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Abstract

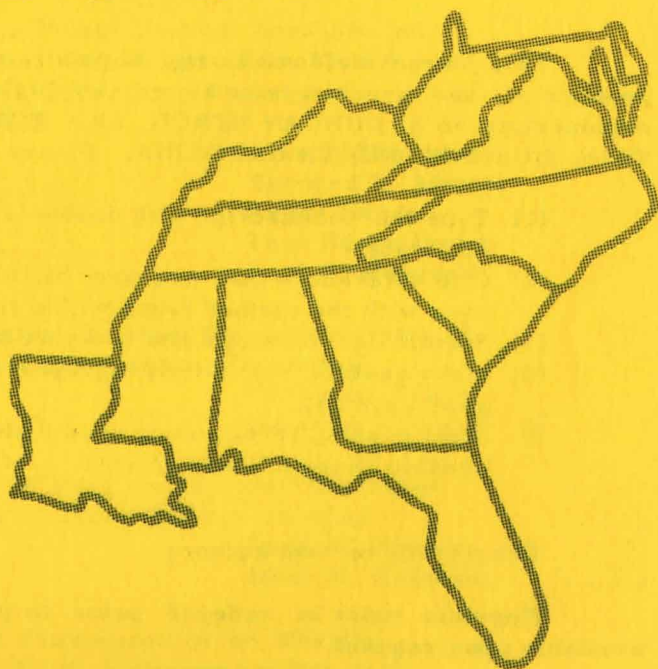
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CARBONIFEROUS PALEONTOLOGICAL ZONATION AND
INTERCONTINENTAL CORRELATION OF THE FOWLER
NO. 1 TRADERS CORE, SCOTT COUNTY, TENNESSEE, U. S. A.

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ABSTRACT

Algae, conodonts, foraminifera and spores were used to correlate a Mississippian subsurface section in the southern part of the Appalachian Basin in Tennessee with the Mississippian section in the Illinois Basin in North America and with the type Lower Carboniferous section in Belgium. Because all samples were obtained from the same core, the different biochronologic schemes could be carefully compared and integrated.

An interval containing eight of Mamet and Skipp's (1971) foraminiferal zones is present in the core beginning with zone 9 in the Fort

Payne Formation and extending to zone 17 in the Bangor Limestone. Eleven conodont zones are recognized in the core beginning with the Gnathodus texanus-Taphrognathus zone in the Fort Payne Formation and extending to the Adetognathus unicornis zone within the Pennington Formation. Three spore zones in the core come from the lower and middle Viséan Warsaw and St. Louis Formation (TC zone of Neves et al., 1972), the early Namurian Pennington Formation (NC zone of Neves et al., 1972), and the Namurian B of the early Pennsylvanian Gizzard Creek Formation.

In the core the boundary between the Fort Payne and Warsaw Formations is apparently equivalent to the Keokuk-Warsaw boundary in the type Mississippian section of the upper Mississippi Valley. This lithologic and biostratigraphic boundary closely approximates the Tournaisian-Viséan boundary in the type Lower Carboniferous section in Belgium. If the type Warsaw Formation is included in the definition of the Meramec Series, then the Osagian-Meramecian boundary is also approximately equivalent to the Tournaisian-Viséan boundary. The Meramecian-Chesterian boundary in the core lies within the Monteagle Limestone and probably lies within or at the top of foraminiferal zone 15 of Mamet.

In the core the Viséan-Namurian boundary lies within the lower part of the Bangor Limestone, slightly above the top of the Hartselle Formation. This boundary is present within the Hardinsburg Sandstone in the type Chesterian in the Illinois Basin and corresponds to the boundary between Mamet's foraminiferal zone 16s (V3cs) and zone 17 (E1). The Mississippian-Pennsylvanian boundary in the core lies in the interval between the highest recognized conodont zone at 227 feet and the lowest occurrence of Florinites at 108 feet.

Continental and intercontinental correlations can be greatly improved by using long cores, especially if different fossil groups are examined. The study of different fossil groups permits biostratigraphic correlation to transcend problems associated with different lithofacies.

INTRODUCTION

This study reports on the use of three biochronologic zonal schemes -- conodonts, foraminifera, and spores -- applied to the correlation of Mississippian sedimentary rocks in the North American section in the Illinois Basin, the southern Appalachian Basin in Tennessee, and the European Lower Carboniferous type section in Belgium.

Many problems in biochronology result from incomplete type sections and lack of consistency in collecting stratigraphic sections. For example, the type Mississippian section of the Illinois Basin contains type sections described from localities spread over a linear distance of some 500 miles (approximately 800 km) around the southern margin of the Illinois Basin. Neither rock types nor formation boundaries

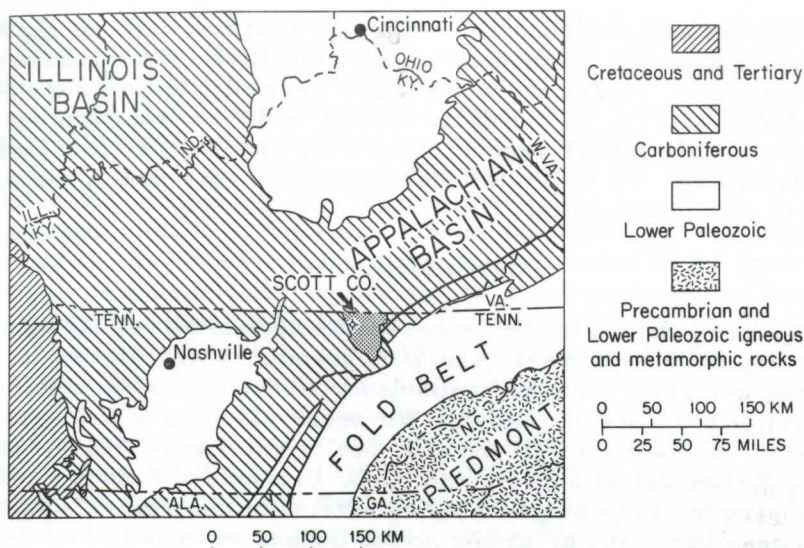


Figure 1. Location of Fowler No. 1 Traders well.

are likely to remain constant over so long a distance. By using a long core in Scott County, Tennessee (Figure 1), inconsistencies in collecting were eliminated and different schemes could be carefully compared and integrated with each other.

The C. L. Fowler No. 1 Traders Well in Scott County, Tennessee, was cored through the lowermost Pennsylvanian and almost completely through the Mississippian System (Burwell, 1967, p. 69-74). Coring was conducted during the period November 1961 to early January 1962. The 868 feet of core recovered from the 896 feet of section penetrated represents about 97 percent core recovery. The geological consultant for this well (Howard, 1962) reported that, because of drilling difficulties, coring ended in the Fort Payne Chert. More recent drilling in the area indicates that the Fort Payne Chert is 125 to 135 feet thick and that coring in the Fowler No. 1 Traders probably stopped 25 to 30 feet above the Chattanooga Shale (A. T. Statler, personal communication). The well was located approximately 11 miles southwest of Oneida, Scott County, Tennessee (Carter Coordinates: 1700 FSL x 850 FEL, 15-1S-59E). The core is now the property of the Tennessee Geological Survey and is housed at their core storage warehouse.

The entire core of the Fowler No. 1 Traders well was transported to Bloomington, Indiana, from Nashville, Tennessee, in June 1974. That portion of the core that had not been split (halved) was sawed in two. Half of the core was then returned to the Tennessee Geological Survey. The carbonate rocks in the half of the core remaining for study were again halved using a rock saw. One quarter of the cored

carbonates was used for conodont studies by Rexroad, and one quarter was sent to Mamet for determination of calcareous foraminifera and calcareous algae. Shales and a few cherts were sent to Neves for palynological analysis. A. S. Horowitz helped with the sampling of the core and wrote the initial report integrating the results provided by those cited above. P. E. Potter described the core and assisted in editing the final manuscript.

Acknowledgments

We are indebted to the Tennessee Geological Survey for permission to study the core and are especially grateful to A.T. Statler for his assistance in making the core available for study and for his comments on an earlier draft of this report. We would also like to thank H. H. Gray and J. B. Patton of the Indiana Geological Survey, W. J. Sando of the U. S. Geological Survey, and P. B. Brenckle of Amoco Production Company for reviewing an earlier version of this report. The project has been supported by grants to the Indiana University Foundation from the following companies: Atlantic-Richfield Company, British Petroleum Alaska Exploration, Inc., Chevron Oil Field Research Company, and Mobil Oil Corporation. Mamet's study was funded partially by the National Research Council of Canada. In addition, we thank the Indiana Geological Survey and the Geology Department of Indiana University for the use of their facilities in preparing and processing the core.

FORAMINIFERAL AND ALGAL ZONATION

Several thousand thin sections were prepared and 65 productive samples were obtained. The zonal scheme into which these samples fall is indicated in Figure 2. The ranges of the foraminifera in the Fowler No. 1 Traders core are given in Appendix IC.

Many calcareous algae and calcispheres have previously been referred to the Foraminiferida and are recognized and identified in carbonate rocks using the same techniques applied to foraminifera. A formal zone scheme based on algae has not been proposed because the evolution of their skeletal characters within lineages is not well understood and many algal taxa have rather long stratigraphic ranges. Nevertheless, they provide a useful supplement to the foraminiferal data and the ranges of algal taxa encountered in this study are given in Appendix IA.

The foraminiferal zonal scheme of B. L. Mamet was summarized at the 6th and 7th International Congresses on Carboniferous Stratigraphy and Geology (Mamet and Skipp, 1971; Mamet, 1974) and was based on work in the Carboniferous of the Tethys region of Eurasia and Africa. The zonal scheme was extended subsequently to North America.

Mamet et al. (1965) discussed zones 1-6 of which the first five are regarded as latest Devonian and the age of the sixth depends on the selection of the Devonian-Carboniferous boundary.

Mamet (1967) also discussed zones 3 to 7 with respect to the Devonian-Carboniferous boundary in Eurasia. In 1965, Mamet discussed zones 9 to 11 in relation to the position of the "Marbre Noir de Dinant" with respect to the Tournaisian-Viséan boundary. In 1968, Mamet (1968a, 1968b, 1968c) and Mamet and Belford (1968) published tables and discussions for most of the zones included in the Lower Carboniferous (approximately equivalent to the Mississippian System). These works included zones 15 to 19 (Mamet, 1968a), zones 6 to 19 (Mamet and Belford, 1968), zones 10 to 16 (Mamet, 1968b), and zones 10 to 19 (Mamet, 1968c). Zones 20 and above are Pennsylvanian. The 1968 papers generally contain tables showing the equivalence of the type Tournaisian and Viséan carbonate units in Belgium to the foraminiferal zones. Mamet and Belford (1968) also indicated the correlation of the foraminiferal zones with the goniatite zonation of Germany. The foraminiferal zonal scheme of Mamet has been applied worldwide by Mamet and his coworkers (Australia, Mamet and Belford, 1968; North America, Mamet and Skipp, 1971, and papers cited therein; Africa, Mamet and Omara, 1969; Asia, Mamet and Saurin, 1970). In North America, Mamet (1968a) related the zonal schemes to Mississippian formations in the Canadian Rockies, and in the following year Sando et al. (1969) reviewed previous North American foraminiferal zonal schemes and applied Mamet's zonal scheme to the northern Cordillera of the United States. Subsequently, Mamet and Skipp (1971) reviewed the foraminiferal zonation for the Mississippian System (pre-zone 7 and zones 7-18) and compared the ranges of numerous taxa in North America and Eurasia. Mamet has continued to publish the relation of specific North American sections to his zonation (for example, Sando et al., 1976, Mamet, 1975).

The interval between 912 and 909 feet in the core, which is near the top of the Fort Payne Formation, contains foraminifera that Mamet believes are characteristic of zone 9. However, Brenckle (personal communication) has indicated that none of the taxa from this interval are confined to zone 9 and that at best this interval is no older than zone 9. Both Brenckle and Mamet consider the foraminiferal fauna as of Keokuk age, but Brenckle suggests the conodont evidence, which also indicates a Keokuk age, is better than the foraminiferal evidence for comparisons with the type Keokuk. According to Mamet, this interval represents a portion of the upper part of the Keokuk Limestone (but not the highest part) in the standard upper Mississippi Valley sequence and the Tn3c of the late (highest) Tournaisian stage of the standard European succession. However, Brenckle (personal communication) does not believe the foraminifera can be unequivocally assigned to the Tn3c of Europe. Hewitt and Conil (1969) have also suggested that the Fort Payne in southern Tennessee is probably Keokuk equivalent, although

they reported no foraminifera from it.

Mamet's foraminiferal zones 10-12 are not recognized directly in the core, but they may lie within the interval of the Warsaw Siltstone (890 to 750 feet), which is equivalent to the Warsaw and Salem Formations of the type Mississippian sequence. This interval in the core could represent the early Viséan zones V1a and V1b and the middle Viséan zone V2a of the Viséan stage of the type Lower Carboniferous sequence in Europe. Note that Mamet's foraminiferal zonal scheme recognizes that neither the top nor the base of the Warsaw Formation is isochronal in the Illinois Basin (Mamet and Skipp, 1971, p. 1141, fig. 7). Hewitt and Conil (1969) equated the Warsaw Formation of southern Tennessee with the V1b and V2a of Belgium, which Mamet would equate with the type Salem of Indiana. Thus, the two zonal correlations are consistent, although the stratigraphic names are used in different ways because of the facies relations between the Salem and Warsaw Formations.

Foraminiferal zone 13 is present in the interval 740-724; based on the presence of abundant Archaediscus krestovnikovi Rauzer-Chernoussa and the first appearance of Endothyranopsis compressa (Rauzer-Chernoussa and Reitlinger) and Endothyra of the group E. bowmani. Lithologically, the interval is in the St. Louis Limestone of local terminology. This zone is equivalent to the lower part of the St. Louis Limestone in the upper Mississippi Valley sequence and to the V2b of the type middle Viséan in Europe. Other workers have correlated the lower St. Louis with part of the V2 (Browne and Pohl, 1973, p. 184) or with part of the V2b and V3a (Baxter et al., 1975; Conil et al., 1977) of the European section. The conodont zonal scheme regards this interval as Salem or lower St. Louis; these units cannot be differentiated on the basis of conodonts. Hewitt and Conil (1969) recognized both the V2b and V3a within the St. Louis Limestone of southern Tennessee and correlated it with the Salem and St. Louis of the Mississippi Valley.

The interval 695 to 693 feet contains the passage from zones 13 to 14 and lies within the St. Louis Limestone of local nomenclature. At 683 feet a "Brunsia" facies occurs, which is usually found in zones 14 or 15 in North America and most probably represents zone 14 in this core, because it is overlain by a zone 14 fauna (675 to 660 feet) characterized by dwarfed archaediscids, Endothyranopsis of the group E. hirosei, Eoendothyranopsis ermakiensis (Lebedeva) and E. macra (Zeller). Zone 14 is equivalent to V3a of the type Viséan stage in Europe and represents the upper portion of the St. Louis Limestone and the lowermost part of the Ste. Genevieve Limestone in the Mississippian sequence in the Illinois Basin. Other workers (Browne and Pohl, 1973; Baxter et al., 1975; Conil et al., 1977) have placed the V3a entirely within the St. Louis.

The base of the middle late Viséan (V3b) is represented by the passage from zone 14 to 15 in the interval between 660 and 658 feet,

which is at the top of the St. Louis Limestone of local nomenclature. The interval 658 to 647 feet contains zone 15, which is equivalent to most of the V3b of the type Viséan stage and occurs in the lower part of the Ste. Genevieve Limestone of the upper Mississippian sequence in North America. Hewitt and Conil (1969) equated the Ste. Genevieve Limestone of southern Tennessee to most of the V3b of the type Viséan series. Apparently, the V3b alpha beds are present in the underlying St. Louis Limestone as shown on the chart in Mamet and Skipp (1971, fig. 7). Zone 15 in the Fowler No. 1 Traders well displays Endothyranopsis of the group E. crassa, Eoendothyranopsis robusta (McKay and Green) and Eoforschia sp. Foraminiferal zones and the physical stratigraphy indicate that in the Illinois Basin the top of beds referred to the Ste. Genevieve Limestone is not isochronal and locally so-called Ste. Genevieve beds are time equivalents of the basal beds of the overlying Chesterian sequence (Swann, 1963, p. 30; Mamet and Skipp, 1971, p. 1141, fig. 7). This interval is at the base of the Ste. Genevieve-Gasper in the core. The conodont zonation can not distinguish between foraminiferal zones 15 and 16i; that is, between the Ste. Genevieve Limestone and lowermost Chester. Baxter et al. (1975) and Conil et al. (1977) place the V3b alpha and beta beds in the St. Louis and the V3b gamma beds of the European section in the Ste. Genevieve. Brenckle (personal communication) believes that Eoendothyranopsis is not present in the type Ste. Genevieve and that the type Ste. Genevieve lies within Mamet zone 16i (= V3b gamma) as shown on the correlation charts in Browne and Pohl (1973, p. 189, text-fig. 5) and Conil et al. (1977). On this basis, Mamet foraminiferal zone 15 would lie entirely within the St. Louis where, according to Mamet, it has not been observed.

The passage from zone 15 to zone 16i is at 647 feet. The interval between 646 and 604 feet represents foraminiferal zone 16i and is characterized in part by the first appearance of primitive Neoarchaeodiscus, which first occurs at 639 feet, and by Zellerina as well as by the extinction of Eoendothyranopsis and Eoforschia. Zone 16i is equivalent to the uppermost V3b and the V3ci of the type Viséan stage in Europe and to the lowest Chesterian Renault Formation of the type North American Mississippian standard. The zone is present in the lower part of the Ste. Genevieve-Gasper interval in the core.

Foraminiferal zone 16s, containing Planospirodiscus sp., is present in the interval between 596 and 517 feet and is equivalent to the V3cs of the type Viséan stage in Europe and to the Paint Creek Formation of the upper part of the lower Chesterian and the lower part of the Golconda Group of the lower middle Chesterian in the standard Illinois Basin section. In the core this interval corresponds to the middle of the Ste. Genevieve-Gasper.

The interval between 515 and 478 feet contains the top of zone 16s and includes boundary beds at the Viséan-Namurian transition in a palaeotextulariid facies. This interval is near the top of the Ste.

Genevieve-Gasper interval in the core, but lies below the Hartselle Formation of local terminology. This interval presumably is equivalent to part of the Golconda Group of the Chesterian section in the Illinois Basin. The Golconda conodont zone of Cavusgnathus altus Harris and Hollingsworth lies partially within this interval, and its base may lie even lower than shown as the presence of C. altus, whose base is the definition of the base of the zone, is represented by rare specimens in this interval in the core.

There is a gap in the foraminiferal data in the interval between 478 and 450 feet. This interval includes the top of the Ste. Genevieve-Gasper, the Hartselle Formation, and the basal Bangor Limestone of local terminology. On the basis of conodonts, this interval is believed to be equivalent to the upper part of the Golconda Group of the type Chesterian sequence in the Illinois Basin, and the Hartselle Formation is correlated with the Big Clifty Sandstone and the Fraileys Shale of the Golconda Group. This correlation places the basal Bangor of local stratigraphic terminology in the Golconda Group, probably at the level of the Haney Limestone, the upper member of the group in the Illinois Basin sequence.

Foraminiferal zone 17 is contained in the interval between 450 and 354 feet. This zone is equivalent to the lower part of the Namurian Stage (E1 and lowermost E2) of the European section and corresponds to the Glen Dean through Menard Limestones of the Chesterian section in the Illinois Basin. The conodonts indicate that the Glen Dean portion of the Bangor is in the interval between 457 and 415 feet. Zone 17 is characterized by a burst in the abundance of Asteroarchaediscus and lies entirely within the lower part of the Bangor Limestone of local stratigraphic nomenclature. No foraminiferal data are present above 354 feet in the core; consequently, the remainder of the core is zoned on the basis of conodonts and palynomorphs. In southern Tennessee and in northern Alabama the top of the Bangor Limestone usually contains Biseriella and belongs to zone 18.

Hewitt and Conil (1969) did not compare the Gasper and Bangor Limestones in southern Tennessee directly with European equivalents. They suggested that the Pennington, which overlies the Bangor, contained foraminifera "more advanced than the highest Viséan Beds," which is consistent with a Namurian age for all of the Pennington Formation in southern Tennessee as well as elsewhere in the Appalachian region. Because they illustrate (Hewitt and Conil, 1969, pl. 2, figs. 38, 39) two Quasiarchaediscus from the Pennington Formation at Daisy, Tennessee, the formation belongs in part to zone 19 at that locality.

