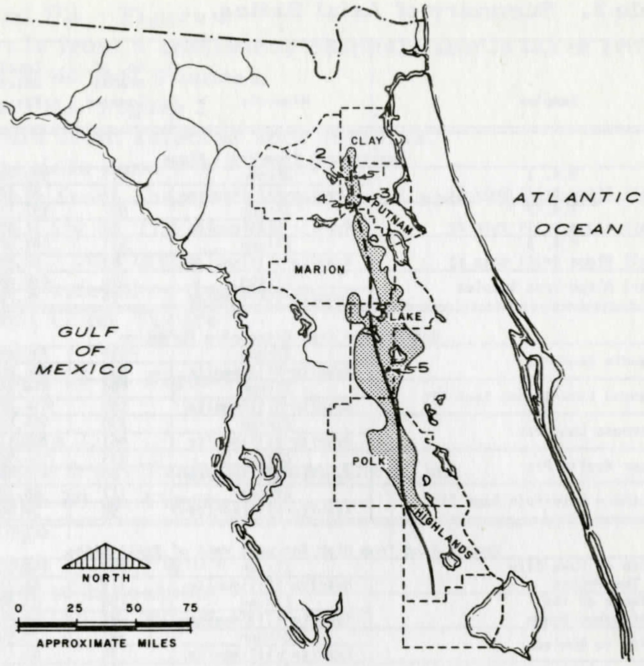

Figure 2. Lake Wales Ridge and sites of sand pits (.). Areas underlain by Citronelle sediments as mapped by Cooke (1945) indicated by stippled pattern. Crest of ridge shown by heavy black line. Numbers designate pits as follows: 1-Grandin sand pit, 2-Southern Materials sand pit, 3-Diamond Interlachen sand pit, 4-Edgar Plastic Kaolin Company pit, and 5-Clermont sand pit.

quartz sand and clayey sand that locally contain important quantities of quartzite granules and pebbles. The clay and coarse sand often occur together, but in some areas there is coarse sand containing little or no clay (Martens, 1928). These sediments underlie the Lake Wales Ridge, a long narrow highland trending northwest-southeast through the central part of the Florida peninsula (Figure 2). This ridge, dividing the peninsula into eastern and western halves, is a conspicuous landform from the northern part of Lake County southward for 120 miles to a point north of Venus in southern Highlands County. At one time the ridge continued northward from Lake County into Clay County where Citronelle sediments now mark its former position. The Interlachen Karstic Highland (Figure 1) is the northernmost area of the Florida peninsula in which Citronelle sediments crop out. The southern part of Trail Ridge rests against, and its sands cover, the northern parts of the Interlachen Karstic Highland.

Table 2. Summary of Axial Ratios.

Samples[1]	Minerals	No. of Grains Counted	Total Axial Ratio	Mean Axial Ratio
Quartz Sand from Trail Ridge				
T.R. 1 Trail Ridge Drill Hole #1	Zircon	611	399.44	0.65
	Kyanite-Sillimanite	57	38.28	0.67
T.R. 2 Trail Ridge Drill Hole #2	Zircon	587	397.11	0.68
	Kyanite-Sillimanite	92	62.89	0.68
T.R. 3 Trail Ridge Drill Hole #3	Zircon	431	287.62	0.67
	Kyanite-Sillimanite	93	59.19	0.64
Trail Ridge Spot Samples	Zircon	206	139.88	0.68
	Kyanite-Sillimanite	38	25.72	0.68
Quartz Sand from Citronelle Formation				
Grandin Sand Pit	Zircon	1238	799.23	0.64
	Kyanite-Sillimanite	532	300.00	0.56
Diamond Interlachen Sand Pit	Zircon	789	514.85	0.65
	Kyanite-Sillimanite	205	116.72	0.57
Clermont Sand Pit	Zircon	750	494.65	0.66
	Kyanite-Sillimanite	463	255.13	0.55
Edgar Kaolin Pit	Zircon	245	154.95	0.63
	Kyanite-Sillimanite	80	39.98	0.50
Southern Materials Sand Pit	Zircon	137	85.30	0.62
	Kyanite-Sillimanite	58	31.86	0.55
Quartz Sand from High Terraces West of Trail Ridge				
North of Lake City to The Pocket	Zircon	159	110.98	0.70
	Kyanite-Sillimanite	113	73.71	0.65
Islands of the Okefenokee Swamp	Zircon	130	91.68	0.70
	Kyanite-Sillimanite	72	43.88	0.61
Edith to Moniac	Zircon	112	73.58	0.66
	Kyanite-Sillimanite	78	53.10	0.68
Cowhouse Island	Zircon	15	10.50	0.70
	Kyanite-Sillimanite	19	12.77	0.67
High Terrace from Trail Ridge to Live Oak	Zircon	356	242.45	0.68
	Kyanite-Sillimanite	181	118.79	0.66
Waycross Ridge	Zircon	175	116.67	0.67
	Kyanite-Sillimanite	52	32.66	0.63
Hill areas west of Macclenny	Zircon	182	122.93	0.68
	Kyanite-Sillimanite	52	34.37	0.66

