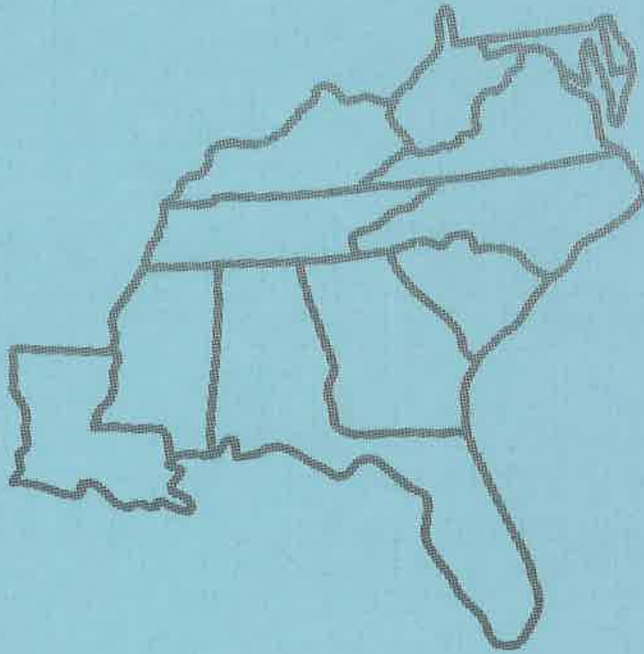
SOUTHEASTERN GEOLOGY



PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL. 15 NO. 4 APRIL, 1974

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY

AT

DUKE UNIVERSITY

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SOUTHEASTERN GEOLOGY

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Vol. 15, No. 4

1974

FACIES INTERPRETATIONS AND DIAGENETIC MODIFICATIONS OF THE SUNNILAND LIMESTONE, SOUTH FLORIDA

By

Stephen O. Sears
Department of Geology
University of Florida
Gainesville, Florida 32601*

ABSTRACT

X-ray and thin section analysis of cores from four wells penetrating the Lower Cretaceous Sunniland Limestone revealed five microfacies: (1) nodular anhydrite, (2) dolomite, (3) algal stromatolite, (4) biomicrite, biopelmicrite and pelmicrite, and (5) fossiliferous micrite, intraclast-bearing micrite and micrite. Evidence of supratidal to shallow water deposition is prevalent. Many samples have recrystallized to microspar and pseudospar. Correlation of facies between wells indicates one major and one minor regression during Sunniland deposition.

Interpretation of shelf and basin slope environments of deposition suggests that the oil-bearing rudistid shoal trend of the Sunniland and Forty Mile Bend Oil Fields might be encountered between the Gulf #1 State Lease 826-G and Humble #1 Collier Corporation wells of this report.

INTRODUCTION

The only oil-producing formation in peninsular Florida is the Sunniland Limestone of Lower Cretaceous age. Petroleum has been found in the Sunniland, Sunoco Felda, West Felda and Lehigh Acres fields in Collier County, and in the now abandoned Forty Mile Bend Field in Dade County. Previous work on this formation has included stratigraphy, structure, paleontology, geophysical and geothermal measurements, and general lithologic descriptions. However, no quantitative petrographic or mineralogic data has been published on the Sunniland Limestone. The purpose of this paper is to present quantitative descriptions, to identify various microfacies and their environments of deposition, and to describe the effects of diagenesis.

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

Acknowledgments

The research for this paper was done in partial fulfillment of the requirements for the degree of Master of Science at the University of Florida. I would like to thank G. M. Griffin, who was chairman of my committee and directed the research, H. J. Bissel and A. F. Randazzo for advice concerning the thin section work, R. G. Stevenson of the University of South Florida for loaning the well cores, and J. E. Banks of Coastal Petroleum Company for providing logs of the wells studied. Appreciation is also due to the graduate school and the Department of geology of the University of Florida for financial support.

STRATIGRAPHY AND CORRELATION

The name Sunniland Limestone was first published by Pressler (1947), and was formally introduced by Applin (1960, p. B209) as, "... a subsurface unit of Middle Trinity age (Comanche) in southern Florida ... " Applin described the Sunniland as (p. B209), "... composed chiefly of limestone, dolomite and shale. It overlies the so-called 'thick anhydrite' or 'lower anhydrite' unit and underlies the so-called 'upper anhydrite' unit, both of Trinity age.... "

Applin and Applin (1965) designated as a type section for the Sunniland Limestone Humble Oil & Refining Co.'s #2 Gulf Coast Realties Corp., from 11,600 feet (4,890 meters) to 11,875 feet (5,700 meters) in depth. The location of this well is shown on Figure 1.

The relationship of the Sunniland Limestone to the formations immediately above and below in the type section well is illustrated in Figure 2. The Lake Trafford Formation, named by Oglesby (1965) corresponds to the "upper anhydrite" of Applin (1960), and the Punta Gorda Anhydrite (Applin and Applin, 1965) is the equivalent of the "thick anhydrite" or "lower anhydrite" unit of Applin (1960). This unit is commonly referred to as the "lower massive anhydrite" in the petroleum industry.

Applin and Applin (1965) mapped the Sunniland Limestone in the subsurface in Florida, and described the characteristic faunal feature as the close association of Orbitolina texana and Dictyoconus floridanus, two foraminifera. They listed 70 wells and gave the depth and thickness of the formation in each well. Four of these wells were selected for this study. (Figure 1 and Table 1).

PROCEDURES

Thin sections and x-ray mounts were made from one hundred and two samples of the Sunniland Limestone, Punta Gorda Anhydrite, and Lake Trafford Formation. Samples were spaced so as to sample

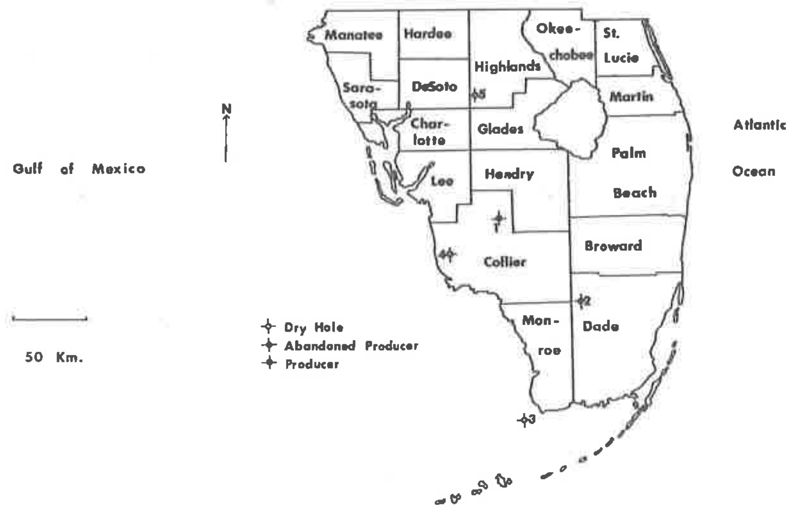

Figure 1. Location of wells studied and type section well.

significant lithologic types rather than at predetermined depth intervals. Three hundred points were counted per slide and percentage determinations made for: intraclasts, oolites, pellets, sparite, micrite, fossils, dolomite rhombs, anhydrite and pores. X-ray mounts consisted of ground powder that had been passed through a 325 mesh sieve and mounted on glass slides. The relative abundance of calcite and dolomite was determined from the 2.88 Å/3.03 Å peak height ratios using the curve of Griffin (1971) to calculate percentages.

DESCRIPTION OF SUNNILAND FACIES

Combined x-ray diffraction and thin section analysis permitted five facies to be recognized in the Sunniland Limestone:

1. a nodular anhydrite facies
2. a dolomitic facies
3. an algal stromatolite facies
4. a pelmicrite, biopelmicrite, biomicrite facies
5. a fossiliferous micrite, intraclast-bearing micrite and micrite facies

The classification of Folk (1962) is followed for the limestone and dolomite facies, and the descriptions of Murray (1964) are used for the anhydrite.

Nodular Anhydrite Facies (Figure 3A)

This facies was encountered in 13 samples from 3 types of stratigraphic situations: (1) in the Punta Gorda Anhydrite, (2) in the

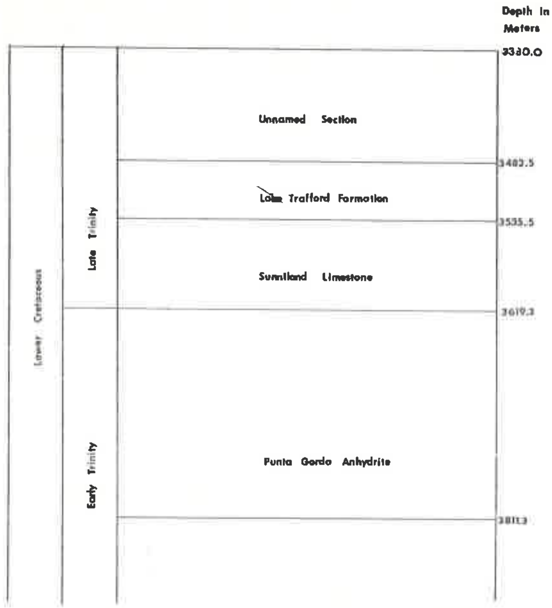

Figure 2. Relationship of Sunniland Limestone to formations above and below in type section well - Humble Oil and Refining Co., #2 Gulf Coast Realties Corp. (After Applin and Applin, 1965, and Oglesby, 1965.

Table 1. Well Names, Locations, Status and Depth.

Well Number in Figures 1 and 5	Well Name	Status	Location	Sampled Intervals
2	Commonwealth Oil Co., #1 M. B. Wisehart - State Board of Education	Abandoned Producer	Dade County T54S, R34E, sect 16	3443.8 - 3515.7 meters
3	Gulf Oil Corps., #1 State Lease 826-G	Dry Hole	in Florida Bay Lat 25° 0' 53" N, Long 81° 5' 54" W	3567.5 - 3632.4 meters
4	Humble Oil & Refining Co., #1 Collier Corp.	Dry Hole	Collier County T50S, R26E, sect 27	3766.2 - 3788.2 meters
5	Continental Oil Co., #1 G. C. Carlten et al.	Dry Hole	Highlands County T38S, R28E, sect 20	3127.7 - 3163.4 meters

middle of the Sunniland in the Gulf #1 826-G well, and (3) in the Lake Trafford Formation.

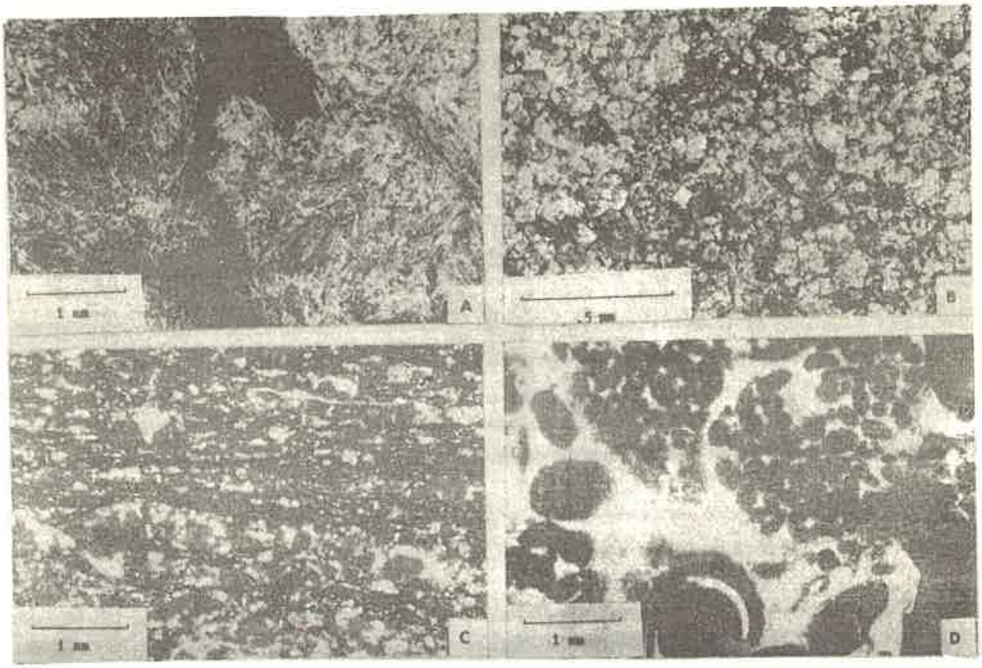

Figure 3. A. Nodular Anhydrite. Fibrous crystals are anhydrite, dark material in center is dolomite; Continental #1 Carlton, 3163.3 meters. (X-Nicols).

B. Crystalline dolomite, obliterating original texture; Continental #1 Carlton, 3149.0 meters.

C. Algal stromatolites. Dark areas are algal laminations, white areas are pseudospar and sparite, and gray material is micrite; Gulf #1 St. Lse 826-G, 3629.3 meters.

D. Recrystallized biopelmicrite. A gastropod filled with pellets and surrounded by pseudospar, Gulf #1 St. Lse. 826-G, 3628.3 meters.

The anhydrite occurs as nodules surrounded by thin layers of micrite and dolomite rhombs. Collectively the nodules compose 50 to 99.7 percent of the rocks. Within the nodules fibrous anhydrite crystals 30μ to 60μ long are most common, with occasional square and rectangular crystals from 12μ to 300μ on a side. X-ray diffraction revealed the surrounding micrite to vary from 100 percent calcite to 100 percent dolomite. Dolomite rhombs from 30μ in the long diagonal dimension are present in the micrite of many of the thin sections. Styolites occur in the micrite and continue into the anhydrite, where they become obscure.

No fossils were observed in the anhydrite nodules. If present in the surrounding micrite they were too sparse to be recorded by point counting. However, a few miliolid foraminifera were observed in the Lake Trafford Formation of the Humble #1 Collier well.

Both Murray (1964) and Kerr and Thompson (1963) inferred this type of anhydrite to result from the recrystallization of gypsum formed by displacement of the host sediment in supratidal areas. They believe that relatively dense hypersaline water produced by evaporation of sea water moved downward through preexisting sediment; gypsum, crystallizing from the water, pushes aside the mud in which it forms. Later, with burial and consequent increase in temperature, the gypsum recrystallizes to anhydrite. Formation of gypsum through the first phase of this process has been observed by Kerr and Thompson in the Laguna Madre of Texas, by Illing and others (1965) in the sebkha flats of the Persian Gulf, and by Deffeyes and others (1965) in Bonaire, Netherlands Antilles. It is believed that the anhydrite noted in this facies resulted from post-burial alteration of gypsum as described above.

Dolomitic Facies (Figure 3B)

Dolomite, identified by x-ray diffraction, was found in 58 samples. The amount of dolomite expressed as a percentage of the total carbonate fraction ranged from barely detectable (but too small to be quantified) to 100 percent; 37 samples contained enough dolomite to be measured by the curve method of Griffin (1971). In 6 of the thin sections, dolomite rhombs constituted over 50 percent of the rock, ranging up to 99 percent in the Continental #1 Carlton well. Where dolomitization had not completely obliterated the preexisting fabric of the rock, all the other facies of the Sunniland Limestone were found among the 37 samples.

Rhombs were observed ranging from 10μ to 750μ along the long diagonal. Replacement and pore-filling anhydrite (Murray, 1964) were associated with many of the dolomites, along with a vuggy porosity.

The formation of dolomite by reflux of hypersaline waters through preexisting sediment in supratidal areas was demonstrated by Deffeyes and others (1965), Illing and others (1965), and Shinn and others (1965). On a geologic time scale this method can be considered penecontemporaneous with sedimentation. An alternative process was proposed by Hanshaw and others (1971), involving dolomitization long after deposition by movement of brackish ground water.

Evidence of supratidal environments including algal stromatolites, nodular anhydrites and birdseye fillings indicate that the first method stated above was probably responsible for much of the dolomite of the Sunniland Limestone. The Hanshaw and others model requires an effective circulation system to recharge the brackish water with magnesium ions. The effective seal of the nodular anhydrite above and below would tend to prevent this type of mixing process in the Sunniland Limestone.

Algal Stromatolite Facies (Figure 3C)

This facies is characterized by thin (about 30 μ) layers of brownish red material, running the entire length of the thin section. Although many of the rocks not included in this category had evidence of algae, only 19 thin sections which had more than one lamination crossing the entire thin section are included here. Under high magnification, the layers show up as aggregates of very fine filaments, with over 100 filaments per layer. The laminations are wavy, with an amplitude about five times their thickness. They often split and then come together again, enclosing a lenticular space. The layers may include a lense of biomicrite while the rest of the thin section is micrite. Material trapped by the algae includes skeletal fragments, intraclasts and pellets. Allochems are well sorted, mostly between 0.1 and 0.3 mm. Many of the fossils are unbroken, and the edges of the broken ones are angular. Foraminifera, including Orbitolina Texana, are predominant.

Recrystallization of the matrix to microspar and pseudospar was recognized, as well as sparite filling in birdseye cavities and veins created through the dessication of algal material.

The algal facies in the Sunniland Limestone suggests a supratidal and intertidal environment. Inferred is an elevation slightly lower than the dolomite and nodular anhydrite sebkha flat environment and higher than the biomicrite, biopelmicrite, and pelmicrite facies described below. A slight drop in sea level could generate supratidal conditions and produce dolomitization of the algal facies. Although algal mats have been reported in the subtidal environment, crinkling of the laminations and the presence of birdseye fillings indicate periodic subaerial exposure. Shinn (1968) suggested that the voids which later form birdseye structures are produced by air bubbles, and that fairly stiff supratidal sediments are necessary for their preservation, since these voids would collapse before lithification in soft subtidal mud.

Pelmicrite, Biopelmicrite and Biomicrite Facies (Figure 3D)

Folk (1962) defined these rocks as having greater than 10 percent allochems, with less than 25 percent of the allochems composed of intraclasts or oolites. If the ratio of fossils to pellets is greater than 3:1, the rock is a biomicrite, if it is less than 1:3; it is a pelmicrite, and if it is between 1 and 3 it is a biopelmicrite. Biomicrites were represented by 9 samples, biopelmicrites by 7 samples, and pelmicrites by 3 samples.

Fossils encountered were pelecypods, gastropods, algal filaments and foraminifera including Dictyoconus floridanus and Orbitolina texana. Skeletal particles were mostly unbroken, with the few broken fragments having angular edges. The fossils were poorly sorted, with sizes ranging from 0.03 mm to larger than the thin section.

Pellets are assumed to be mostly fecal in origin, although some may represent intraclast type particles less than 0.2 mm in diameter. Two thin sections contained several small gastropods almost completely filled with pellets (Figure 3D). Pellet sizes ranged from 0.05 mm to 0.2 mm.

Secondary alterations of the fabric included (1) replacement and porefilling by anhydrite; (2) recrystallization of calcite to microspar or pseudospar; (3) dolomitization; (4) solution, as indicated by styolites; and (5) infilling with sparry calcite of cavities produced by decay of organic material.

Fossiliferous Micrite, Intraclast-bearing

Micrite and Micrite Facies

These rocks are defined by Folk (1962) as being composed of micrite with less than 10 percent allochems. Micrite has less than one percent allochems, fossiliferous micrite and intraclast-bearing micrite have between one and 10 percent. If intraclasts are more than 25 percent of the allochems present, it is intraclast-bearing micrite, otherwise it is fossiliferous micrite if the fossils are more numerous than pellets. In this study, fossiliferous micrite was represented by 27 samples, intraclast bearing micrite by 3 samples and micrite by 18 samples.

Allochems included pellets, intraclasts, and the same fossils described in the previous facies with the exception of gastropods. Fossils were mostly unbroken or angular fragments. Secondary alterations included replacement and pore-filling with anhydrite, recrystallization of calcite into microspar and pseudospar, and dolomitization. In several thin sections, decay of organic material had provided voids which were filled with sparry calcite cement.

It is difficult to say anything about the environment of deposition of these rocks, except that it was of low energy. Samples containing fossils and pellets probably originated in the same environment as the biomicrite, pelmicrite and biopelmicrite described in the previous section, where these constituents were less concentrated.

RELATION OF SUNNILAND FACIES TO SEA LEVEL

Figure 4 is a cross section of the environments which are believed to have existed at the time of formation of the Sunniland Limestone and which produced the facies described above. Changes in the depositional facies could have been caused by changes in local conditions, such as opening of tidal passes, local subsidence, differing rates of deposition, or changes in the shoreline produced by hurricanes. Regional transgressions and regressions caused by wider spread changes

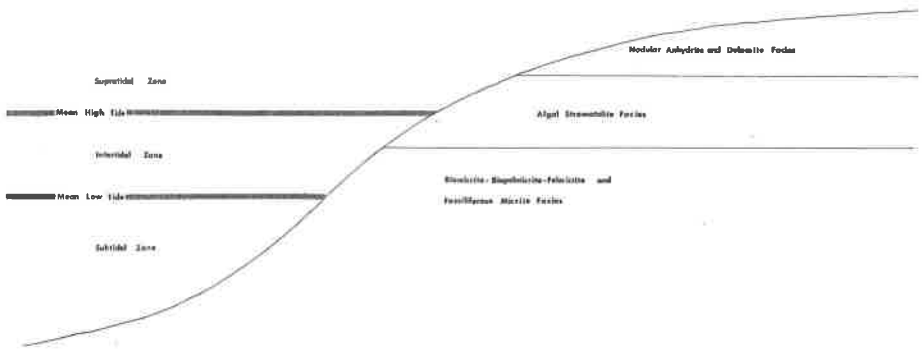

Figure 4. **Relationship** of Sunniland Limestone Facies to sea level.

in sea level could also have produced transitions from one depositional facies to another.