Hewitt and Conil (1969), using the terminology of the Viséan type area of Belgium, suggested essentially the same correlations as Mamet for the middle and upper Viséan portion of the Belgian and upper Mississippi Valley sequence. Brenckle et al. (1974) believe that a section of the Keokuk Limestone they studied contains foraminifera that occur in Europe in V1b and V2 beds, which represent a zone no older

than 10 and possibly as young as 13 in Mamet's zonal scheme. Mamet places the Keokuk Limestone in his Tournaisian zones 8 and 9. Through the kindness of Amoco Production Company, Mamet has examined the thin sections used by Brenckle et al. (1974). The first appearance of the Globoendothyridae, which usually marks the Tournaisian-Viséan transition, is in the uppermost part of the Keokuk. The Osagean-Meramecian boundary is therefore not exactly coincident with the Tournaisian-Viséan boundary, but Mamet believes that this discrepancy is negligible. Baxter et al. (1975) reported that the Burlington Limestone did not contain any guide foraminifera and equated the Keokuk Limestone with the V1 and V2a beds of the Belgium type section.

PALYNOLOGICAL ZONATION

A set of 207 samples, most of which represented the more shaly upper half of the core, were selected for possibly palynological analysis. Of the 42 samples processed, only 17 yielded identifiable palynomorphs. The remaining samples were either barren or contained only wood plant debris in various states of preservation. The ranges of identified taxa are presented in Appendix ID.

Several palynological zonation schemes have been proposed for the Lower Carboniferous (Dinantian) of Europe (for example, Smith and Butterworth, 1967; Neves et al., 1972; and papers cited therein), but none has been attempted for North America. The North American Mississippian sequence on the craton is largely carbonates (hence unlikely to have well preserved palynomorphs) and very few papers have described palynomorphs from the type area in the upper Mississippi Valley. This understandably limits the correlation of the European schemes with North America. On the basis of spores, three zones are recognized in the core.

All three species appearing in the lowest sample at 984 feet are long ranging forms. Lycospora pusilla (Ibrahim) Schopf, Wilson and Bentall can occur as low as the upper Tournaisian, which is consistent with the foraminiferal evidence of a late Tournaisian age for the interval between 909 and 912 feet. Although Apiculatisporites pineatus Hoffmeister, Staplin and Malloy is present only in the lowest sample processed, this species was originally described from the Chesterian Hardinsburg Sandstone, which lies near the Viséan-Namurian boundary in the Illinois Basin.

Samples at 876 and 657 feet are in the interval of the lower and middle Viséan of the European section and are partly equivalent to the TC zone of Neves et al. (1972). These are the only productive samples processed between 984 (essentially the base of the core) and 410 feet, above which point shales are more abundant and productive samples are more common.

An examination of the ranges of fossils shown by Neves et al.

(1972) indicates that some species have somewhat different ranges in North America than in Great Britain. At the generic level such discrepancies have been tabulated for various basins in North America and Asia by Butterworth (1969).

According to the foraminiferal and conodont evidence, the base of the Namurian should be about 445 feet and the Namurian would extend up at least to 227 feet. The spores in this interval are generally consistent with zone NC of Neves *et al.* (1972). This zone spans the Viséan-Namurian boundary in England. On the basis of spores, the Namurian A, which corresponds to the late Mississippian, extends up at least to 181 feet, which is above the highest samples yielding foraminifera or conodonts but is consistent with a Mississippian age for the Pennington Formation, whose upper boundary was placed by Burwell (1967) at 127 feet (the top of the highest carbonate observed in the core).

Samples in the interval between 108 and 91 feet are of Pennsylvanian age (Namurian B = R1 = Kinderscoutian) on the basis of spores, principally the presence of the genera Florinites and Reinschospora.

CONODONT ZONATION

The portion of the core processed for conodonts was divided into 163 sampling intervals approximately 3 to 5 feet in length and 120 of these intervals yielded identifiable conodonts. The samples were processed in the usual manner using acetic acid to reduce the carbonate content of approximately 1 kg. samples. About 50 taxa of discrete elements were recognized at the specific level and the ranges for all conodont taxa are given in Appendix IB.

Conodonts can be used to divide the core of the Fowler No. 1 Traders into 10 zones discussed below in ascending order (see also Figure 2).

1. Gnathodus texanus-Taphrognathus zone (979.5-893.8 feet). This zone is characterized by the presence of common to abundant Gnathodus texanus Roundy below the first common Taphrognathus varians Branson and Mehl and is present in the Keokuk Limestone of the type Mississippian sequence in North America. In the core this zone is present in the Fort Payne Formation.

2. Gnathodus texanus-Taphrognathus varians subzone (893.8-746.2 feet). This zone, which represents the overlap of the range of common Gnathodus texanus and common Taphrognathus varians represents principally the Warsaw Siltstone of drillers or the Warsaw Formation of current Tennessee stratigraphic usage. The zone is equivalent to the Waraw of the type Mississippian sequence in North America.

3. Upper Taphrognathus varians-Apatognathus subzone (746.2-690.6 feet). This subzone is defined by the range of Taphrognathus varians above the highest common occurrence of Gnathodus texanus and below the first appearance of Cavusgnathus. This subzone contains the

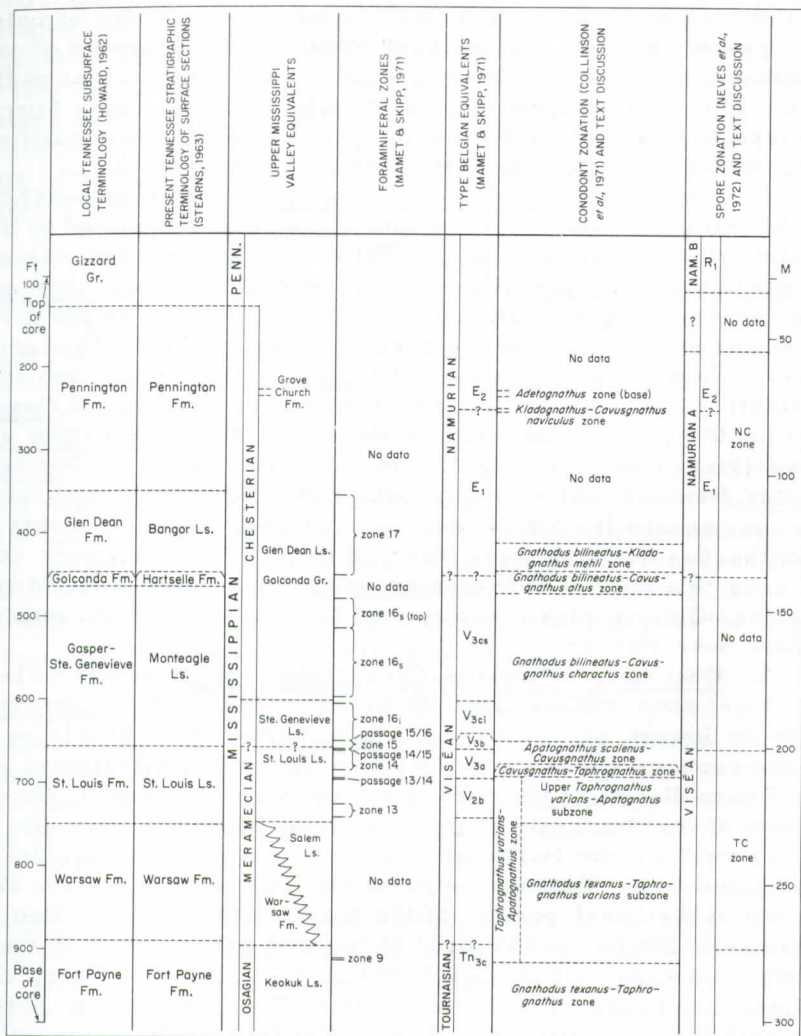


Figure 2. Comparison of zonal schemes in Fowler No. 1 Traders.

Salem Limestone and lower part of the type St. Louis Formation in the type Mississippian sequence in North America. In the core these beds have been referred to the St. Louis Formation. The Salem Limestone of the Illinois Basin section is not recognized as a distinct formation in Tennessee and its chronologic equivalents are included in the St. Louis Formation or in a lower member of the Newman Limestone.

4. Cavusgnathus-Taphrognathus zone (690.6-684.8 feet). This very narrow zone represents the overlap of the ranges of the genera Cavusgnathus and Taphrognathus. The transition between these two

genera occurs in the interval indicated, but the size of the sampled interval prevents a more precise determination of the amount of overlap or whether a small amount of separation exists in the ranges of the two genera. This zone is present in the middle of the St. Louis Formation in the type Mississippi Valley sequence and is at the same position with respect to the local Tennessee stratigraphic terminology.

5. Apatognathus scalenus-Cavusgnathus zone (684.8-657.0 feet). In the Mississippi Valley type sequence this zone is confined to the upper part of the type St. Louis Formation and is characterized by Spathognathodus scitulus (Hinde) and several species of Apatognathus that do not occur higher than the top of the St. Louis. In the core this and the preceding two zones are present in the St. Louis Formation.

6. Gnathodus bilineatus-Cavusgnathus charactus zone (648.7-471.1 feet). This zone ranges from the base of the range of Gnathodus bilineatus (Roundy) to the base of the range of Cavusgnathus altus in the overlying zone. It includes most of the range of Cavusgnathus charactus Rexroad which ranges both higher and lower than this zone. This zone contains the Ste. Genevieve and Lower Chester strata (to the base of the Beech Creek Limestone) of the type Mississippian section. In the core this zone is represented by the lower part of the Monteagle Formation. Older geologic reports and drillers refer to the interval as Ste. Genevieve-Gasper.

7. Gnathodus bilineatus-Cavusgnathus altus zone (471.1-437.0 feet). This zone ranges from the lowest occurrence of Cavusgnathus altus to the lowest occurrence of Kladognathus in the overlying zone. The zone contains the Golconda Group of the type Mississippian section in the Illinois Basin. In the core this zone is represented by the uppermost part of the Monteagle Formation, lying below the Hartselle Sandstone, as well as the Hartselle Sandstone and the basal portion of the Bangor Limestone. Drillers refer to the Hartselle Sandstone as Golconda and to the basal portion of the Bangor Limestone as Glen Dean. The Hartselle Sandstone has been correlated previously with the Hardinsburg Sandstone, which lies between the Golconda Group and the Glen Dean Limestone in the Illinois Basin. The Hartselle is correlated herein with the Big Clifty Formation (= Fraileys Shale) of the Golconda Group because beds of Golconda age lie above and below the Hartselle.

The occurrence of Cavusgnathus altus is rather spotty in the core of the Fowler No. 1 Traders. The interval, assigned to the upper part of the Gnathodus bilineatus-Cavusgnathus charactus zone and containing foraminiferal zone 16s (top) of Mamet (515-478 feet, might also be Golconda. The conodonts in this restricted interval are not diagnostic.

Butts (1926, p. 195) correlated the Hartselle Sandstone of Alabama with the Hardinsburg Sandstone because he (1926, p. 192) found Pterotocrinus capitalis (Lyon), a fossil restricted to the middle Golconda Fraileys Shale (=Big Clifty Sandstone) in the Illinois Basin, from just below the Hartselle Sandstone on Lookout Mountain in Tennessee.

Horowitz has also observed wing plates of Pterotocrinus capitalis in limestones below the Hartselle along Tennessee Highway 156-A near the Alabama-Tennessee border. Burdick (thesis, 1971, p. 12-15) has noted that the crinoid fauna of the lower Bangor overlying the Hartselle Sandstone in northwest Alabama is very similar to the middle and upper formations of the Golconda Group in the Illinois Basin. Apparently the Bangor Limestone represents more than one marine limestone of the standard Chesterian section.

8. Gnathodus bilineatus-Kladognathus mehli zone (437.0-415.2 feet). This zone represents the overlap of the highest part of the range of Gnathodus bilineatus and the lowest portion of the range of Kladognathus. In the Illinois Basin this is the position of the Glen Dean Limestone at the top of the Middle Chesterian. In the core this zone occurs within beds now ascribed to the Bangor Limestone, which lies between the Hartselle Sandstone and the Pennington Formation. Drillers refer to a portion of this interval as Glen Dean Limestone.

9. The Kladognathus primus zone of the type Chesterian in the Illinois Basin section includes the Vienna and lowermost part of the Menard Limestone (within the Walche Limestone Member), but the zone is not recognized in this core. The conodonts recovered from the interval 415.2 to 255.0 are not diagnostic. The interval includes the upper part of the Bangor Limestone and the lower part of the Pennington Formation of Tennessee stratigraphic usage.

10. Kladognathus-Cavusgnathus naviculus zone (255.0-250.6 feet). This zone which originally was identified only with the Kinkaid Formation of the type Chesterian sequence in the Illinois Basin, was subsequently expanded to include all but the lowest part of the Menard Limestone and represents much of the late Chesterian in the type Chesterian section. In the core this zone occurs within the Pennington Formation.

11. Adetognathus zone (235.3-227.3 feet). The indicated footage contains the transition from Cavusgnathus to Adetognathus and represents the base of the Adetognathus unicornis zone, which is present in the Grove Church Formation, the highest formation of the Chester Series in the type Chesterian. In the core this interval occurs within the Pennington Formation.

The upper two conodont zones are above the highest foraminiferal zone recognized in the core and below the Pennsylvanian shales (above 108 feet) identified by Neves on the basis of spores.

Provinciality of conodont faunas and the restriction of some taxa to a limited number of lithologic facies prevent detailed comparison of the Viséan and early Namurian conodont zones in western Europe and equivalent zones in North America. Although disparate ranges of taxa in the two areas and use of zonal genera and species that are not common to both areas are also problems in the Tournaisian, there is general accord between North American Kinderhookian and lower

Valmeyeran zones (Collison et al., 1971) and those of the Belgian Tournaisian (Groessens et al., 1973). Nonetheless, the position of the Tournaisian-Viséan boundary in North America is still under debate.

Mamet does not report any gaps in the type sections of the Keokuk and Burlington Limestones with respect to his foraminiferal zones. This is the interval involving varying placements of the boundary. An important hiatus as suggested by Austin et al. (1973) and Brenckle et al. (1974) would greatly hinder correlations with the type Mississippian sequence, but we do not see any evidence for such a missing interval. We believe that any conodont faunal gaps are the result of ecologic control. Brenckle (personal communication) believes the lack of diagnostic foraminiferal faunas in the type Burlington precludes zonation according to the Mamet foraminiferal scheme.

In Belgium the boundary between the Tournaisian and Viséan has been modified and placed by Conil et al. (1976) at the highest occurrence of Scaliognathus anchoralis Branson and Mehl and the lowest occurrence of Mestognathus beckmanni Bischoff and Gnathodus homopunctatus Ziegler (Conil et al., 1976). In the Mississippi Valley S. anchoralis, Doliognathus latus Branson and Mehl and Eotaphrus burlingtonensis Pierce and Langenheim are present in a middle part of the Burlington Limestone below the Bactrognathus-Taphrognathus zone. It is for this reason that several authors (Rhodes and Austin, 1971; Paproth et al., 1973; and Austin et al., 1973) placed the base of the Viséan at the base of the Bactrognathus-Taphrognathus zone within the Burlington. Brenckle et al. (1974) however, reported E. burlingtonensis from the top of the Burlington at one locality and placed the Tournaisian-Viséan boundary at the top of the Burlington, as did Conil et al. (1976). Although this placement is based on conodont evidence, the absence of Mestognathus in the mid-continent of North America and the much later first occurrence of G. homopunctatus preclude an exact determination on the basis of conodonts alone. Thus, conodonts suggest that the bottom of the Tennessee core is not as old as Tournaisian, a position supported by foraminiferal evidence of Baxter et al. (1975), but not by Mamet's interpretation of the foraminiferal data in the core.

Further complications are shown in assessing the boundary position in correlations made through Great Britain. Butler (1973) proposed a correlation scheme between Germany-Belgium-England and the United States using Groessens (1971) data for Belgium. Mamet has examined foraminifera contained in the Halecombe Quarry, Somerset, England, from which Butler reported the conodonts. Mamet's study indicates that the Scaliognathus anchoralis zone ranges from the late Tournaisian into what are normally regarded as Viséan horizons. The zone straddles the Tournaisian-Viséan boundary and the base of the Vallis Limestone is considerably younger than the Vla age reported by Butler because the upper part of the underlying Black Rock Group is early Viséan.

A few key intervals show that there is a very generalized

correspondence between the Viséan and early Namurian conodont faunas of western Europe and North America. The German anchoralis-bilineatus interregnum and the Belgian Mestognathus-Gnathodus cf. commutatus commutatus zone are approximately equivalent to each other and to the North American zones between the top of the Burlington and the base of the Ste. Genevieve Limestone. The base of the Gnathodus bilineatus zone in Belgium has been placed at the base of V3b beta beds by Conil et al. (1976), who also placed the base of the zone in Germany, Great Britain and Ireland at the same position. In the Mississippi Valley area, however, they consider the first occurrence of G. bilineatus to be younger and at the base of V3b gamma beds. Whether or not this is correct, the base of the G. bilineatus-Cavusgnathus charactus zone approximates the base of the G. bilineatus zone in western Europe.

Adetognathus unicornis (Rexroad and Burton) is present in the Grove Church Formation in Illinois, and the species has been reported in Belgium (Varker and Austin, 1975) from the Tramaka beds, whose precise position in the Belgian sequence is unclear at present. Both occurrences appear to be within the Namurian E2 interval. The Adetognathus unicornis zone is the highest one recognized in the Mississippian of the Mississippi Valley, but it continues into rocks considered to be Pennsylvanian in age. Thus the upper part of the Gnathodus girtyi simplex zone of Webster (1969) in Nevada and the Rachistognathus muricatus zone of Lane and Straka (1974) in Arkansas and Oklahoma probably represent ecologically controlled faunas equivalent to the upper part of the A. unicornis zone. The faunal change marking the top of the A. unicornis zone in conjunction with studies by Higgins and Bouckaert (1968) and Bouckaert and Higgins (1970) of Namurian conodonts in Belgium suggest that the Mississippian-Pennsylvanian boundary falls in the Arnsbergian-Chokerian (E2-H1) interval of Belgium, above the upper limit of diagnostic conodonts in the Tennessee core. This corresponds to the boundary suggested by Brenckle et al. (1977).

Mamet following the Ukrainian usage extends his zone 19 with the Homoceras zone that lies above E2 in the European succession. Brenckle et al. (1977) believe that Mamet's zone 19 includes beds of Menard through Grove Church age in the Illinois Basin and chronostratigraphic equivalents elsewhere. Consequently, they would assign the Adetognathus unicornis zone to the upper part of Mamet zone 19 where it spans portions of the E2a and E2b zones of the European succession. In addition, they assign the Homoceras zone to the Pennsylvanian as well as to the base of Mamet zone 20.

The position of zone 20 in the Ukrainian standard has recently been lowered by Aizenberg (unpublished, 8th International Congress on Carboniferous Stratigraphy, Moscow, 1975). Although zone 20 is certainly present in association with the Reticuloceras zone (Krasnopoliansk), the zone would now include part of the Homoceras D₆ and D₇ interval (upper part of the Protvinsk) of the Ukrainian sequence. This apparently

conflicts with the microfauna (including Mediocris, Endothyranopsis and Eosigmoilina) previously reported by Brazhnikova et al. (1967) from the Homoceras D₆ and D₇ interval. Mamet regards this evidence as incompatible with a zone 20 age.

CONCLUSIONS

Our integrated paleontological study of a long core in the Lower Carboniferous sediments of the southern Appalachian Basin in Scott County, Tennessee (Figure 1), yielded the following conclusions.

1. The foraminiferal and conodont zonal schemes are in agreement with respect to the biochronologic correlation of the Fowler No. 1 Traders core with the Mississippian sequence in the Illinois Basin (Figure 2). Both zonal schemes show that the base of the core is in the Keokuk interval of the type section. Mamet did not recover any foraminifera that represent his zones 10-12, which represent the Warsaw-Salem interval, in the Fowler No. 1 Traders core. Rexroad recognizes a Warsaw zone in this interval and the base of an overlying zone that he would equate with the Salem and lower St. Louis, but which includes foraminiferal zone 13 regarded by Mamet as occurring completely within the lower St. Louis of the type Mississippi Valley sequence. Published figures (Mamet and Skipp, 1971, p. 1141, fig. 7; Collinson et al., 1971, p. 362, fig. 2) for both the foraminiferal and conodont zonal schemes recognize that the boundary between the Warsaw and Salem Formations is not everywhere chronologically equivalent in the Illinois Basin. Recent conodont work suggests that the St. Louis-Salem boundary is also time transgressive in the Illinois Basin (Nicoll and Rexroad, 1975, p. 16, fig. 2). Mamet would place the top of the St. Louis at 662 feet in the core whereas Rexroad would place it at 657 feet (also Burwell, 1967, p. 74), a difference of five feet in the two zonal schemes.