[1] Trail Ridge Drill Hole #1 (T. R. 1) - Figure 1
Heavy minerals from a continuous channel sample taken from land surface to depth of 63 feet.
Trail Ridge Drill Hole #2 (T. R. 2) - Figure 1
Heavy minerals from a continuous channel sample taken from land surface to depth of 46 feet 6 inches.
Trail Ridge Drill Hole #3 (T. R. 3) - Figure 1
Heavy minerals from a continuous channel sample taken from land surface to depth of 42 feet 6 inches.
Trail Ridge spot samples
Samples 1 through 6 on Figure 1.
Grandin Sand Pit - Figure 2
Heavy minerals from a continuous channel sample taken from land surface to depth of 62 feet 2 inches.
Diamond Interlachen Sand Pit - Figure 2
Heavy minerals from a continuous channel sample taken from land surface to depth of 43 feet 9 inches.

Clermont Sand Pit - Figure 2
Heavy minerals from a continuous channel sample taken from land surface to depth of 42 feet 9 inches.
Edgar Kaolin Pit - Figure 2
Heavy minerals from selected spot samples.
Southern Materials Sand Pit - Figure 2
Heavy minerals from channel samples and spot samples.
North of Lake City to The Pocket
Sites 1 through 5 on Figure 7.
Islands in the Okefenokee Swamp
Sites 6 through 11 on Figure 7.
Edith to Moniac
Sites 12 through 15 on Figure 7.
Cowhouse Island
Site 16 on Figure 7.
150-foot surface from Trail Ridge to Live Oak
Sites 17 through 29 on Figure 7.
Waycross Ridge
Sites 30 through 34 on Figure 7.
Hill areas west of Macclenny
Sites 35 through 39 on Figure 7.

Sand pits are present along most parts of the Lake Wales Ridge (Figure 2). These pits are the sites from which samples for this study were collected. In most deep pits three distinct zones can be observed. The upper-most zone is a surface blanket of loose quartz sand. Immediately beneath this surface material lies a red and yellow zone which, in turn, overlies a white zone. The sand in the white zone often ranges from very coarse to very fine and is cut by black stringers of heavy minerals. These zones, as well as sections, have been described by Pirkle _et al._ (1963, 1965).

Coarseness of Sediments

Mechnical analyses reveal that Citronelle sediments are definitely coarse enough to supply Trail Ridge sand (Pirkle and Yoho, 1970, Table 10), and a study of the heavy minerals (Pirkle _et al._, 1965, Tables 15, 16 and 17; Garnar, 1972) shows that Citronelle sands have a heavy-mineral suite compatible with that of Trail Ridge. On the basis of sand sizes and heavy-mineral suites the Citronelle sediments can be considered as potential source sediments for Trail Ridge sands. Thus the sphericities of zircon and kyanite-sillimanite were determined to see if conclusions based on that property can be drawn.

Sphericity of Zircon

Axial ratio data are given in Tables 2 and 3 for zircons extracted

Table 3. Total Sphericities.

Minerals	No. of Grains Measured	Total Axial Ratio	Mean Axial Ratio
Trail Rdige			
Zircon	1835	1224.05	0.66
Kyanite-Sillimanite	280	186.08	0.66
Citronelle			
Zircon	3159	2048.98	0.65
Kyanite-Sillimanite	1338	743.69	0.56
Areas West of Trail Ridge			
Zircon	1129	768.79	0.68
Kyanite-Sillimanite	567	369.28	0.65

from Trail Ridge and Citronelle sediments. Study of these data shows that the axial ratios (sphericities) of the zircon from Trail Ridge and Citronelle sands are the same. From a study of zircon sphericities the Citronelle sediments could be the source of Trail Ridge sands.