PALEOGEOGRAPHY

The following structural features (Figure 5) are assumed to have been influential in the deposition of the Sunniland Limestone:

1. The South Florida Embayment (Pressler, 1947), a term used interchangeably with South Florida Basin, designated an area of long continued subsidence in southern Florida, the southeastern Gulf of Mexico, and the Bahamas. Various reports (Winston, 1971a and 1971b; Applin and Applin, 1965; Oglesby, 1965) place the boundaries of this basin at different places during geologic time, and its actual configuration is still rather vague.

2. The Peninsular Arch (Applin and Applin, 1965) is a residual, relatively positive, structural high composed of igneous, metamorphic and pre-Mesozoic rocks. It plunges toward the southeast, forming the northeast flank of the South Florida Basin.

3. The South Florida Shelf (Applin and Applin, 1965) is a broad flat area in the Comanche rocks, southwest of the Peninsular Arch. The Applins indicated that it might continue around the eastern end of Florida Bay and then trend southwest parallel to the Florida Keys. Data from the present study substantiates their interpretation.

4. The Pine Key Arch (Winston, 1971a and 1971b) is a structural high paralleling the Florida Keys on the southeast side. Winston suggests that it forms the south flank of the South Florida Basin, and the present report indicates that this was true during Sunniland deposition.

5. The Largo High (Winston, 1971a and 1971b) is a structural high trending southeast located south of Key Largo. It is more prominent than the Pine Key Arch.

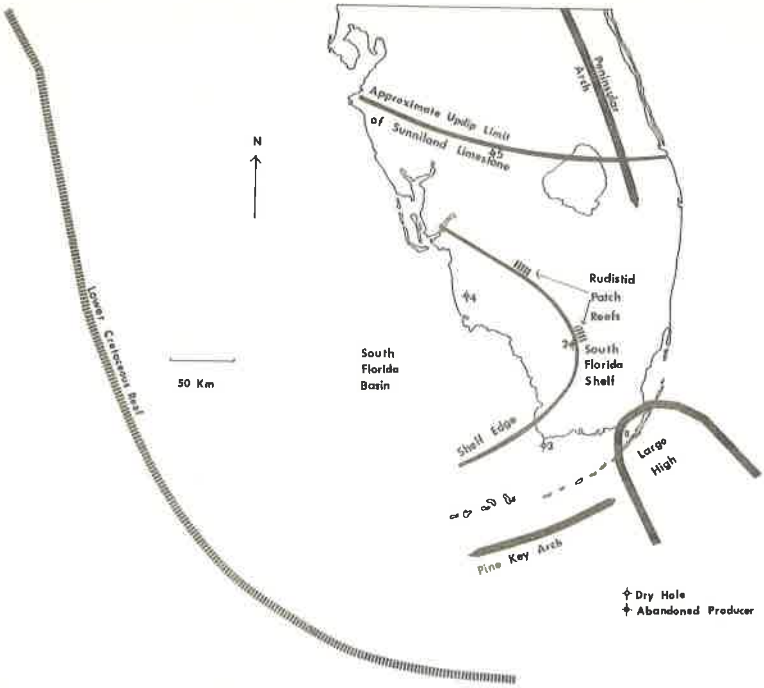

Figure 5. Postulated paleogeography of South Florida Basin during Sunniland deposition. (After Applin and Applin, 1965, Winston, 1971a and b, and Bryant et al, 1969, with additions based on the present study.)

6. The Lower Cretaceous Reef Trend along the Florida Escarpment (Antoine and others, 1967; and Bryant and others, 1969), although not a structural feature, is important because it is believed to have formed the western rim of the South Florida Basin during deposition of the Sunniland Limestone. Seismic profiles, samples dredged from the escarpment, and submarine photographs all indicate the presence of this reef. Its existence created a large back-reef area in the South Florida Basin.

An examination of the map in Figure 5 shows three types of environments: basin, shelf edge and shelf. Facies interpretations indicate the position of each of the four wells studied in relation to these three environments, as described below.

Humble #1 Collier Corporation (#4 in Figure 5)

The section in this well is thinner (69 feet, 21 meters) than in any of the other wells studied in this report, which were all over 100 feet (26.2 meters). It contains rocks of a type not seen in any of the other three wells examined in this study. These samples are micrites darker colored than any of the other rocks studied, containing no more than one percent fossils, and producing a strong odor of hydrogen sulfide during the sawing and grinding of thin sections. No dolomite was detected in x-ray diffraction patterns of these samples.

Applin and Applin (1965) compared the thickness and lithofacies of this well to wells in the Sunniland Oil Field. They postulated that the Sunniland Field was located on the northeast rim of a rapidly subsiding basin, of which the Collier Well of this report is representative. They compared this well with the starved basin environment described by Adams and others (1951) in the Pennsylvanian of west Texas. It is possible that the rocks described above are from a stagnating, oxygen depleted environment below wave base, in a basinal environment similar to that proposed by the Applins (1965).

Thin section and x-ray analyses of other samples from this well reveal the presence of algal stromatolites, miliolid foraminifera (also reported by Oglesby, 1967), and dolomite, suggesting that shallow water to supratidal conditions prevailed at the well site for at least part of Sunniland deposition.

The presence of both shallow and possible basinal rocks in this well suggests that it was located on the basin slope, seaward of the edge of the South Florida shelf. Changes in sea level could have produced rapid migration of facies, leading to abrupt vertical changes from shallow water to basinal type rocks in the stratigraphic column.

Gulf #1 826-G and Continental Carlton et al.

(#3 and #5 in Figure 5)

Samples from the Sunniland Limestone in both of these wells appear to be typical shelf deposits. The presence of 100 percent dolomite rocks in the Carlton well and 40 feet (12.2 meters) of nodular anhydrite in the 826-G well are indicative of prolonged supratidal environments. The 826-G well also contains a greater amount of algal material than any of the other wells. The Peninsular Arch probably limited carbonate deposition north of the Carlton well, and the 826-G well is postulated to have been on a shelf sloping gently northward from the Pine Key Arch. The absence of nodular anhydrite in the Carlton well may have been caused by greater rainfall and fresh water runoff due to a closer proximity to land. Shinn and others (1965) reported dolomite forming in the absence of gypsum on Andros Island, Bahamas, and attributed the absence of evaporites to washing away by spring and storm tides and rain.

Commonwealth #1 Wisehart-State Board of

Education (#2 in Figure 5)

The degree of dolomitization in this well is relatively low, comparable with that of the #1 Collier, suggesting an environment which was not subjected to supratidal conditions for the length of time of the 826-G and Carlton wells. The most common rocks in this well are pelmicrites, biomicrites and fossiliferous micrites. These facies, plus the location of the well just to the basinward side of a rudistid shoal, suggests that the #1 Wisehart well was at the top of the basin slope, but not as far seaward of the shelf edge as the #1 Collier well.

Location of the Shelf Edge

The interpretation of the environment of deposition of the four wells studied permits the shelf edge to be approximated in Figure 5. Applin and Applin (1965) interpreted the edge of the Sunniland Oil Field to be at the northeast edge of the basin. The location of this field between the shelf facies characteristic of the Carlton well and the basin slope characteristic of the Collier well substantiates this. Southward, the Wisehart well falls near the top of the basin slope, which was apparently located just west of the Forty Mile Bend Oil Field. The rudistid shoal characteristic of the top part of the section in these oil fields (Raasch, 1954, and Banks, 1960) agrees with this interpretation.

South of the Forty Mile Bend Field, the shelf edge appears to swing southward, paralleling the Florida Keys. It must pass somewhere between the shelf facies of the 826-G well and the basin slope facies of the Collier well. At the present time, no wells have been drilled along this potential trend, so the exact location of the shelf edge is speculative.

The rudistid shoals of both the Sunniland and Forty Mile Bend Oil Fields are located along the edge of this shelf, making its location of economic as well as scientific interest. Due to the presence of a much larger, more continuous reef further west, along the Florida escarpment, (Bryant and others, 1969), the rudistid shoals were probably patch reefs, comparable to the coral patch reefs being formed behind the Florida Keys reef tract today. The edge of the South Florida Shelf was probably at the top of a gentle slope rather than an abrupt break to deeper water, with the Florida escarpment further to the west being the point where very deep water began.

SEQUENCE OF EVENTS DURING SUNNILAND DEPOSITION

Examination of the cross section in Figure 6 shows a major dolomite-evaporite facies present in the middle of the Sunniland Limestone in all four wells studied, in addition to a lesser dolomitic facies

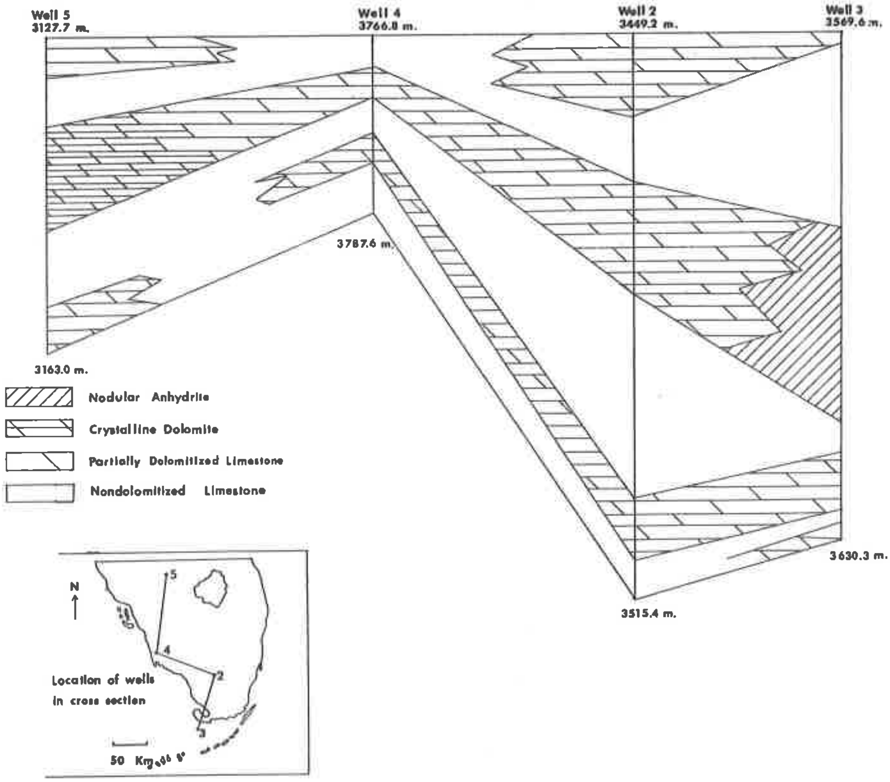

Figure 6. Diagrammatic cross section of the Sunniland Limestone, showing stratigraphic position of dolomite-evaporite facies.

in three of the wells. This study has resulted in the following interpretation of the depositional history of this formation.

Following deposition of the Punta Gorda Anhydrite, a transgression caused the eastward migration of marine facies, with deposition of a basal limestone, including algal stromatolite; biomicrite - pelmicrite - biopelmicrite; and fossiliferous micrite - intraclast-bearing micrite - micrite facies. A dolomitic facies is present above this in the #1 826-G, Collier and Wisehart wells, suggesting a possible minor regression at this point. This facies is not represented in the Carlton well, possibly because samples from the proper intervals were not available.

A second limestone occurs above the dolomitic facies, including all the limestone facies mentioned above. This indicates either another transgressive phase, or a continuation of the first one with local conditions producing the dolomitic facies immediately below.

After deposition of the second limestone unit, there was a definite regression, causing deposition of 40 feet (12.2 meters) of nodular anhydrite in the 826-G well, 100 percent dolomite in the Carlton well, and limestone with about 47 percent dolomite in the Collier and Wisehart wells. The relative position of the two dolomite-evaporite facies is shown in the diagrammatic cross section of Figure 6.

After this regression, limestone of all three facies mentioned before reappears in the columns; and dolomite is not detected again in measurable quantities (except for 1 sample in the 826-G well) until the regression which produced the Lake Trafford Formation.

The rudistid shoal facies penetrated in the Forty Mile Bend and Sunniland Oil Fields appear along the edge of the South Florida Shelf in the upper part of the Sunniland Limestone in both fields (Raasch, 1954, and Banks, 1960). This would make them roughly equivalent in time to the uppermost limestone facies described above.

SUMMARY AND CONCLUSIONS

Through petrographic and mineralogic analysis, it has been possible to establish the environment of deposition of the Sunniland Limestone as a shallow, subtidal area similar to the sebka flats described by Illing and others (1965). The presence of algal stromatolites, supratidal dolomite, nodular anhydrite and pellet muds are all suggestive of environments similar to those described from the Persian Gulf (Illing and others, 1965).

The location of the shelf edge between the South Florida Basin and the South Florida Shelf is of potential economic importance because the oil-bearing rudistid reefs of both the Sunniland Oil Field and the abandoned Forty Mile Bend Oil Field are located near the same shelf edge. Facies relationships from this report suggest that the shelf passes between the 826-G and Collier wells, trending southwest parallel to, and north of, the Florida Keys. No wells have been drilled along this trend, but it is believed that future exploration may well reveal reservoir rocks of the rudistid shoal facies in this location. According to the gradient map of Reel and Griffin (1971) this is also one of the most favorable areas in the state from a geothermal standpoint.

X-ray and thin section analyses reveal the presence of a major dolomite-evaporite facies in the middle of the Sunniland Limestone, indicating a regression of the Cretaceous sea at this time. A less dolomitic facies occurs below this point in three wells, indicating a possible minor regression. However, based on samples from only three wells, it is impossible to state whether this minor second regression is caused by local or regional conditions.

Recrystallization to microspar and pseudospar is common in the Sunniland Limestone. Distinction of these types from void filling calcite is often difficult. Most of the true sparite is filling secondary voids created by diagenesis, rather than primary (interparticle) voids.

In a low energy environment such as the South Florida Basin, the presence of supratidal dolomite and anhydrite is useful for recognition of transgressive and regressive phases. These minerals, which form slightly after deposition, displace or replace previously existing sediment.

The dolomite evaporite cycles in the Sunniland are probably time transgressive, reflecting a supratidal environment moving seaward as sea level declined. Sea level changes were probably caused by different rates of subsidence of the South Florida Basin, accompanied by varying rates of carbonate sedimentation. Eustatic changes are also possible, but are not necessary to explain the observed results.

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EXTENSION OF THE KNOWN RANGE OF THE PLESIOSAURIA IN THE ALABAMA CRETACEOUS[1/]

By

Samuel W. Shannon
Geological Survey of Alabama
University, Alabama 35486

ABSTRACT

Plesiosaurs from the Cretaceous of Alabama are not, as previously thought, confined to the Mooreville Chalk. They also occur in the Tombigbee Sand Member of the Eutaw Formation and the Bluffport Marl Member of the Demopolis Chalk, as shown by remains now in the collection of the Geological Survey of Alabama.

INTRODUCTION

The Plesiosauria were marine reptiles that lived during the Mesozoic Era. Marine, fossiliferous strata of Late Cretaceous age are well exposed in central Alabama (Figure 1).

Plesiosaur remains from the Cretaceous deposits of Alabama are rare, consisting of four isolated centra that have previously been reported in the literature plus the five specimens reported here. Leidy (1865, p. 23) and Lydekker (1889, p. 211) each describe single centra that appear to be from the Mooreville Chalk of the Selma Group. The remaining two centra are noted as being from . . . "the Cretaceous deposits of Alabama" (Leidy, 1865, p. 22). Because of the poor locality data, these last two specimens are of no use in a biostratigraphic study. Undescribed material in the collection of the Geological Survey of Alabama indicates the presence of plesiosaurs not only in the Mooreville Chalk, but in the underlying Eutaw Formation and the overlying Demopolis Chalk (Figure 2). The letters GSATC in specimen numbers refer to the Geological Survey of Alabama Type Collection.

SYSTEMATIC PALEONTOLOGY

Class REPTILIA
Order SAUROPTERYGIA Owen, 1859
Suborder PLESIOSAURIA de Blainville, 1835
Superfamily PLESIOSAUROIDEA Welles, 1843
Family ELASMOSAURIDAE Cope, 1869
Genus undetermined

Figure 3 a, b, c, d

Specimen. -- GSATC-212, centrum of an anterior cervical

1/ Approved for publication by the State Geologist.

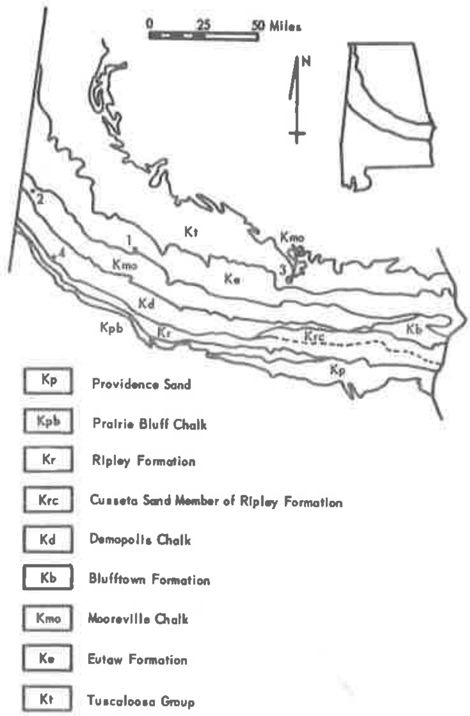

Figure 1. Generalized geologic map of the Gulfian Series (Upper Cretaceous) of Alabama, showing the locations of the plesiosaur remains discussed in this paper.

vertebra.

Occurrence. -- Eutaw Formation, Tombigbee Sand Member, exposed in a road-cut in the SE1/4NW1/4 sec. 16, T. 19 N., R. 6 E., Perry County, Alabama (Figure 1, location 1). The location is within the *Exogyra ponderosa* faunal zone, indicating the upper half of the Tombigbee Sand Member (Stevenson and Monroe, 1948). The Tombigbee Sand Member of the Eutaw Formation is an upper Austin equivalent.

Remarks. -- The centrum is well preserved. Marrow cavities are open and show no permineralization or crushing. There are two nutrient foramina on the ventral surface separated by a narrow keel. On the dorsal surface, there is a single, rectangular foramen located on the midpoint of the sagittal plane. The articular faces are notched on the mid-ventral margin. There are distinct dorso-lateral ridges on each side of the centrum. The ribs are fused. Indices for the specimen (after Welles, 1952), are 72, 82:129.

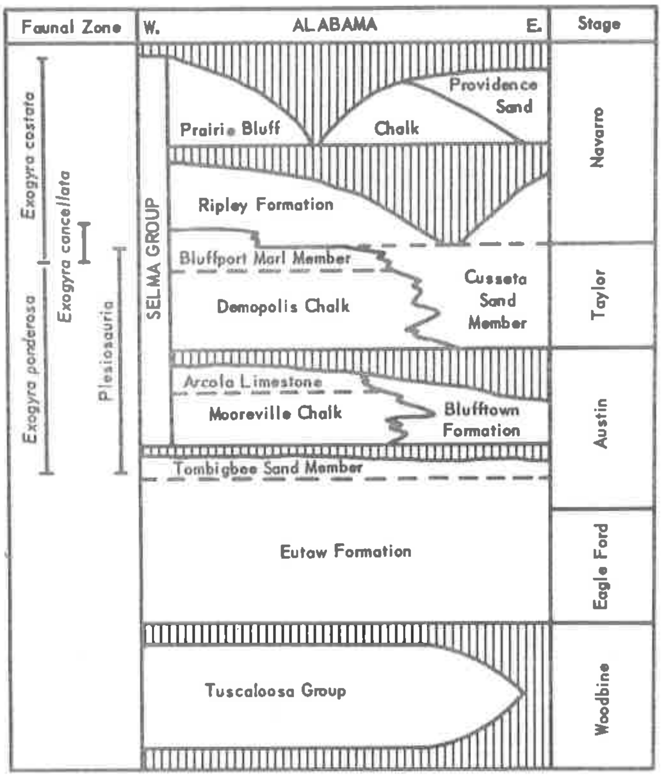

Figure 2. Correlation chart of Upper Cretaceous formations in Alabama showing Texas Stage equivalents, faunal zones, and the known range of occurrence of the Plesiosauria in Alabama (Modified from LaMoreaux and Toulmin, 1959).

Genus undetermined

Figure 3 e, f

Specimen. -- GSATC-213, centrum of posterior cervical vertebra.

Occurrence. -- Eutaw Formation, Tombigbee Sand Member, from the same outcrop as GSATC-212 (Figure 1, location 1).

Remarks. -- The specimen is well preserved except for the outer layer of bone, which is absent in places. There has been no deformation. The articular face is oval in outline and lacks a ventral notch. No keel separates the foramina on the ventral surface. The ribs appear to be free with the facet projecting laterally. The rib facet is an oval depression created by two smaller, subcircular depressions aligned in an anterior-posterior line, with the anterior subcircular depression the larger. This may be an aberrant specimen. Indices for this specimen are 55, 114:117.