2. The core did not penetrate beds equivalent to the lowest Osage and the Kinderhook of the Illinois Basin section. Consequently, the controversy concerning the position of the Tournaisian-Viséan boundary in the type Illinois Basin section based on different fossil groups is unresolved. The basal portion of the core below 908 feet, which is mapped in the sub-surface of Tennessee as the Fort Payne Formation, is Tournaisian (Tn3c) according to the foraminiferal data and is believed to be equivalent to the upper Osage (Keokuk) of the Illinois Basin section. On the other hand, the conodonts suggest a post-Tournaisian age for the sample portion of the Fort Payne.

3. The foraminiferal zones 13 through 17 in the Fowler No. 1 Traders core can be directly correlated with the type Lower Carboniferous areas of Belgium, but the conodonts in the core provide only spotty ties with Europe because of provincial and local ecologic control of the conodont faunas in the two type areas.

4. Conodonts provide some zonation in the Fowler No. 1 Traders core above the highest occurrence of foraminifera; palynological zonation is available principally from the top half of the core including beds above the highest conodont zonation, where nonmarine beds and/or shales are more abundant.

5. Palynomorphical zonation indicates the Mississippian-Pennsylvanian boundary is present in the interval between 181 and 108 feet, which is consistent with the top of the Mississippian Pennington Formation being placed at 127.5 feet on the basis of lithology.

6. Local, regional and intercontinental correlations could be improved by studying long cores that penetrate the entire Lower Carboniferous sequence in the Illinois Basin and by studying similar long stratigraphic sections exposed in the Appalachian region.

7. The combined efforts of several paleontologists working on different groups of fossils is both necessary and important if chronological correlations are to transcend problems associated with different rock types (facies).

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Appendix I. Ranges of taxa in the Fowler No. 1 Traders core, Scott County, Tennessee

A. Ranges of calcareous algae and calcispheres
in the Fowler No. 1 Traders core

	Base	Top
<u>Aoujgalia</u> sp. (new species)	630	478
<u>Aphralysia</u> sp. (notably <u>A. capriorae</u> Mamet and Roux, <u>A. carbonaria</u> Garwood and <u>A. matthewsi</u> Mamet and Roux)	646	354
<u>Asphaltina cordillerensis</u> Mamet	593	354
<u>Atractyliopsis</u> sp. (notably <u>A. cumberlandensis</u> Rich and a new sp.)	646	517
<u>Calcisphaera</u> sp.	912	354
<u>Calcisphaera laevis</u> Williamson	740	660
<u>Calcisphaera pachysphaerica</u> (Pronina)	740	647
<u>Cuneiphyucus johnsoni</u> Flügel	647	416
<u>Diplosphaerina</u> sp.	675	478
<u>Epistacheoides</u> sp.	740	351
<u>Epistacheoides connorensis</u> Mamet and Rudloff	740	351
<u>Epistacheoides nephroformis</u> Petryk and Mamet	636	515
<u>Kamaena</u> sp.	683	683
<u>Koninckopora inflata</u> (de Koninck)	740	660
<u>Koninckopora tenuiramosa</u> Wood	740	660
<u>Mametella skimoensis</u> (Mamet and Rudloff)	740	725
<u>Mitcheldeania nicholsoni</u> Wethered	658	517
<u>Nostocites</u> sp.	515	354
<u>Ortonella</u> sp.	740	724
<u>Orthriosiphon</u> sp.	590	564
<u>Orthriosiphonoides</u> sp. (notably <u>O. cf. salterensis</u> Petryk and Mamet)	675	354
<u>Palaeoberesella</u> sp. (notably <u>P. lahuseni</u> (von Möller))	740	658
<u>Palaeocancellus</u> sp.	740	724
<u>Proninella</u> sp.	740	354
<u>"Pycnostroma densius"</u> Gürich	724	724
<u>Radiosphaerina</u> sp.	675	478
<u>Rectangulina</u> sp. (notably <u>R. geniculosa</u> (Bykova) and <u>R. tortuosa</u> (Antropov))	668	351
<u>Sphaeroporella?</u> sp.	450	354
<u>Stacheoides</u> sp.	740	354
<u>Stacheoides tenuis</u> Petryk and Mamet	740	660
new algal genus A	740	723
new algal genus B	724	351
new dasyclad genus	611	517

B. Ranges of Conodonts in the Fowler No. 1 Traders core

<u>Apatognathus</u> spp.	684.8	657
<u>Apatognathus geminus</u> (Hinde)	684.8	657
<u>Apatognathus porcatus</u> (Hinde)	684.8	671.8
<u>Cavusgnathus</u> spp.	690.6	227.3
<u>Cavusgnathus altus</u> Harris and Hollingsworth	471.1	350
<u>Cavusgnathus charactus</u> Rexroad	684.8	445.7
<u>Cavusgnathus convexus</u> Rexroad	671.8	227.3
<u>Cavusgnathus naviculus</u> (Hinde)	(? 405)	251.9
<u>Cavusgnathus regularis</u> Youngquist and Miller	684.8	305.6
<u>Cavusgnathus unicornis</u> Youngquist and Miller	690.6	227.3
<u>Cavusgnathus-Adetognathus</u> transition	235.3	227.3
<u>Gnathodus</u> spp.	974.5	415.2
<u>Gnathodus bilineatus</u> (Roundy)	648.7	415.2
<u>Gnathodus commutatus</u> (Branson and Mehl)	644.4	424.3
<u>Gnathodus girtyi</u> Hass	644.4	639.9

	Base	Top
<u>Gnathodus homopunctatus</u> Ziegler	644.4	639.9
<u>Gnathodus mononodosus</u> Rhodes, Austin and Druce	497.1	493.2
<u>Gnathodus texanus</u> Roundy	974.5	749.1
<u>Hibbardella</u> spp.	(? 902.3)	681.4
<u>Hibbardella abnormis</u> Branson and Mehl	678	532.5
<u>Hibbardella milleri</u> Rexroad	644.4	227.3
<u>Hibbardella ortha</u> Rexroad	681.4	227.3
<u>Hindeodus</u> spp.	673.9	227.3
<u>Hindeodus alatoides</u> (Rexroad and Burton)	606.3	603
<u>Hindeodus imperfectus</u> (Rexroad)	469.4	227.3
<u>Kladognathus</u> spp.	(? 613.1)	437
<u>Lambdagnathus</u> spp.	644.4	227.3
<u>Lambdagnathus fragilidens</u> Rexroad	644.4	353
<u>Ligonodina</u> spp.	979.5	227.3
<u>Ligonodina levis</u> Branson and Mehl	690.6	227.3
<u>Ligonodina magnilaterina</u> Rhodes, Austin and Druce	690.6	361.3
<u>Ligonodina roundyi</u> Hass	441.2	415.2
<u>Ligonodina tenuis</u> Branson and Mehl	657	227.3
<u>Lonchodina</u> spp.	962	333.7
<u>Lonchodina</u> aff. <u>L. clarki</u> (Ellison)	(? 433-429)	962
<u>Lonchodina furnishi</u> Rexroad	437	415.2
<u>Lonchodina paraclaviger</u> Rexroad	445.7	441.2
<u>Magnilaterella</u> spp.	690.6	250.6
<u>Magnilaterella robusta</u> Rexroad and Collinson	690.6	356.1
<u>Metalonchodina</u> spp.	955	912.7
<u>Metalonchodina</u> aff. <u>M. bidentata</u> (Branson and Mehl)	955	912.7
<u>Neoprioniodus</u> spp.	970.3	227.3
<u>Neoprioniodus camurus</u> Rexroad	681.4	227.3
<u>Neoprioniodus</u> cf. <u>N. conjunctus</u> (Gunnell)	563.9	561.5
<u>Neoprioniodus</u> aff. <u>N. conjunctus</u> (Gunnell)	970.3	914.1
<u>Neoprioniodus loxus</u> Rexroad	953.1	227.3
<u>Neoprioniodus peracutus</u> (Hinde)	588	356.1
<u>Neoprioniodus singularis</u> (Hass)	648.7	429.1
<u>Neoprioniodus tulensis</u> (Pander)	684.8	227.3
<u>Neoprioniodus varians</u> (Branson and Mehl)	690.6	346
<u>Ozarkodina</u> spp.	955.8	227.3
<u>Ozarkodina compressa</u> Rexroad	588	227.3
<u>Ozarkodina curvata</u> Rexroad	684.8	231.3
<u>Ozarkodina laevipostica</u> Rexroad and Collinson	684.8	661.2
<u>Ozarkodina recta</u> Rexroad	588	227.3
<u>Ozarkodina roundyi</u> (Hass)	955.8	886
<u>Ozarkodina stipans</u> (Rexroad)	231.3	227.3
<u>Roundya</u> spp.	955.8	493.2
<u>Roundya subacoda</u> (Gunnell)	588	493.2
<u>Roundya</u> aff. <u>R. subacoda</u> (Gunnell)	955.8	912.4
<u>Spathognathodus</u> spp.	690.6	227.3
<u>Spathognathodus campbelli</u> Rexroad	644.4	297
<u>Spathognathodus cristula</u> Youngquist and Miller	(? 657)	644.4
<u>Spathognathodus penescitulus</u> Rexroad and Collinson	(734.6)	711.6)?
<u>Spathognathodus scitulus</u> (Hinde)	(? 639.9)	690.6
<u>Spathognathodus spiculus</u> Youngquist and Miller	411	309.6
<u>Synprioniodina</u> spp.	970.3	411
<u>Synprioniodina denticamura</u> Rexroad and Liebe	588	584.5
<u>Synprioniodina laxilabrum</u> Rexroad and Collinson	970.3	893.8
<u>Taphrognathus</u> spp.	893.8	684.8
<u>Taphrognathus varians</u> Branson and Mehl	893.8	684.8
<u>Taphrognathus-Cavusgnathus</u> transition	684.8	678

C. Ranges of foraminifers in the Fowler No. 1 Traders Core

	Base	Top
<u>Ammoverbella</u> sp.	515	354
<u>Apterrinellids</u>	450	354
<u>Archaeodiscus</u> sp.	740	478
<u>Archaeodiscus</u> <u>koktjubensis</u> Rauzer-Chernousova	740	660
<u>Archaeodiscus</u> <u>krestovnikovi</u> Rauzer-Chernousova	740	647
<u>Archaeodiscus</u> of the group <u>A. krestovnikovi</u> Rauzer-Chernousova	695	354
<u>Archaeodiscus</u> <u>moelleri</u> Rauzer-Chernousova	675	647
<u>Archaeodiscus</u> of the group <u>A. moelleri</u> Rauzer-Chernousova	596	478
" <u>Archaeodiscus</u> " <u>pachythea</u> Petryk	646	604
dwarfed <u>Archaeodiscidae</u>	675	658
<u>Asteroarchaeodiscus</u> sp.	450	354
primitive <u>Asteroarchaeodiscus</u> sp.	515	478
<u>Asteroarchaeodiscus</u> of the group <u>A. baschkiricus</u> (Krestovnikov and Teodorovitch)	450	354
<u>Asteroarchaeodiscus</u> <u>gnomellus</u> Brenckle	450	354
<u>Biseriammina</u> ? <u>windsorensis</u> Mamet	515	478
<u>Brunsia</u> sp.	740	478
<u>Brunsia</u> <u>lenensis</u> Bogush and Yuferev	683	658
<u>Brunsia</u> <u>spirillinoides</u> (Grozdilova and Glebovskaya)	683	658
<u>Dainella</u> sp.	740	693
<u>Earlandia</u> sp.	912	693
<u>Earlandia</u> of the group <u>E. clavatula</u> (Howchin)	740	693
<u>Earlandia</u> of the group <u>E. elegans</u> (Rauzer-Chernousova and Reitlinger)	740	724
<u>Earlandia</u> <u>vulgaris</u> (Rauzer-Chernousova and Reitlinger)	740	354
<u>Earlandia</u> of the group <u>E. vulgaris</u>	675	478
<u>Earlandiella</u> sp.	695	660
<u>Endothyridae</u>	912	909
<u>Endothyra</u> sp.	912	478
cf. <u>Endostaffella</u> ? sp.	515	478
<u>Endothyra</u> <u>bowmani</u> Phillips emend. Brady	660	658
<u>Endothyra</u> of the group <u>E. bowmani</u>	740	354
<u>Endothyra</u> <u>excellens</u> (Zeller)	450	354
<u>Endothyra</u> <u>similis</u> Rauzer-Chernousova and Reitlinger	596	517
<u>Endothyranella</u> sp.	695	478
<u>Endothyranopsis</u> sp.	740	648
<u>Endothyranopsis</u> <u>compressa</u> (Rauzer-Chernousova and Reitlinger)	740	660
<u>Endothyranopsis</u> of the group <u>E. crassa</u> (Brady)	658	647
<u>Endothyranopsis</u> <u>hirosei</u> Okimura	660	658
<u>Endothyranopsis</u> of the group <u>E. hirosei</u>	695	647
<u>Eoendothyranopsis</u> sp.	740	660
<u>Eoendothyranopsis</u> <u>ermakiensis</u> (Lebedeva)	695	647
<u>Eoendothyranopsis</u> of the group <u>E. ermakiensis</u>	740	693
<u>Eoendothyranopsis</u> <u>macra</u> (Zeller)	675	660
<u>Eoendothyranopsis</u> of the group <u>E. rara</u> (Grozdilova, in Lebedeva)	740	724
<u>Eoendothyranopsis</u> <u>robusta</u> (Mckay and Green)	660	647
<u>Eoendothyranopsis</u> <u>scitula</u> (Toomey)	740	724
<u>Eoforschia</u> sp.	658	647
<u>Eostaffella</u> sp.	646	354
<u>Eotuberitina</u> sp.	515	354
<u>Globoendothyra</u> sp.	675	354
<u>Globoendothyra</u> <u>paula</u> (Vissarionova)	740	660
<u>Glomospiranella</u> sp.	912	909
primitive <u>Neoarchaeodiscus</u> sp.	639	604
<u>Neoarchaeodiscus</u> sp.	596	517
<u>Neoarchaeodiscus</u> <u>incertus</u> (Grozdilova and Lebedeva)	515	354
<u>Neoarchaeodiscus</u> <u>parvus</u> (Rauzer-Chernousova)	515	478
<u>Neoarchaeodiscus</u> <u>regularis</u> (Suleimanov)	596	354

	Base	Top
<u>Palaeotextularia asper</u> Cooper	450	354
" <u>Palaeotextularia</u> " of the group " <u>P</u> ", <u>consobrina</u> Lipina	695	478
<u>Parathurammina</u> sp.	695	354
<u>Planoarchaediscus</u> sp.	683	683
<u>Planoendothyra</u> sp.	740	724
<u>Planospirodiscus</u> sp.	596	354
<u>Planospirodiscus altiluminis</u> Brenckle	515	478
<u>Priscella</u> sp.	912	354
cf. <u>Propermodiscus</u> ? sp.	740	724
<u>Pseudoammodiscus</u> sp.	740	354
<u>Pseudoendothyra</u> sp.	646	354
<u>Pseudoglomospira</u> sp.	740	354
<u>Pseudotaxis</u> sp.	912	909
" <u>Septabrunsiina</u> " sp.	740	693
<u>Skippella</u> sp.	740	660
<u>Tetraxis</u> sp.	912	354
<u>Tournayellinae</u>	912	909
<u>Tuberitina</u> sp.	450	354
<u>Zellerina</u> sp.	646	354
<u>Zellerina discoidea</u> (Girty)	515	354
<u>Zellerina designata</u> (Zeller)	450	354

D. Ranges of palynomorphs in the Fowler No. 1 Traders Core

<u>Acanthotriletes castanea</u> Butterworth and Williams	243	91
<u>Anaplanisporites baccatus</u> (Hoffmeister, Staplin and Malloy)		
Smith and Butterworth	346	211
<u>Apiculatisporis pineatus</u> Hoffmeister, Staplin and Malloy	984	984
<u>Auroraspora balteola</u> Sullivan	349	211
<u>Auroraspora macra</u> Sullivan	411	211
<u>Auroraspora solisortus</u> Hoffmeister, Staplin and Malloy	346	91
<u>Baculatisporites fusticulus</u> Sullivan	346	243
<u>Calamospora</u> spp.	876	91
<u>Calamospora nigra</u> Leschik	349	349
<u>Campotriletes verrucosus</u> Butterworth and Williams	108	99
<u>Cingulizonates loricated</u> (Loose) Butterworth and Williams	108	106
<u>Colatisporites decorus</u> (Bharadwaj and Venkatachala) Williams	211	211
<u>Convolutispora ampla</u> Hoffmeister, Staplin and Malloy	254	91
<u>Convolutispora florida</u> Hoffmeister, Staplin and Malloy	346	91
<u>Crassispora kosankei</u> (Potonie and Kremp) Bhardwaj	108	91
<u>Crassispora maculosa</u> (Knox) Sullivan	410	346
<u>Crassispora trychera</u> Neves and Ioannides	657	243
<u>Densosporites anulatus</u> (Loose) Smith and Butterworth	876	91
<u>Densosporites intermedius</u> Butterworth and Williams	876	91
<u>Densosporites spinosus</u> Dybova and Jachowicz	876	91
<u>Discernisporites macromanifestus</u> (Hacquebard) Neves and Owen	876	106
<u>Discernisporites micromanifestus</u> (Hacquebard) Neves and Owen	349	243
<u>Florinites visendus</u> (Ibrahim) Schopf, Wilson and Bental	108	91
<u>Florinites similis</u> Kosanke	108	91
<u>Grandispora echinata</u> Hacquebard	876	181
<u>Grandispora spinosa</u> Hoffmeister, Staplin and Malloy	410	211
<u>Granulatisporites microgranifer</u> Ibrahim	211	99
<u>Hymenospora caperata</u> Felix and Burbridge	346	211
<u>Knoxisporites stephanephorus</u> Love	346	243
<u>Knoxisporites triradiatus</u> Hoffmeister, Staplin and Malloy	346	106
<u>Leiotriletes subintortus rotundatus</u> Waltz	211	211
<u>Lophotriletes commisuralis</u> (Loose) Potonie and Kremp	346	91
<u>Lophotriletes tribulosus</u>	211	91

	Base	Top
<u>Lophozonotriletes muricatus</u>	876	346
<u>Lycospora pusilla</u> (Ibrahim) Schopf, Wilson and Bentall	984	91
<u>Microreticulatisporites punctatus</u> Knox	876	211
<u>Murospora intorta</u> (Waltz) Playford	876	343
<u>Perotriletes perinatus</u> Hughes and Playford	657	91
<u>Potonieisporites elegans</u> (Wilson and Kosanke) Wilson and Venkatachala	108	106
<u>Pulvinispora scolecophora</u> Neves and Ioannides	412	243
<u>Punctatisporites solidus</u> Hacquebard	984	108
<u>Punctatisporites trifidus</u> Felix and Burbridge	254	99
<u>Raistrickia saetosa</u> (Loose) Smith and Butterworth	108	91
<u>Reinschospora speciosa</u> (Loose) Smith and Butterworth	91	91
<u>Retusotriletes incohatus</u> Sullivan	410	181
<u>Rugospora corporata</u> Neves and Owens	876	106
<u>Rugospora minuta</u>	657	91
<u>Savitrissporites nux</u> (Butterworth and Williams) Sullivan	346	91
<u>Schopfipollenites ellipsoides</u> (Ibrahim) Potonie and Kemp	346	91
<u>Schopfites claviger</u> Sullivan	410	211
<u>Schulzospora</u> spp.	410	211
<u>Spelaeotriletes triangulus</u> Neves	876	243
<u>Tholisporites</u> ? <u>bianulatus</u> Neves	346	346
<u>Tricidarissporites serratus</u> (Playford) Sullivan and Marshall	346	346
<u>Tripartites distinctus</u> Williams	349	91
<u>Tripartites vetustus</u> Schemel	254	211
<u>Triquitrites comptus</u> Williams	876	181
<u>Triquitrites marginatus</u> Hoffmeister, Staplin and Malloy	346	91
<u>Vallatisporites microgalearis</u>	346	240
<u>Verrucosisporites baccatus</u> Staplin	410	211
<u>Verrucosisporites nodosus</u> Sullivan and Marshall	876	181
<u>Vestispora lucida</u> (Butterworth and Williams) Potonie	211	211
<u>Waltzisporea planiangularata</u> Sullivan	254	91

PALEOGENE BARNACLES FROM THE COASTAL PLAIN
OF NORTH CAROLINA (CIRRIPEDIA, THORACICA)

By

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ABSTRACT

Six cirripeds are described from Paleogene rocks of the North Carolina Coastal Plain south of the Neuse River. Verruca (Verruca) rocana Steinman occurs on brachiopods and oysters in an updip outcrop of the Paleocene (Thanetian) Beaufort Formation along Mosley Creek at the Lenoir-Craven county line. Carinae of Euscalpellum sp., cf. E. eocenense (Meyer) and Arcoscalpellum subquadratum (Meyer and Aldrich) occur in the upper bryozoan biomicrudite facies of the Castle Hayne Limestone near Castle Hayne, New Hanover County. Arcoscalpellum jacksonense Withers and Bathylasma corrugatum n. sp. are represented by carinae in the same facies at Maple Hill, Pender County. Bathylasma corrugatum is the geologically oldest record of the genus Bathylasma Newman and Ross. Solidobalanus (Hesperibalanus) kellumi n. sp. is found in the lower Oligocene Trent Formation at localities along and near the Trent River in Jones, Craven and Onslow counties. It may also occur in Jones County in the underlying New Bern Formation which has been tentatively assigned to the upper Eocene.