Sphericity of Kyanite-Sillimanite

Analyses of the kyanite-sillimanite from the Citronelle and Trail Ridge sands, however, bring out significant differences in sphericities (Tables 2 and 3). The mean axial ratio for kyanite-sillimanite from Trail Ridge sands is 0.66 while that from Citronelle sands is 0.56. Examination of both the frequency vs. axial ratio graph (Figure 3) and the per cent vs. axial ratio graph (Figure 4) for the Citronelle kyanite-sillimanite reveals that the mode in each case is the class that occurs between 0.40 and 0.50. In contrast, study of the same two graphs constructed for Trail Ridge kyanite-sillimanite (Figures 5 and 6) shows the modal class occurring between 0.60 and 0.70. Unless the reworking and redeposition of Citronelle sediments as Trail Ridge sands caused the Citronelle kyanite-sillimanite to achieve a marked increase in sphericity (from 0.56 to 0.66), the Citronelle sediments could not be the source materials of Trail Ridge sands.

Uniformity of Sphericity within the Sediments

Study of the axial ratios of kyanite-sillimanite in the Citronelle sediments brings out interesting relationships. The axial ratio of these minerals in the northern sector of the Citronelle (Grandin sand pit,

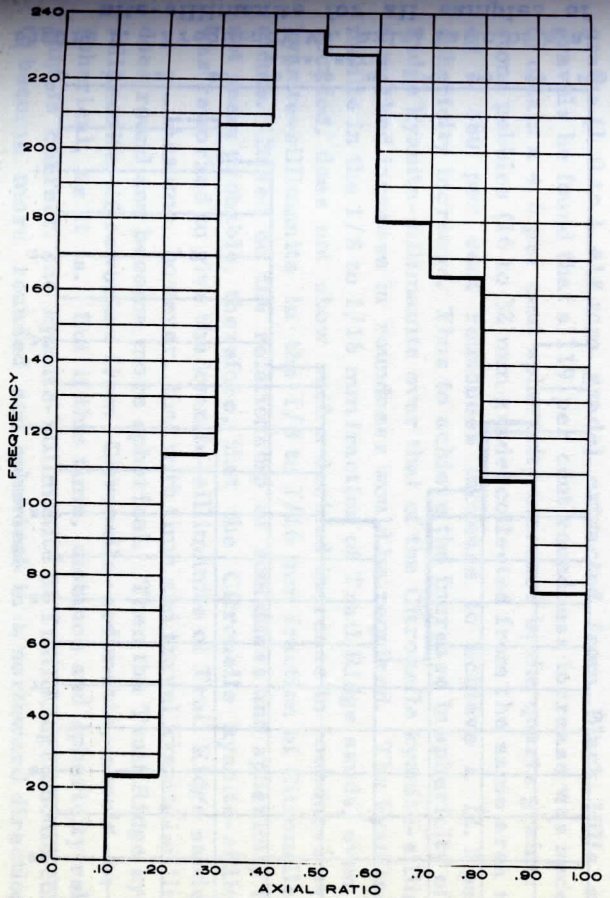

Figure 3. Frequency vs. axial ratio of kyanite-sillimanite for total Citronelle of peninsular Florida.