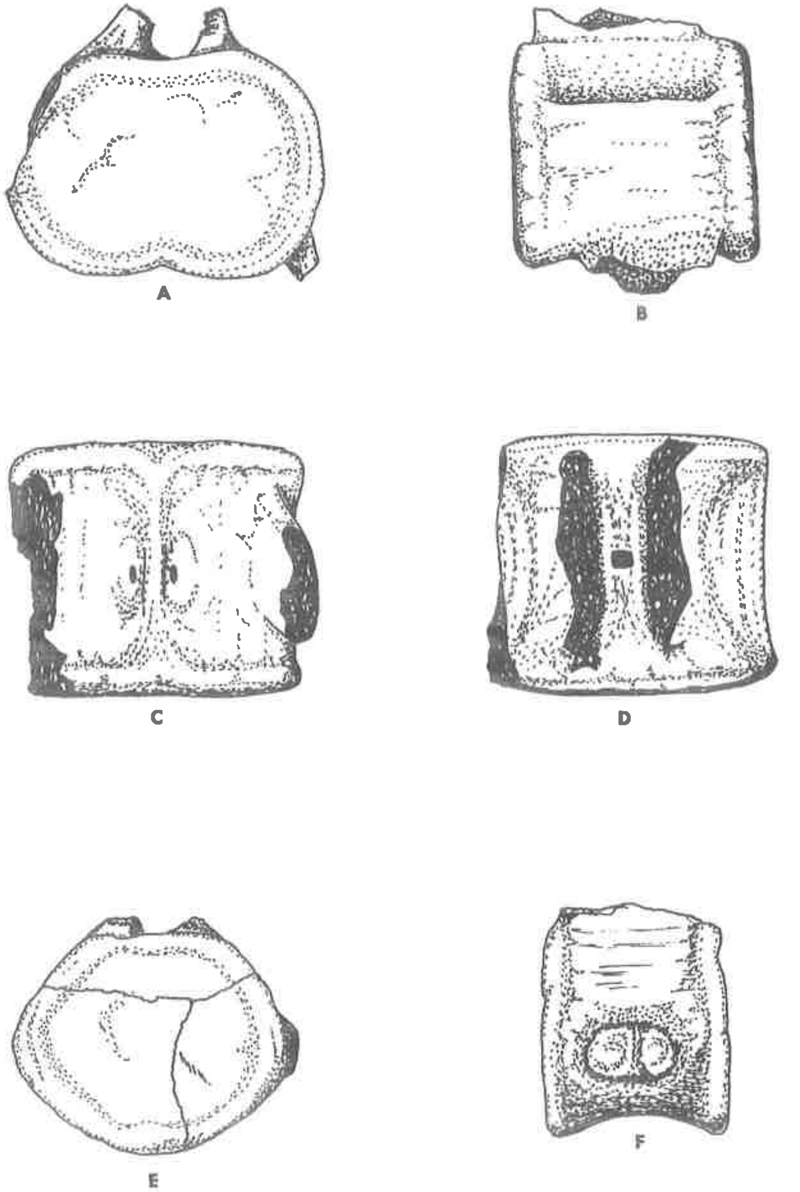

Figure 3. A-D GSATC 212 anterior cervical vertebra of an Elasmosaur; E, F GSATC 213 posterior cervical vertebra of an Elasmosaur. A-anterior view, B-left lateral view, C-ventral view anterior up, D-dorsal view-anterior down, E-anterior view, F-left lateral view.

Genus undetermined

Figure 4 c, d

Specimen. -- GSATC-214, centrum of a cervical vertebra.

Occurrence. -- Mooreville Chalk, found while excavating a foundation for a pier on the west side of the Tombigbee River in the SE 1/4NW1/4 sec. 7, T. 24 N., R. 2 W., Pickens County, Alabama (Figure 1, location 2). The location is covered by Quaternary alluvium but is approximately in the middle of the Mooreville Chalk, an upper Austin equivalent (Stevenson and Monroe, 1940).

Remarks. -- The specimen resembles GSATC-212 but lacks the ventral notch on the articular face margin. Also, the ventral keel is not as pronounced as in GSATC-212. The rib attachments are poorly preserved, and it cannot be determined whether the ribs were fused or free. Indices for the specimen are 78, 91:129.

Superfamily PLIOSAUROIDEA
Family POLYCOTYLIDAE Williston, 1908
Genus *Cimoliasaurus* Leidy, 1851
Cimoliasaurus magnus Leidy, 1851

Figure 4 a, b

Specimen. -- GSATC-215, centrum of a pectoral or dorsal vertebra.

Occurrence. -- Selma Group, Mooreville Chalk, exposed in a road ditch in the SE1/4 sec. 19 or SW1/4 sec. 20, T. 18 N., R. 19 E., Elmore County, Alabama (Figure 1, location 3). The area of this location is believed to be a cryptoexplosion structure (T. L. Neathery, Geological Survey of Alabama, personal communication) and the exact horizon of the location within the Mooreville Chalk cannot be ascertained.

Remarks. -- The centrum is in poor condition. The right rib articulation and the left dorsal surface are missing. Also, parts of the margin of both articular faces are lacking, but enough remain to be reasonably sure of the identification. Since the posterior articular face is nearly complete, these measurements serve as the indices. Indices for the specimen are 68, 144:181.

There are two widely separated foramina on the ventral surface and two closely spaced foramina on the dorsal surface. The ribs were free and appear to have projected posteriorly. There is no indication of dorso-lateral ridges.

This specimen compares very well with Leidy's figures (1865, pl. 5, figs. 13-15) and indices for the pectoral vertebrae of the type of *Cimoliasaurus magnus* Leidy. Indices for the type pectoral are 68, 130:170 (Welles, 1952, p. 109) as compared with 68, 144:181 for GSATC-215. Even though the type material is not considered to be diagnostic and the genus is considered a *nomen vanum* by Welles (1962, p. 59), the similarities between Leidy's type and the present specimen cannot be ignored.

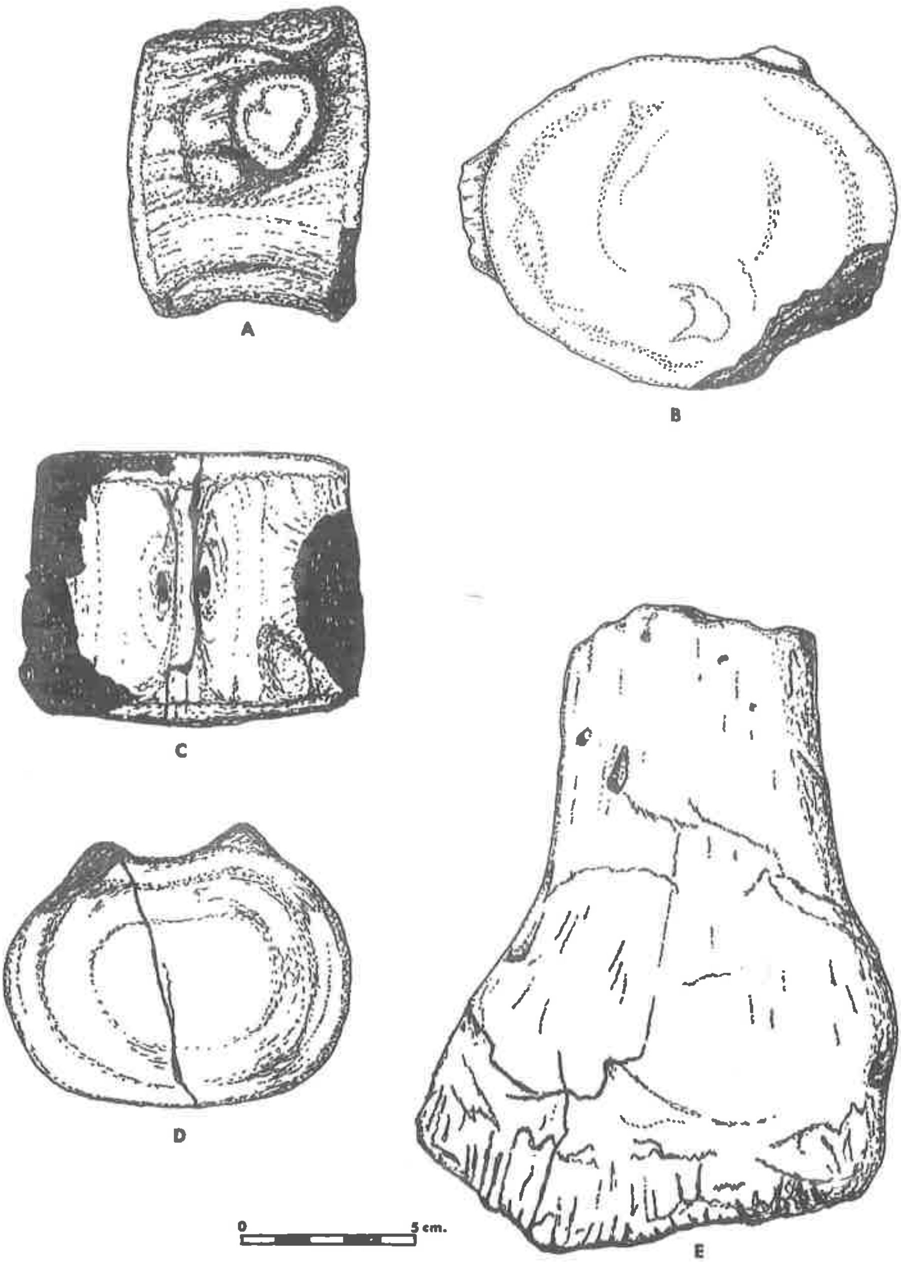

Figure 4. A, B GSATC 215 pectoral or dorsal vertebra of Cimoliasaurus magnus Leidy; C, D GSATC 214 cervical vertebra of an Elasmosaur; E-distal end of a plesiosaur propodial A-left laterial view, B-posterior view, C-vertical view, D-anterior view, E-lateral view.

Superfamily undetermined

Figure 4 f

Specimen. -- GSATC-216, distal end of a propodial.

Occurrence. -- Demopolis Chalk, Bluffport Marl Member, in the NE1/4SW1/4 sec. 19, T. 20 N., R. 1 W., Sumter County, Alabama (Figure 1, location 4). The Bluffport Marl Member is within the *Exogyra cancellata* sub-zone of the *Exogyra costata* faunal zone and is Navarro in age (Monroe, 1946).

Remarks. -- The specimen is poorly preserved. Only the distal epiphysis and a small part of the diaphysis remain. There is a large iron concretion in the epiphysis that seems to have expanded and cracked this area to a limited extent. The diaphysis is roughly oval in cross-section where it is broken, with the long axis being anteroposterior. The breadth and width at this point are 74 mm and 50 mm respectively.

CONCLUSIONS

Plesiosaurs are not confined to the Mooreville Chalk in the Cretaceous deposits of Alabama but are a part of the fauna in at least one other of the four formations of the Selma Group and in the underlying Eutaw Formation (Figure 2). This represents the Austin, Taylor, and basal Navarro equivalents in Alabama, or the section comprising the Santonian, Campanian, and Maestrichtian European stages (Monroe, 1946).

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EVALUATION OF TEXTURAL PARAMETERS AS BEACH-DUNE ENVIRONMENTAL DISCRIMINATORS ALONG THE OUTER BANKS BARRIER, NORTH CAROLINA

By

Gerald L. Shideler
Department of Geophysical Sciences
& Institute of Oceanography
Old Dominion University
Norfolk, Virginia 23508

ABSTRACT

The relative effectiveness of several textural parameter combinations as environmental discriminators was evaluated for sediments of the Outer Banks barrier chain along the Middle Atlantic coast. Combinations of moment measures, maximum particle size, and total heavy mineral contents were evaluated in differentiating foreshore, berm, and dune populations.

The more effective parameters in distinguishing beach and dune sands along the barrier are the less sensitive measures that reflect basic competence differentials between the aeolian and hydraulic regimes. The more sensitive parameters that reflect differences in component sub-populations are of more limited utility because of their greater susceptibility to bias induced by local physiography and source materials, sampling techniques, and analytical procedures. Comparisons of total heavy mineral contents are effective in differentiating adjacent foreshore-berm couplets and foreshore-dune couplets, but ineffective in distinguishing berm-dune couplets. Relative differences in heavy mineral concentrations among the three populations reflect both the varying degrees of aeolian influence, and the relative amounts of sediment interchange between populations.

INTRODUCTION

The establishment of reliable textural criteria for differentiating sedimentary environments of modern and ancient sand deposits has been a field of extensive research over the past three decades. Among the various genetic sand populations, the differentiation between beach and dune sands has received relatively widespread attention. It is believed that the intrinsic differences in transport dynamics associated with air and water media should be manifested in a sediment's size frequency distribution. Several workers have made important contributions in relating beach-dune textural differences to environmental processes. Among the more recent contributions are the studies of Mason and Folk (1958), Friedman (1961), Shepard and Young (1961), Hails (1967), Hand (1967), Hails and Hoyt (1969), and Visher (1969).

Studies designed to determine textural differences between beach and dune sands have not always produced consistent results, and the present state of knowledge is still largely inconclusive. Environmentally-induced textural differences should be most readily apparent for adjacent beach and dune sands which reflect an evolutionary sequence, whereby the dune population represents a daughter product derived from an adjacent parent beach population. Such "genetic couplets" frequently exist along coastal sectors which experience significant onshore winds that result in the development and maintenance of coastal dune fields. However, as noted by Shepard and Young (1961), textural differentiation of beach and dune populations is much more difficult in areas with a variable aeolian regime characterized by offshore and longshore winds; in such areas, textural distinctions might tend to be obscured by population interchange. Another obscuring factor is the substantial textural variability within a beach environment itself, possibly resulting from variations in hydraulic conditions and source materials. As noted by Bascom (1951), median grain size can be highly variable across a beach profile. Variations in median size and sorting along beaches also have been noted by Strahler (1966). Other textural studies further indicate that within the beach population itself, foreshore and berm sediments appear to be texturally and genetically distinct beach sub-populations (e. g. Shepard and Young, 1961; Shideler, 1973b), thus tending to further obscure textural distinctions between beach and dune sediments. In addition, the history of the source materials is also an influential factor (Hails, 1967), with polycyclic sediments tending to be less amenable to textural differentiation than monocyclic sediments.

During the past few years, the writer has been engaged in comparative textural studies of adjacent foreshore, berm, and dune sands along the Outer Banks barrier chain of the Middle Atlantic Bight (Shideler, 1973a, 1973b). These studies have indicated that not only do the three populations appear to be texturally and genetically distinct, but that they also exhibit independent textural trends along the length of the barrier chain. The foreshore population appears to be generated largely through aqueous processes associated with the normal swash-backwash hydraulic regime, with only minor response to aeolian processes; whereas, the berm population is generated by high water swash-backwash hydraulic regimes, and is substantially modified by subsequent aeolian processes. The dune population is generated entirely by the aeolian regime, and represents a winnowed clastic filtrate derived from adjacent berm and aeolian flat deposits. The Outer Banks barrier is characterized by a combination of onshore, offshore, and longshore winds. The purpose of the present study is to evaluate the relative effectiveness of various textural parameters as discriminators in the differentiation of foreshore, berm, and dune sands along the Outer Banks barrier, an area characterized by a highly variable aeolian regime and polycyclic source materials.

Acknowledgments

This study was financially supported by research grants from the Old Dominion University Research Foundation (No. GR-72) and Educational Foundation (No. 8028). Gratitude is also expressed to Mrs. Laura Poracsky for drafting services.

DESCRIPTION OF STUDY AREA

The studied sector of the Outer Banks consists of a well-developed coastal barrier chain of the Middle Atlantic Bight, located between Cape Henry, Virginia and Cape Hatteras, North Carolina (Figure 1). This barrier sector is approximately 115 nautical miles in length, and varies in width from about three miles to less than one-third mile in areas of past or potential breaching. It is comprised of well-defined beach, dune field, and aeolian flat environments. The coastal dunes are variable in height and width, depending on geographic location and effectiveness of dune stabilization techniques.

Winds along the barrier chain are highly variable, both in velocity and direction. The prevailing winds are offshore or longshore from the south or southwest, with mean annual velocities increasing toward the south from 10 mi. /hr. at Cape Henry to 13 mi. /hr at Cape Hatteras (U. S. Dept. of Commerce, 1968). However, the strongest and most competent winds for transporting sediment are onshore winds. Relatively high velocity onshore winds from the northeast are especially active during the winter months, and are frequently associated with "northeaster storms" along this sector of the Atlantic coast. In addition, the barrier is highly prone to hurricane devastation. The offshore hydraulic regime along the barrier is controlled largely by the bathymetry of the adjacent continental shelf. Studies of textural trends exhibited by the barrier sediments within the present study area (e. g. Swift, et al. , 1971; Shideler, 1973a) indicate a progressive southward increase in the average wave energy level, as well as a concomitant decrease in energy consistency. This energy differential has been attributed to both the regional wave refraction pattern, and to a progressive southward reduction in shelf width.

Regarding barrier source materials, Swift (1969) has noted that textural and heavy mineral studies indicate that barrier sediments along the Middle Atlantic Bight appear to be derived primarily through coastal erosion of Pleistocene substrate, being supplied both vertically by surf erosion along the shore face, and laterally by longshore drift from eroding headlands. In addition, a budget study of barrier sediments southwest of the present study area (Pierce, 1969), suggests that offshore reservoirs along the continental shelf may constitute supplemental sources of sediment. The drowning of local estuarine systems during the Holocene transgression has rendered them effective sediment traps; consequently, the influx of modern fluvial sediments for barrier construction appears to be relatively minor, and a Pleistocene substrate appears to be the dominant source. The Pleistocene stratigraphy of the study area has been described in both the outer coastal plain region (Oaks, 1964), and along the adjacent Virginia-North Carolina shelf (Shideler, et al. , 1972; Shideler and Swift, 1972). It can be characterized as a heterogeneous assemblage of fluvial, paralic, and neritic lithosomes. The section's complex facies pattern reflects a series of transgressive and regressive episodes associated with glacio-eustatic fluctuations. The heterogeneous Pleistocene substrate provides a wide textural spectrum of polycyclic source materials ranging from clay to gravel lithosomes, which are available for subsequent barrier construction.

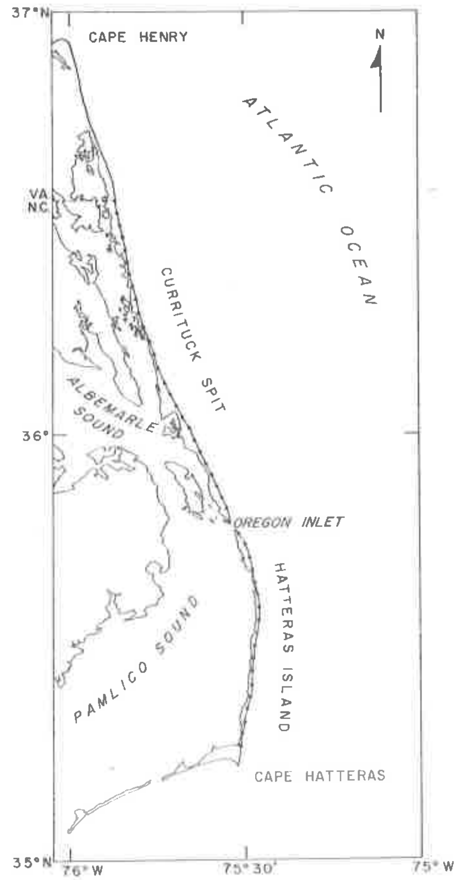

Figure 1. Location map of the studied sector of the Outer Banks barrier illustrating the 45 sample stations.

PROCEDURES

Field Methods

Samples for the study were obtained along a 90-nautical mile segment of the Outer Banks barrier, extending from the Virginia-North Carolina state line to Cape Hatteras. Samples were collected at forty-five stations spaced at intervals of two nautical miles. At each station, a sample suite was obtained along a transect perpendicular to the shoreline. Each suite consists of three genetically distinct sand populations derived from adjacent foreshore, berm, and dune environments. The foreshore samples were obtained from the center of the wetted intertidal zone, while berm samples were obtained from the center of the adjacent berm; the dune samples were obtained from the crest of the nearest prominent dune adjacent to the berm. The sampling device was a 4-inch diameter cylindrical can, which was inserted into the sediment to a depth of 5.5 inches; a relatively large channel sample was acquired, in order to obtain the average textural characteristics of several sedimentation units. Most of the stations along the barrier were sampled over a two-day field period; however, the ten northernmost stations were sampled a few weeks later.

Laboratory Methods

The foreshore, berm, and dune populations sampled along the forty-five transects resulted in a total of 135 samples, which were subjected to size analysis. All samples were analyzed by the same person, thus minimizing the possibility of operator bias. Each sample was passed through a -1 phi sieve to remove any gravel, and the maximum inorganic particle size (longest diameter) was measured. The sand fractions were then split into 50-60 gram samples, which were sieved at a 0.25 Φ interval; the fractions are quartzose, with only minor quantities of shell fragments which did not appear to warrant separate treatment. The samples were sieved using a Ro-Tap for ten minutes, and a sieve range from 0.0Φ to 4.0 Φ. Reduction of the size frequency distribution data was accomplished by means of a FORTRAN computer program that derived the four moment measures (mean, standard deviation, skewness, kurtosis). The moment measures were utilized because of their relatively greater sensitivity.

Heavy mineral separations were performed on the 135 samples, utilizing the 3.0 Φ - 4.0 Φ fraction. Initial samples of approximately 2 grams were separated in bromoform and analyzed in terms of their total heavy mineral content by weight percent. Analytical errors were maintained below a 1 percent level.

After derivation of the foregoing parameters, they were plotted in various combinations on scatter diagrams. The plots were then evaluated to determine the relative effectiveness of individual parameter combinations in differentiating beach and dune environments along the barrier chain. Optimum dune environmental fields were delineated on the scatter diagrams by visually constructing parabolic curves which best encompassed the maximum number of dune samples, while simultaneously minimizing the number of included beach samples. Although parabolas appeared to be the most effective curves in accommodating the present data, other studies might conceivably employ different geometric forms. The significant factor is the use of a consistent variety of curve, in order to standardize the technique for delineating environmental fields, thus minimizing subjectivity. As a quantitative estimate of the relative effectiveness of different parameter combinations, each delineated dune environment field is expressed in terms of its "inclusion ratio"; this ratio is here defined as the percent Dune Samples Included/percent Beach Samples Included. Ratio values could theoretically range from infinity for a perfect environmental field with total separation, to a value of 1.00 for a totally ineffective field which includes equal proportions of both dune and beach samples.