INTRODUCTION

The Paleogene cirriped fauna of the southeastern United States is poorly documented, although there is indication in the literature of

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the presence of barnacles in several Eocene formations of the Coastal Plain. With the exception of Kathpalmeria georgiana Ross (1965) from the Georgia and Florida Eocene, and of Emersonius cybosyrinx Ross (in Ross and Newman, 1967) from the Florida Eocene, no other taxonomically valid species has been recorded. On the basis of reviews of Eocene barnacles reported from the southeastern United States (Ross, 1965, 1967; Zullo, 1966) the following conclusions can be drawn:

Balanus calceolus Ellis, of Holmes (1859), Eocene marl of the Ashley River, South Carolina (=Cooper Marl?). Species inquirenda, not identifiable from description or illustration.

Balanus digitatus Holmes (1859), Eocene marl of the Ashley River, South Carolina (=Cooper Marl?). Nomen dubium, not identifiable from description or illustration.

Balanus humilis Conrad (1846), Eocene limestone in Tampa Bay region, Florida. Nomen dubium, based on steinkern probably from the Miocene (Ross, 1967).

Balanus ostrearum Conrad, in Morton (1834), no locality. Nomen nudum.

Balanus peregrinus Morton (1834), Eocene of South Carolina. Nomen dubium, not identifiable from description or illustration.

The present paper is based on collections made by us from Eocene and Oligocene formations exposed in the North Carolina Coastal Plain south of the Neuse River, and on collections provided by Druid Wilson (United States National Museum) from the Paleocene and by Sarah Z. Nunnally (Wrightsville Beach, North Carolina) from the Eocene of the same area (Figure 1). Six species are recognized, including three lepadomorphs, one verrucomorph, and two balanomorphs. The oldest of the cirripeds is the verrucomorph, here ascribed to Verruca rocana Steinman, which is represented by a number of well preserved whole specimens attached to the brachiopod Oleneothyris harlani (Morton) and the pelecypod Pycnodonte dissimilaris (Weller) from the Paleocene Beaufort Formation. All of the lepadomorph remains are from the Eocene Castle Hayne Limestone. They are represented solely by carinae, and include those of Euscalpellum sp., cf. E. eocenense (Meyer), and of two previously described species of Arcoscalpellum Hoek; A. subquadratum (Meyer and Aldrich) and A. jacksonense Withers. Two small balanomorph carinae also were collected from the Castle Hayne Limestone, and are described as a new species of Bathylasma Newman and Ross. These specimens represent the earliest record for the genus. The remaining balanomorph is described as a new species of Solidobalanus Hoek. Compartmental and opercular plates, and occasional whole specimens are encountered throughout the Oligocene Trent Formation. This species also may occur in the upper part of the underlying uppermost Eocene New Bern

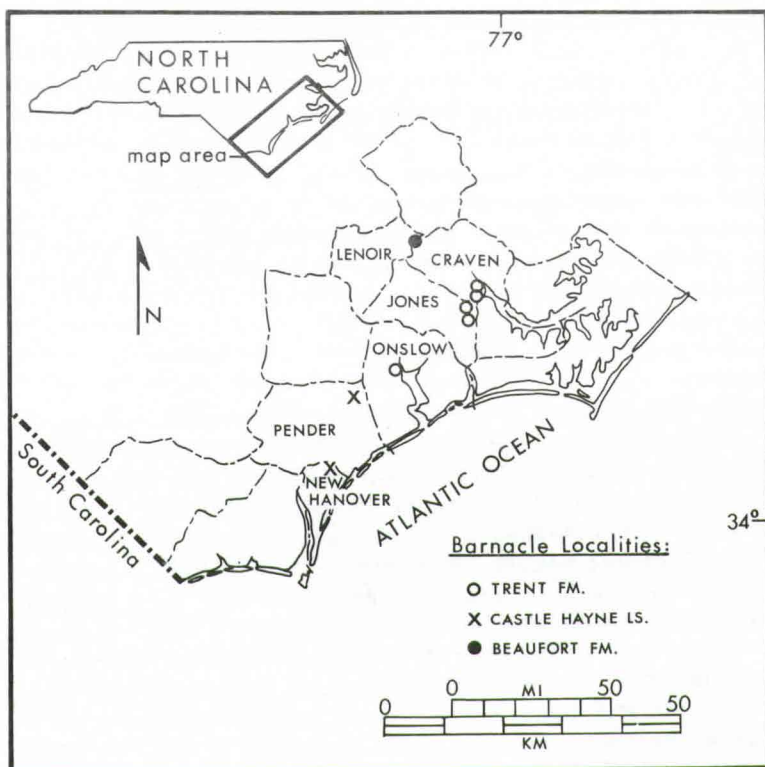


Figure 1. Generalized locality map of Paleogene barnacle localities in the North Carolina Coastal Plain.

Formation.

Some of the cirripeds reported herein appear to be useful stratigraphic indicators. *Arcoscalpellum subquadratum* and *A. jacksonense* are indicators of the Claiborne and Jackson, respectively, in the Gulf Coastal Plain of the United States (Cheetham, 1963). Their mutually exclusive occurrence at separate localities within the upper bryozoan biomicrudite facies of the Castle Hayne Limestone suggests the possibility that this unit is time transgressive. The new species of *Solidobalanus* is slightly more advanced morphologically than the related species *S. (Hesperibalanus) cornwalli* (Zullo, 1966) from the upper Eocene (Bartonian) of the northwest Pacific coast of the United States, and thus lends support to the assignment of the Trent Formation to the Oligocene.

Acknowledgments

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E. Weisbord, Department of Geology, The Florida State University for his suggestions and review of the manuscript.

STRATIGRAPHIC SUMMARY

The following is a summary of the stratigraphy of Paleogene formations known from outcrop in North Carolina. The descriptions and parameters of these units are based on studies by Baum (1977), Baum et al. (1977, 1978) and Harris and Baum (1977). A tabular summary is provided in Figure 2.

Paleocene

Beaufort Formation. The Beaufort Formation was originally described from subsurface data (Brown, 1959), but more recently has been found to crop out in a narrow belt in Lenoir and Craven counties (Swift, 1964; USGS, 1972; Harris and Baum, 1977). An updip outcrop at Mosely Creek on the border between Lenoir and Craven counties is 3.3 m thick, is disconformable on the upper Cretaceous (Maastrichtian) Peedee Formation, and is overlain disconformably by the middle Eocene Castle Hayne Limestone (Harris and Baum, 1977). Downdip, to the east, the Beaufort Formation thickens appreciably, and surpasses 600 m in thickness in a well at Cape Hatteras (Brown, 1958; Brown et al., 1972). Harris and Baum (1977) identified a Thanetian (late Paleocene) foraminiferal assemblage representative of the Globorotalia pseudomenardii (P4) planktonic foraminiferal zone, and obtained a radiometric age of 56.8 million years B. P. from Sr-Rb ratios of glauconites from the outcrop along Mosely Creek. Brown (1958) assigned a Midway (Danian through early Thanetian) age to the formation on the basis of ostracodes from the subsurface.

Eocene

Castle Hayne Limestone. The Castle Hayne Limestone was named by Miller (1912) for "exposures in the vicinity of the town of Castle Hayne". The section exposed in the Martin Marietta quarry northeast of Castle Hayne was selected by Baum et al. (1978) as the type section. In New Hanover, Pender, and Duplin Counties, the Castle Hayne Limestone lies disconformably on the Peedee Formation and the Maastrichtian Rocky Point Member of the Peedee Formation. To the northeast and east the formation overlies progressively younger rocks. In Craven County, the Castle Hayne Limestone is disconformable on the Beaufort Formation (Harris and Baum, 1977), and to the east in subsurface Brown et al. (1972) recognized an unnamed lower Eocene (Sabinian) unit underlying the downdip, deeper water lithology of the Castle Hayne Limestone.

Three lithologies are represented in the type section. The type section includes a basal phosphate pebble biomicrudite, an overlying bryozoan biosparrudite, and an uppermost bryozoan biomicrudite. The phosphate pebble biomicrudite, indicative of a transgressing sea, is discontinuous in distribution, but occurs sporadically at the base of the formation throughout its lateral extent. The overlying bryozoan biosparrudite represents an inshore, high energy facies and is exposed in a broad, northeast-southwest-trending belt to the west of a parallel, but narrower belt of the offshore, lower energy bryozoan biomicrudite facies. The sequence of lithologies in the Castle Hayne area indicate that the bulk of the Castle Hayne Limestone was deposited in a westwardly transgressing sea. However, there are suggestions, based on dolomitization of the upper biomicrudite lithology in the type section (Harris, et al., 1977; Baum, 1977) and on faunal indicators, such as the separate occurrences of Arcoscalpellum subquadratum and A. jacksonense, that the uppermost beds in the formation were deposited during a northeast regression of the sea, possibly in response to uplift along the Cape Fear Arch. Thus, it would appear that most of the Castle Hayne Limestone was deposited during Claibornian (early late Eocene) time as concluded by Brown et al. (1972), but there is the suggestion that the uppermost beds of the formation were deposited during an early Jacksonian (latest Eocene) regression of the sea.

New Bern Formation. The New Bern Formation was proposed by Baum (1977) and Baum et al. (1978) for a predominantly sandy, pelecypod-mold biomicrosparrudite that disconformably overlies the Castle Hayne Limestone and is overlain disconformably by the Oligocene Trent Formation. This unit crops out only in Craven and Jones Counties and was formerly considered a downdip barrier facies of the Castle Hayne Limestone by Brown et al. (1972). However, along the Trent River, the New Bern lithology can be seen to overlie the sandy, foraminiferal biomicrite of the Castle Hayne Limestone. The contact is disconformable and marked by phosphatized crusts that were subsequently bored by pholad pelecypods. At the type section in the Martin Marietta quarry at New Bern, Craven County, the base of the unit is concealed and known only from cores. The contact with the overlying Trent Formation is well defined, however, and is also marked by a phosphatized corrosion surface (Thayer and Textoris, 1972).

Baum (1977) and Baum et al. (1978) concluded that the New Bern Formation represented an uppermost Eocene transgressive sequence composed of a predominantly sandy inshore facies to the west and a predominantly calcareous offshore facies to the east.

Oligocene

Trent Formation. The age and stratigraphic position of the Trent Formation have been the source of considerable controversy during the past sixty years. Originally described as underlying the

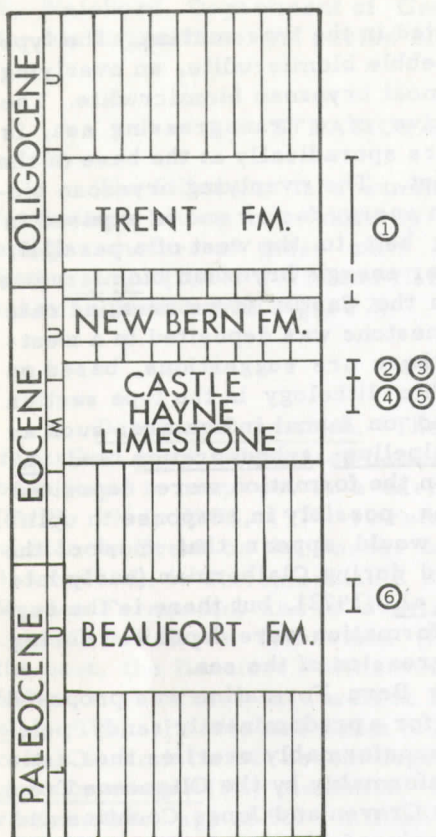


Figure 2. Composite stratigraphic column and barnacle fauna of exposed Paleogene formations, North Carolina Coastal Plain. (1), Solidobalanus, n. sp.; (2), Bathylasma, n. sp.; (3) Arco-
scalpellum jacksonense; (4) Arco-
scalpellum subquadratum; (5) Euscalpellum sp., cf. E.
eocenense; (6) Verruca rocana.

Castle Hayne Limestone and correlated with the Eocene upper Claibornian or lower Jacksonian of the Gulf Coast sequence (Miller, 1912), the unit was later perceived to overlie the Castle Hayne Limestone and was assigned to the lower Miocene

(Kellum, 1926). Subsequently, some of the exposures were re-assigned to the Castle Hayne Limestone, and the name Trent Formation was abandoned (Brown, 1955). The confusion over stratigraphic position, age, and distinctiveness of the Trent Formation is the result of the absence or poor preservation of contained fossils, contradictions in the original formation description, and over-reliance on lithologic correlation between widespread exposures.

Baum et al. (1977, 1978) have shown that the term Trent Formation has been applied to a variety of rock-stratigraphic units, including the New Bern and Trent Formations as recognized herein, as well as exposures at Belgrade, Silverdale and Pollocksville, North Carolina which can be shown to disconformably overlie the Trent Formation. The well preserved fauna of the Silverdale region has come to be taken as the biostratigraphic standard for the traditional concept of the Trent Formation (e.g. Richards, 1950), and is the basis for the early Miocene age assigned to all supposed exposures, including those of the type section along the Trent River. The so-called "Crassostrea gigantissima facies", best exposed at Pollocksville, North Carolina, and previously included in either the Castle Hayne Limestone or the Trent Formation (Brown, 1955; Lawrence, 1976), is now recognized as a regressive channel deposit that cuts across both Oligocene (Trent Formation) and lower Miocene (Silverdale and

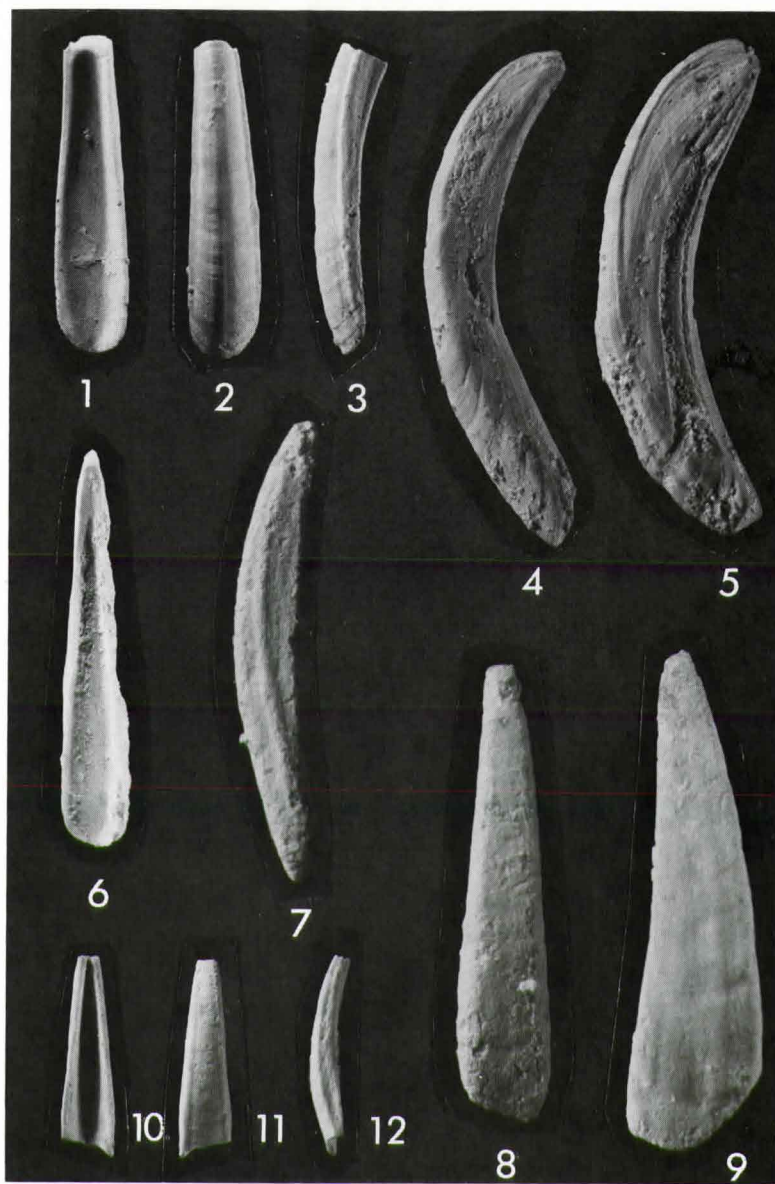


Plate 1. Paleogene Lepadomorpha. Figures 1-3, interior, exterior, and side views of carina of *Euscalpellum* sp., cf. *E. eocenense* (Meyer), Castle Hayne Limestone, hypotype USNM 252254, height 20.72mm. Figures 4-6, carinae of *Euscalpellum eocenense*, Santee Limestone, South Carolina: (4,6), side and interior views of young individuals, hypotype USNM 252255, height 32.62mm; (5), side view of older individual, hypotype USNM 252256, height 33.42mm. Figures 7-9, carinae of *Arcoscalpellum jacksonense* Withers, Castle Hayne Limestone: (7-8), side and exterior views, hypotype USNM 252257, height 10.72mm; (9), exterior view, hypotype USNM 252258, height 11.22mm. Figures 10-12, interior, exterior and side views of carina of *Arcoscalpellum subquadratum* (Meyer and Aldrich), Castle Hayne Limestone, hypotype USNM 252259, height 11.02mm.

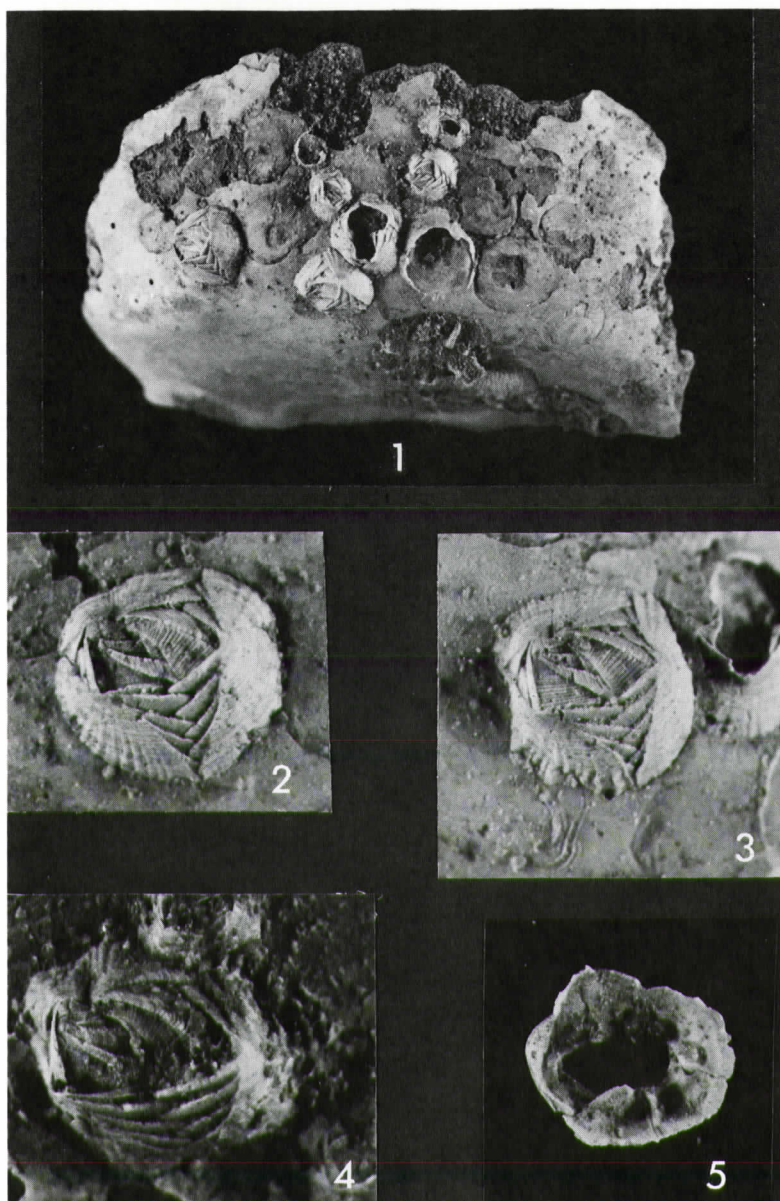


Plate 2. *Verruca (Verruca) rocana* Steinman, Beaufort Formation. Figure 1, group of shells on *Pycnodonte dissimilaris* (Weller), hypotype lot USNM 252260, length of oyster 37.02mm. Figures 2-3, close-ups of individuals shown in figure 1: (2), hypotype USNM 252260A, greatest diameter 4.82mm; (3), hypotype USNM 252260B, greatest diameter 4.22mm. Figure 4, shell on *Oleneothyris harlani* (Morton), hypotype USNM 252261, greatest diameter 6.42mm. Figure 5, basal view of interior of shell with myophore (lower left), hypotype USNM 252262, greatest diameter 4.82mm.