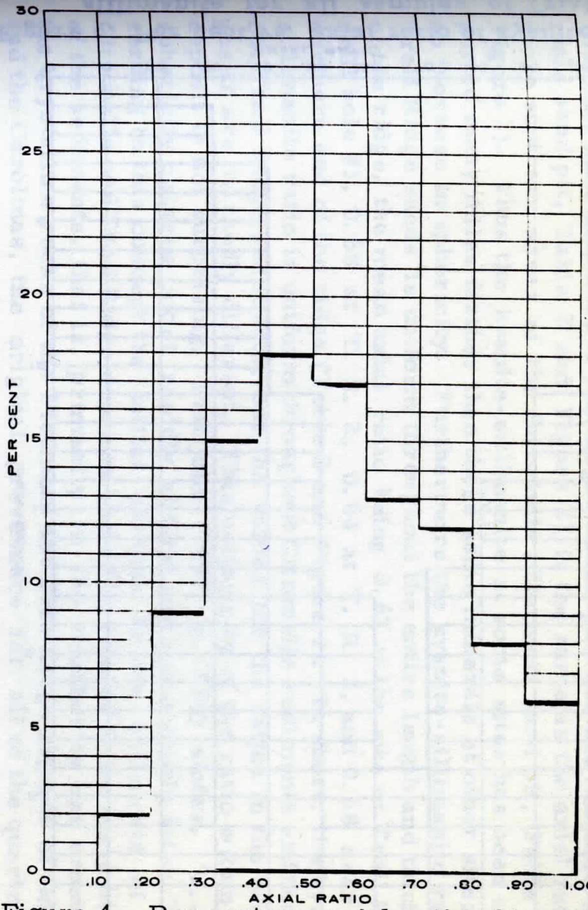

Figure 4. Per cent vs. axial ratio of kyanite-sillimanite for total Citronelle of peninsular Florida.

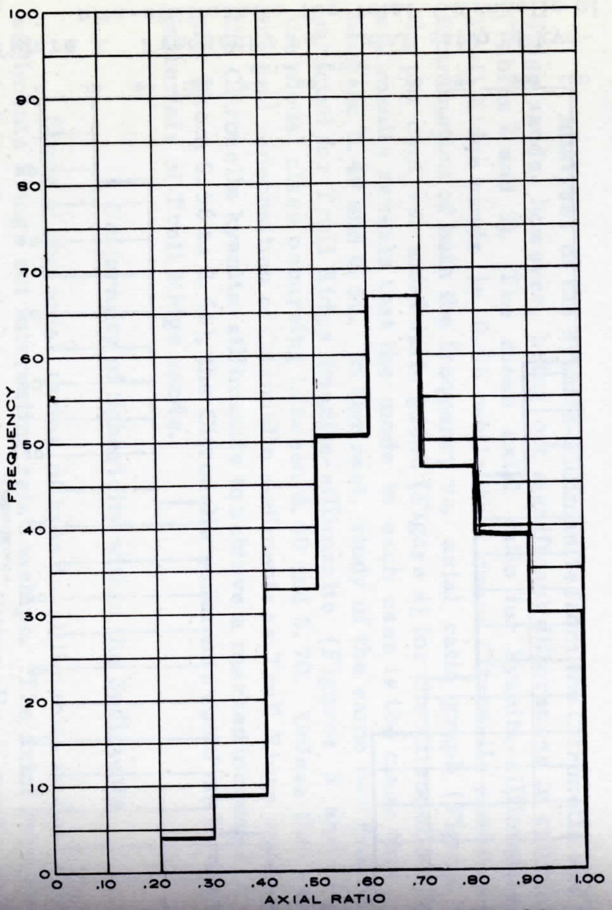

Figure 5. Frequency vs. axial ratio of kyanite-sillimanite for all samples of Trail Ridge sediments.

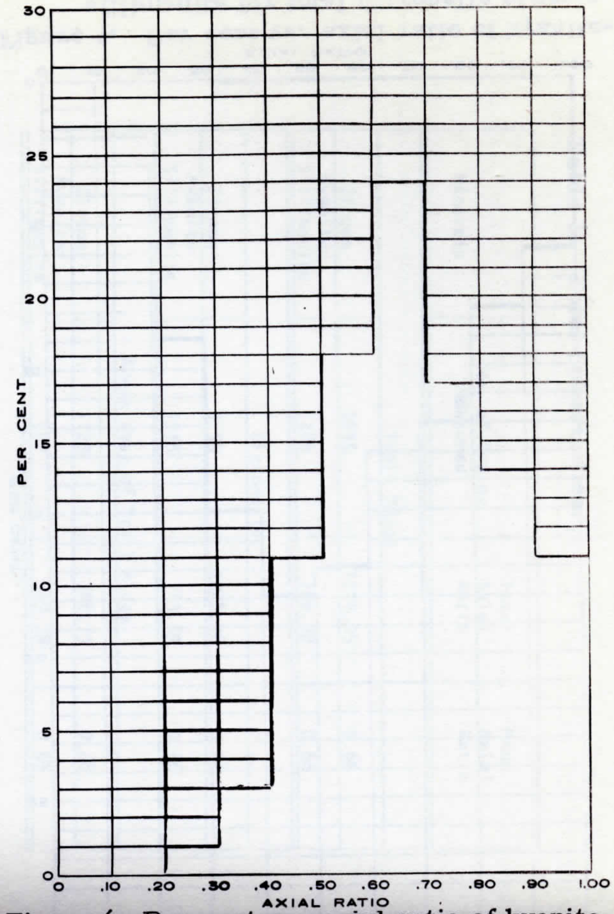

Figure 6. Per cent vs. axial ratio of kyanite-sillimanite for all samples of Trial Ridge sediments.