Table 1. Comparison of the relative effectiveness of dune environmental fields established by different parameter combinations.

Fig. No.	Parameter Combinations	No. of Dune Samples Included in Field	No. of Beach Samples Included in Field	% Dune Samples Included	% Beach Samples Included	Dune Field Inclusion Ratio
2	Mean vs. Standard Deviation	37	11	82.2	12.2	6.73
3	Mean vs. Skewness	38	21	84.4	23.3	3.62
4	Mean vs. Kurtosis	38	23	84.4	25.5	3.30
5A	Standard Deviation vs. Skewness	38	7	84.4	7.7	10.96
5B	Standard Deviation vs. Kurtosis	36	6	80.0	6.6	12.12
6	Skewness vs. Kurtosis	36	12	80.0	13.3	6.01
7	Maximum Dia. vs. Mean	44	24	97.7	26.6	3.67
8	Maximum Dia. vs. Standard Deviation	40	16	88.8	17.7	5.01
9A	Maximum Dia. vs. Skewness	44	25	97.7	27.7	3.52
9B	Maximum Dia. vs. Kurtosis	36	13	80.0	14.4	5.55
10	Maximum Dia. vs. Heavy Mineral Content	34	5	75.5	5.5	13.72

DISCUSSION OF RESULTS

The scatter diagrams examined for their relative utility as environmental discriminators along the Outer Banks barrier are classed into three general groups: 1) diagrams employing only moment measure combinations, 2) diagrams employing maximum particle diameter combinations, and 3) diagrams employing total heavy mineral content combinations. It should be emphasized that the following results are based on the average characteristics of several sedimentation units.

Moment Measure Combinations

Scatter diagrams of moment measures, as well as their graphic measure counterparts, have been widely employed in the past in attempts to distinguish sands from different sedimentary environments. Many of these previous studies have been reviewed by Friedman (1961, 1967), Folk (1966), Visher (1969), and others. A one-way analysis of variance previously performed on the samples employed in the present study indicates that differences in mean values of corresponding moment measures between the foreshore, berm, and dune populations are statistically significant at the 95 percent confidence level; the only non-significant difference is between foreshore and berm kurtosis (fourth moment) values (Shideler, 1973b). Scatter diagrams showing six combinations of moment measures are illustrated in Figures 2-6, and their relative effectiveness in environmental field separation is indicated by their inclusion ratios (Table 1).

Among the six combinations evaluated, the mean diameter-standard deviation plot (Figure 2) proved to be the third most effective combination in separating dune and beach environments along the Outer Banks barrier. The parabolic dune field is restricted to mean diameter values smaller than 1.4 Φ, and standard deviation values of less than 0.65 Φ. Both parameters are nearly equal in their effectiveness as environmental discriminators, with the dune sediments tending to be

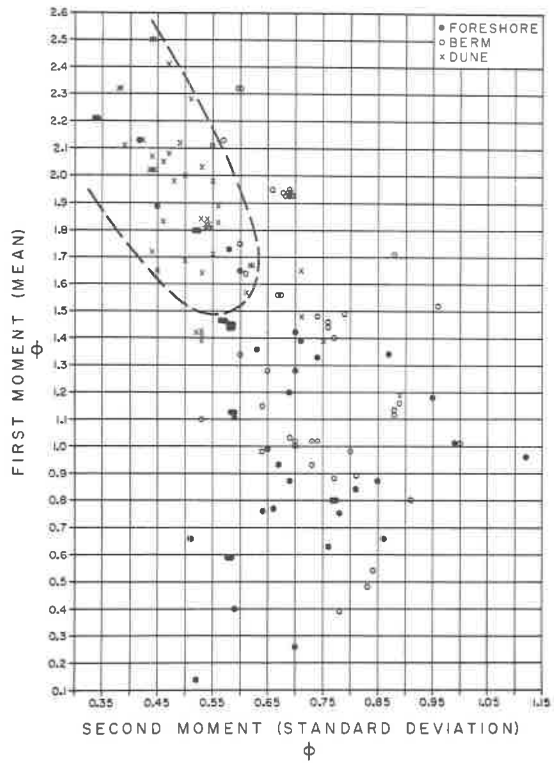

Figure 2. Scatter diagram of the first moment (mean) and second moment (standard deviation) for adjacent foreshore, berm, and dune populations. Optimum dune environmental field is delineated by dashed line.

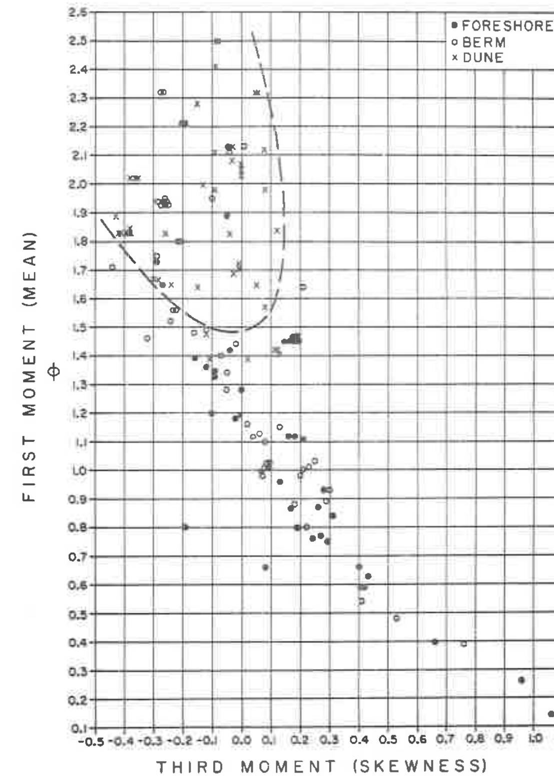

Figure 3. Scatter diagram of first moment (mean) and third moment (skewness), illustrating optimum dune field.

finer-grained and better sorted than the beach sediments; this reflects the lower and more limited competency range of the aeolian regime relative to the swash-backwash hydraulic regime. In contrast to beach-dune differentiation, no effective separation is apparent between foreshore and berm populations within the beach environmental field, although there is a general tendency for the berm samples to be somewhat finer-grained and poorer-sorted than the foreshore samples. The dune samples appear to exhibit a slight linear trend of improved sorting with decreasing grain size, indicating some degree of parameter dependence; however, no such trends are apparent among the foreshore and berm samples. Similar mean-standard deviation plots have been utilized by other workers with lower degrees of success. Shepard and Young (1961) found such plots ineffective in comparing beach and dune sediments on a worldwide distribution basis. Similar negative results were obtained by Mason and Folk (1958) in their study of Mustang Island barrier sediments; they attributed the plot's ineffectiveness to the extreme homogeneity of the barrier source sediments. As suggested by Folk and Robles (1964) in a study of Yucatan carbonate sediments, the limits of variability for sediment size and sorting may be largely inherited from source materials; whereas, variations within the inherited limits can result from environmental processes. It appears that the effectiveness of grain size and sorting as environmental discriminators may be largely reliant upon the establishment of a sufficiently wide variability range by the initial size frequency distribution of local source materials. Sediments derived from relatively heterogeneous monocyclic sources might be most amenable to differentiation; whereas, sediments derived from more homogeneous polycyclic sources might be less amenable. Although sediments of the Outer Banks are derived from polycyclic sources, the moderate utility of the mean diameter-standard deviation plot suggests that the source materials were still sufficiently heterogeneous for permitting a moderate degree of differentiation.

The mean diameter-skewness plot (Figure 3) is the fifth most effective method among the six evaluated moment measure combinations. The dune field is confined to mean diameter values smaller than 1.4Φ, and skewness values within the -0.5 to 0.2 range. The more effective discriminator is mean grain size, probably reflecting the competence differential between the aeolian and swash-backwash regimes; whereas, skewness appears to be of relatively minor usefulness. The relative ineffectivenss of this parameter combination for the Outer Banks barrier is in contrast to the results obtained by Friedman (1961) who found that mean-skewness plots provided nearly complete beach-dune separation. In addition, Friedman noted a general coarse skewness for beach sands, and fine skewness for dune sands. On Mustang Island, Mason and Folk (1958) also found that most dune sands are finely skewed, but that most beach sands had near-symmetrical distributions. In a study of western Pamlico Sound sediments, Duane (1964) also found skewness to be environmentally sensitive, and related it to winnowing energy; strongly winnowed environments such as beaches were characterized by coarse skewness, while low energy areas such as dunes were finely skewed. Similar results were obtained in studies of barrier sediments of Australia (Hails, 1967), and along the lower Georgia Coastal Plain (Hails and Hoyt, 1969). Within the present study area, the beach sands exhibit both coarse and fine skewness, while most dune sands are either nearly symmetrical or coarsely skewed. This inconsistency suggests that both the absolute values and relative utility of the sensitive skewness measure are reliant upon the size spectrum of the local source materials, local physiography, sampling and analytical techniques, or a combination of the foregoing factors. The local aeolian regime may be of particular importance in influencing relative skewness values of adjacent beach and dune sediments. As noted by Chappell (1967), in areas of prevailing offshore winds, such as the Outer Banks, the feedback of fine-grained dune admixtures to the beach inhibits the development of coarsely-skewed beach sands. Within the beach environmental field, no effective separation is apparent between foreshore and berm populations. Both the foreshore and berm samples exhibit linear trends denoting an increasing degree of fine skewness with increasing mean grain size, thus indicating parameter dependence; however, no similar trend is apparent within the dune population.

The mean diameter-kurtosis plot (Figure 4) is the least effective moment measure combination tested in differentiating beach and dune sediments. The dune field is confined to mean diameter values smaller than 1.5 Φ, and kurtosis values within the -0.5 to 3.5 range. The more effective environmental discriminator is mean grain size, with the generally finer-grained dune sands reflecting the lower competence level of the aeolian regime. Kurtosis is of relatively minor usefulness, although there is a general tendency for most dune sands to be slightly leptokurtic, while most beach sands tend towards slightly platykurtic distributions, thus affording some separation. The relative ineffectiveness of kurtosis as an environmental discriminator has also been noted by Friedman (1961) and Shepard and Young (1961), although this parameter was found to be effective in the relatively homogeneous sediments of Mustang Island (Mason and Folk, 1958). Within the beach environmental field, no effective separation between foreshore and berm sediments is apparent. Poorly-developed linear trends within the three populations are suggested which denote increasing platykurtic tendencies with increasing mean grain size.

A standard deviation-skewness plot (Figure 5A) proved to be the second most effective measure combination for discriminating between beach and dune sands. The dune field is restricted to standard deviation values within the range of 0.35 Φ to 0.60 Φ, and skewness values within the -0.5 to 0.3 range. The more effective discriminator is standard deviation, whereas skewness is of relatively minor usefulness. The standard deviation contrast between beach and dune sediments may reflect populations resulting from one-cycle and two-cycle sorting processes, respectively. Beach sands are subjected to a single cycle of hydraulic sorting along the foreshore. In contrast, dune sediments comprising a genetic couplet are derived from previously sorted parent beach sands by a second-cycle sorting process consisting of subsequent aeolian winnowing; the more limited competence range of the aeolian regime results in a relatively better sorted dune population. The effectiveness of standard deviation as a discriminator along the Outer Banks might have been enchanced by the heterogeneous nature of the barrier source materials. However, even for the homogeneous barrier sediments of Mustang Island, Mason and Folk (1958) found standard deviation to be an effective parameter. In contrast, standard deviation-skewness plots by Shepard and Young (1961) on a worldwide distribution basis showed no major differences between beach and dune populations.

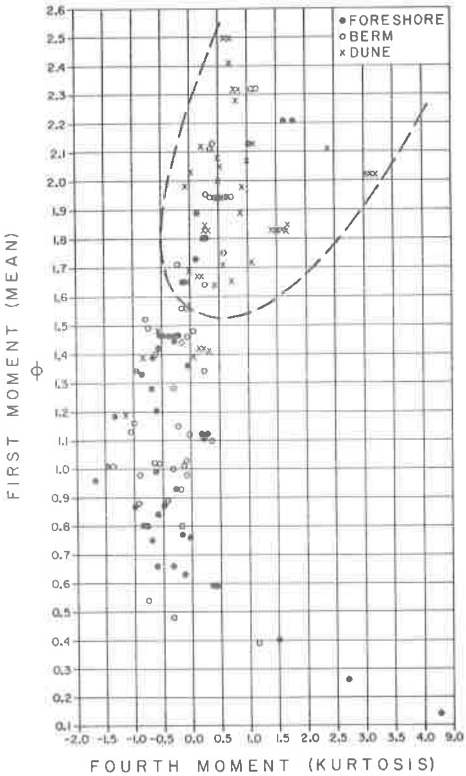

Figure 4. Scatter diagram of first moment (mean) and fourth moment (kurtosis), illustrating optimum dune field.

Within the beach environment field, no effective separation was feasible between foreshore and berm deposits. In addition, no linear trends are apparent among the three genetic populations, thus indicating parameter independence.

A scatter diagram of standard deviation-kurtosis (Figure 5B) proved to be the best of the six moment measure combinations for differentiating beach and dune environments along the Outer Banks. The dune field is restricted to standard deviation values lower than 0.60Φ, and kurtosis values within the -0.5 to 3.5 range. Once again, the more effective discriminator is standard deviation, with a better-sorted dune population apparently reflecting two-cycle sorting by both the hydraulic and aeolian regimes, relative to the one-cycle hydraulic sorting experienced by the beach population. Kurtosis is of relatively minor usefulness, although the majority of beach samples do tend to be slightly platykurtic, while dune samples tend to be slightly leptokurtic. Within the beach field, no effective separation is apparent between foreshore and berm sediments. Linear trends are present within both the foreshore and berm populations, which exhibit an increase in platykurtic tendencies with increasing standard deviation; although not well defined,

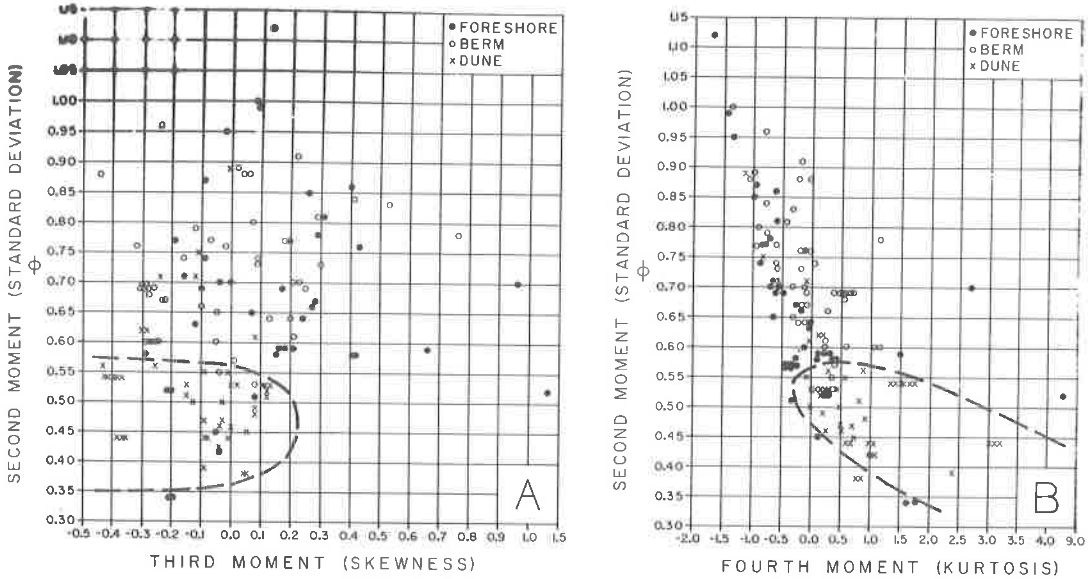

Figure 5. Scatter diagrams of second moment (standard deviation) plotted against: (A) third moment (skewness), and (B) fourth moment (kurtosis). Optimum dune fields delineated by dashed lines.

a similar trend is also suggested within the dune population.

A scatter diagram of skewness-kurtosis (Figure 6) is the fourth most effective moment measure combination for differentiating beach and dune sediments. The dune field is limited to skewness values within the -0. 5 to 0. 2 range, and kurtosis values within the -0. 5 to 3. 5 range. Between the two parameters, kurtosis is a somewhat more effective discriminator, with a predominantly leptokurtic dune population and a predominantly platykurtic beach population. This contrast in kurtosis might reflect intrinsic differences in component sub-populations within the beach and dune populations. As noted by Folk (1966), platykurtic size frequency distributions tend to reflect the mixing of log-normal component sub-populations that are present in nearly equal proportions; whereas, leptokurtic distributions suggest the mixing of a predominant sub-population with a highly subordinate sub-population. Other studies of the size frequency distributions of beach sands have indicated the presence of texturally distinct swash and backwash sub-populations (e. g. Visher, 1969; Kolmer, 1973; Shideler, 1973b); their presence in nearly equal proportions might tend to produce slightly platykurtic beach distributions. In contrast, the mixing of log-normally distributed dune sands with minor admixtures of aeolian flat sediments might tend to produce slightly leptokurtic dune distributions. In previous studies, the use of both skewness and kurtosis for environmental differentiation has produced mixed results. In the homogeneous Mustang Island barrier sediments, Mason and Folk (1958) found skewness-kurtosis plots to be the most successful combination for distinguishing beach and dune sands. They attributed the plot's effectiveness to the parameters' sensitivity in detecting subtle variations in the "tail" por-

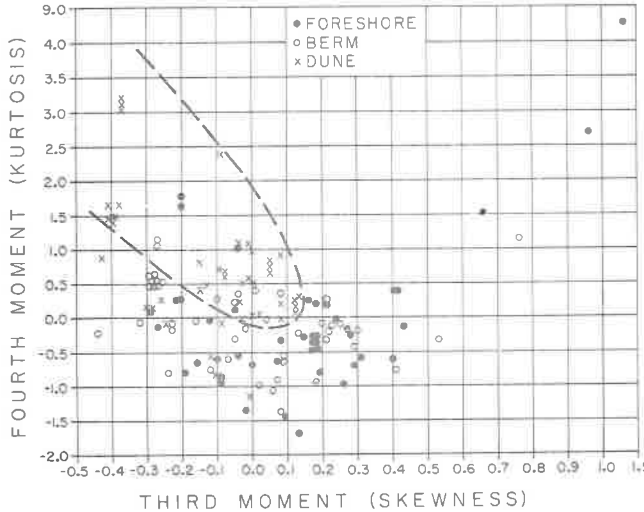

Figure 6. Scatter diagram of third moment (skewness) and fourth moment (kurtosis), illustrating optimum dune field.

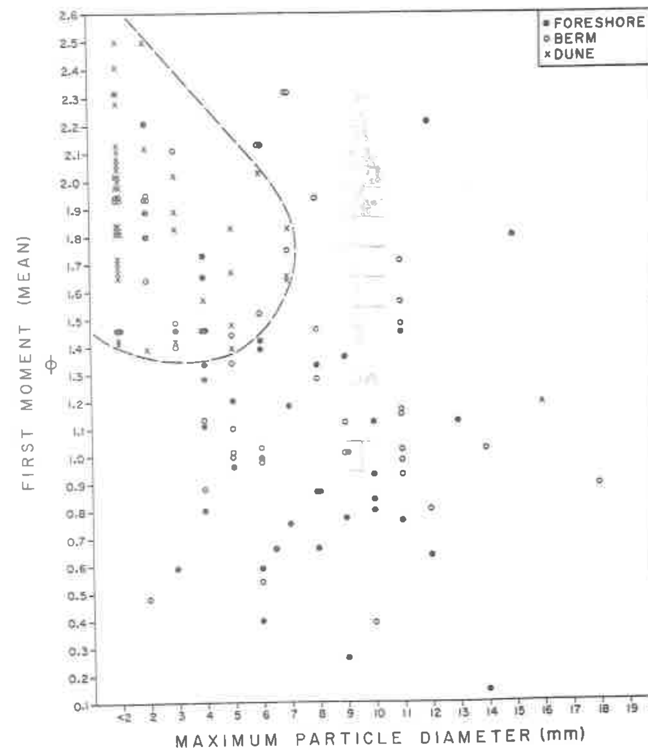

Figure 7. Scatter diagram of maximum particle size plotted against first moment (mean), illustrating optimum dune field.

tions of size frequency distributions, as the result of either subpopulation mixing or truncation. In contrast, Friedman's (1961) study concluded that although skewness was diagnostic of environment, kurtosis was found to be of no usefulness. Shepard and Young (1961) concluded that neither skewness nor kurtosis were effective in environmental differentiation; however, their size analysis by means of a settling tube, rather than by sieving, has been criticized by Folk (1962) as being incapable of producing meaningful skewness and kurtosis values. The skewness-kurtosis plot in the present study is of intermediate effectiveness, relative to other moment measure combinations. This diversity of results suggests that although skewness and kurtosis have potential as effective environmental discriminators, their relatively great sensitivity may render them highly vulnerable to the acquisition of bias. In essence, their specific values may be largely reliant upon the size distribution of local source materials, field sampling techniques, or analytical procedures, as well as environmental processes. In addition, the moment measures and various graphic measures of these two parameters may have varying degrees of utility. The two parameters are not effective in differentiating foreshore and berm sediments within the beach field. No strong linear trends are developed within any of the three genetic populations, although a trend of decreasing coarse skewness with decreasing leptokurtosis is suggested within the dune field.