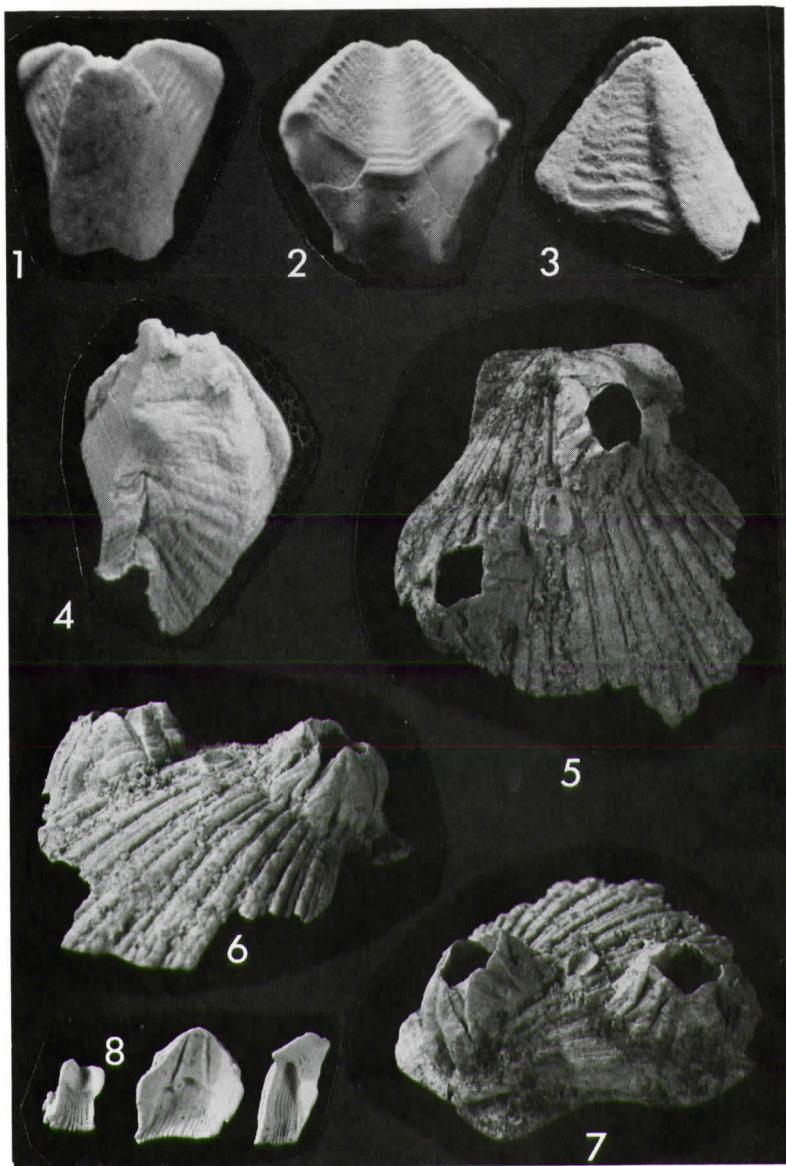


Plate 3. *Bathylasma corrugatum* n. sp. and *Solidobalanus (Hesperibalanus) kellumi* n. sp. Figures 1-4, carinae of *Bathylasma corrugatum*, Castle Hayne Limestone: (1-3), exterior, interior and side views of holotype USNM 252263, height 3.22mm; (4), exterior view of paratype USNM 252264, height 4.72mm. Figures 5-7, top, side and oblique views of two shells of *Solidobalanus (Hesperibalanus) kellumi* attached to *Chlamys trentensis* (Harris), Trent Formation, locality J-21, paratypes USNM 252265 and 252266, greatest length of pecten shell 36.22mm. Figure 8, interior views of carina, rostrum and lateral of *S. (H.) kellumi*, Trent Formation, locality J-3, paratypes USNM 252267-252269, height of carina 4.02mm.

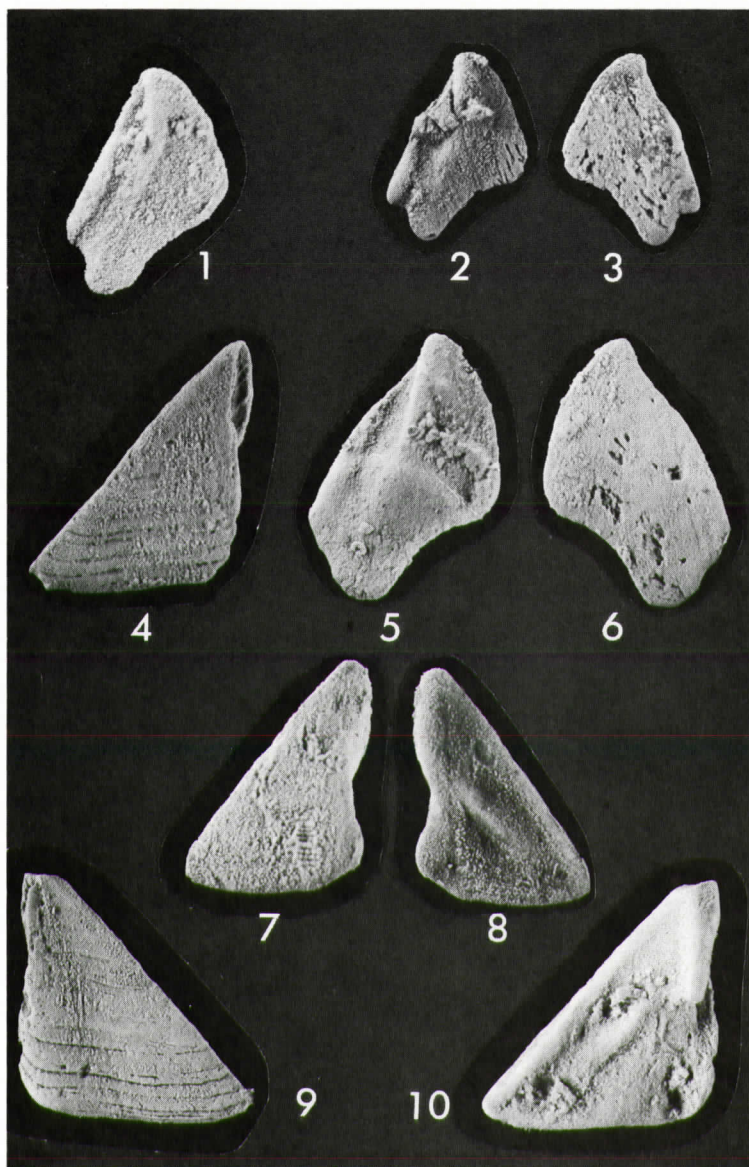


Plate 4. Opercular plates of *Solidobalanus (Hesperibalanus) kellumi* n. sp., Trent Formation, locality J-3. Figure 1, interior of scutum, paratype USNM 252270, height 4.52mm. Figures 2-3, interior and exterior of tergum, paratype USNM 252271, height 3.82mm. Figure 4, exterior of scutum, paratype USNM 252272, height 4.82mm. Figures 5-6, interior and exterior of tergum, paratype USNM 252273, height 5.12mm. Figures 7-8, exterior and interior of scutum, paratype USNM 252274, height 4.62mm. Figures 9-10, exterior and interior of scutum, holotype USNM 252275, height 4.92mm.

Belgrade Formations) units.

The Trent River section, designated as the type section of the Trent Formation (Miller, 1912), was shown by Baum (1977) and Baum et al. (1977, 1978) to include two distinct rock-stratigraphic units separated by a disconformity. These are the same two units that disconformably overlie the Castle Hayne Limestone at the Martin Marietta quarry at New Bern. The name Trent Formation was restricted to the Oligocene rocks, and its type section was designated as that part of the Trent River section between New Bern and 0.7 km of Pollocksville. As previously indicated, a new formational name, the New Bern Formation, was proposed for the underlying uppermost Eocene unit.

As presently recognized, the Trent Formation consists of three lithologies: a basal echinoid biosparite, a gastropod-pelecypod-mold biomicrudite and an upper barnacle, pelecypod-mold biosparrudite. These lithologies disconformably overlie the New Bern Formation, and are disconformably overlain by the lower Miocene Belgrade and Silverdale Formations. The restricted Trent Formation is considered to be early to medial Oligocene in age.

The lower Miocene units exposed at the Martin Marietta quarry at Belgrade and at various quarries in the Silverdale area where re-named the Belgrade and Silverdale Formations, respectively, by Baum (1977) and Baum et al. (1978). As presently interpreted, the Belgrade Formation represents the inshore, high energy facies, and the Silverdale Formation an offshore, lower energy facies of a local, early Miocene transgression. The "Crassostrea gigantissima facies" is tentatively considered to represent a regressive phase of this early Miocene sea.

SYSTEMATIC ACCOUNT

Suborder LEPADOMORPHA Pilsbry, 1916

Family SCALPELLIDAE Pilsbry, 1916

Genus EUSCALPELLUM Hoek, 1907

Euscalpellum sp., cf. E. eocenense (Meyer)

Plate 1, figures 1-3

Scalpellum eocenense Meyer, 1885: 70, figs. a-c; Meyer and Aldrich, 1886: 50.

Scalpellum chamberlaini Pilsbry, 1897: 332, fig. 1; Adkins, 1928: 84.

Euscalpellum eocenense (Meyer). Withers, 1951: 158, pl. 13, figs. 1-4; 1953: 186, pl. 21, figs. 1-10, pl. 22, figs. 7-10, text fig. 79.

Localities. Upper bryozoan biomicrudite, Castle Hayne Limestone, Martin Marietta quarry, Castle Hayne, New Hanover County, North Carolina, Sarah Nunnally, collector; unnamed limestone, Santee Portland Cement quarry near Holly Hill, Orangeburg County, South Carolina.

Material Examined. Two basal fragments of carinae (Castle Hayne Limestone), and six complete carinae (South Carolina).

Geologic Range. Claibornian (middle Eocene); Weches Formation, Texas; Wautubbee Formation, Mississippi; Lisbon Formation, Alabama; unnamed limestone, South Carolina; ? Castle Hayne Limestone, North Carolina.

Description. The carinal fragments from the Castle Hayne Limestone are 14 and 21 mm in length. The plate is relatively narrow and bowed. The tectum is strongly arched in cross section and separated from adjacent parietes by a narrow, but prominent raised ridge. Weak longitudinal striae are present on the surface of the tectum. The parietes are wide, concave in cross section, perpendicular to the plane of the tectum, and narrow towards, but reach the basal margin. Intraparietes are lacking. The basal margin is broadly and evenly rounded, and the inner surface is deeply concave.

Discussion. The two carinal fragments most closely resemble that of Euscalpellum eocenense, a middle Eocene (Claibornian) guide fossil in the Gulf Coastal Plain. Based on the work of Withers (1953) and on comparison with well preserved carinae from South Carolina, the carina of E. eocenense is seen to vary considerably as a function of age of the individual. Carinae of young individuals are slender, moderately bowed, and their inner surface is concave to the apex. With age, the parietes broaden and thicken considerably, the inner concavity becomes less pronounced, the ridges bounding the edges of the tectum are less conspicuous, and in general the plate takes on a more solid aspect. There appears to be little correlation between age and size in individuals, however. The two figured carinae from South Carolina (Plate 1, figures 4-6) are of nearly the same length, but exhibit different forms here attributed to age. The carinal fragments from the Castle Hayne Limestone appear to represent the young stage of E. eocenense, but in the absence of the apical region, positive identification cannot be made.

Two additional species of Euscalpellum have been described from the North American Paleogene. Euscalpellum isneyensis Weisbord (1977) from the lower upper Eocene North Creek Member of the Yazoo Group in Alabama and Mississippi is known only from scuta and terga, and cannot be compared with the Castle Hayne specimens. The carina of Euscalpellum? latunculus Cheetham (1963) from the upper Eocene Shubuta Clay in Alabama and Mississippi differs markedly in its greatly attenuated form, its outwardly flaring and narrow parietes, and its well developed intraparietes.

Genus ARCOSCALPELLUM Hoek, 1907

Arcoscalpellum jacksonense Withers, 1953

Plate 1, figures 7-9

Arcoscalpellum jacksonense Withers, 1953: 210, pl. 27, figs. 7-15; Cheetham, 1963: 396.

Locality. Upper bryozoan biomicrudite, Castle Hayne Limestone, Lanier Quarry, Maple Hill, Pender County, North Carolina.

Material Examined. Three partial carinae.

Geologic Range. Jacksonian (late Eocene), Moddys Marl, Pachuta Marl, Gulf Coast; Castle Hayne Limestone, North Carolina.

Description. The specimens range in length from 9 to 11 mm, and all lack the basal margin. The tectum is flat and very narrow, the parietes are concave and flare outwards slightly, and the intraparietes are not reflexed inwardly. The basal margin, as suggested by the growth lines, is broadly rounded.

Discussion. The carina of A. jacksonense differs from that of the older and closely related species A. subquadratum (Meyer and Aldrich) in having a narrower tectum, more obviously flared parietes, unreflexed intraparietes, and a broadly rounded, rather than angular basal margin. The stratigraphic significance of the occurrence of this species is discussed under A. subquadratum.

Arcoscalpellum subquadratum (Meyer and Aldrich, 1886)
Plate 1, figures 10-12

Scalpellum subquadratum Meyer and Aldrich, 1886: 110, pl. 2, fig. 25;
Meyer, 1887: 13, pl. 2, fig. 15.

Arcoscalpellum subquadratum (Meyer and Aldrich), Withers, 1953:
208, pl. 27, figs. 1-6; Cheetham, 1963, p. 396.

Locality. Upper bryozoan biomicrudite, Castle Hayne Limestone, Martin Marietta quarry, near Castle Hayne, New Hanover County, North Carolina, Sarah Nunnally, collector.

Material Examined. One incomplete carina.

Geologic Range. Claibornian (middle Eocene), Lisbon, Wauttubbee, Crockett, Gosport, and Claiborne formations, Gulf Coast; Castle Hayne Limestone, North Carolina.

Description. The single carina is 11 mm in length and is lacking the basal portion. The tectum is nearly flat, the parietes are slightly concave and nearly perpendicular to the plane of the tectum, and the intraparietes are reflexed inwardly. The growth lines suggest that the basal margin was angular.

Discussion. Differences in carinal morphologies of A. subquadratum and A. jacksonense are discussed under the latter species. Arcoscalpellum subquadratum is a guide fossil of Claibornian deposits on the Gulf Coast of the United States, whereas A. jacksonense is found only in deposits of Jacksonian age (Cheetham, 1963). If these temporal relationships are equally valid for late Eocene deposits of the southeastern United States, they would indicate that the upper bryozoan biomicrudite of the Castle Hayne Limestone is older in the southwest along the flank of the Cape Fear Arch than it is to the northeast (Maple Hill). The differences in ages of the upper bryozoan biomicrudite suggest that it was

deposited in a northeastward-regressing sea during uplift along the Cape Fear Arch.

Suborder VERRUCOMORPHA Pilsbry, 1916

Family VERRUCIDAE Darwin, 1854

Genus VERRUCA Schumacher, 1817

Verruca (Verruca) rocana Steinman, 1921

Plate 2, figures 1-5

Balanus. Windhausen, 1918: 44.

Verruca rocana Steinman, 1921: 4, pl. 2, fig. 1, pl. 3, fig. 7; Withers, 1935: 347, pl. 45, figs. 16-17.

Locality. Thanetian (Paleocene), Beaufort Formation, Mosley Creek at Lenoir County line, near Kinston, North Carolina, U. S. Geological Survey locality, Druid Wilson, collector.

Material Examined. Thirty-four complete or partial specimens on four examples of the brachiopod Oleneothyris harlani (Morton) and eight complete or partial shells on a single example of the oyster Pycnodonte dissimilaris (Weller).

Geologic Range. Danian (Paleocene), Roca Formation, Rio Negro, Argentina; Thanetian (Paleocene), Beaufort Formation, Lenoir County, North Carolina.

Description. The shells, which are up to 7 mm in greatest basal diameter, are depressed and slope toward the scuto-tergal side. The basal margin is sharp and unreflexed. The carina and rostrum bear sharp, narrow longitudinal ribs that are especially prominent on the lower half of these plates. The suture between fixed tergum and fixed scutum is linear. The articular ribs between carina and rostrum are broad and flat, and number between three and five on the rostrum. The fixed scutum bears a prominent dependant myophore internally. The movable scutum is narrow and ornamented externally by closely spaced growth lines. The lower articular ridge of the movable scutum is wider than the upper articular ridge. The apico-basal ridge of the movable tergum is narrow and nearly straight, and the lower articular ridge is wider than the upper ridge.

Discussion. The movable plates of shells from Mosley Creek, as those of the type lot of V. rocana, are cemented in place and cannot be removed intact for detailed examination. However, based on visible characters the Mosley Creek specimens agree completely with the description and illustrations of V. rocana provided by Withers (1935).

Verruca rocana is otherwise known only from its type locality in the Roca Formation. The marine Danian rocks (Salamancan) of Argentina are dated at between 63 and 65 million years B. P. (Marshall et al., 1977), whereas the updip outcrop of the Beaufort Formation at

Mosley Creek contains Thanetian microfossils (Globorotalia pseudo-menardii zone) and has been dated radiometrically at 56.8 million years B. P. (Harris and Baum, 1977). The temporal and, more importantly, the spatial separation of these localities causes considerable concern in ascribing the Mosley Creek specimens to V. rocana, yet based on morphologic comparison, no distinguishing characteristics can be recognized.

Two other species of Verruca are known from rocks of the same or slightly older ages. Verruca pusilla Bosquet (1857) from the Maastrichtian (Cretaceous) of Holland and Belgium is closest morphologically to V. rocana, but is readily distinguished by the narrower, rounded, and more numerous (up to 7) articular ribs between carina and rostrum, and by the broad, flat-topped longitudinal ribs of the shell. Verruca prisca Bosquet (1854) from the "upper Senonian" (latest Cretaceous) of Holland, Belgium, and England, and from the Danian of Denmark clearly differs in possessing an erect shell lacking longitudinal ribs.

Suborder BALANOMORPHA Pilsbry, 1916

Superfamily CORONULIDAE Leach, 1817

Family BATHYLASMATIDAE Newman and Ross, 1971

Subfamily BATHYLASMATINAE Newman and Ross, 1971

Genus BATHYLASMA Newman and Ross, 1971

Bathylasma corrugatum n. sp.

Plate 3, figures 1-4

Locality. Upper bryozoan biomicrudite, Castle Hayne Limestone, Lanier quarry, Maple Hill, Pender County, North Carolina.

Material Examined. Two carinae, holotype USNM 252263, paratype USNM 252264.

Diagnosis. Carinal alae with regular and prominent transverse corrugations.

Description. Carina solid, without internal ribbing or basal denticulation; basal margin thin; sheath occupying at least half of the interior of the plate, with regularly spaced, prominent growth ridges; exterior of paries not bowed, nearly rectangular in shape, and ornamented by coarse, low, transverse ridges; alae triangular, as wide as paries, crossed by widely and regularly spaced, prominent ridges parallel to inferior alar margin; welt formed by upturned growth increments along superior alar margin occupies about one-fourth of alar area.