Diamond Interlachen sand pit, Edgar kaolin pit, and the Southern Materials sand pit, Table 2 and Figure 2) is the same as the axial ratio in more southern areas of the Citronelle (Clermont sand pit, Table 2 and Figure 2). Thus the kyanite-sillimanite at some sites has been transported many miles farther than these same minerals at other sites with no increase in sphericity. Furthermore the kyanite-sillimanite ratio in Trail Ridge sands is uniform throughout the entire length and thickness of the ridge, the mean axial ratio being 0.67 at the site of Trail Ridge drill hole #1, 0.68 at T. R. 2, 0.64 at T. R. 3, and 0.68 near the northern end of the ridge (Table 2 and Figure 1). In short, the kyanite-sillimanite ratio is uniform throughout Citronelle sediments and throughout Trail Ridge sediments, but the values for the ratios in the two deposits are markedly different. This uniformity of the ratio within each deposit is not surprising. Pettijohn (1957, p. 550) states, "... the sphericity changes most rapidly at first and more slowly later." According to this concept the initial changes in the sediments of the Citronelle and Trail Ridge deposits should be related to the early history of the sediments, that is, primarily to the weathering and erosion of the crystalline rocks of the Piedmont and Blue Ridge regions of Georgia and the Carolinas, the original provenance for all of the quartz sand and heavy minerals of the Citronelle and Trail Ridge sediments.

Relationship of Rounding and Sphericity

According to Pettijohn a great increase in rounding is needed to obtain an increase in the sphericity of sediments. Pettijohn (1957, p. 61) cites several examples to illustrate this point. In discussing quartz grains (1.0 to 1.414 mm grade) extracted from Black Hills stream gravels he found that a 119 per cent roundness increase was necessary to obtain a 4.6 per cent sphericity increase in the quartz grains. Limestone pebbles (16 to 32 mm grade) collected from the same area required a 380 per cent roundness increase to achieve a 12.3 per cent sphericity increase. Thus to achieve the increase in sphericity of Trail Ridge kyanite-sillimanite over that of the Citronelle kyanite-sillimanite a marked increase in roundness would be required. The kyanite-sillimanite in the 1/8 to 1/16 mm fraction of Trail Ridge sands, even though rounded, does not show such a decided increase in roundness over the kyanite-sillimanite in the 1/8 to 1/16 mm fraction of Citronelle sediments. Based on the relationship of roundness and sphericity it does not seem probable, therefore, that the Citronelle kyanite-sillimanite was reworked to give the kyanite-sillimanite of Trail Ridge sands.

Assume, however, that with time and travel kyanite-sillimanite does round and become more spherical. Then the Trail Ridge kyanite-sillimanite, if reworked from Citronelle sediments, should be more spherical, as it is. But if this time, distance and sphericity relationship is correct, the kyanite-sillimanite of Trail Ridge should continue to become more rounded and spherical in a northward direction, the direction of transport, which it does not. There is no real difference in the sphericity of kyanite-sillimanite along the entire length of Trail Ridge.

Fragmentation of Kyanite-Sillimanite

Fracturing of relatively large grains of kyanite-sillimanite during erosion of Citronelle sediments to give the more spherical kyanite-sillimanite of Trail Ridge sands might seem to be a logical way to obtain a marked increase in sphericity. More thought, however, tends to cast doubt on this process as an explanation to obtain the greater sphericity of Trail Ridge kyanite-sillimanite. For example, fracturing of a Citronelle kyanite grain larger than 1/8 to 1/16 mm could give grains with increased sphericity, but would not give 1/8 to 1/16 mm particles with sphericities greater than Citronelle unfractured 1/8 to 1/16 mm kyanite grains. Furthermore, one would expect that the fractured grains would be more angular than the unfractured grains. However, the sphericity of the 1/8 to 1/16 mm kyanite-sillimanite grains of Trail Ridge is much greater than the sphericity of the 1/8 to 1/16 mm grains of these same minerals in Citronelle sediments, and the kyanite-sillimanite grains of Trail Ridge are not any more angular than those of the Citronelle sediments. It does not seem, therefore, that the kyanite-sillimanite of Trail Ridge sands could have come from the fragmentation of Citronelle kyanite-sillimanite as Citronelle sediments were being reworked to form Trail Ridge sands. It must be concluded that the area of Citronelle sediments to the south of Trail Ridge is not a viable source region for Trail Ridge sands. Furthermore, Trail Ridge could not be a continuation of the Lake Wales Ridge.