Maximum Particle Diameter Combinations

The potential utility of maximum particle size for environmental differentiation has been noted by Passega (1957), who employed the one-percentile as an approximation of maximum grain size in the construction of CM diagrams diagnostic of various depositional agents. He noted that the coarse fraction of a sediment's size frequency distribution is generally more representative of the depositional agent that the fine fraction, because it provides insight into the competence and turbulence level of the transporting medium.

In view of the substantial competence differential between the swash-backwash hydraulic regime and the aeolian regime, it was believed that maximum particle size might be an effective parameter in differentiating beach and dune sands along the Outer Banks barrier. Therefore, the second group of evaluated scatter diagrams consists of the maximum inorganic particle diameter plotted against each of the four moment measures, as well as total heavy mineral content. These five combinations are illustrated in Figures 7-10, and their relative effectiveness in environmental field separation is indicated by their inclusion ratios (Table 1).

Among the five evaluated combinations, the maximum particle diameter-mean grain size plot (Figure 7) proved to be the fourth most effective combination in separating beach and dune environments along the Outer Banks barrier. The parabolic dune field is restricted to maximum particle diameters less than 7.5 mm and mean grain sizes smaller than 1.3 Φ, with mean grain size being the more effective discriminator of the two parameters. The dune sands are generally finer-grained, and the majority do not contain gravel-size clasts; whereas,

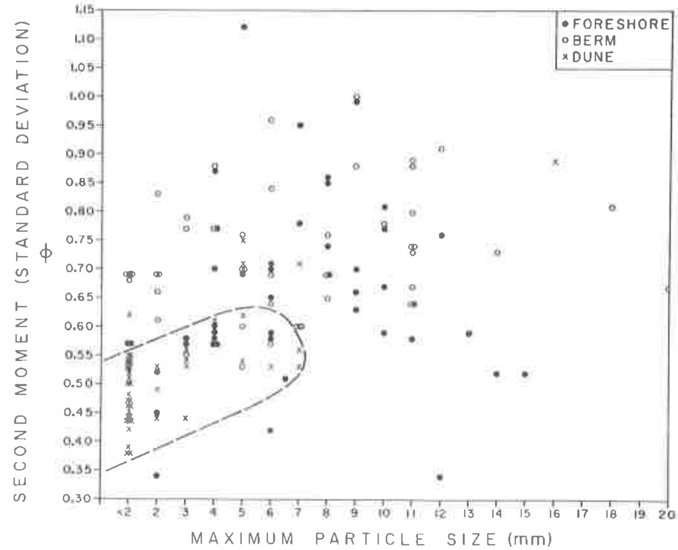

Figure 8. Scatter diagram of maximum particle size plotted against second moment (standard deviation), illustrating optimum dune field.

most beach sands do contain a gravel fraction. In addition, there is a general tendency for beach gravels to be of larger size grades than the dune gravels. Both parameters reflect the lower competence level of the aeolian regime, relative to the higher energy swash-backwash hydraulic regime. This particular parameter combination most closely approximates the attributes of Passega's (1957) CM plots, which were based on the one-percentile and median grain size, two parameters which he felt most adequately reflected the depositional agent. In contrast to beach-dune differentiation, no effective separation is apparent between foreshore and berm populations within the beach environmental field. No well-developed linear trends are apparent among the three populations, thus indicating parameter independence.

A plot of maximum particle diameter-standard deviation (Figure 8) is the third most effective parameter combination in differentiating beach and dune sands. The dune field is confined to maximum particle diameters less than 7.5 mm and standard deviation values less than 0.65ϕ, with standard deviation being a substantially more effective discriminator. The dune population tends to be better sorted than the beach population, with gravel fractions being much less common and of generally smaller size grades. This appears to reflect both the lower

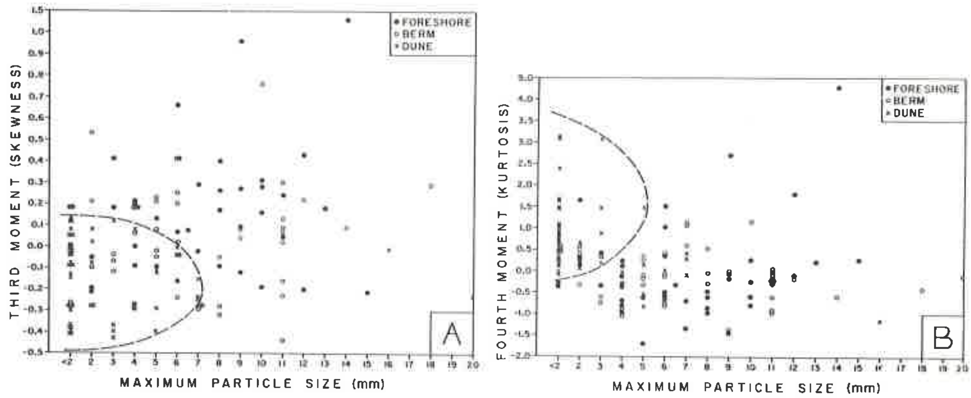

Figure 9. Scatter diagrams of maximum particle size plotted against: (A) third moment (skewness), and (B) fourth moment (kurtosis). Optimum dune fields delinated by dashed lines.

competence level, as well as the more limited competence range of wind, relative to aqueous currents. Within the beach field, no effective separation between foreshore and berm sediments is apparent. A weakly-developed linear trend appears to be present within the dune population, possibly suggesting a decrease in sorting with increasing maximum particle size.

The scatter plot of maximum particle diameter-skewness (Figure 9A) is the least effective of the five parameter combinations in differentiating beach and dune sands. The dune field is restricted to maximum particle diameters less than 7. 5 mm, and skewness values within the -0. 5 to 0. 2 range. The maximum particle diameter, which reflects the competence level differential between the aeolian and hydraulic regimes, is the slightly more effective discriminator of the two parameters. Within the beach field, no significant separation of foreshore and berm sands is apparent. Linear trends between the two parameters are not apparent within any of the three genetic pbpulations.

A scatter diagram of maximum particle diameter-kurtosis (Figure 9B) was found to be the second most effective parameter combination in beach-dune differentiation. The dune field is confined to maximum particle diameters less than 5. 5 mm, and kurtosis values within the -0. 5 to 4. 0 range. Once again, maximum particle size which reflects competence level is the more effective discriminator of the two parameters. Within the beach field, no significant separation is apparent between foreshore and berm sediments. No well-defined linear trends are present within any of the three populations, thus indicating parameter independence.

The scatter plot of maximum particle diameter-total heavy mineral content (Figure 10) proved to be the best combination for differentiating between beach and dune sands among the five tested combinations. The dune field is confined to maximum particle diameters of less than 4. 5 mm, and total heavy mineral contents by weight of less than 70 percent. The maximum particle diameter which reflects competence level is the significant discriminator, with the absolute percentage values of

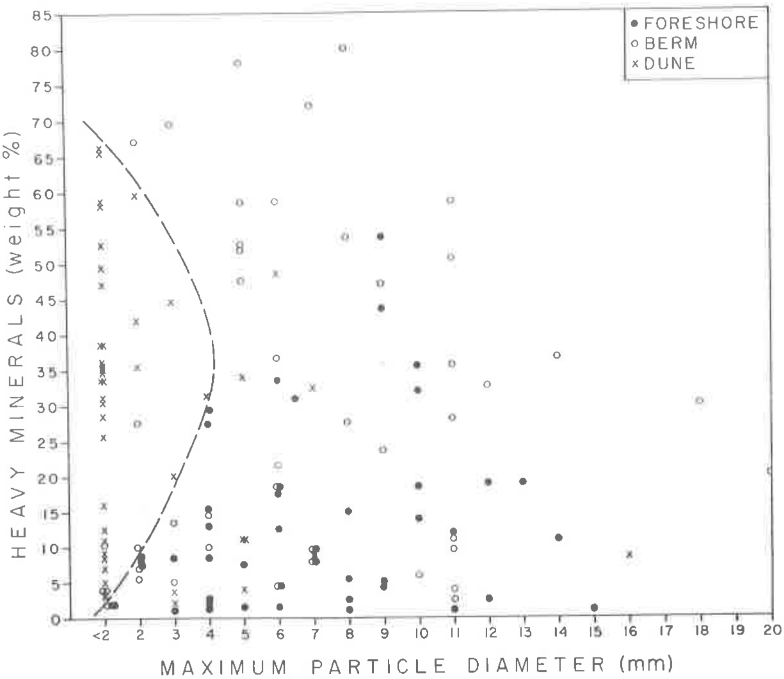

Figure 10. Scatter diagram of maximum particle size plotted against total heavy mineral content, illustrating optimum dune field.

total heavy mineral content being of relatively minor usefulness. The effectiveness of this parameter combination might be largely attributed to its ability to reflect differences in the "hydraulic equivalence" (Rittenhouse, 1943) of the maximum-size particles which are largely quartzose, and the higher density heavy mineral suite. In studying settling velocities of the light and heavy mineral fractions of beach and dune sands, Hand (1967) noted that the hydraulic equivalence of minerals of different densities is notably different for water and air media; he was also able to obtain good environmental separation by plotting settling velocity differences between selected heavy minerals and associated quartz grains. The scatter diagram of maximum particle size-total heavy mineral content presented in this study appears to reflect some of the same differences in fluid dynamics between air and water media. Within the beach environmental field, there does appear to be some separation of foreshore and berm sediments, with the berm sediments tending toward higher heavy mineral contents. This might be attributed to the substantially greater influence of the aeolian regime on the berm population, relative to the foreshore population. Aeolian winnowing of the berm sediments might result in the selective removal of lower density light materials, and a corresponding enrichment of the heavy mineral fraction. No linear trends are apparent among the three populations, thus indicating parameter independence.

Total Heavy Mineral Content Combinations

As a final evaluated technique for environmental differentiation along the Outer Banks barrier, scatter diagrams were constructed illustrating the total heavy mineral contents by weight percentage for each combination of the three genetic populations. Although absolute values of heavy mineral percentages within the populations overlap considerably, it was believed that the relative values of adjacent sample which comprise genetic couplets might be effective discriminators. A study of heavy mineral contents on Mustang Island by Bradley (1957) showed a progressive inland increase in the volume percentage of heavy minerals from the beach to the dune fields. Additionally, on a worldwide distribution basis, Shepard and Young (1961) noted that dune sands generally contain higher proportions of silt-size black heavy minerals than found in adjacent beaches. In the present study, comparisons were made for adjacent sample couplets by employing the type of diagrams used by Shepard and Young, which are illustrated in Figure 11.

A comparison of total heavy mineral contents for the 45 foreshore-berm couplets (Figure 11A) illustrates that in 40 couplets (89%) berm sands have higher heavy mineral contents than adjacent foreshore sands. Using a non-parametric Sign Test (Dixon and Massey, 1969), this difference is statistically significant at the 1 percent level. In addition, the heavy mineral percentage differential exceeds 5 percent in 30 of the 45 couplets. This contrast in heavy mineral content may reflect the substantially greater influence of the aeolian regime on berm sediments, as compared to the foreshore population where aeolian effects are relatively minor. The more extensive winnowing of berm sediments might tend to differentially remove greater quantities of light minerals, thus concentrating relatively higher proportions of the denser heavy mineral fractions as lag deposits. The brief exposure and wetted nature of foreshore sands would result, not only in minimal aeolian winnowing, but also in minimal sediment interchange with adjacent berm sands by onshore wind transport. Similarly, interchange resulting from offshore wind transport would also be minimal because of the berm's leeward location within the wind shadow of coastal dune ridges. The lack of substantial sediment interchange between the two populations would tend to enchance the preservation of their distinctively different heavy mineral concentrations. Differential aeolian effects on foreshore and berm populations have also been noted by Shepard and Young (1961), who found significantly higher grain roundness values within the berm population.

A comparison of the heavy mineral contents for the berm-dune couplets (Figure 11B) illustrates an equal division, with both berm and dune sands each having higher contents in 22 couplets (49%); contents are equal in 1 couplet (2%). The heavy mineral percentage differential

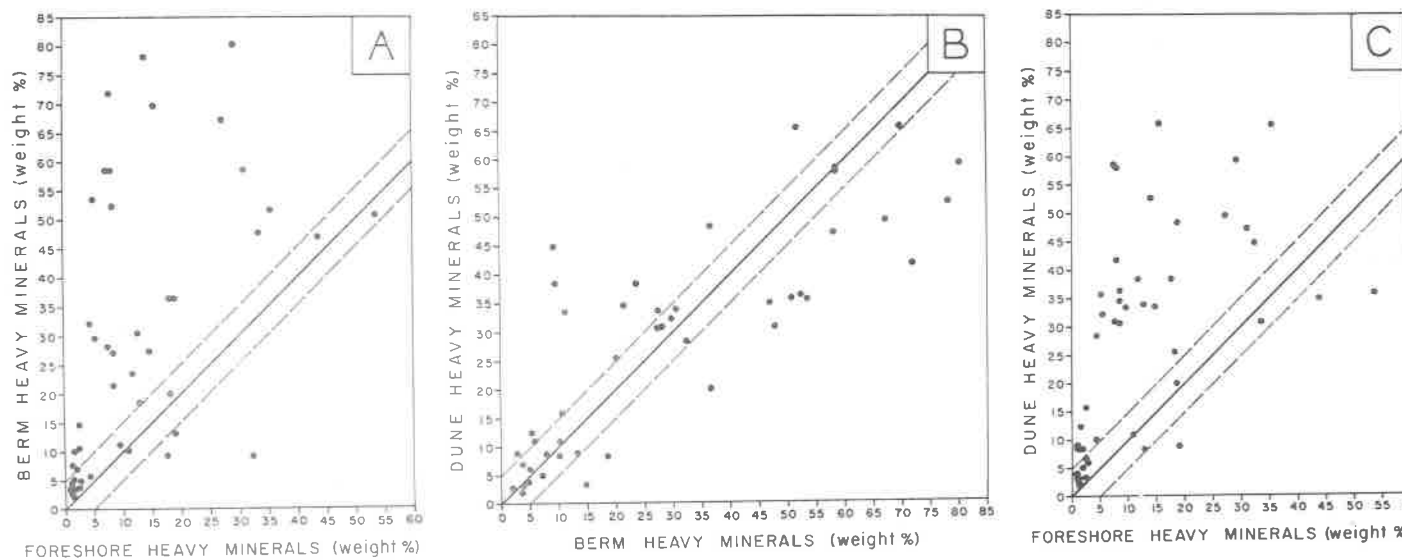

Figure 11. Comparison diagrams of total heavy mineral contents for adjacent population couplets:
A. Foreshore-Berm couplets,
B. Berm-Dune couplets,
C. Foreshore-Dune couplets,
Solid diagonal line indicates equal contents, while paired dashed lines encompass couplets with content differentials less than 5 percent.

exceeds 5 percent in 26 of the couplets, fewer than exhibited by the foreshore-berm couplets. The absence of a significant difference in the total heavy mineral contents of adjacent berm and dune sands might be attributed to the strong aeolian influence exerted on both populations, as well as the extensive amount of sediment interchange between the two populations resulting from both onshore and offshore wind transport. This interchange could result in a certain degree of homogenization between the two populations, thus tending to obscure differences in heavy mineral contents.

A comparison of the heavy mineral contents for the 45 foreshore-dune couplets (Figure 11C) illustrates that dune heavy mineral contents are higher than in the adjacent foreshore sands for 39 couplets (87%), with 1 couplet (2%) being equal; this difference is statistically significant at the 1 percent level. In addition, the heavy mineral percentage differential exceeds 5 percent in 33 of the couplets, the highest number among the three combinations. Once again, this contrast in heavy mineral content probably reflects the relative influence of the aeolian regime on the two populations. In this couplet combination, the aeolian influence is of two extreme degrees, being of minor significance on the foreshore population, while essentially generating the dune population. This extreme contrast in aeolian influence, in conjunction with a lack of significant sediment interchange between the two populations, have resulted in the development and preservation of strong contrasts in the heavy mineral contents of foreshore and dune sands. Contrasts in other parameters have also been noted for adjacent foreshore and dune populations (Shepard and Young, 1961); these parameters include roundness, silt content, silt-size heavy minerals, shell contents, and mica content. These contrasts indicate that the foreshore population, rather than the berm, is more effectively employed in the differentiation of beach and dune environments.

CONCLUSIONS

The variable aeolian regime and heterogenous source sediment associated with the Outer Banks barrier chain rendered it a rigorous test site for evaluating the relative effectiveness of various textural parameters as environmental discriminators. An effective comparison technique consists of constructing optimum parabolic curves on scatter diagrams to delineate dune environmental fields which can then be evaluated in terms of their respective "inclusion ratios". Such a standardized technique tends to minimize the subjectivity associated with delineating environmental fields.

The evaluation of moment measure discriminators in differentiating beach and dune sands of the Outer Banks indicates that standard deviation-kurtosis is the most effective parameter combination, while mean grain size-kurtosis is the least effective combination. However, as individual discriminators, mean grain size and standard deviation are the most effective parameters, while skewness and kurtosis are the least effective. The greater utility of mean size and standard deviation results from their ability to reflect the more basic differences between the aeolian regime and the swash-backwash hydraulic regime, namely, their competence levels and ranges. Within the study area, the dune sands are finer-grained and better-sorted than adjacent beach sands, thus reflecting the lower and more limited competence range of the aeolian regime. In comparison, the relatively high sensitivity of the skewness and kurtosis measures which largely reflects sub-population mixing may be a self-limiting factor. These measures appear to be much more vulnerable to the acquisition of bias, with their values being not only reliant upon environmental processes, but also upon local physiography and source sediment characteristics, sampling techniques, and analytical procedures. Regarding foreshore-berm differentiation, no effective separation was feasible by plotting moment measure combinations, even though statistically significant textural differences do exist between the two populations.

The evaluation of maximum particle size combinations indicates that within this group, the maximum size-total heavy mineral content combination is the most effective discriminator in beach-dune differentiation along the Outer Banks, apparently reflecting hydraulic equivalence differences between the aeolian and hydraulic regimes. The least effective discriminator is the maximum size-skewness combination. Maximum size is an effective discriminator because it also reflects the basic competence level differential between the aeolian and hydraulic regimes. In the study area, the lower competence level of the aeolian regime is reflected by a dune population containing substantially less gravel, and of generally smaller size grades than contained within the beach population. The main factor limiting the utility of this parameter in beach-dune differentiation is the availability of gravel-size clasts within the source materials. No effective separation between foreshore and berm populations is feasible with this parameter.

The evaluation of total heavy mineral contents as environmental discriminators indicates significant contrasts between adjacent foreshore-berm couplets and foreshore-dune couplets; whereas, berm-dune couplets exhibit no significant differences. These relationships appear to reflect the relative influences of the aeolian regime on the three populations, as well as the degree of sediment interchange between the populations. Greater degrees of aeolian winnowing tend to generate larger heavy mineral lag concentrations by the selective removal of lower density light mineral fractions. Within the study area, the poorly winnowed foreshore sediments have relatively low heavy mineral contents, while the extensively winnowed adjacent berm and dune sediments have relatively high concentrations. After the development of contrasting heavy mineral concentrations, their preservation is enhanced by maintaining minimal sediment interchange among the three populations. In utilizing heavy mineral contents to differentiate beach and dune environments along the Outer Banks barrier, the use of foreshore deposits, rather than berm deposits, appears to offer the best opportunities for success.

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LATE MIOCENE TERRESTRIAL MAMMALS

ECHOLS COUNTY, GEORGIA

By

M. R. Voorhies
Geology Department
University of Georgia
Athens, Georgia 30602

ABSTRACT

Fossil beaver, horse and rhinoceros remains occur along with shark teeth in phosphorite-rich clastic sediments at Statenville, extreme southern Georgia. The sediments appear to be part of a deltaic sequence built by streams flowing south from the upper Georgia coastal plain. The joint occurrence of two fairly advanced species of the three-toed horse *Merychippus* and a small species of the rhinoceros *Teleoceras* indicate an age of Barstovian (upper Miocene on the North American land mammal time scale) for the Statenville Local Fauna (new name). The beaver, almost certainly belonging to the genus *Monosaulax*, is the only known Tertiary representative of its family in eastern North America.

INTRODUCTION

Knowledge of the North American land vertebrate fauna east of the Mississippi River during the Tertiary is based almost wholly on fossils collected in Florida. Even in the comparatively rich Floridian sequence of fossil mammal assemblages the Upper Miocene is sparsely represented, the first and only recorded sample being that described by Olsen (1963). Therefore, the discovery of a new locality in southern Georgia yielding late Miocene mammalian remains is of unusual importance. The Statenville Local Fauna described herein comprises both terrestrial and marine vertebrates including remains of horses, rhinoceroses, rodents and fishes. Particularly noteworthy is the presence in the new fauna of a beaver, cf. *Monosaulax*, the first Tertiary member of the Castoridae to be recorded in eastern North America.

Acknowledgments

My thanks go to Jane Voorhies and Miss Mary Frances Boyce for help in making the collection and to Messrs. Reavis Lindsay and

Jerry Elkins for taking the photographs. Jane Voorhies prepared Figure 8. E. A. Stanley kindly identified microfossils.

GEOGRAPHIC AND GEOLOGIC SETTING

The fossils described below were collected from an outcrop on the east bank of the Alapaha River at Statenville in southern Echols County, extreme southern Georgia. Except for the rhinoceros remains, all fossils were obtained from a small exposure about 15 yards long at the mouth of the small tributary that enters the river approximately 150 yards north (upstream) of the Georgia Highway 94 bridge at the western city limits of Statenville. The rhinoceros bones were collected 50 yards south (downstream) from the mouth of the tributary. Being one of the few bedrock exposures in the county, the Statenville outcrop is well known to Coastal Plain geologists. A photograph of the impressive, uniformly-dipping foreset(?) beds at the base of the exposure appears in Veatch and Stephenson's (1911) report on the geology of the Georgia Coastal Plain (Plate XXV. A, opp. page 352). The stratigraphy of the locality has recently been described at some length by Brooks (in Brooks and others, 1966, p. 74-78) so only a brief summary of the lithologic sequence will be provided here.