Discussion. Assignment of these carinae to the genus Bathylasma is based on the narrowness of the basal margin, the absence of interior ribbing or basal denticulation, and the welting and growth line pattern of the alae. Newman and Ross (1971, 1976) recognized three species of Bathylasma, including B. aucklandicum (Hector) from the Miocene

of New Zealand, B. corolliforme (Hoek) from the Pleistocene and Recent of circum-Antarctic waters, and B. hirsutum (Hoek) from the Recent of the eastern North Atlantic. Although it is not normal procedure to describe new species on the strength of a single compartmental plate, B. corrugatum can be readily distinguished from previously described species by the regularly spaced and prominent corrugations of the alae. In this feature, as well as in the general form of the plate, B. corrugatum most closely resembles B. corolliforme. The presence of Bathylasma in the Eocene lends support to the phylogeny of the coronuloids (=balanomorphoids) proposed by Newman and Ross (1976) in which the bathylasmatids are regarded as the basal stock leading to the tetracitids and perhaps the balanoids.

Etymology. From the Latin, corrugatus, wrinkled or ridged.

Superfamily BALANOIDEA Leach, 1817

Family ARCHAEOBALANIDAE Newman and Ross, 1976

Subfamily ARCHAEOBALANINAE Newman and Ross, 1976

Genus SOLIDOBALANUS Hoek, 1913

Subgenus HESPERIBALANUS Pilsbry, 1916

Solidobalanus (Hesperibalanus) kellumi n. sp.

Plate 3, figures 5-8; plate 4, figures 1-10

Localities. Trent Formation: CR-J, poorly washed, barnacle, pelecypod-mold biosparrudite, core sample, latitude 35°5'6" N, longitude 77°8'22" W, Craven County; CR-R, poorly washed, barnacle, pelecypod-mold biosparrudite, Martin Marietta quarry, New Bern, Craven County; J-3, Type Locality, barnacle, pelecypod-mold biosparrudite grading upward to a barnacle, pelecypod-mold biomicrudite, north bank of Trent River, 1.1 km west of Bells Landing, at apex of S-shaped bend in river, New Bern quadrangle (1901, 15'), Jones County; J-21, poorly washed, echinoid biosparite, state road quarry, 2.8 km northeast of Pollocksville, west side of Trent River, Jones County; ON-1, sandy, pelecypod-mold biomicrudite, east bank of New River at junction with SSR 1402 (old bridge over New River at Jacksonville), small outcrop at water's edge, Onslow County.

? New Bern Formation: J-5, east bank of Trent River, 0.7 km east of Pollocksville, ?below disconformity with overlying Trent Formation, New Bern quadrangle (1901, 15'), Jones County.

Material Examined. Two whole shells without opercular valves on Chlamys trentensis (Harris), over 1000 disarticulated compartmental plates, and over 60 opercular plates.

Geologic Range. ?Upper Jacksonian (uppermost Eocene), lower to middle Oligocene, North Carolina.

Diagnosis. Solid, smooth to plicate, low conic shell with narrow radii and thin, solid, calcareous basis; scutum with widely spaced growth

lines, short adductor ridge, and no internal rugosities, tergal spur broad, placed close to basiscutal angle; spur furrow not depressed.

Description. Shell small, low conic; orifice half as large as carinorost-
tral diameter of shell, diamond shaped; parietes solid, smooth to pli-
cate in lower half; radii narrow with oblique summits; alae broad, pro-
jecting above radii; sutural edges of radii and alae thin, without dentic-
ulation; sheath about one-third length of compartmental plate, lower
edge slightly overhanging interior of parietal wall; interior of parietes
irregularly and coarsely ribbed; parietal ribs form coarse denticula-
tion on basal margin; basis calcareous, thin, solid.

Scutum thin, exterior bowed transversely between apex and
basal margin and ornamented by widely spaced growth lines; articular
ridge high, slightly reflexed, one-half or less than one-half length of
tergal margin, articular furrow broad, deep; adductor ridge short,
prominent, centrally located and parallel to occludent margin; interior
of scutum smooth; depressor muscle pit oval, deep; basal margin equal
to or less than length of tergal margin.

Tergum thin, broad; articular ridge prominent, erect; articular
furrow broad, deep; depressor muscle crests short, weak, four or
five in number; interior of tergum smooth; tergal spur short, broadly
rounded or sub-truncate, about one-third width of basal margin, and
placed one-third its own width from basiscutal angle; spur furrow not
depressed, bounded by impressed line on scutal side only.

Discussion. Solidobalanus kellumi has been found in all three facies of
the Trent Formation. The onshore sandy, echinoid biosparite contains
in situ whole barnacles sometimes attached to pectens (locality J-21).
Barnacles are rare in the offshore sandy, pelecypod-mold biomicru-
dite and occur only as isolated compartmental plates (locality ON-1).
Solidobalanus kellumi is most abundant in the pelecypod-mold biospar-
rudite where it forms coquinas of disarticulate compartmental and
opercular plates. This facies probably represents a shoaling regres-
sive phase of Trent deposition. The evidence suggests that S. kellumi
was a nearshore, immediately subtidal species; a habitat similar to
that indicated for the allied species S. cornwalli of the upper Eocene
Cowlitz Formation (Zullo, 1966).

Disarticulated opercular and compartmental plates were re-
covered also from a sandy zone that appears to be immediately below
the disconformity between the Trent and the underlying New Bern For-
mations (locality J-5) on the Trent River. However, the upper surface
of the New Bern Formation is bored and fractured, and the resulting
voids are filled with Trent sediment. The sandy, barnacle bearing
zone could represent basal Trent Formation, and its stratigraphic posi-
tion must remain questionable.

Although archaeobalanids appear to have obtained widespread
distribution after their appearance in the middle Eocene, few of the
named Eocene and Oligocene species have been described adequately.
The following list includes those species whose opercular plates and

shells are well enough known to permit comparison with Solidobalanus kellumi:

North America

Solidobalanus (Hesperibalanus) cornwalli (Zullo, 1966), upper Eocene, Cowlitz Formation, southern Washington.

Kathpalmeria georgiana Ross (1965), upper Eocene, Barnwell Formation, Georgia.

South America

Solidobalanus (Hesperibalanus) stenonotus (Pilsbry and Olsson, 1951), Oligocene, Ecuador.

Europe

"Balanus" unguiformis Sowerby (1846), upper Eocene through lower Oligocene, Britain.

Solidobalanus (Hesperibalanus) paraesperius (Menesini, 1971), lower Oligocene, France.

Solidobalanus kellumi can be distinguished from all of these species by its well developed adductor ridge on the scutum. It further differs from S. cornwalli in having somewhat wider radii, more widely spaced scutal growth lines, a shorter scutal articular ridge, a broader tergal spur placed closer to the basiscutal angle, and in lacking interior rugosities on the opercular plates. Compartmental plates of S. kellumi lack the reentrant buttressing and the very narrow and crenulate radii that characterize Kathpalmeria georgiana. Solidobalanus stenonotus possesses broad, coarsely crenulate radii, thick opercular plates, an unusually prominent scutal articular ridge whose lower margin continues onto the interior of the plate as a low ridge, and a nearly parallel sided tergal spur. Solidobalanus paraesperius can be distinguished from S. kellumi by its irregularly costate shell, wider, crenulate radii, and internal rugosities on the interior of the opercular plates. "Balanus" unguiformis differs from S. kellumi in having broader, finely crenulate radii, internally rugose opercular plates, and a long, narrow, parallel sided tergal spur.

The generic and subgeneric status of "B." unguiformis is continually debated. Although this species shares many characteristics with those Eocene and Oligocene archaeobalanids currently assigned to the subgenus Hesperibalanus, it possesses an unusual feature, irregular parietal pores, that sets it apart from the solid walled hesperibalanids. By consensus, this unusual British species has been included in the typical subgenus of the genus Chirona Gray (Davadie, 1963; Zullo, 1966; Newman and Ross, 1976), but a nomenclatorial problem has arisen that requires consideration.

The subgenus and species Balanus (Archaeobalanus) semicanaliculatus Menesini (1971) was proposed for balanoid shells without opercular plates from the Bartonian (upper Eocene) through Stampian (i.e., Rupelian or lower Oligocene) of France. Archaeobalanus was created to include balanoids with partially or irregularly porous parietes, solid,

relatively narrow radii with finely crenulate sutural margins, and thin, solid, calcareous bases. Later, Newman and Ross (1976) raised Archaeobalanus to generic rank.

Menesini (1971) did not compare Archaeobalanus semicanaliculatus to "Balanus" unguiformis, although Darwin (1854; 29-31) in his detailed description of "B." unguiformis noted the following characteristics:

"As already stated, in about half the specimens, there were no traces of parietal pores; in the other half there were either distinct or obscure pores; the pores are circular, generally of unequal sizes, and never large; in the same individual they would sometimes be almost wholly absent in some of the compartments, and quite plain in the other compartments. The radii are either moderately wide or are rather narrow, and have their upper margins very oblique, and not distinctly arched, and not quite smooth; their sutural edges are very finely crenulated, the teeth or septa not being denticulated. ... The basis is thin, and without any trace of pores; the upper surface is sometimes furrowed in radiating lines. "

Clearly, "B." unguiformis can be assigned to the genus Archaeobalanus, but the similarity between it and A. semicanaliculatus is more than congeneric. On comparison of Menesini's (1971) description and illustrations of A. semicanaliculatus with those of A. unguiformis, and taking into consideration the contiguity of Tethys in Britain and France during the Bartonian and Rupelian, it would appear that the type species of Archaeobalanus is a junior subjective synonym of A. unguiformis.

The question remains as to whether there is any value in maintaining a distinct genus-group taxon for A. unguiformis. A survey of nominate Eocene and Oligocene archaeobalanids indicates that all possess a thin calcareous basis. In addition, with the exception of the North American species of Solidobalanus, all exhibit some indication of crenulation on the radial sutural edges. The sole feature separating Archaeobalanus from other genus-group taxa would appear to be the presence of irregular pores in the parietes. One other archaeobalanid, "Balanus" vialovi Kolosvary (1961), from the upper Eocene of the USSR possesses this feature, but it is known only by basal fragments of the shell wall and the exterior of a scutum.

It is possible that the irregularly porous wall is not a significant character, and that it would be best to unite all the known Eocene and Oligocene archaeobalanids (with the exception of Kathpalmeria) under Hesperibalanus until more becomes known of their specific characteristics.

Types. Type locality, J-3, barnacle, pelecypod-mold biosparrudite, Trent Formation, Trent River, Jones County, North Carolina. Holotype USNM 252275; paratypes USNM 252267 through 252274; additional

paratypes, locality J-21, echinoid biosparite, Trent Formation, Trent River, Jones County, North Carolina, USNM 252265 and 252266.

Etymology. This species is named for Lewis Burnett Kellum in recognition of his contribution to the paleontology and stratigraphy of the Castle Hayne Limestone and Trent Formation.

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AN EXPOSURE OF MARGINAL MARINE PLEISTOCENE
SEDIMENTS, PITT COUNTY, NORTH CAROLINA

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ABSTRACT

A sedimentary unit containing an abundance of estuarine and shallow water marine fossils is exposed in the Martin Marietta Quarry at Fountain, Pitt County, North Carolina. Although none of the numerically dominant foraminiferal species are biostratigraphically diagnostic, an age of early Pleistocene is indicated by representatives of the Noetiinae (Bivalvia). Based upon shell elongation, position of the beaks, and the number and nature of the ribs, these specimens closely resemble those from lower Pleistocene sediments exposed in other areas of the southeastern Atlantic Coastal Plain. The specimens are assigned to Noetia (Eontia) variabilis. The foraminiferal assemblage does provide detailed paleoecologic information. The dominant species, in order of decreasing relative abundance, are Elphidium excavatum forma selseyensis, Ammonia beccarii forma sobrina, Elphidium excavatum forma lidoensis, Elphidium gunteri, Elphidium cf. E. sagrum, Ammonia beccarii forma tepida, Elphidium excavatum forma clavatum and Buccella frigida. This assemblage indicates shallow, brackish water and a temperate climate. The lack of open ocean foraminiferal species suggests either a restricted bay or estuarine environment, an interpretation which is supported by evidence from the molluscan fauna.

INTRODUCTION

Location and Geologic Setting

A richly fossiliferous marginal marine sedimentary unit is exposed along the northern wall of the Martin Marietta Quarry at Fountain, North Carolina. Fountain lies at the western edge of Pitt County, approximately 26 kilometers west and slightly north of Greenville (Figure 1).

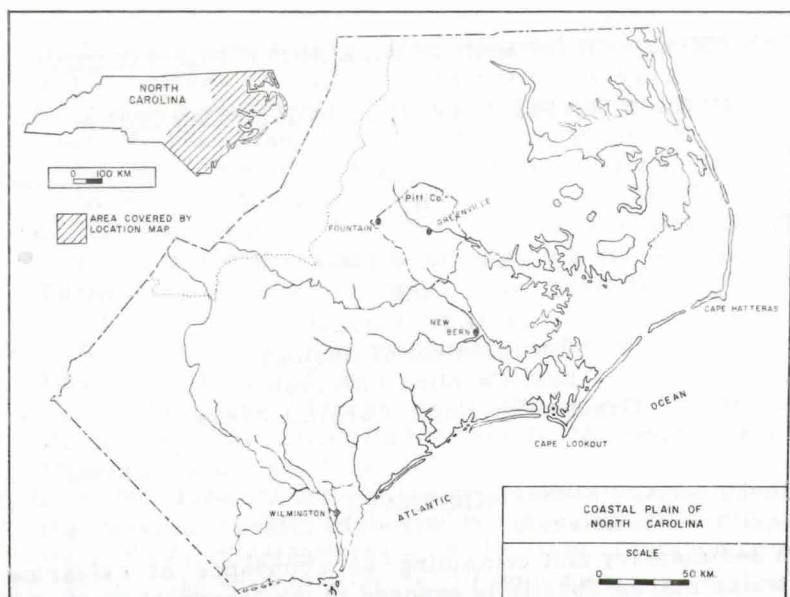


Figure 1. Location map.

A nonconformity separates the fossiliferous deposit from the granite gneiss that is being exploited at the quarry. Extensive weathering of the crystalline rock has produced an irregular surface that controls variations in the thickness of the overlying shell bed.

The exposure of the fossiliferous unit is only several meters wide. Although the precise nature of this abrupt lateral discontinuity is partially obscured by slumping of the overlying sands, the marine deposit appears to occupy a narrow topographic low on the granite gneiss surface. The shell bed attains a maximum thickness of 2.2 meters and is composed of fine to coarse, subangular quartz sands with varying amounts of mud and gravel (Figure 2). There are occasional lenses of nearly pure clay and several layers are firmly cemented by limonite. Fossils are common to abundant throughout this unit, occurring as molds within cemented intervals and as original shell material within unconsolidated sediments. Representatives of the macrofauna are abraded, fragmented, randomly oriented, and, in the case of the bivalves, almost entirely disarticulated.

Nonmarine quartz sands lie above the shell bed and the contact between these units, although unconformable, is uniform. These sands, which are 7.4 meters thick, contain remains of terrestrial vertebrates.

Objectives

Although this exposure has been known to geologists of the immediate area for some time, statements concerning the relative age of

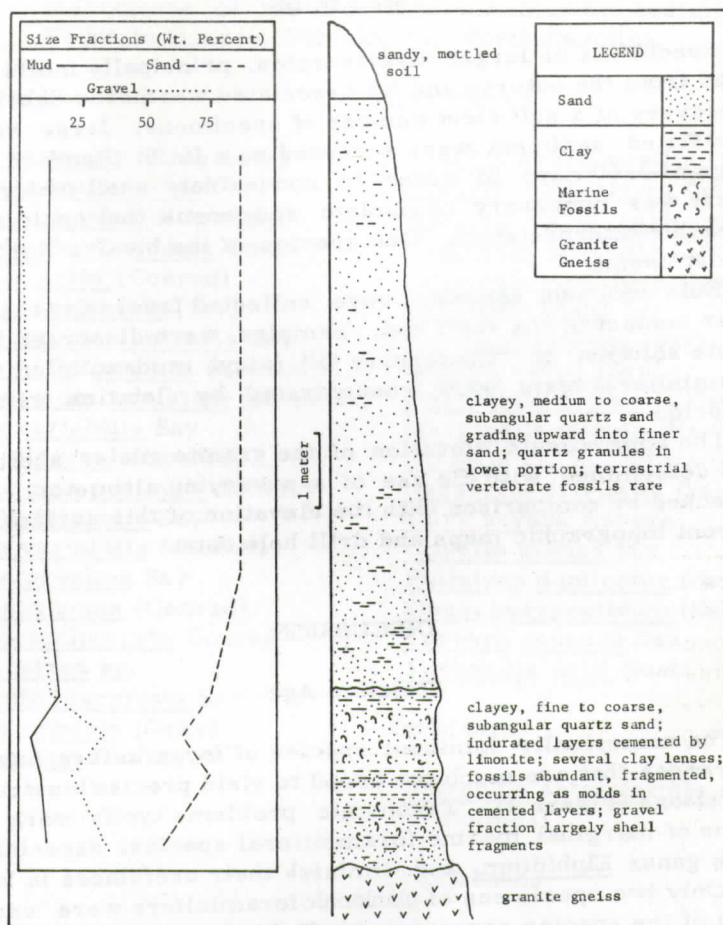


Figure 2. Measured section.

the shell bed have been purely conjectural. Also, there has been no detailed interpretation of paleoecology. The objectives of this study are to consider these factors in detail.

Acknowledgments

John Hutchins, superintendent of the quarry at Fountain, graciously permitted numerous visits to the exposure. Through discussions dealing with taxonomic considerations, Druid Wilson, Martin Buzas, and Frank Whitmore have been most helpful. Mervin Kontrovitz supplied scanning electron photomicrographs of the dominant foraminiferal species.

METHODS

Specimens of larger invertebrates, principally mollusks, were collected from the outcrop and its associated weathered debris. To insure recovery of a sufficient number of specimens, large volumes of unconsolidated sediment were screened on a U. S. Standard Sieve #10 (openings of 2.00 mm) in order to concentrate shell material. This procedure was necessary to isolate specimens that could aid in biostratigraphic interpretation. One species of the bivalve Noetia proved to be most useful.

Bulk sediment samples were collected from near the base and the upper contact of the shell bed. Samples were dispersed by boiling in a dilute solution of "Quaternary O" (alkyl imidazolinium chloride) and foraminiferal tests were concentrated by flotation using carbon tetrachloride.

The approximate elevation of the granite gneiss-shell bed contact was determined with the use of a surveying altimeter. Readings were checked by comparison with the elevation of this surface as determined from topographic maps and drill hole data.

DISCUSSION

Relative Age

The numerically dominant species of foraminifera have stratigraphic ranges that are much too broad to yield precise biostratigraphic interpretations (Figure 4). Taxonomic problems typify work based on specimens of marginal marine foraminiferal species, especially those within the genus Elphidium, and diminish their usefulness in biostratigraphy. Only two specimens of planktonic foraminifera were encountered. Both of the species represented, Globigerinoides ruber (d'Orbigny) and Globigerinella siphonifera (d'Orbigny), range from late Miocene to Recent (Blow, 1969, p. 268, 277).

Biostratigraphic analysis of the shell bed is, therefore, based upon selected elements of the molluscan fauna. The shell bed is numerically dominated by extant species of mollusks. However, many of these species have long stratigraphic ranges and yield little biostratigraphic precision. Of the 39 species of mollusks that are present (Table 1), only three have not been recorded in the Recent. Cardita arata (Conrad) and Ostrea sculpturata Conrad, although extinct, are long ranging and have limited value for making an accurate age assignment. The other extinct species is an elongate form of Noetia that occurs, albeit rarely, throughout the shell bed. The evolution of this genus has involved 1) progressive reduction of shell elongation, 2) posterior migration of the beaks, 3) a gradual decrease in the number of ribs since the Miocene, and 4) a gradual increase in the prominence of

Table 1. Macrofauna of the Fossiliferous Marine Sediments at the Fountain Quarry, Pitt County, North Carolina.