Influence of Original Provenance

The last alternative in exploring the differences in the sphericity of kyanite-sillimanite in these sediments is to invoke the idea of original source regions, not immediate source areas. This concept is strengthened by the findings of several investigators. For example, Folk (1968, p. 14) says, "Impact fracturing of grains (i. e. breaking them into several subequally-sized chunks) is not an important process except possibly in mountain tourrents; 'normal' rivers carry few fractured pebbles, and beach or river sands only rarely contained rounded and refractured grains." Davies (1950) says "... within any one unconsolidated deposit, sand grains of given size have the same coefficient of angularity [sphericity]."

In summary, it does not seem probable that a ridge 130 miles in length could have kyanite-sillimanite grains which, from the reworking of local sediments, had increased in sphericity from 0. 56 to 0. 66 so uniformly along its entire length. It seems more likely that the sphericity of the grains reflects original provenance.

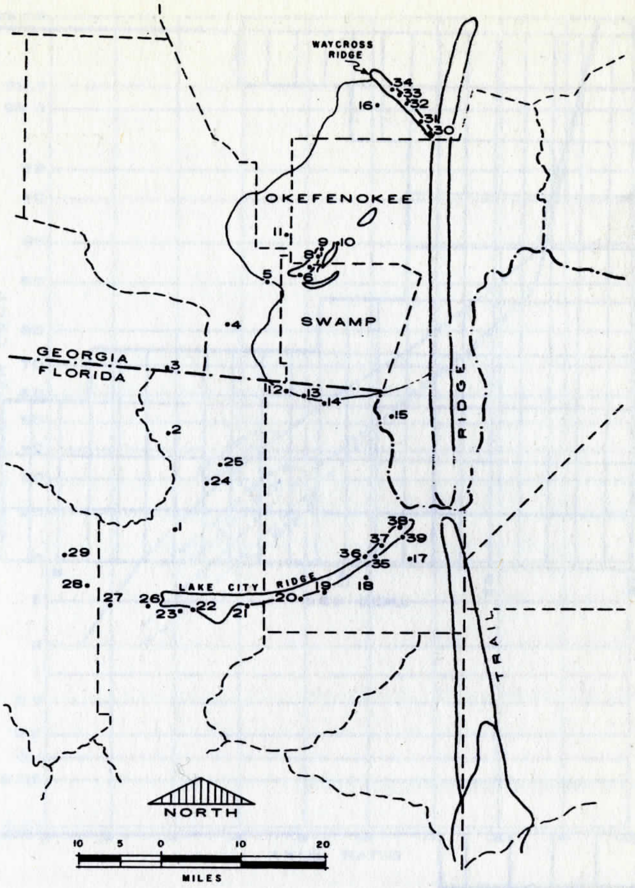

Figure 7. Sites west of Trail Ridge from which sands were collected and analyses run for particle size distributions, heavy-mineral suites, and sphericity studies.

HIGH TERRACE SANDS WEST OF TRAIL RIDGE

With the elimination of the Citronelle area as a source region there is only one major source region left for consideration. This last region is the area of high terrace sands west of Trail Ridge. Large areas of these sands have been dated as Pliocene by Brooks (1966). A study of mechanical analyses (Pirkle, F., 1974) indicates the presence in the sediments of medium and fine-grained sand particles in quantities sufficient for the sands to be source sands for Trail Ridge. Furthermore the heavy-mineral suite is the same as that of Trail Ridge (Cannon, 1950). Therefore, on the basis of sand sizes and heavy-mineral suites, the high terrace sands west of Trail Ridge, like the Citronelle sediments,