At times of extreme low water (usually in October and November) about 30 feet of phosphorite-bearing Tertiary clastic sediments are exposed at the Statenville outcrop. The lowermost unit (Brooks' bed 1), exposed in the stream bed, consists of strikingly uniform, 4-8-inch-thick cross beds of gray, dolomitic, clayey sandstone dipping south at angles of 10-12 degrees. Small black phosphorite pebbles and some small sharks teeth were found in this unit that may represent the foreset beds of a delta. A maximum thickness of 8 feet was measured. Brooks' beds 2 through 5, which unconformably overlie the steeply cross-bedded unit, consist of greenish brown sand containing numerous phosphorite pebbles, grading upward into phosphatic silts and clays. These strata are cross-bedded also but not on such a large scale as the underlying bed 1 and the dips of the cross sets show much less preferred orientation and lower dips. I measured a total thickness of 13 feet of this unit. All fossils in the Statenville Local Fauna, except for the rhinoceros, were collected from a phosphorite pebble lens at the base of unit no. 2. A layer of fine gray sand with a few phosphorite pebbles at the base (Brooks' bed 6) overlies the preceding strata, possibly disconformably although no evidence of profound erosion was observed. The rhinoceros bones were collected from near the top of this unit, which measures about 6 feet in thickness.

No useful purpose would be served by assigning a formational name to these beds until they have been traced areally into more completely studied localities. On the State Geologic Map of Georgia (1939, see also Olson, 1966) the beds are mapped as Hawthorn Formation - a name that has been applied, sometimes indiscriminately, to a wide variety of Miocene and even Pliocene rocks with a broad spectrum of lithologies. The age of the sediments at Statenville has been questionable because of the lack of diagnostic fossils. Veatch and Stephenson (1911) regarded them as Oligocene, Olson (1966) as Middle Miocene (?), and Brooks (1966) as Upper Miocene (?). The present study concludes that at least bed 2 is of Barstovian (Late Miocene) age on the North American land mammal time scale (Wood and others, 1941). (For a recent cross-calibration of the fossil mammal and marine invertebrate and microfossil time scales see Berggren, 1972).)

PRESERVATION OF THE FOSSILS

The collection consists almost entirely of isolated teeth of mammals and fish. Except for the associated rhinoceros bones the fossils all show signs of transportation - abrasion and breakage - although very few are badly rounded. The rhinoceros bones were collected in fine grained sediment and show no evidence of transportation. The color of the teeth ranges from black and gray through tans and browns, much like the range of colors in the phosphorite pebbles associated with them. Because the color changes do not appear to correlate with either taxonomy or degree of abrasion and because several colors often occur within a single fossil, color does not appear to provide a useful criterion for distinguishing fossils of different chronological or environmental provenance. Although some of the fossils may be reworked there is no biostratigraphic evidence of heterochroneity and reworking need not be invoked to account for the presence of both marine and terrestrial fossils in the same bed, particularly in such deltaic/estuarine sediments as those at Statenville.

Preservation of several complete and unabraded bones of a single individual rhinoceros in the fine-grained sandstone at the top of the Statenville exposure suggests a different mode of origin from that of the principal fossil concentration in the phosphorite pebble zone. Although the rhinoceros bones were not articulated they were not widely scattered, indicating that no significant transportation had occurred after disarticulation. Perhaps the remains represent a bloated carcass that floated down from the adjacent mainland and then sank in relatively quiet water where it was buried by fine sand and silt before much scattering occurred. A sample of the sediment enclosing the rhinoceros bones was submitted to Dr. E. A. Stanley for microfaunal analysis. Dr. Stanley reports (oral communication) that no calcareous microfossils or pollen could be found in the sample but that hystricosphaerids are present. Hystricosphaerids, so far as is known, are restricted to strata deposited in marine or brackish waters (Wilson and Hoffmeister, 1955).

INVERTEBRATES

Mega-invertebrate fossils appear to be rare in the cross-bedded clastics at Statenville. Occasional obscure molds and some barnacle plates were observed. Burrows of the *Ophiomorpha* type are fairly common in the sands below the principal bone-bearing horizon. These structures are regarded (Weimer and Hoyt, 1964) as indicators of littoral and shallow neritic marine environments. In the fossiliferous phosphorite pebble horizon, sinuous, ramifying burrows about one inch in diameter and up to a yard long were observed to penetrate the sediment in a more-or-less horizontal orientation. They resemble the burrows of the shrimp *Upogebia affinis* investigated by Frey and Howard (1969) in tidal stream deposits on Sapelo Island, Georgia. These burrows lack the pelletoid wall structure typical of *Ophiomorpha*.

VERTEBRATES

All specimens are housed in the collections of the Geology Department, University of Georgia (abbreviation UGV-).

Class Chondrichthyes

Order Selachii

Sharks belonging to six genera can be identified among the approximately 200 elasmobranch teeth in the Statenville Local Fauna (catalog no. UGV-19 applies to the entire lot). They are listed below in order of abundance from greatest to least:

Negaprion
Carcharhinus
Hemipristis
Galeocerdo
Odontaspis
Carcharodon

The composition of the shark fauna is generally similar to that reported by Webb and Tessman (1968) from a Pliocene site in Manatee County, Florida that also yielded fossil mammals. The predominance of sharks whose modern analogues prefer a coastal and estuarine habitat (*Negaprion* and *Carcharhinus*) and the scarcity of pelagic types (*Carcharodon*) are congruent with the hypothesis of a nearshore (deltaic or estuarine) depositional environment.

Order Batoidea

Skate and ray teeth are surprisingly uncommon in the Statenville Local Fauna in contrast with their abundance at most localities on the

Atlantic Coastal Plain where shark teeth can be collected. Besides one rostral tooth of a large sawfish (Pristis) (UGV-21), only about a dozen recognizable ray teeth were collected. All appear to pertain to Aetobatis, the spotted eagle ray, this identification being based on the notable angularity ("boomerang shape") of the tooth bands. The comparative scarcity of batoid remains is certainly not due to selective mechanical or diagenetic destruction; the dental batteries of the myliobatids are remarkably robust structures compared to sharks teeth of equivalent size. Eagle rays are adapted to a diet of heavy-shelled mollusks; therefore perhaps their poor representation in the Statenville assemblage correlates with the scarcity of invertebrates noted above. The rapid rate of sedimentation in the murky waters of an estuary or delta may have been inhospitable to both shelly invertebrates and their batoid predators but the area may still have supported sizable shark populations.

CLASS REPTILIA

Water-rolled pieces of turtle carapace were the only reptilian fragments recovered.

CLASS MAMMALIA

Order Rodentia

Family Castoridae

cf. Monosaulax (Figure 8)

An isolated right first or second lower molar reveals the presence of a small beaver in the fauna (UGV-29).

Description

The crown is well preserved but the roots, which appear to have been well developed, are abraded. The tooth may be termed subhypsodont because of its possession of roots and the comparatively weak development of the striids. The occlusal pattern is dominated by two infoldings of the enamel wall (the hypoflexid and mesoflexid) and two enamel 'lakes' (the parafossetid and metafossetid). The flexids and fossetids are elongate and subparallel at the stage of wear shown by the specimen. The mesostriid is quite short but the hypostriid extends well down the enamel crown. The tooth would not exhibit the S-pattern at any stage of wear because the mesoflexid would close before the para- (and, probably, the meta-) fossetid would be obliterated by wear.

Discussion

Either of the two recognized genera of small subhypsodont beavers in the late Tertiary (Monosaulax and Eucastor) could be represented by the Georgia specimen. The shallowness of the striids, however, and the lack of an S-pattern, both argue for its inclusion in the former genus, which is regarded as a characteristic Hemingfordian-Barstovian (medial and late Miocene) form, rather than in the latter, which is confined to the Clarendonian (early Pliocene). Monosaulax and Eucastor differ significantly in crown height, the former being notably less hypsodont (Stirton, 1935; Shotwell, 1963, 1968). Although the original (unworn) crown height of an isolated tooth such as UGV-29 cannot be accurately determined, the fact that large para- and metafossetids are still present when the mesoflexid is about to close indicates that the Statenville beaver was less hypsodont than even the most primitive species of Eucastor described by Stirton. In the wear series of lower molars of the early Clarendonian species E. dividerus (Stirton, 1935, p. 435) such large fossetids are present only in very early wear and are completely obliterated before the teeth are worn to a crown height equivalent to that of the Georgia specimen. Thus, the beaver in the Statenville Local Fauna appears to be more primitive than the earliest Eucastor. It is distinctly more advanced than the earliest known Monosaulax species (Monosaulax n. sp. from the Quarry A assemblage of Wilson, 1960) and approaches such Barstovian species as M. pansus, M. curtus and M. typicus in evolutionary grade.

The Statenville Monosaulax is the only known pre-Pleistocene castorid east of the Mississippi River. The closest reported Miocene beaver occurs in the Burkeville Fauna in eastern Texas some 800 miles away (Quinn, 1955, p. 72).

Order Carnivora

Tooth fragments and a proximal phalanx appear to be referable to a small canid but are too incomplete for further classification.

Order Sirenia

Several rib sections lacking cancellous tissue obviously belong to a sea cow but are not more completely identifiable.

Order Perissodactyla

Family Equidae

Horse teeth are the most abundant terrestrial mammal remains in the collection; they provide further evidence for dating the deposit as Barstovian. Two distinct species of mesodont (subhypsodont) horses are present and both readily fall within the confines of the genus Merychippus as recognized by most workers in vertebrate paleontology. The concept of the genus Merychippus held by Osborn (1918) and modified by Stirton (1940) is an extreme example of a horizontally defined taxon, comprising at least six separate lineages thought to be ancestral to such later genera as Pliohippus, Hipparion, etc. Within this exceedingly complex group of species is a bewildering amount of morphological diversity. Tooth characters held in common by most if not all Merychippus species are 1) cheek teeth mesodont (height/length ratio of unworn teeth falling roughly between 1. 0 and 2. 0), 2) cheek teeth moderately to strongly curved and 3) cement-covered crowns on the cheek teeth.

The great majority of described Merychippus species are Barstovian in age although primitive species are known from the Hemingfordian and at least one lineage persisted into the Clarendonian (Webb, 1969). Morris F. Skinner has recently solved one of the more vexing problems regarding the genus by demonstrating that the genotypic species, M. insignis, is Barstovian in age (Skinner and Taylor, 1967).

Merychippus sp. A

The larger of the two Statenville horse species is about the size of M. insignis. It is represented by two upper and two lower cheek teeth (Figures 1, 2, 4, and 5). UGV-25 is a left upper third or fourth premolar from a young adult animal. At this early stage of wear there is a prominent anterobuccal 'spur' on the protocone and the protoconule is not yet connected to the metaloph; neither has the metaloph yet joined to the ectoloph. The enamel pattern is simple, a pli prefossette and a pli hypostyle are the only accessory folds present. The anteroposterior length of the tooth crown divided into its height along the mesostyle (28. 0/18. 5) gives an index of hypsodonty of 1. 5, well within the range of Merychippus.

UGV-22 is a well worn upper left second premolar. The protocone is connected to the protoloph but the protoloph is not yet connected to the metaloph. The hypoconal groove is still open indicating that it was deep and persistent. The metaloph has not yet joined the ectoloph. A prominent pseudoparastyle (see Skinner and Taylor, 1967, p. 24) is present. The tooth is 15. 3 mm high along the mesostyle.

UGV-23 is a lower right third or fourth premolar at a moderate state of wear. The ectoflexid is deep, a shallow notch still separates the metaconid and metastylid, and an ectoparastylid down the antero-external corner of the tooth although it is weak. UGV-24 is a lower right molar, either M_1 or M_2. As is usually the case, it is a smaller tooth than the premolar, especially in transverse diameter. It is otherwise similar except for a more advanced state of wear.

Merychippus sp. B

A second, considerably smaller, equine species is represented by one lower and two upper cheek teeth (Figures 3, 6, and 7). UGV-26 is an upper right first or second molar at a mature stage of wear; its height along the mesostyle is 18.0 mm. The protocone is connected to the protoloph, the metaloph is connected to the ectoloph, and the hypoconal groove is shallow and about to be obliterated by wear. No plications are present in the fossette borders. UGV-27 is a badly abraded right P^2, probably at an early stage of wear but no measurement of crown height can be made because of the severe abrasion. The tooth has a disconnected, teardrop-shaped protocone, a connected metaloph, and rather complicated fossette borders. UGV-28, a right M_1 or M_2, is little worn. The ectoflexid is very deep, the metaconid and metastylid small but distinct, and the ectoparastylid strong and sharp for the entire length of the tooth.

Comparisons

In addition to a size difference of approximately 50% the two species of Merychippus found at Statenville differ in several morphological details such as the timing of the metaloph-ectoloph union and the persistence of the hypoconal groove on the upper teeth and the prominence of the ectoparastylid on the lowers. Without more complete material it would be unwise to allocate either of the Georgia horses to one of the dozens of described Merychippus species. Their inclusion in the genus seems solidly based and their comparatively high degree of hypsodonty suggests a Barstovian age but beyond that one cannot go

Figure 1-7. Horse teeth, Statenville Local Fauna (Barstovian), Georgia Bars equal 10 mm.

Figure 1. UGV-25, left P^3 or P^4 of Merychippus sp. A. a. occlusal view; b. posterior view.

Figure 2. UGV-24, right M_1 or M_2 of Merychippus sp. A. a. occlusal view; b. buccal view.

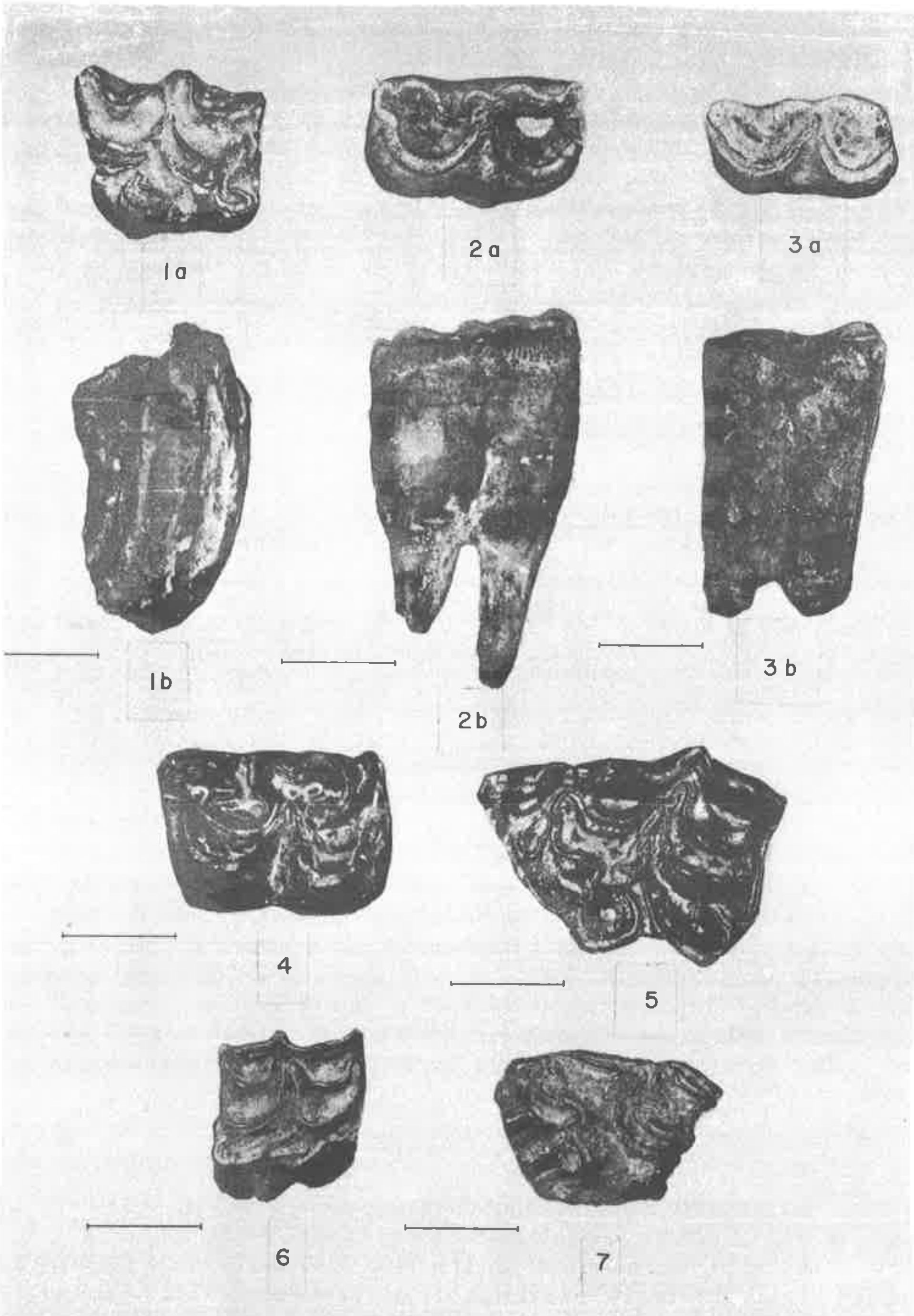
Figure 3. UGV-28, right M_1 or M_2 or Merychippus sp. B. a. occlusal view; b. buccal view.

Figure 4. UGV-23, right P_3 or P_4 of Merychippus sp. A, occlusal view.

Figure 5. UGV-22, left P^2 of Merychippus sp. A, occlusal view.

Figure 6. UGV-26, right M^1 or M^2 of Merychippus sp. B, occlusal view.

Figure 7. UGV-27, left P^2 of Merychippus sp. B, occlusal view.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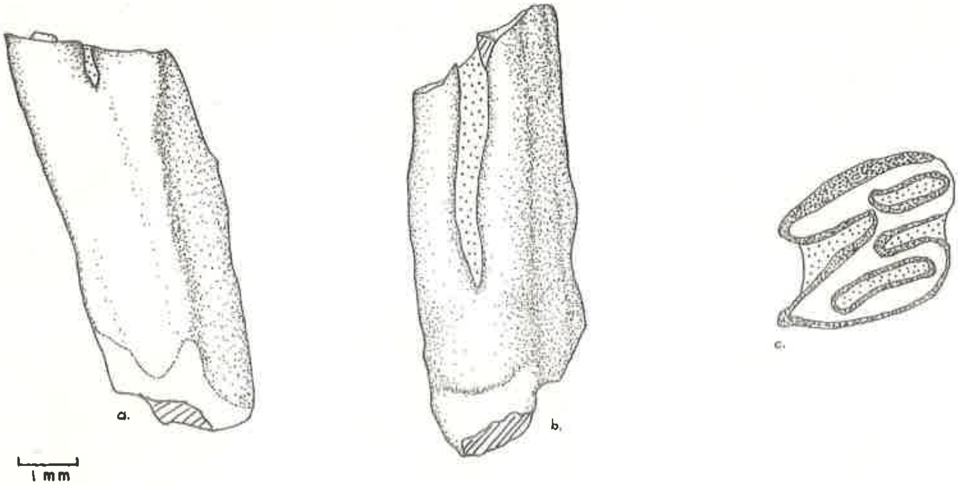

Figure 8. cf. Monosaulax, first or second right lower molar. a. lingual view. b. buccal view. c. occlusal view.

on the basis of present evidence. The Barstovian Merychippus sp. teeth from northern Florida figured by Olsen (1963) appear to be similar in size to the larger Statenville form, similar in hypsodonty, but with perhaps a more complex enamel pattern in the upper molars.

Family Rhinocerotidae

Teleoceras sp. (Figure 9)

A short-limbed, hypsodont rhinoceros is represented by some fragmentary limb bones and tooth scraps (probably from the same individual because no skeletal elements were duplicated) collected from fine-grained sediments about 15 feet above the rest of the fossils as noted above. The specimens were collected in situ and from talus immediately below the exposure from which the bones were weathering out. The fossils are somewhat leached and crushed but show no evidence of postmortal transportation.

Description

Identifiable elements include a left metatarsal III (UGV-30), left metatarsal IV (UGV-31), left metacarpal IV (UGV-32), proximal end of left tibia (UGV-33), proximal end of left ulna (UGV-34), proximal end of left radius (UGV-35), proximal end of right radius (UGV-36), ungual phalanx (UGV-37), proximal phalanx (UGV-38), right magnum (UGV-39) and miscellaneous tooth fragments (UGV-40). The metapodials are short and stout and the preserved portions of the other limb elements

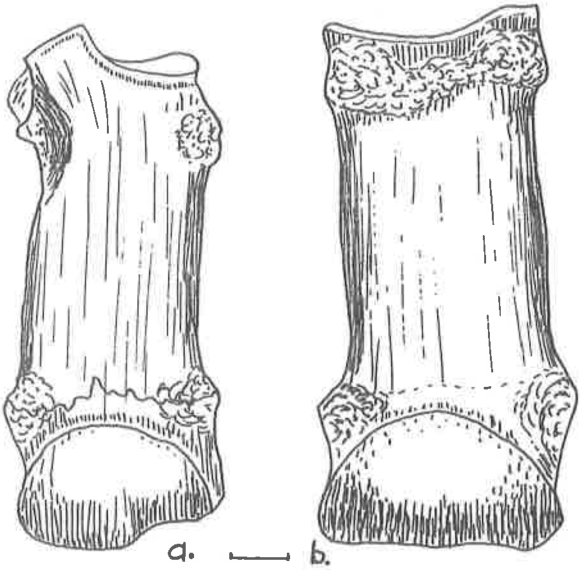

Figure 9. Teleoceras sp. a. left metacarpal IV, anterior view. b. left metatarsal III, anterior view. Bar equals 10 mm.

are also ruggedly constructed. Measurements are given below:

Left Metatarsal III	length - 94 mm width across epicondyles - 46 mm
Left Metacarpal IV	length - 90 mm width across epicondyles - 36 mm
Left Radius	width of proximal end - 72 mm
Left Tibia	width, across condyles, of proximal end - 98 mm

The tibia was not ankylosed with the fibula. The tooth fragments are too incomplete for detailed comparisons but indicate that the animal had fairly high-crowned teeth (over 50 mm in little worn molars).