Bivalves

Anadara ovalis (Bruguiere)
Anadara transversa (Say)
Anomia simplex d'Orbigny
Astarte cf. A. undata Gould
Cardita arata (Conrad)
Cardita tridentata (Say)
Caryocorbula contracta Say
Crassinella lunulata (Conrad)
Dinocardium robustum (Solander)
Donax variabilis Say
Ensis directus (Conrad)
Glycymeris pectinata Gmelin
Mulinia lateralis Say
Noetia variabilis MacNeil
Nucula proxima Say
Nuculana acuta (Conrad)
Ostrea sculpturata Conrad
Crassostrea sp.
Plicatula marginata Say
Rangia cuneata (Gray)
Tellina sayi Deshayes

Gastropods

Anachis avara similis (Ravenel)
Busycon contrarium Conrad
Busycon cf. B. caricum Gmelin
Crepidula fornicata (Linne)
Crepidula maculosa Conrad
Crepidula plana Say
Eupleura caudata (Say)
Lunatia heros (Say)
Marginella guttata Dillwyn
Marginella minuta Pfeiffer
Mitrella cf. M. lunata (Say)
Nassarius trivitatta (Say)
Oliva sayana Ravenel
Olivella mutica Say
Polinices duplicatus (Say)
Sinum perspectivum (Say)
Terebra concava Say
Turbonilla dalli Bush

Anthozoans

Astrangia astreiformis (Tuomey & Holmes)

Crustaceans

Balanus sp.

interstitial ribs (MacNeil, 1937; Bird, 1965). On the basis of these characters the specimens encountered during this study are assigned to Noetia (Eontia) variabilis MacNeil (1937, p. 20). Although originally described as a Pliocene form, this species is characteristically found within sediments of the southeastern Atlantic Coastal Plain that are now interpreted as lower Pleistocene. Bird (1965, p. 34) plotted shell elongation (the height to length ratio) against the position of the beaks (the ratio of the distance from the anteriormost tooth to the beak to that from the posteriormost tooth to the beak) for species of Noetia that occur in sediments ranging in age from Miocene to Recent. Plotting these same measurements for specimens from the Fountain Quarry shell bed strongly supports the interpretation of these forms as early Pleistocene (Figure 3).

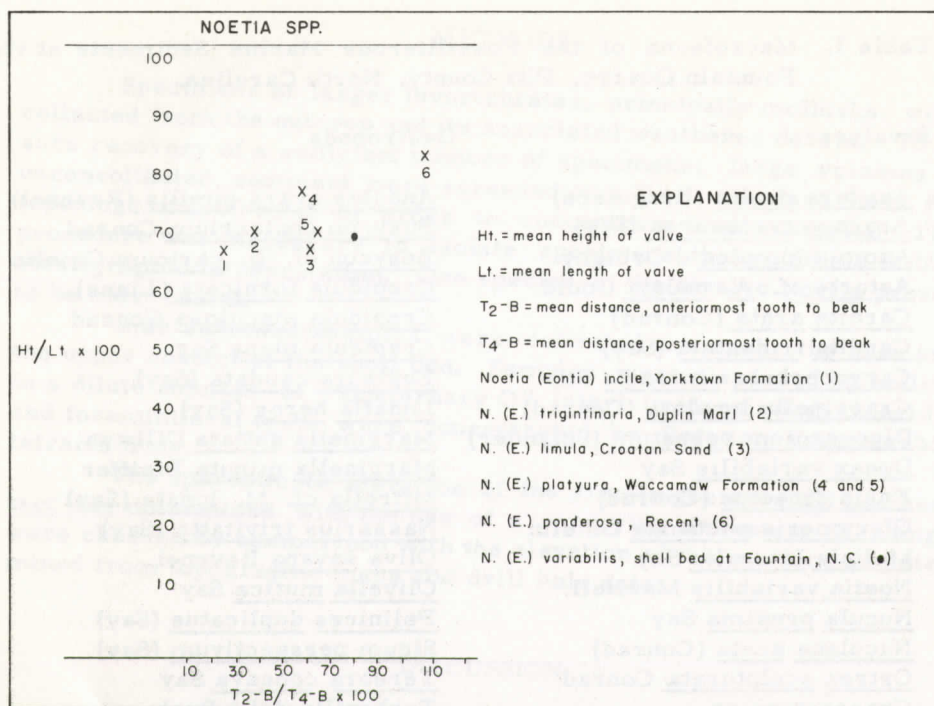


Figure 3. Comparison of shell elongation and position of beaks among species of Noetia (modified from Bird, 1965).

The sands that lie above the shell bed at Fountain contain remains of terrestrial vertebrates. Although fossils from this unit are extremely rare, several horse teeth have been collected. These specimens are cheek teeth from a fairly large Pleistocene horse, of a size often referred to Equus complicatus Leidy. However, identification of single teeth to the species level is not advisable because there is significant intraspecific variation among species of Pleistocene horses (Frank Whitmore, personal communication). The genus Equus occurs in Pleistocene deposits ranging in age from Kansan to late Wisconsin. The age of these sands is, therefore, consistent with the interpretation of the shell bed as early Pleistocene.

Ecologic Data

The foraminiferal fauna does supply good paleoecologic information because all species identified from the shell bed are extant. Many of these species have been extensively studied and detailed information is available concerning their respective ecological tolerances. Information on each species' temperature and salinity tolerances, bathymetric distribution, fossil record and the references from which this information

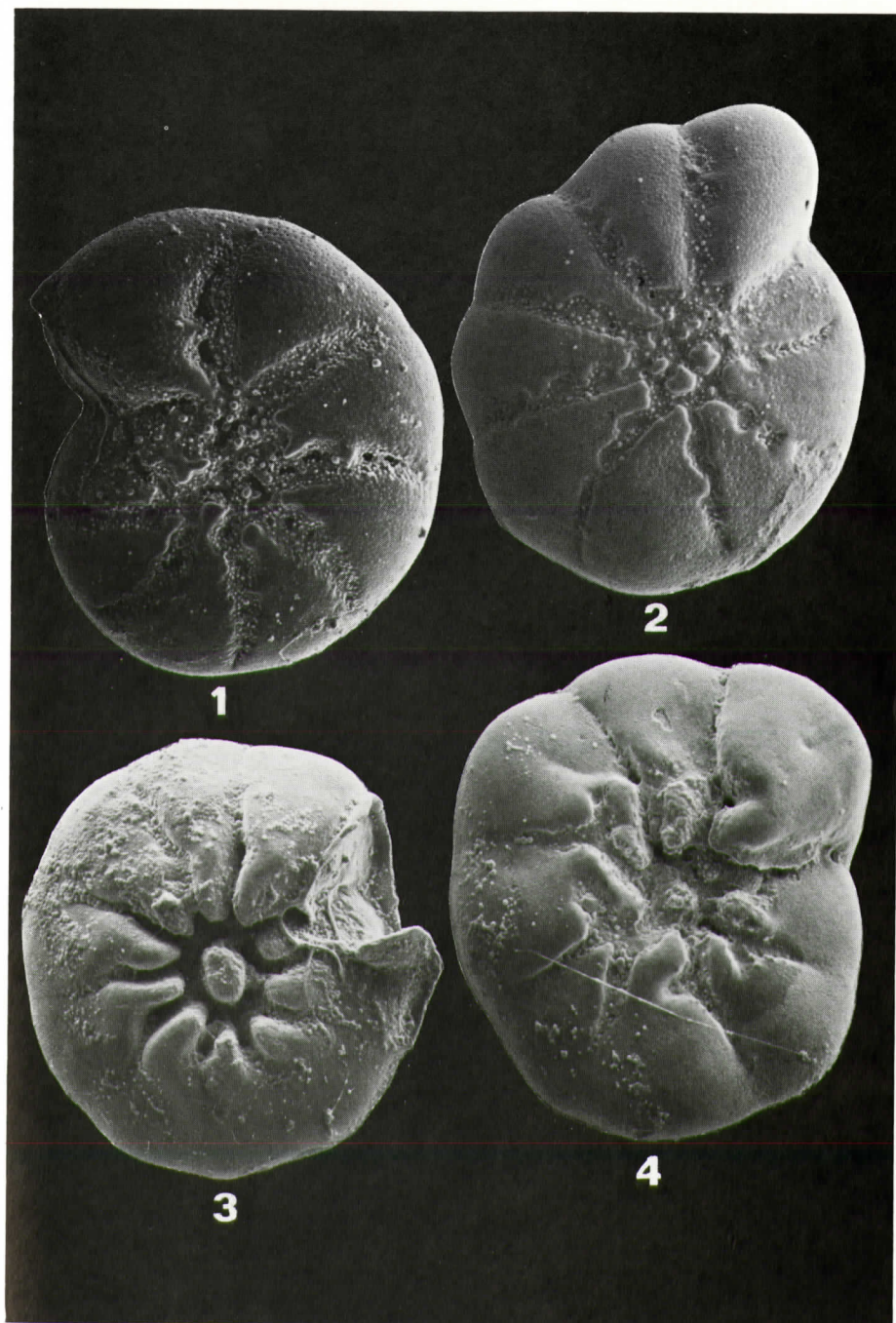


Plate 1. Figures 1 and 2. *Elphidium excavatum* (Terquem) forma *selseyensis* (Heron-Allen and Earland), x2200
Figure 3. *Ammonia beccarii* (Linné) forma *sobrina* (Shupack), x2200
Figure 4. *Ammonia beccarii* (Linné) forma *tepida* (Cushman), x2200

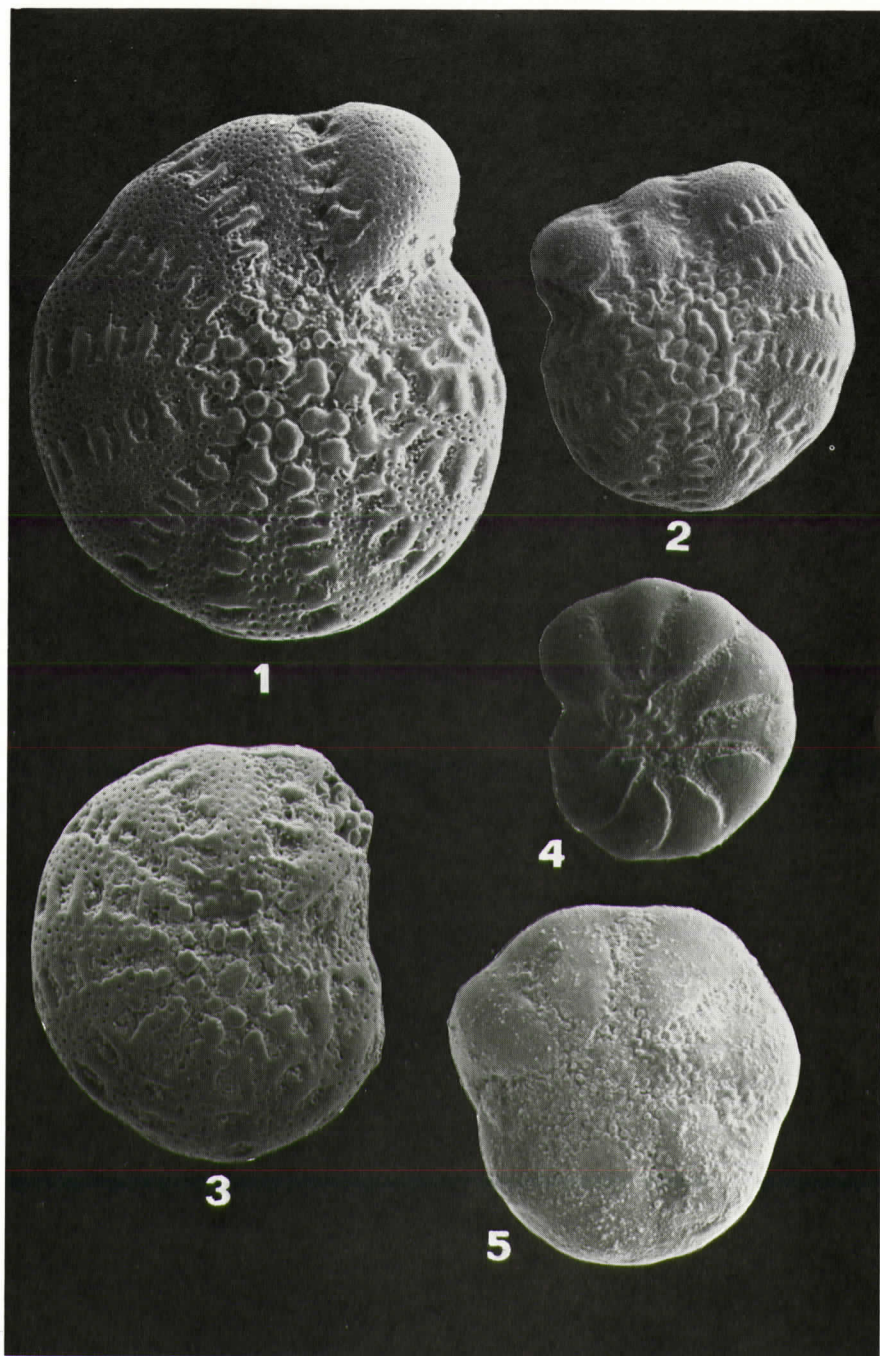


Plate 2. Figures 1 and 2. *Elphidium gunteri* Cole, x2200

Figure 3. *Elphidium* cf. *E. sagram* (d'Orbigny), x2200

Figure 4. *Elphidium excavatum* (Terquem) forma *lidoensis* Cushman, x2100

Figure 5. *Buccella frigida* (Cushman), x2200

Species	Optimum Temp. Range (°C)	Optimum Salinity Range (‰)	Optimum Depth (Meters)	Major Faunal Group	Fossil Record	Sources of Information
ELPHIDIUM EXCAVATUM FORMA SELSEYENSIS	?	?	?	TEMPERATE TO COLD TEMPERATE	QUATERNARY TO RECENT	FEYLING-HANSEN (1972), PARKER (1952)
AMMONIA BECCARII	20-30	19-36	3-20	SUBTROPICAL TO COLD TEMPERATE	MIOCENE TO RECENT	BANDY (1954), LANKFORD (1959), BRADSHAW (1961), NICHOLS & NORTON (1969), BUZAS (1969), AKERS (1971), AKPATI (1975)
ELPHIDIUM EXCAVATUM FORMA LIDOENSIS	?	?	?	TEMPERATE TO WARM TEMPERATE	MIOCENE TO RECENT	FEYLING-HANSEN (1972)
ELPHIDIUM GUNTERI	11-30	19-36	< 18	WARM TEMPERATE TO SUBTROPICAL	MIOCENE TO RECENT	AKERS (1971), HOWARD (1974), ANDERSEN (1975)
ELPHIDIUM CF. E. SAGRUM	?	?	?	WARM TEMPERATE TO SUBTROPICAL	MIOCENE TO RECENT	TODD & LOW (1971), ANDERSEN (1975)
ELPHIDIUM EXCAVATUM FORMA CLAVATUM	2-16	14-32	5-25	COLD TEMPERATE TO SUBPOLAR	MIOCENE TO RECENT	PHLEGER & WALTON (1950), NICHOLS & NORTON (1969), SCHNITKER (1971), FEYLING-HANSEN (1972), HOWARD (1974), AKPATI (1975)
BUCCELLA FRIGIDA	2-25	25-30	2-55	TEMPERATE TO COLD TEMPERATE	PLIOCENE (?) TO RECENT	LIDZ (1965), HOWARD (1966), MURRAY (1968), MURRAY (1969), HOWARD (1974)

Figure 4. Optimum ecological conditions for numerically dominant foraminiferal species.

was gathered is presented in Figure 4. Because the optimum ecological conditions for any given species will differ from those for other species, the relative abundance of each species must be determined in order to attain an accurate paleoecologic reconstruction. The relative abundance of each species, defined as the number of specimens within that species expressed as a percentage of the total benthonic foraminiferal assemblage, is shown in Figure 5. Accurate taxonomy is, of course, prerequisite to applying this sort of information.

Speciation within the genus Elphidium, which constitutes 68% of the foraminiferal assemblage at Fountain, presents difficulties. The authors follow Feyling-Hanssen (1972) in viewing Elphidium excavatum (Terquem) as a highly variable species which contains several forms that are each associated with certain environments.

Of the forms considered conspecific with Elphidium excavatum, only forma clavatum has been widely recognized along the eastern coast of North America. Diagnostic features of this form include a translucent, yellowish-brown wall, several distinct sutural bridges, and sutures that close before reaching the umbilical region. It thrives in cold temperate to subpolar conditions but comprises only 1% of the assemblage at Fountain.

The dominant faunal element, Elphidium excavatum forma selseyensis (Plate 1, Figures 1 and 2), comprises 34% of the foraminiferal fauna. This form, characterized by numerous small papillae in

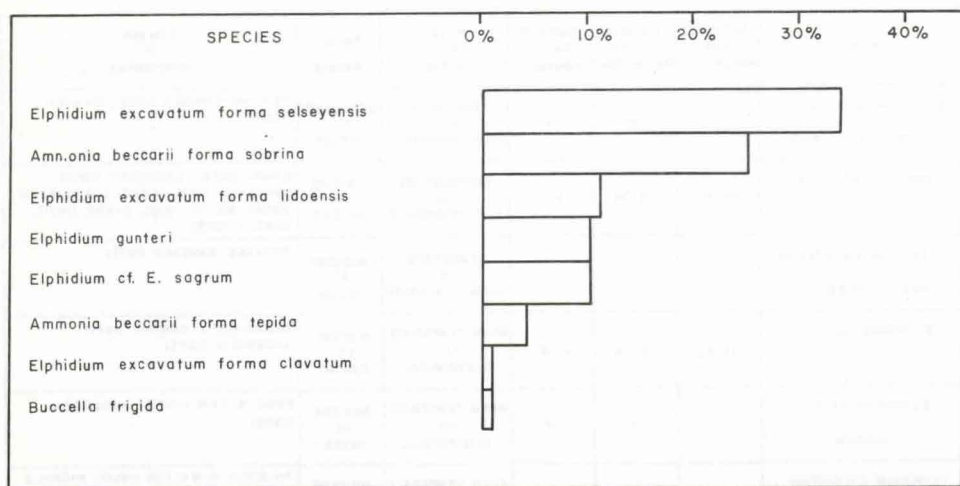


Figure 5. Relative abundance of numerically dominant foraminiferal species.

the umbilical region, poorly developed sutural bridges, and distinct sutures that broaden and open into the umbilicus, has not been widely recognized in North America. Parker (1952) recorded it from Recent sediments in the Long Island Sound-Buzzards Bay area, and Schnitker (1970) recorded it from Neogene sediments in Pitt County, North Carolina. This form attains maximum relative abundances in temperate to cold temperate regions.

Elphidium excavatum forma *lidoensis* (Plate 2, Figure 4) is also an important faunal element (11% of the foraminiferal assemblage). This form differs from forma *selseyensis* in that the sutures broaden more dramatically toward the umbilicus, sutural bridges are absent, and the papillae of the central area have fused into a number of larger, irregular knobs. As might be expected when dealing with ecotypic variants, some specimens are gradational between forma *selseyensis* and forma *lidoensis*. The specimen pictured in Plate 1, Figure 2 possesses features characteristic of forma *selseyensis* except that it has developed several larger knobs in the umbilical region. Forma *lidoensis* attains maximum relative abundances in temperate to warm temperate waters.

Elphidium gunteri Cole (Plate 2, Figures 1 and 2), characterized by a coarsely perforate wall, numerous but irregular umbilical bosses, and numerous strongly developed sutural bridges, constitutes 10% of the fauna. This form thrives in warm temperate to subtropical waters.

A form here designated as *Elphidium* cf. *E. sagram* (Plate 2, Figure 3), comprises 10% of the fauna. Representatives of this species, which is characteristic of subtropical waters, are severely abraded and

occur only in the basal portion of the shell bed. Their presence in the Fountain exposure is probably the result of re-working or extensive post-mortem transport.

Schnitker (1974) documented that many described species within the genus Ammonia are actually ecotypic variants of a single species, Ammonia beccarii (Linne). The dominant variant in sediments from Fountain is forma sobrina, which is characterized by a prominent umbilical plug (Plate 1, Figure 3). It comprises 25% of the foraminiferal fauna. Forma tepida (Plate 1, Figure 4), which differs from forma sobrina in having an open umbilicus, accounts for 4% of the fauna. Ammonia beccarii is the most cosmopolitan of the species encountered during this study.

Buccella is also a genus for which species determinations are difficult. The specimens present in the shell bed are placed in Buccella frigida (Cushman) (Plate 2, Figure 5). This species is a cold water indicator but it comprises only 1% of the foraminiferal fauna.