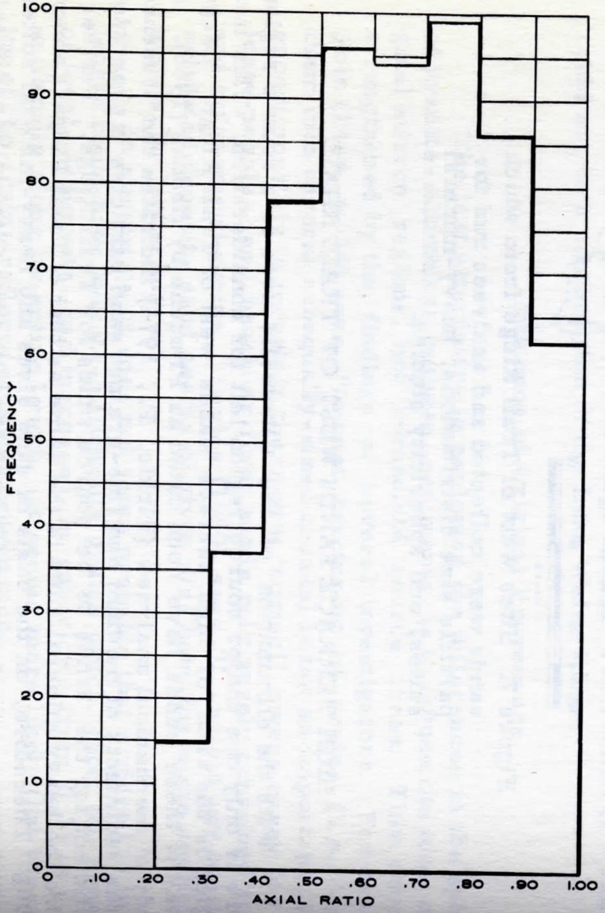

Figure 8. Frequency vs. axial ratio of kyanite-sillimanite for highterrace sands of the Northern Highlands west of Trail Ridge.

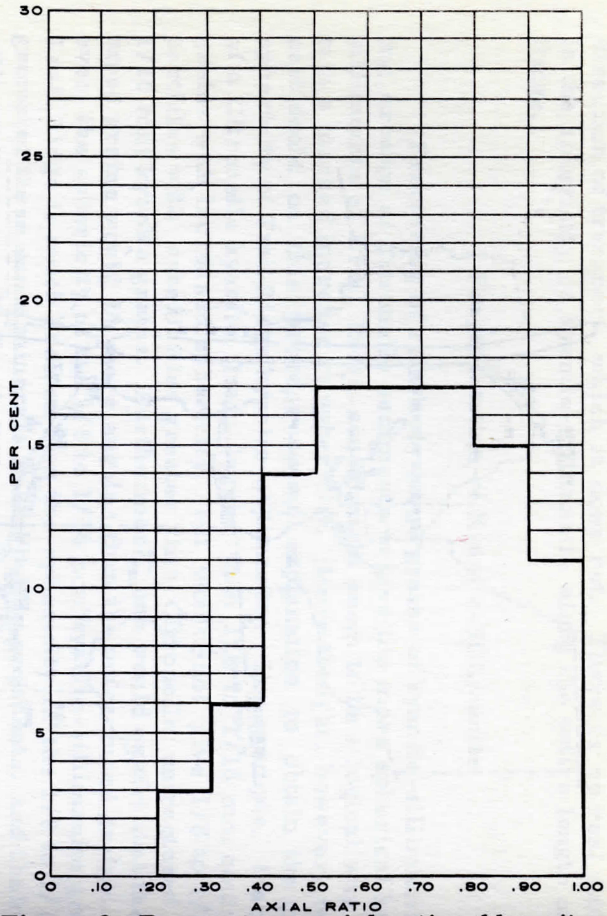

Figure 9. Per cent vs. axial ratio of kyanite-sillimanite for high terrace sands of the Northern Highlands west of Trail Ridge.