Discussion

No rhinoceros genus except Teleoceras has such stubby metapodials. Other rhinoceros genera reported from Florida (Aphelops, Diceratherium, Floridaceras) are all cursorial or semicursorial types with comparatively long, slender limbs. Although the genus is best represented in numerous Clarendonian and Hemphillian faunas of the western United States, Teleoceras is also reported from faunas of Barstovian age (Lower Snake Creek, Pawnee Creek, Cold Spring). In the southeastern United States the only previously reported Teleoceras specimens are of Hemphillian age. By far the best population sample to be described is that in the Mixson bone bed in Alachua County, Florida (Leidy and Lucas, 1896; Simpson, 1930). T. proterus from that locality, judging from the descriptions, measurements, and illustrations given by Leidy and Lucas, has considerably larger limbs and feet than the rhinoceros from Statenville. The Georgia specimen is also smaller than the referred specimens of Teleoceras fossiger from various Clarendonian faunas on the Great Plains measured by Gregory (1942). Without a good skull, no specific identification of a Teleoceras should be attempted. Whether the Statenville form represents a separate lineage leading toward T. proterus or is conspecific with one of the described western Barstovian species must be decided when more complete material is available. In any case, compared with Pliocene examples the specimen has shorter, distinctly less robust metapodials - a fact consistent with its postulated Barstovian age.

CONCLUSIONS

Patton (1969) has emphasized the similarity of Florida Miocene vertebrate faunas to western ones, especially those of Texas. Our first glimpse of Miocene land mammals in Georgia reemphasizes the similarity; differences, if any, between the Statenville horses, rhinos and beavers and their western counterparts must be at the specific and not at the generic level. Further collecting in Florida will reveal whether the absence of Tertiary beavers there is a fact of real biogeographical significance or is merely an artifact of preservation or collection.

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ROCKS OF THE BASEMENT COMPLEX AND OCOEE SERIES IN THE OTEEN QUADRANGLE, NORTH CAROLINA

By

Dennis O. Nelson
Oregon State University
Corvallis, Oregon 97331

ABSTRACT

The Oteen quadrangle, located in the Blue Ridge geologic and physiographic provinces of western North Carolina, is composed of complexly folded and polymetamorphosed rocks of the basement complex, Ocoee Series, and Brevard Zone. Similar lithologies in the metasedimentary Ocoee Series and the basement complex are distinguished by the former's relict sedimentary textures. The basement complex consists primarily of a layered muscovite - biotite - feldspar - quartz gneiss. The Ocoee Series is represented by biotite-plagioclase-quartz gneiss, garnet-biotite-muscovite schist, metasandstone, metaconglomerate, and biotite-muscovite schist.

A pre-Ocoee Series episode of deformation, consisting of northwest trending open (?) folds recognized in the basement complex, reflects the unconformity that exists between these units. A later episode, of uncertain character, produced the regional foliation. This foliation was later deformed by similar folds into a northeasterly trending anticlinorium.

The post-basement metamorphic history consists of a progressive episode reaching the almandine-amphibolite facies, followed by a retrogressive episode causing widespread formation of chlorite.

A sedimentary origin for the basement lithologies is suggested, with probable rock types including muddy subarkosic to arkosic sandstones and sandy shales. Rounded grains, relict bedding, graded bedding, and conglomerate beds reflect the sedimentary origin of the Ocoee Series. Rock types consisted primarily of subarkosic to arkosic sandstones interbedded with pelitic rocks.

The rocks of the Ocoee Series in the Oteen quadrangle are correlated with the Roaring Fork Sandstone of the Snowbird Group, and the basal schist and lower and middle Thunderhead Sandstone of the Great Smoky Group.

INTRODUCTION

Blue Ridge Belt

The Blue Ridge Belt of western North Carolina includes gneisses and other plutonic rocks that range in age from Paleozoic to Middle Precambrian (King, 1955, p. 358). The Middle Precambrian basement rocks of the belt are complexly folded and polymetamorphosed sedimentary and plutonic rocks from which radiometric ages on the order of one billion years have been obtained (Long, Kulp, and Eckelmann, 1959, p. 588-590; Tilton and others, 1960, p. 4175-4177), representing a thermal event, probably orogenic, comparable to the major event in the Grenville Province of the southeastern part of the Canadian Shield (King, 1964, p. 17). Overlying the basement complex is the Ocoee Series, a thick accumulation of clastic rocks that have been divided into three major groups; the Snowbird Group, the Great Smoky Group, and the Walden Creek Group (Hadley and Goldsmith, 1963, p. 24).

In the Blue Ridge of North Carolina and Tennessee, the basement complex and its cover have been thrust over Paleozoic miogeosynclinal rocks to the northwest (King, 1969, p. 60). The location of some windows, occurring as much as 40 miles behind the leading edge of the thrust sheet, indicate considerable displacement (King, 1969, p. 60).

General Geology of the Oteen Quadrangle

The Oteen quadrangle is located on the eastern edge of the Blue Ridge Belt just east of Asheville, North Carolina (Figure 1). Traversing the southeast portion of the quadrangle is the Brevard Zone, a narrow belt of intense shearing consisting of cataclastic rock types including mylonite and phyllonite, along with lenses and pods of strongly deformed gneiss and schist. Rocks of the basement complex occur both southeast and northwest of the Brevard Zone. To the southeast is a biotite gneiss. Northwest of the Brevard Zone, the dominant basement lithology is a layered muscovite-biotite-feldspar-quartz gneiss. The Ocoee Series comprises the bulk of the rocks in the quadrangle, consisting of the following units: biotite-plagioclase-quartz gneiss, garnet-biotite-muscovite schist, metasandstone, metaconglomerate, and a biotite-muscovite schist.

Within the Ocoee Series, metamorphism and deformation have locally obliterated stratigraphic relationships and, to some extent, the characteristic features of the units. This situation makes it difficult to distinguish between portions of the Ocoee Series and the basement complex. Adding to this problem are the factors of poor exposures and similarities in the lithologies of different units.

Small bodies of pegmatite, metagabbro, amphibolite, and ultramafic (?) rocks are also found in the quadrangle.

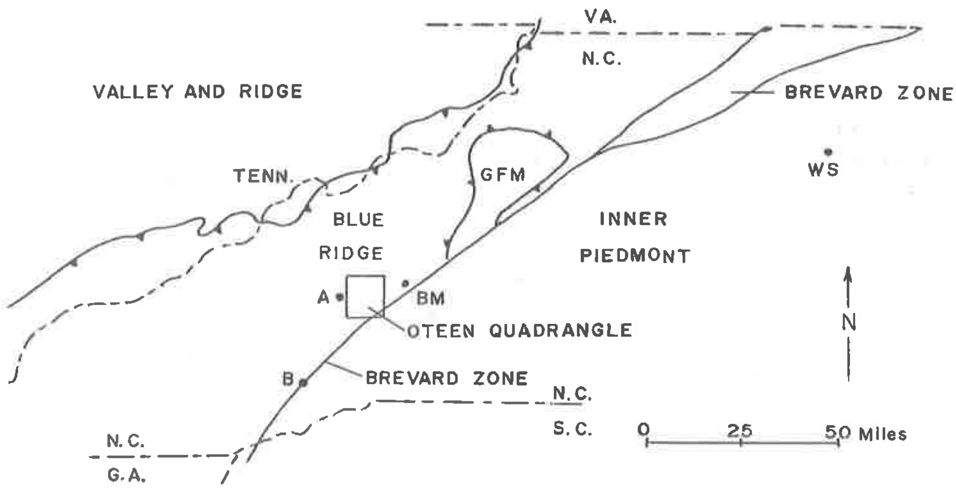

Figure 1. Geologic setting of the Oteen quadrangle in western North Carolina. Localities: A-Asheville, N. C.; B-Brevard, N. C.; BM-Black Mountain, N. C.; WS-Winston-Salem, N. C.; GFM-Grandfather Mountain window.

Present Study

This paper represents a portion of a masters thesis project for the University of North Carolina at Chapel Hill. Field work was completed during the summer months of 1968. This study was initiated in order to provide a detailed geologic map of the Oteen quadrangle, thereby distinguishing between rocks of the basement complex and the Late Precambrian Ocoee Series.

Acknowledgments

I thank J. R. Butler of the University of North Carolina at Chapel Hill for his assistance and valued suggestions in the field and laboratory, and for his comments regarding the improvement of this manuscript, I appreciate the comments of J. B. Hadley of the U. S. Geological Survey regarding his work in the Oteen quadrangle.

I also thank the National Park Service for permission to collect specimens from the Blue Ridge Parkway, and the park rangers of the area for their cooperation and encouragement.

I am particularly indebted to the Division of Mineral Resources of the North Carolina Department of Natural and Economic Resources and to the Tennessee Valley Authority for their financial support.

STRUCTURE

The earliest episode of deformation recognized in the area involves only the basement complex, and consists of broad open (?) folds trending in a northwest direction. The absence of these folds in the overlying Ocoee Series reflects the unconformity existing between these units.

The first episode of deformation involving the Ocoee Series was of uncertain character. The regional foliation produced during this episode is parallel to the original bedding planes of the Ocoee Series. Later deformation by similar folding, resulted in the formation of a northeast trending anticlinorium (Figure 2).

METAMORPHISM

In the Oteen quadrangle, the Ocoee Series exhibits recognizable sedimentary textures, displaying little evidence of extensive constituent mobilization. These rocks, however, overlie migmatized basement rocks, suggesting at least one pre-Ocoee episode of metamorphism. Further evidence is provided by the occurrence of retrogressed high-rank metamorphic rocks of the basement complex in direct contact with rocks of the Ocoee Series, metamorphosed to a lesser degree, in the Great Smoky Mountain National Park southwest of the present area of study (Hadley and Goldsmith, 1963, p. 104).

Hatcher (1973, p. 671-672) concluded that in the northeastern corner of Georgia and adjacent South Carolina, migmatite-bearing gneisses, previously considered basement, are actually high grade, mobilized equivalents of lower grade (Ocoee equivalent) metasedimentary and metavolcanic rocks.

In the present area of study this does not appear to be the case, as the migmatite-bearing gneiss does not coincide with the highest grade of metamorphism, and in fact, seems to be independent of it, being surrounded by mineralogically similar, yet less mobilized, younger rocks that do extend into the higher zones of metamorphic grade.

Within the quadrangle, rocks of the Ocoee Series have been subjected to two episodes of metamorphism. The first episode reached conditions favorable for the formation of staurolite, kyanite, and sillimanite, minerals indicative of the almandine - amphibolite facies (Winkler, 1967, p. 106). Metamorphic grade increases to the west and north in the area. A later episode of lower grade resulted in widespread retrogression in the area, as evidenced by the extensive formation of chlorite after biotite and garnet.

The progressive and retrogressive episodes of metamorphism are considered separable because of their respective association with the first and second episodes of deformation (described above) involving the Ocoee Series (Nelson, in preparation).

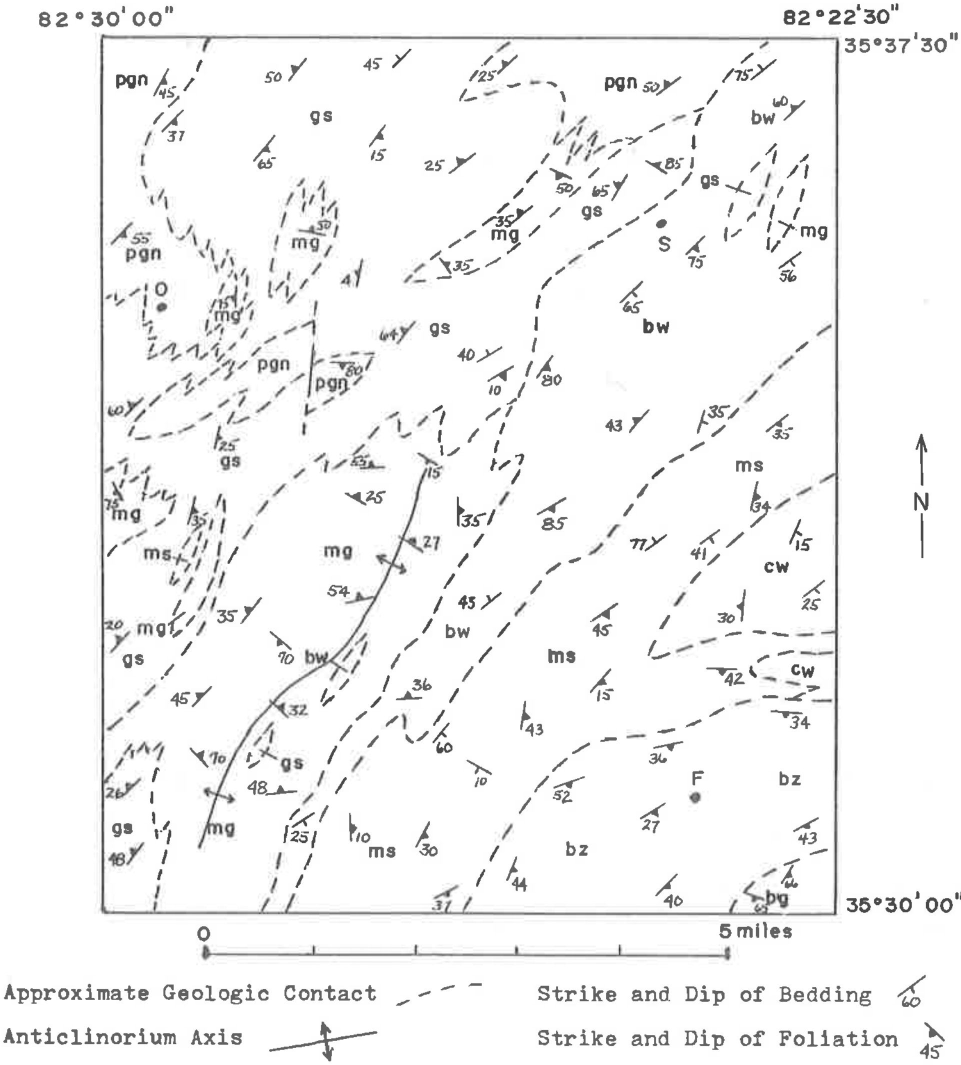

Figure 2. Generalized geologic map of the Oteen quadrangle, after Nelson (1972). Localities: F-Fairview, N. C.; O-Oteen, N. C.; S-Swannanoa, N. C. Brevard Zone lithologies designated as bz. Ocoee lithologies: ms-biotite-muscovite schist; cw-metaconglomerate; bw-metasandstone; gs-garnet-biotite-muscovite schist; pgn-biotite-plagioclase-quartz gneiss. Basement lithologies: mg-muscovite-biotite-feldspar-quartz gneiss; bg-biotite-gneiss.

ROCK UNITS

Basement Complex

Biotite Gneiss. As a result of its position adjacent to the Brevard Zone, the biotite gneiss is strongly crushed and sheared.

The rock is dark gray to black and fine to medium grained, with porphyroclasts of potassium feldspar ranging in size from several millimeters to greater than one centimeter. Foliation is marked by subparallel mica with streaks of quartz and feldspar alternating with layers rich in biotite.

Mineralogically, the rock consists of clasts of feldspar, dominantly microcline of high triclinicity (Butler, 1968, personal communication), and subordinate plagioclase. Clasts of quartz are seen only rarely, while those of plagioclase are extensively altered to sericite. Individual clasts are surrounded by a fine-grained crushed matrix. Grains of muscovite, the primary mica, are curved or fractured in some specimens.

Muscovite-Biotite-Feldspar-Quartz Gneiss. This unit is well foliated, distinctly layered, and consists of a muscovite-biotite-feldspar-quartz gneiss interlayered with subordinate garnet-muscovite-biotite schist, biotite schist, and quartz-feldspar layers. Migmatites can be seen in some outcrops.

The unit is dominated by a light gray to gray, weakly to moderately foliated muscovite-biotite-feldspar-quartz gneiss. Foliation varies with percentage of mica, and is defined by subparallel flakes of biotite and to a lessor extent, muscovite.

Always associated with the gneiss are thin layers of biotite schist, ranging in thickness from one centimeter to two meters. These layers are generally continuous, but may occur as pods or lenses, and normally display intense folding.

A medium- to coarse-grained dark gray garnet-muscovite-biotite schist occurs locally and ranges in thickness from one to five meters.

The quartz-feldspar layers are generally less than ten centimeters thick and vary from pegmatitic quartz and feldspar to a more intimately interlayered rock consisting of quartz, feldspar and mica. These are almost always seen as discontinuous layers, lenses, or pods, and are intensely folded.

The most common minerals of the gneiss unit are quartz, K-feldspar, plagioclase, biotite, and muscovite. Quartz and feldspar generally show extensive fracturing, and recrystallization is common. Plagioclase usually is extensively altered to sericite. Consequently, determination of An-content is difficult and I am uncertain, because of the small number of measurable grains, just how representative the values obtained are. A maximum value of An_{55} was obtained using the michel-levy technique on a flat stage. In some thin sections, biotite displays ragged grain boundaries, and in many cases is altered to chlorite. Muscovite, appearing curved or fractured in some specimens, generally is fresh, but may be extensively altered to fine-grained phyllosilicates. Garnet occurs primarily in the schistose layers, may carry inclusions of quartz and biotite, and often is retrogressed to chlorite. Epidote can be seen associated with some altered plagioclase grains. Sillimanite is seen in many thin sections, either associated with quartz or muscovite.

Ocoee Series

Biotite-Plagioclase-Quartz Gneiss. This unit is dominated by a massive light gray to gray, weakly to moderately foliated, medium grained biotite-plagioclase-quartz gneiss interbedded with thin beds of muscovite-biotite schist. Thickness of individual layers of gneiss generally exceeds one to two meters, and locally reaches ten meters. The thickness of the layers of muscovite-biotite schist are generally less than two centimeters, often less than five millimeters, but locally attaining a thickness of one meter.

Common minerals in the gneiss are quartz, plagioclase, biotite, garnet, muscovite, and K-feldspar. Quartz is always abundant, but percentage varies between layers. Individual grains usually appear angular, but may be rounded in many specimens. Recrystallization can be seen in some sections. As in the basement complex, the alteration of plagioclase to sericite made the determination of An-content difficult. Determinations using the michel-levy and Slemmons techniques on the universal stage yielded values in a range from An_{25} to An_{30}. Again, because of the altered state of the feldspar, and the small number of measurable grains, these values are probably more indicative than representative. Biotite is the most abundant mica, defines the foliation, and is altered to chlorite in some specimens. Muscovite occurs in minor amounts and appears to have in some cases grown from altered plagioclase grains. Garnet carries inclusions of quartz, biotite, and plagioclase, is partly retrogressed to chlorite in some sections, and appears to be metamorphic in origin, having conformed to available space. Calcite is a conspicuous constituent in some layers. Zoisite, zircon, and sillimanite are seen in some slides.

Garnet-Biotite-Muscovite Schist. This unit consists of a gray to dark gray, medium to coarse grained garnet-biotite-muscovite schist interbedded with a light gray medium-grained feldspathic metasandstone. The schist is generally not a massive unit, but rather consists of many thin layers of schist, two centimeters to one meter thick. Variation in grain size between layers is common as is a variation in relative proportions of mica, quartz, and feldspar. Large grains of muscovite, one centimeter in diameter, can locally give the schist a lumpy appearence. Common minerals include garnet, quartz, biotite, and muscovite. K-feldspar, plagioclase, kyanite, sillimanite, and staurolite occur locally.

The metasandstone is always subordinate to the schist, generally occurring as thin layers ranging in thickness from two centimeters to two meters. The metasandstone locally contains conglomerate layers. A garnetiferous quartz-rich metasandstone can be seen in some outcrops.

In thin section the garnet-biotite-muscovite schist exhibits evidence of extensive shearing. Recrystallization of the tectosilicates is common. Most phases have undergone alteration: muscovite to fine-grained phyllosilicates, biotite and garnet to chlorite, and the feldspars to sericite. Quartz and the feldspars show extensive fracturing, and the plane of foliation, defined by muscovite and biotite is very irregular.

Metasandstone and Metaconglomerate. The metasandstone unit consists of a light gray to gray medium-to coarse-grained meta-arkose interbedded with thin layers of a gray medium to coarse grained muscovite-biotite schist.

The metasandstone portion of this unit consists of a sequence of thin layers, generally ten centimeters to one meter in thickness, rarely reaching five meters, and locally exhibiting gradational contacts between one another. Grain size and modal percentage of major constituents may vary between layers. The most prominent mineralogical variation is the mica content, which when low, gives the rock a rather massive appearance, and when high, imparts to the rock a distinct foliation. Quartz-rich layers and pods can be found locally, as can a garnetiferous quartz-rich metasandstone. Common minerals are quartz, K-feldspar, plagioclase, biotite, and muscovite. Sphene and zircon can be found in some specimens. The schist consists of muscovite and biotite, with lesser quartz, feldspar, and garnet.

Within the unit, quartz is rounded and may be fractured; recrystallization has occurred locally. Some grains show no evidence of either strain or recrystallization. This phase may occur as clasts in the schistose rocks. Feldspar occurs in both the groundmass and as clasts, and is fractured in most specimens. Either K-feldspar or plagioclase may dominate. Biotite is the dominant mica in the sandy rocks, where it defines the foliation and generally occurs as small elongate flakes with irregular ragged edges. Coarse biotite is often associated with feldspar clasts. Muscovite occurs as flakes or larger wisps, or in undulatory layers by itself or interlayered with biotite. Muscovite grains are often subparallel and, in many sections, define a second less prominent foliation than that defined by biotite. This feature, seen in many of the rocks in the area, is most obvious in this unit.

The metasandstone unit becomes more massive with conglomerate layers more prominent in the eastern portion of the area, and on this basis was mapped as separate units (Figure 2). Mineralogically, the metasandstone and metaconglomerate units are very similar.

Biotite-Muscovite-Schist. This unit consists of a light-colored medium to coarse grained biotite-muscovite schist, interlayered with a light gray to gray medium-grained arkosic metasandstone and lesser amounts of a dark fine-grained micaceous feldspathic metasandstone and associated dark fine-grained muscovite-biotite schist. Conglomerate layers are seen locally.

The biotite-muscovite schist is the dominant lithology, and is composed primarily of muscovite with lesser biotite. Locally, biotite may be the dominant mica. Quartz is always present, and feldspar is commonly seen, as are garnet and chlorite.

The arkosic metasandstone is moderately sorted and consists primarily of quartz and feldspar, with muscovite and biotite comprising less than ten percent. The mineralogy of the feldspathic micaceous metasandstone is similar; however, the mica content may be 35 to 40 percent. The muscovite-biotite schist consists almost entirely of biotite with subordinate muscovite. Minor amounts of quartz and feldspar can be seen.

Planes of foliation, defined by the mica, are commonly undulatory, with individual muscovite and biotite grains appearing curved and having ragged boundaries. Quartz occurs in minor amounts, generally rounded and in many sections appearing strained; recrystallization is common. Plagioclase, altered in part to sericite, is the major feldspar. K-feldspar, generally associated with muscovite, can be seen in some sections. Garnet, carrying inclusions of quartz and biotite, is a common constituent. Chlorite occurs after biotite and garnet. Zircon and actinolite are seen only rarely.

STRATIGRAPHY

The stratigraphic sequence of the rocks in the area has, to a considerable extent, been obscured because of multiple deformational episodes. This problem is compounded by the fact that the stratigraphic relations between the units are themselves very complicated, being characterized by probable interfingering and gradational contacts. The most probable stratigraphic column for units northwest of the Brevard Zone, and their stratigraphic relationships are given in Figure 3.

I was unable to establish any stratigraphic relationships between the biotite gneiss and the other rocks of the quadrangle because of the intervening Brevard Zone. Butler (1972) has given an age of Middle Precambrian for this unit where it occurs in the Black Mountain quadrangle immediately to the east of the present area of study, so it at least pre-dates the Upper Precambrian Ocoee Series.

The oldest rock in the area northwest of the Brevard Zone is the layered muscovite-biotite-feldspar-quartz gneiss that appears to underlie all other rocks in the quadrangle. The following features suggest that this unit belongs to the basement complex; (1) Distinctively layered structure, (2) The presence of migmatites, (3) The more complex

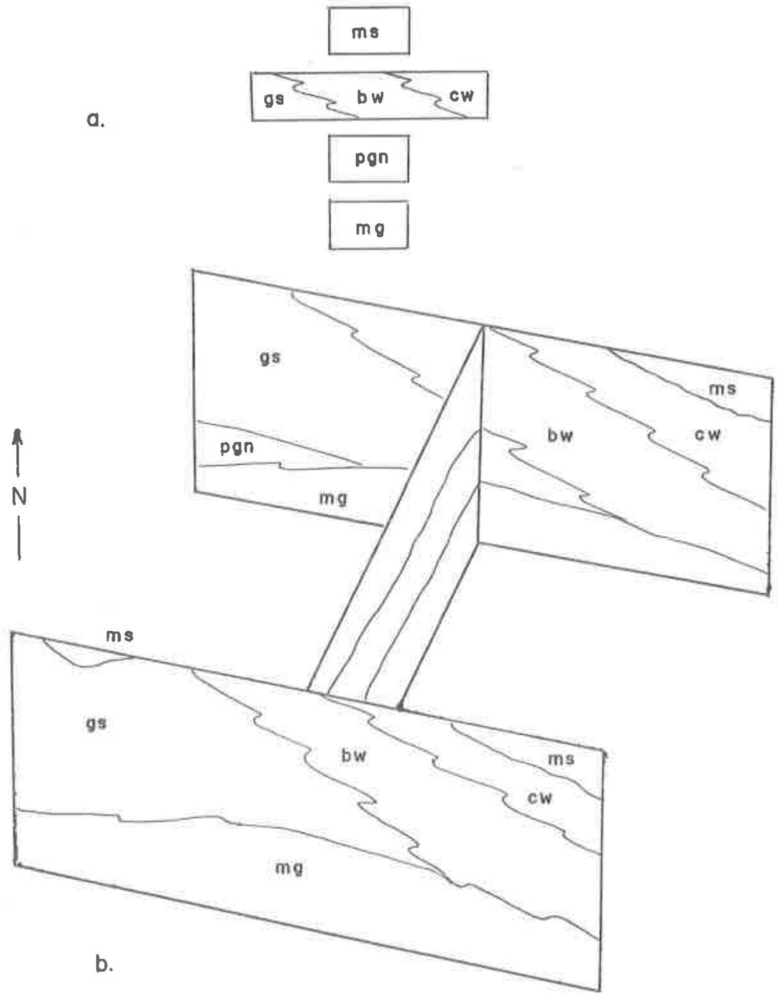

Figure 3. Possible stratigraphic column (a) and generalized fence diagram (b) of units northwest of the Brevard Zone, prior to folding episodes. Units depicted are biotite-muscovite schist (ms), metaconglomerate (cw), metasandstone (bw), garnet-biotite-muscovite schist (gs), and biotite-plagioclase-quartz gneiss (pgn), all of the Ocoee Series, and the muscovite-biotite-feldspar-quartz gneiss (mg) of the basement complex. No absolute thicknesses implied.

deformational history, and (4) Lack of relict sedimentary textures, probably indicating extensive recrystallization.

The Oteen quadrangle was mapped as a portion of the two degree

Knoxville sheet by Hadley and Nelson (1971), and their published map shows no rocks of the basement complex in the quadrangle. Rocks of the basement complex were not shown on this map because a definite boundary between suspected basement and Ocoee Series could not be found, and because the area of suspected basement was too small to be shown in the Oteen quadrangle at a scale of 1:250,000 (Hadley, 1969, personal communication).

Overlying the layered gneiss (mg), is a massive biotite-plagioclase-quartz gneiss (pgn). A southeasterly thinning of this unit is suggested by the fact that in the northwest corner of the quadrangle (Figure 2), the biotite-plagioclase-quartz gneiss dips beneath a garnet-biotite-muscovite schist (gs) that in the southwest portion of the area rests directly on the layered gneiss (Figures 2 and 3).

At its eastern contact, the garnet-biotite-muscovite schist (gs) grades laterally and vertically (?) into the metasandstone (bw) (Figure 3). In the eastern portion of the quadrangle, the metasandstone (bw) rests directly upon the basement complex, suggesting, along with the lateral gradation, partial equivalence of gs and bw (Figure 3). The metasandstone (bw) becomes more conglomeratic eastward where it grades into the metaconglomerate unit (cw).

In the eastern portion of the quadrangle, the metasandstone (bw) and metaconglomerate (cw) units are overlain by the biotite-muscovite schist (ms). This unit (ms) overlies the garnet-biotite-muscovite schist (gs) in the western portion of the quadrangle (Figures 2 and 3), again suggesting equivalence of the metasandstone (bw), metaconglomerate (cw), and the garnet-biotite-muscovite schist (gs).

CORRELATION AND PARENT LITHOLOGIES

Ocoee Series

Parent Lithology. The sedimentary origin of the rocks of the Ocoee Series in the Oteen quadrangle is well evidenced by relict sedimentary textures (rounded grains, relict bedding, graded bedding, and conglomerate beds) and by the mineralogy. Most significant in the latter respect is the high quartz content.

In order to display compositional variation and to indicate possible parent lithologies, the modal percentages of mica, feldspar, and quartz were recalculated to 100 percent and plotted on Figure 4. Subdivisions and terminology are those given by Hadley and Goldsmith (1963, p. 40). From this diagram, it can be seen that the pre-metamorphic lithologies of the Ocoee Series in the Oteen quadrangle consisted primarily of subarkosic to arkosic sandstones interbedded with pelitic rocks.

Correlation. The Ocoee Series has been divided into three groups; the Snowbird Group, the Great Smoky Group, and the Walden

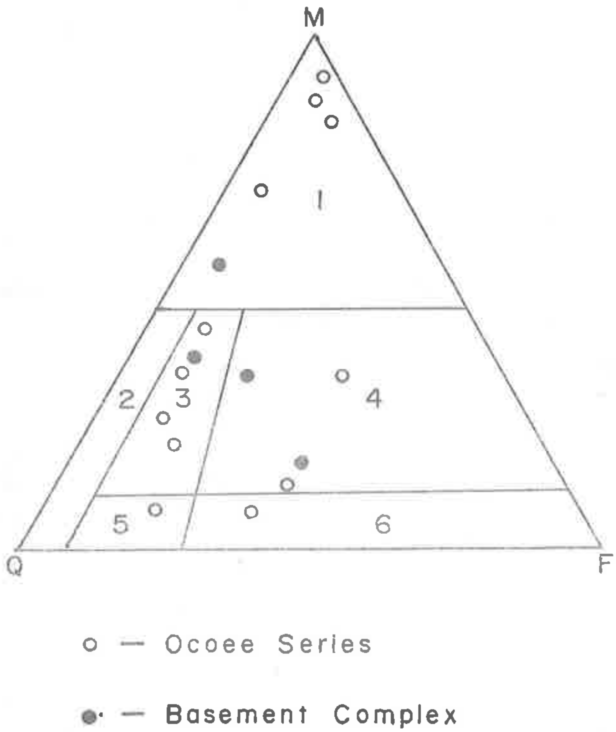

Figure 4. Composition and classification of metasedimentary rocks of the Oteen quadrangle. M = mica, Q = quartz, and F = feldspar. Subareas: 1 - pelite; 2 - muddy sandstone; 3 - muddy subarkose and feldspathic siltstone; 4 - muddy arkose and feldspathic siltstone; 5 - subarkose; 6 - arkose. Subdivisions and terminology after Hadley and Goldsmith (1963, p. 40).

Creek Group. The Snowbird rests unconformably upon the basement complex, is apparently the oldest, and is divided into four formations, which are, in ascending order, the Wading Branch Formation, the Longarm Quartzite, the Roaring Fork Sandstone, and the Pigion Siltstone (King, Neuman, and Hadley, 1968, p. 4). In the southern portion of the Great Smoky Mountains, the Snowbird Group is overlain by the Great Smoky Group, consisting of the Elkmont Sandstone, the Thunderhead Sandstone, the Anakeesta Formation, and an unnamed sandstone (King, Newman, and Hadley, 1968, p. 4). In the northern portion of the Great Smoky Mountains, the Snowbird Group is overlain by a series of unclassified formations that are overlain with a fault contact by the Walden Creek Group (Licklog Formation, Shields Formation, Wilhite Formation, and the Sandsuck Formation) (King, Neuman, and Hadley, 1968, p. 4). The characteristics of these formations are described in various reports, and will not be discussed here unless pertinent to arguments of correlation. In the following discussion of correlation, the reader is referred to Figures 2 and 3 for further clarification of the stratigraphic relationships.

The garnet-biotite-muscovite schist (gs) in the Oteen quadrangle appears to rest upon basement rocks (mg) in the southwest portion of the area, and, based upon the literature and my own observations, resembles mineralogically and in appearence, the metamorphosed basal pelite of the Snowbird Group in the Dellwood-Cherokee belt east of the Great Smoky Mountain Park (Hadley and Goldsmith, 1963, p. 25). In the present area of study, however, this unit grades into an interbedded arkosic metasandstone and metapelite unit (bw) that lacks both the quartzite compositional character and current-bedded nature of the Longarm Quartzite that overlies the basal pelite (Wading Branch Formation) of the Snowbird Group in the Great Smoky Mountains. Also, in the northwestern portion of the quadrangle, the garnet-biotite-muscovite schist (gs) is underlain by a quartz-rich subarkosic metasandstone (the biotite-plagioclase-quartz gneiss (pgn) described above).

Hadley and Nelson (1971) included all of the rocks of the Ocoee Series in the Oteen quadrangle in the Great Smoky Group (see also Hadley, 1970, p. 249). Although at the time stating the above intention, Hadley (1969, personal communication) suggested the possibility that the quartz-rich subarkosic metasandstone (pgn) might be a member of the Snowbird Group, possibly "... equivalent to the Roaring Fork Sandstone of the Great Smoky Mountains; less likely to the Longarm Quartzite, which is lighter colored and generally crossbedded." From descriptions given in the literature, I prefer a correlation of the quartz-rich subarkosic metasandstone (pgn) with the Roaring Fork Sandstone for the following reasons: (1) The unit is massive as contrasted with the current-bedded character of the Longarm Quartzite, (2) The primary feldspar is plagioclase, (3) The primary mica is biotite, and (4) Calcareous layers can be found in some outcrops. A point of variance in this correlation is the high quartz content, more characteristic of the Longarm Quartzite than the Roaring Fork Sandstone. Gross similarities were also noted between the quartz-rich subarkosic metasandstone (pgn) of the Oteen quadrangle and the Pigeon Siltstone and Rich Butt Sandstone of the Great Smoky Mountains. The Pigeon Siltstone, however, appears to pinch out, or grade laterally into the Roaring Fork Sandstone to the north (?) and east of the Great Smoky Mountains (Hadley and Goldsmith, 1963, plate 1), while the mineralogy of the Rich Butt Sandstone is not in agreement with that found in the Oteen quadrangle.

Hadley (1969, personal communication) regards the garnet-biotite-muscovite schist (gs) in the Oteen quadrangle as the basal schist of the Great Smoky Group, overlain by rocks he believes "... resemble the metasandstone, arkosic conglomerate, and feldspathic schist of the

Thunderhead Sandstone of the Great Smoky Group." A possible correlation could exist between the garnet-biotite-muscovite schist (gs) and the highly argillaceous rocks found in the upper part of the Roaring Fork Sandstone, but the fact that the schist is not everywhere associated with the Roaring Fork Sandstone in the Oteen quadrangle suggests that this is not the case, and that the schist is part of the Great Smoky Group.

Field evidence indicates that the garnet-biotite-muscovite schist (gs) grades laterally and vertically (?) into rocks (bw and cw) that Hadley called the Thunderhead Sandstone. Perhaps the explanation for the stratigraphic relationships between gs, bw, and cw (Figure 3) lies in the difference in respective depositional environments. If we assume, as field evidence suggests, that the deposition of gs, bw, and cw began at approximately the same time, then the energies of the depositional environments must have decreased westward, as indicated by the transition from coarse-grained (cw) to fine-grained (gs) material. If, as deposition continued, these environments of deposition migrated westward with time, the stratigraphic relation between gs, bw, and cw, given in Figure 3, would result. This would explain the observation that although bw and gs seem to occupy the same stratigraphic position at their bases (both in contact with the basement complex), bw appears to overlie gs at their contact. A similar relation probably exists between bw and cw, and a vertical section involving all three units would give the ascending sequence, gs, bw, and cw. These arguments would indicate an eastward source for these units, and the relationships produced are similar to the facies association formed during regression. It is probably noteworthy that the transition from sediments indicative of a high energy environment (cw) to those of a low energy environment (gs) is true only in the general case, as each separate unit contains lithologies similar to the others in subordinate amounts.

Rocks equivalent to the Elkmont Sandstone are apparently not represented in the Oteen quadrangle, as all metasandstones have conglomerate layers. I agree with Hadley's correlation of the arkosic metasandstone and metaconglomerate (bw and cw) in the quadrangle with the Thunderhead Sandstone of the Great Smoky Mountains, because of its massive and locally graded bedding, the presence of conglomerates, and the general agreement of mineralogy. I also agree with Hadley's inclusion of the biotite-muscovite schist (ms) in his correlation with the Thunderhead Sandstone, as its lithology is very different from the Anakeesta Formation that overlies the Thunderhead Sandstone. The biotite-muscovite schist unit seems most similar to the middle portion of the Thunderhead Sandstone as described by Hadley and Goldsmith (1963, p. 54), because of the presence of dark fine-grained argillaceous metasandstones and schist in the upper portions of the unit. This suggests that the arkosic metasandstone unit (bw) of the Oteen quadrangle is equivalent to the lower Thunderhead Sandstone. The reader is referred to Table 1 for a correlative stratigraphic column for units in the

Table 1. Correlative stratigraphic column for units in the Oteen quadrangle northwest of the Brevard Zone. Rocks above the unconformity are the Ocoee Series of late Precambrian age.

Biotite-Muscovite Schist (ms)	middle Thunderhead Sandstone	GREAT
Metasandstone (bw) and Metaconglomerate (cw)	lower Thunderhead Sandstone	SMOKY
Garnet-Biotite-Muscovite Schist (gs)	Basal Schist of the Great Smoky Group	GROUP
Biotite-Plagioclase-Quartz Gneiss (pgn)	Roaring Fork Sandstone	SNOWBIRD GROUP
----------UNCONFORMITY----------		
Muscovite-Biotite-Feldspar-Quartz Gneiss (mg)	BASEMENT COMPLEX	

Oteen quadrangle.

A different stratigraphic sequence for the metasandstone (bw), metaconglomerate (cw), and biotite-muscovite schist (ms) was given by Butler (1972) where these units occur in the adjacent Black Mountain quadrangle to the east. He believes the sequence for these units is, in ascending order, cw, ms, bw. His interpretation is of course, not in agreement with the conclusions reached by myself regarding the relations of bw, gs, and cw. The structural complexities will have to be resolved before these conflicting interpretations can be brought into agreement.

ORIGIN OF THE BASEMENT ROCKS

Determining the pre-metamorphic origin of the basement rocks is difficult because of textural and chemical (?) changes during their complex metamorphic and deformational histories. The rocks are sufficiently layered to suggest that they were at one time a sequence of stratified rocks (Hadley and Goldsmith, 1963, p. 12; King, Neuman, and Hadley, 1968, p. 3-4). Although the layering exhibited could have possibly resulted from some process of metamorphic differentiation, the high quartz content of the gneisses certainly suggests a sedimentary origin. The high muscovite content in the schists, and in some of the gneisses, indicates that these rocks were derived from argillaceous sedimentary rocks (Hadley and Goldsmith, 1963, p. 12). The fact that the biotite content exceeds that of the muscovite indicates that these rocks were probably originally sandy in character (Brobst, 1953).

When the compositions of these rocks are plotted in Figure 4, they indicate that if these rocks were sedimentary in origin, they consisted of muddy subarkosic to arkosic sandstones, interbedded with sandy shales. They appear to be similar in composition to the Ocoee metasandstones, though consistantly poorer in quartz.

CONCLUSIONS

Rocks of the basement complex, Ocoee Series, and the Brevard Zone are found in the Oteen quadrangle. Lithologies of the basement complex northwest of the Brevard Zone consist primarily of a layered muscovite-biotite-feldspar-quartz gneiss and subordinate garnet-muscovite-biotite schist. The layered nature suggests a sequence of stratified parent rocks. The mineralogy, especially the high quartz content, suggests sedimentary rocks as parent material, in particular, muddy subarkose-arkose and feldspathic siltstone. The Ocoee Series is represented by biotite-plagioclase-quartz gneiss, garnet-biotite-muscovite schist, metasandstone, metaconglomerate, and biotite-muscovite schist. Relict sedimentary textures can be found in most units within the Ocoee Series. Parent-rock considerations of the Ocoee Series in the area indicate premetamorphic lithologies varying from arkose to muddy subarkose and feldspathic siltstone associated with pelitic rocks.

Northwest of the Brevard Zone the oldest rock is the layered gneiss. This unit is considered part of the basement complex because of the layered structure, lack of relict sedimentary texture, local migmatization, and the recognition within the unit of a pre-Ocoee folding episode, indicating the presence of an unconformity.

The complicated deformational history is not fully understood. The pre-Ocoee deformational episode probably consisted of broad open folds with a northwest axial trend. The first episode involving the Ocoee Series was of uncertain character, but produced a prominent foliation parallel to original bedding. This foliation was later folded into a northeast trending anticlinorium.

Episodes of progressive and retrogressive metamorphism are recognized in the area. During the progressive episode, metamorphic grade reached the almandine-amphibolite facies, increasing in grade from staurolite in the southeast portion of the quadrangle to sillimanite in the west and north. Retrogression resulted in the formation of greenschist facies minerals.

The stratigraphic relationships, already complex, were obscured by the deformational episodes. The biotite-plagioclase-quartz gneiss pinches out southeastward beneath the younger units. The garnet-biotite-muscovite schist grades laterally and vertically (?) into the metasandstone, which in turn grades into the metaconglomerate. These units are all overlain by a biotite-muscovite schist.

Correlation studies of the rocks of the Ocoee Series in the quadrangle resulted in the biotite-plagioclase-quartz gneiss being correlated with the Roaring Fork Sandstone of the Snowbird Group, the garnet-biotite-muscovite schist with the basal schist of the Great Smoky Group; the metasandstone and metaconglomerate with the lower Thunderhead Sandstone; and the biotite-muscovite schist with the middle Thunderhead Sandstone.

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