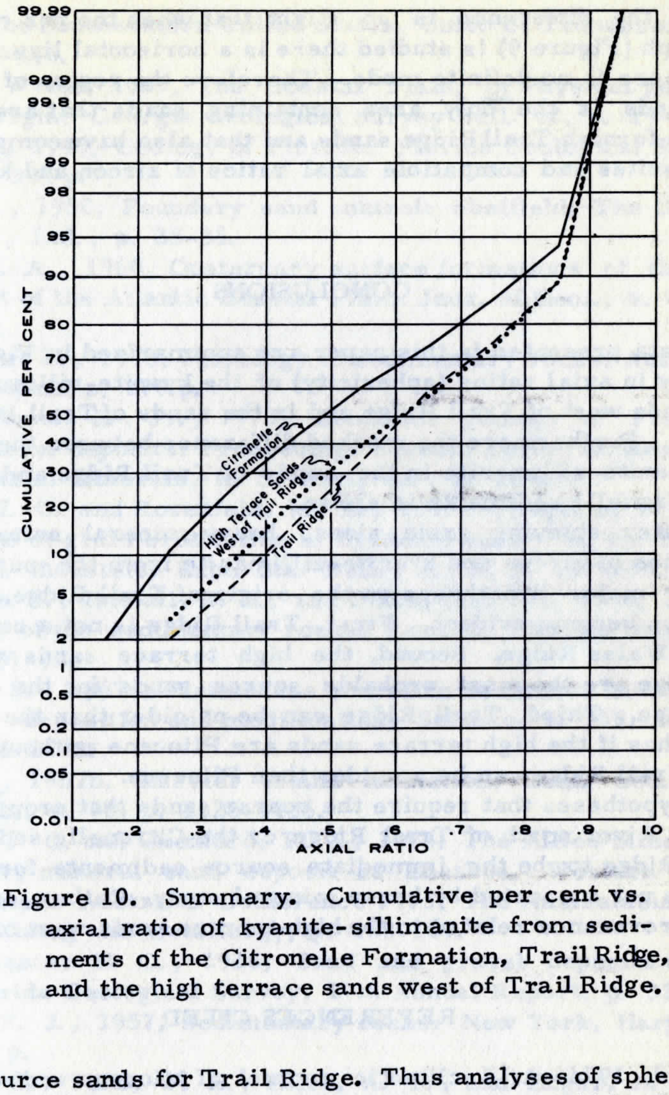

Figure 10. Summary. Cumulative per cent vs. axial ratio of kyanite-sillimanite from sediments of the Citronelle Formation, Trail Ridge, and the high terrace sands west of Trail Ridge.

could be source sands for Trail Ridge. Thus analyses of sphericity were undertaken to determine if definitive conclusions could be drawn based on that characteristic.

The zircon of the high terrace sands has an axial ratio (Tables 2 and 3; Figure 7) that is the same as that of zircon in Trail Ridge and Citronelle sands. Thus on the basis of the sphericity of zircon no definitive conclusions can be drawn. From a consideration of kyanite-sillimanite, however, definite results are obtained. The mean axial ratio of the kyanite-sillimanite in the high terrace sands west of Trail Ridge is 0.65 (Table 3), the same as that of Trail Ridge kyanite-sillimanite. The frequency graph (Figure 8) presents a bimodal picture with the two modes being the 0.50 to 0.60 and the 0.70 to 0.80 classes.

However, the difference is so slight that when the per cent vs. axial ratio graph (Figure 9) is studied there is a horizontal line from 0. 50 to 0. 80. There is no definite mode. Therefore the region of the high terrance sands is the only area containing sands that are sufficiently coarse to furnish Trail Ridge sands and that also have compatible heavy-mineral suites and compatible axial ratios of zircon and kyanite-sillimanite.

CONCLUSIONS

Data presented in this paper are summarized in Figure 10. The similarity in axial ratios (sphericity) of the kyanite-sillimanite present in the sands west of Trail Ridge and in the sands of Trail Ridge is clearly shown. Furthermore the marked difference between the axial ratios of the kyanite-sillimanite in the sands of Trail Ridge and in the sands of the Citronelle sediments is shown.

After studying grain sizes, heavy-mineral suites, and the sphericities of zircon and kyanite-sillimanite from the source areas required by major hypotheses on the origin of Trail Ridge, several relationships become evident. First, Trail Ridge is not a continuation of the Lake Wales Ridge. Second, the high terrace sands to the west of Trail Ridge are the most probable source sands for the sediments of Trail Ridge. Third, Trail Ridge can be no older than the high terrace sands. Thus if the high terrace sands are Pliocene as thought by Brooks (1966), Trail Ridge can be no older than Pliocene.

Hypotheses that require the coarse sands that crop out along the Altamaha River north of Trail Ridge or the Citronelle sediments south of Trail Ridge to be the immediate source sediments for Trail Ridge sands are not supported by heavy mineral study. Rather, evidence suggests a provenance related to the high terrace sands west of Trail Ridge.

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