The molluscan fauna also provides detailed paleoecologic information. Nearly all of the species identified from the shell bed at Fountain are extant. Their distributions in modern marine environments suggest a paleoecologic setting very similar to that indicated by the foraminifera. Mulinia lateralis Say, an estuarine form, is the numerically dominant species among the mollusks. Many of the other species that are present in the shell bed still inhabit the coastal regions of North Carolina. Whereas most of these species occur in a variety of habitats, all have been recorded in shallow water, nearshore environments (Kirby-Smith and Gray, 1973). All but one, Donax variabilis Say, live in protected portions of the sounds (Table 2). Of the extant molluscan species that have not been recorded by Kirby-Smith and Gray (1973), all have been recorded elsewhere in water depths of less than five fathoms (Smith, 1951; Perry and Schwengel, 1955). Several of these species have not been found in water depths that exceed 5 or 6 fathoms.

CONCLUSIONS

Based upon evolutionary trends within the genus Noetia, the shell bed exposed at Fountain, North Carolina is interpreted as early Pleistocene. The remainder of the molluscan fauna and the foraminiferal fauna are consistent with this interpretation.

This isolated exposure of lower Pleistocene marine sediments is unique because it lies farther to the west and at a much higher elevation than the better known marine Pleistocene sections of North Carolina. Among the marine Pleistocene units that lie nearest to Fountain is the James City Formation (early Pleistocene), which crops out along the Neuse River approximately 110 kilometers to the southeast. The James City, equivalent to the Croatan Sand of earlier authors, is

Table 2. Habitats of Molluscan Species Common to the Fountain Shell Bed and to Modern Marine Environments along North Carolina (data from Kirby-Smith and Gray, 1973).

	Sand Flats	Mud Flats	Pilings, Jetties	Sound	Outer Beaches	Open Sea
<u>Anadara ovalis</u>	x					
<u>Anadara transversa</u>	x			x		
<u>Anomia simplex</u>			x	x		
<u>Dinocardium robustum</u>	x					
<u>Donax variabilis</u>					x	
<u>Ensis directus</u>	x			x		
<u>Crassostrea sp.</u>		x	x	x		
<u>Anachis avara</u>		x	x	x		x
<u>Busycon caricum</u>	x					x
<u>Busycon contrarium</u>	x					x
<u>Crepidula fornicata</u>		x	x	x		
<u>Crepidula plana</u>		x		x		
<u>Eupleura caudata</u>		x				
<u>Mitrella lunata</u>	x			x		x
<u>Oliva sayana</u>	x				x	x
<u>Olivella mutica</u>	x		x	x		
<u>Polinices duplicatus</u>	x				x	x
<u>Sinum perspectivum</u>	x					x

exposed just above mean sea level (DuBar, Solliday, and Howard, 1974). The base of the shell bed at Fountain is 18.5 meters above mean sea level.

Although the faunas of the Fountain shell bed and the James City Formation have many species in common, both the mollusks and foraminifera are much more diverse in the latter (DuBar, Solliday, and Howard, 1974; Howard, 1974). More importantly, Noetia variabilis MacNeil has not been recognized in the James City. Both units are early Pleistocene in age, but the faunal similarities are not strong enough to suggest that they are correlative.

The dominant foraminiferal species from the Fountain shell bed are a mixture of cold temperate and warm temperate forms, which indicates either a temperate climate (15 - 25°C) or the juncture of current systems, each with distinct temperature characteristics. The fact that all identified foraminiferal and molluscan species thrive in

shallow water suggests that the water depth was probably less than 10 meters. A restricted bay or estuarine environment is likely because the great majority of taxa and individuals that comprise the foraminiferal fauna thrive in brackish water (Figure 4). The lack of open marine foraminifera and the numerical dominance of Mulinia lateralis Say among mollusk specimens support this interpretation.

The most likely paleogeographic reconstruction for the exposure at Fountain is that of a shallow sea lapping upon the margins of a positive topographic area composed of granite gneiss. Perhaps the granite gneiss surface, which is known to dip away in all directions from the site of quarrying operations, had irregularities of sufficient scale to limit marine deposits to narrow embayments. If so, the outcrop described represents the only such embayment yet exposed. A question remains concerning the elevation of the crystalline rock surface at the time when marine sediments were accumulating.

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ABSTRACT

The stratigraphic sequence of the sand dune field at Wharton Station is representative of the near-coastal part of the Tar-Pamlico Valley in Washington. It is being composed of three distinct sedimentary units: 1) Pleistocene Terraces, 2) Holocene dunes, and 3) Holocene alluvial fans. The dunes are composed of irregularly shaped dunes that have been partially eroded into a series of ridges and a railroad cut. The dunes are well-sorted, with a fine-grained sand that is consistently in the environment. The dunes are composed of sand and siltstone, and are well-sorted.

Dune sand appears to have originated from the Tar-Pamlico River, which is located to the west of the dunes. The dunes are well-sorted, with a fine-grained sand that is consistently in the environment. The dunes are composed of sand and siltstone, and are well-sorted.

INTRODUCTION

The highest dunes in the Tar-Pamlico Valley near Washington, North Carolina, are located at the mouth of the Pamlico River. These dunes are composed of sand and siltstone, and are well-sorted. The dunes are composed of sand and siltstone, and are well-sorted.

- 1) Southeast of Wharton Station, between Main Branch and Mitchell Branch.
- 2) Northwest of junction of Heavy Run and Tar-Pamlico River.

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STRATIGRAPHIC FRAMEWORK OF THE WHARTON STATION

DUNE FIELD, EASTERNMOST BEAUFORT COUNTY,

NORTH CAROLINA

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ABSTRACT

The stratigraphic framework of the dune field at Wharton Station is representative of the northeastern part of the Tar-Pamlico Valley at Washington in being composed of three shallow subsurface units: 1) Pliocene Yorktown Formation, 2) Pleistocene alluvium (herein named Tranters Creek sand), and 3) Holocene eolian sands. The eolian sands comprise irregularly shaped dunes that have been penetrated by numerous borrow pits and a railroad cut. The pits expose well-sorted sands with cross-stratification that dips consistently to the northeast. Northeastern sides of dunes are composite slip faces.

Dune sands appear to have originated when soil A₂ horizon material located in the top of the Tranters Creek sand became mobilized by winds blowing from the southwest across the Tar-Pamlico Valley. Winds were able to disturb and transport the sandy soils during periods of depressed water tables and temporary denudation of vegetation.

INTRODUCTION

The highest elevations in the Tar-Pamlico Valley near Washington, North Carolina, are attained at the summits of irregularly shaped sand dunes. These dunes are scattered throughout the valley and occur at seven localities within the Washington and Blounts Bay 7.5 minute quadrangles:

- 1) Southeast of Wharton Station, between Maple Branch and Mitchell Branch,
- 2) Northwest of confluence of Cherry Run and Tranters Creek,

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- 3) Southeast of Hootentown,
- 4) Northwest of the old River Road School,
- 5) Southeast of intersection of River Road and Asbury Church Road,
- 6) At the Washington Yacht and Country Club on Broad Creek, and
- 7) Northwest of Camp Leach Road bridge over Mallard Creek.

Elevations at the crests of the dunes range from +7 to +10 m; dunes rise to about 4 to 6 m above the surrounding valley plane surface. The morphology of the individual dune bodies is low-amplitude stellate to transverse (McKee, 1966). The general areas in which the dunes occur were mapped by Cobb and others (1919) within the Norfolk sand soil series on the old Beaufort County soils map. Similar valley dunes have been described by Daniels and others (1969) from the Neuse River, Hanna Creek, and Toisnot Swamp Valleys in the middle Coastal Plain of North Carolina.

The purpose of this report is to describe the stratigraphic framework of one of the Tar-Pamlico Valley dune fields and to reconstruct the depositional history of the dunes using the stratigraphic relationships observed in outcrops in borrow pits, a railroad cut, and along Tranters Creek. The Wharton Station dune field (Figures 1, 2), located 5 km northwest of Washington, is typical of the eolian sand bodies found in the valley, and the stratigraphic relationships identified at this location allow a general understanding of shallow subsurface stratigraphy throughout the northeastern side of the Tar-Pamlico Valley--an area that is essentially unknown geologically.

Acknowledgments

The constructive criticisms of an earlier version of this paper by S. D. Heron and R. B. Daniels are gratefully acknowledged. Bertie Cartwright assisted with the field work.

SHALLOW SUBSURFACE STRATIGRAPHIC UNITS OF THE

WHARTON STATION AREA

Three lithostratigraphic units occur in the shallow subsurface of the Wharton Station dune field. These units are, in ascending stratigraphic order, the Pliocene Yorktown Formation, Pleistocene alluvium, and the eolian sands (Figure 3, Table 1)*.

*During my most recent visit to the area (December, 1978), a fourth unit of very limited extent had been penetrated in a new borrow pit just southeast of the railroad trestle over Maple Branch. The unit occurs stratigraphically between the Pleistocene alluvium and the Yorktown

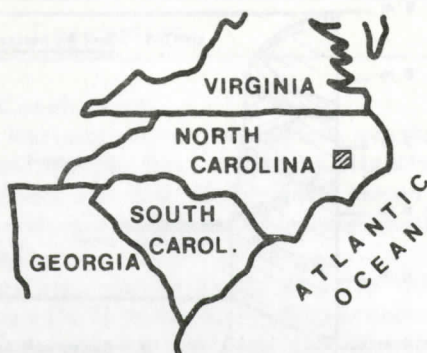


Figure 1. Map showing general location of the Wharton Station dune field, Beaufort County, North Carolina.

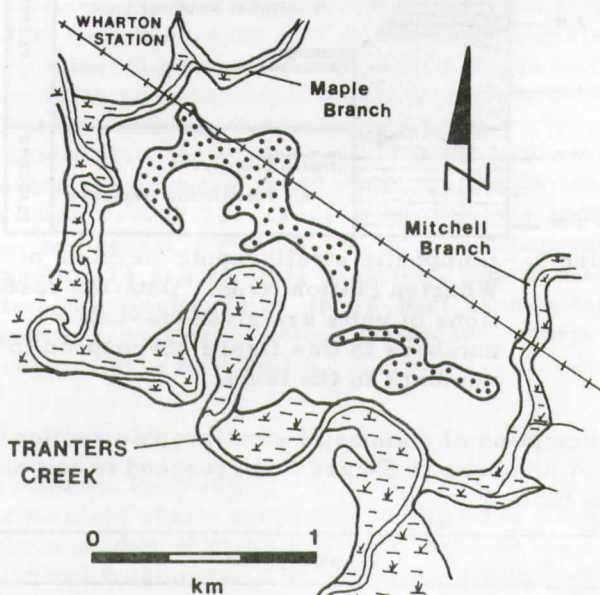


Figure 2. Wharton Station dune field. Dunes are shown as stippled areas.

Formation, and appears to be a discontinuous, erosional outlier of the lithostratigraphic unit that underlies the Talbot geomorphic surface in the Washington area outside of the Tar-Pamlico Valley. The unit is composed of a dark gray, fossiliferous clay with abundant shells of Crassostrea virginica (Gmelin) in living positions. This clay is very similar in appearance to sediments that crop out in the high bluffs near Camp Hardee, Blounts Bay 7.5 minute quadrangle (northern equivalent of Flanner Beach Formation?).

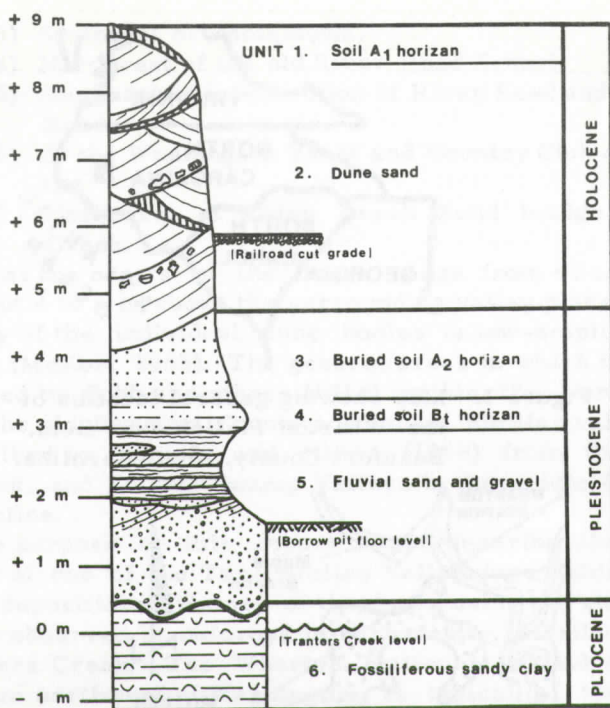


Figure 3. Composite stratigraphic section of the Wharton Station area. Detailed descriptions of units are given in Table 1. Unit numbers in this figure correspond to unit numbers in the table.

Table 1. Description of composite stratigraphic section in Figure 3*. (Unit numbers in Figure 3 correspond to unit numbers used in this table.)

Unit	Description	Thickness
HOLOCENE		
1.	Modern soil A ₁ horizon; fine to medium quartz sand, grayish-brown (10 YR 2/2), with abundant roots; in places intertongues with Unit 2.....	0 - 0.3 m
2.	Dune sand; fine to medium quartz sand, well-sorted, subangular, loose, dark yellowish-orange (10 YR 6/6) to grayish-orange (10 YR 7/4); contains buried soil A ₁ horizon layers similar to Unit 1, aboriginal artifacts, modern trash, lag grains, and traces of opaque heavy mineral grains; trough cross-bedded; top boundary intertongued with Unit 1, bottom boundary with Unit 3 very indistinct.....	0 - 6 m

Unit	Description	Thickness
PLEISTOCENE (TranTERS Creek sand)		
3.	Buried soil A ₂ horizon; fine to medium quartz sand, well-sorted, subangular, loose to slightly cohesive, grayish-orange (10 YR 7/4); top boundary with Unit 2 indistinct, bottom boundary with Unit 4 gradational.....	0 - 0.7 m
4.	Buried soil B _t horizon; clayey sand, slightly indurated, light gray (N 7) with pale reddish-brown (10 R 5/4) and dark yellowish-orange (10 YR 6/6) mottles; top and bottom boundaries gradational...	0.4 m
5.	Fluvial sand and gravel; fine quartz sand to fine quartz pebbles, well-sorted per bed, subangular to subrounded, slightly cohesive, very light gray (N 8) to yellowish-gray (5 Y 8/1); contains opaque heavy mineral grains concentrated in layers up to 5 mm thick and occasional feldspar grains; interbedded horizontally laminated and tabular cross-laminated fine to coarse sand layers with subordinate very coarse sand lenses, grading downward into trough (?) cross-bedded pebbly sand; rare horizontal burrows 1.2 cm in diameter (<u>Planolites</u> ?) and vertical burrows 2 mm in diameter (<u>Sabellarifex</u> ?) in upper part of unit; top boundary gradational, bottom boundary sharp, disconformable with Unit 6.....	~2.5 m

Disconformity

PLIOCENE (Yorktown Formation)

- | | | |
|----|--|--------|
| 6. | Marine clay; shelly sandy clay, slightly indurated, various shades of green and brown; contains many whole and fragmental bivalve and gastropod shells (especially <u>Mercenaria</u> , <u>Astarte</u> , <u>Cyclocardia</u> , <u>Glycymeris</u> , and <u>Turritella</u>); poorly exposed with top boundary sharp, disconformable and base not exposed..... | +1.5 m |
|----|--|--------|

*Section compiled from exposure in Seaboard Coast Line Railroad cut, borrow pits in the southern flanks of dunes, and from exposures in low, eroding banks along TranTERS Creek. Surface exposures were supplemented by hand-auger borings to depths of about 2 m.

Yorktown Formation

The Yorktown Formation crops out just above the water line in the banks of Tranters Creek in the southern part of the study area. Richards (1950) recorded exposures of Yorktown beds along Runyons Creek just east of Washington and listed Yorktown fossils collected from spoil that was dredged from the Pamlico River at Washington. Fossils of Yorktown age from Chocowinity have been described by Gardner (1943, 1948), and Dawson (1958) and Schnitker (1970) described Yorktown fossils from the banks of the Tar River at Grimesland, Pitt County. Mansfield (1943) placed the Yorktown beds at Chocowinity and Grimesland within his "Group D." At Washington, I have collected fossils from exposures of the Yorktown derived from excavations that penetrated the formation at about mean sea level.

In the Washington and Tranters Creek areas, the Yorktown is a green, shelly sandy clay of marine origin. Diagenetic cap-rock, described by Bailey (1975) from the top of the Yorktown in river bank exposures in the vicinity of Murfreesboro, North Carolina, is not present in this study area. Common megascopic fossils from the Yorktown in the Washington area are: Mercenaria mercenaria (Linné), Astarte spp., Cyclocardia granulata (Say), Glycymeris subovata (Say), Ostrea spp., Argopecten eboreus (Conrad), Plicatula marginata Say, Turritella spp., Dentalium spp., and Balanus concavus Bronn. Because most of the Yorktown localities in this area are either spoil piles associated with temporary exposures or low, eroding creek banks, no physical or biogenic structures have been observed.

A disconformity separates the Yorktown from superjacent Pleistocene alluvium. The top of the Yorktown is an aquiclude in the Wharton Station area, and polluted ground-water originating at the Beaufort County sanitary landfill within the dune field is concentrated at and conducted above this impermeable boundary zone to the local creek valleys.

Fluvial Sands and Gravels (Tranters Creek Sand)

Fine to coarse pebbly sands of fluvial origin overlies disconformably the Yorktown beds. The fluvial deposits crop out at the base of vertical exposures in the many borrow pits that dot the landscape near Wharton Station and in the tops of eroding banks along Tranters Creek. The sands and gravels are previously undescribed, but appear to be the up-valley equivalent of a late Pleistocene nearshore marine unit, located immediately to the east of the Suffolk Scarp, that has been variously named Pamlico Formation, Pamlico morphostratigraphic unit, Cherry Point unit, Neuse Formation, and Core Creek sand (Stephenson, 1912; Daniels and others, 1972; DuBar and others, 1974; Fallaw and Wheeler, 1969; Mixon and Pilkey, 1976).

The fluvial sands and gravels that occur stratigraphically between the Yorktown Formation and the eolian sands within the Tar-

Pamlico Valley, and crop out in the lower parts of borrow pits throughout the valley around Washington, are here named informally the Tranters Creek sand for Tranters Creek, Beaufort County, North Carolina (Figure 3, Table 1). The basal 1.5 m of exposure in the south wall of a borrow pit located 600 m west of the intersection of county roads 1440 and 1427 is designated the type section.

The Tranters Creek sand is a light gray, slightly cohesive, fine sand to fine pebble gravel in unweathered exposures. Horizontally laminated sands alternating with tabular cross-laminated sands in the upper half of the unit succeed trough (?) cross-bedded pebbly sands in the lower half. Rare vertical and horizontal burrows resembling the ichnogenera Sabellarifex and Planolites were observed in the upper beds within the Tranters Creek sand. The overall coarse texture of sediments, vertical sequence of horizontally laminated and tabular cross-laminated sands above trough (?) cross-bedded pebbly sands, and the lack of fine-grained overbank deposits point to a fluvial channel and bar depositional environment for this unit (Selley, 1976; Harms and others, 1975; Reineck and Singh, 1973; Visser, 1972).

The Tranters Creek sand is capped by a well defined soil zone that is buried beneath and grades imperceptibly into superjacent dune sands. The soil zone consists of a lower, slightly indurated, clayey sand B_t horizon and an upper, slightly cohesive, fine to medium sand A_2 horizon (Figure 3, Table 1). These soil layers can be traced into adjacent valley areas not covered by dunes. Northeast of the dunes the A_2 layer is replaced by a soil A_p horizon in plowed fields. The soil zone at the top of the Tranters Creek sand is 0.4 to 1.1 m thick; total thickness of unaltered subjacent fluvial beds is about 2.5 m.

Dune Sands

Two irregularly shaped eolian sand dunes occur between Maple Branch and Mitchell Branch. Well-sorted, loose, yellowish-orange, fine to medium sands comprising the dune bodies crop out in the Seaboard Coast Line Railroad cut and in the upper parts of borrow pit exposures. The long axes of dunes are oriented northwest-southeast. Northeastern sides are characterized by steep slopes (composite slip faces); southwestern slopes are comparatively gentle (windward slopes).

Borrow pit walls cut into the northwestern dune at various orientations, and expose low (5° to 15°) and high (20° to 30°) angle trough cross-bedding as well as massive bedding (Figure 4). All cross-stratification observed dips to the northeast away from the creek valley.

Intercalated with the dune sands are occasional layers of soil A_1 horizon material that were buried by the mobile dune sands. A discontinuous modern soil A_1 horizon covers parts of the dunes and attains a maximum thickness of 0.3 m. The dune sands are up to 6 m thick in the Wharton Station dune field. This is the thickest accumulation of eolian sand in the Tar-Pamlico Valley. The relationship of the

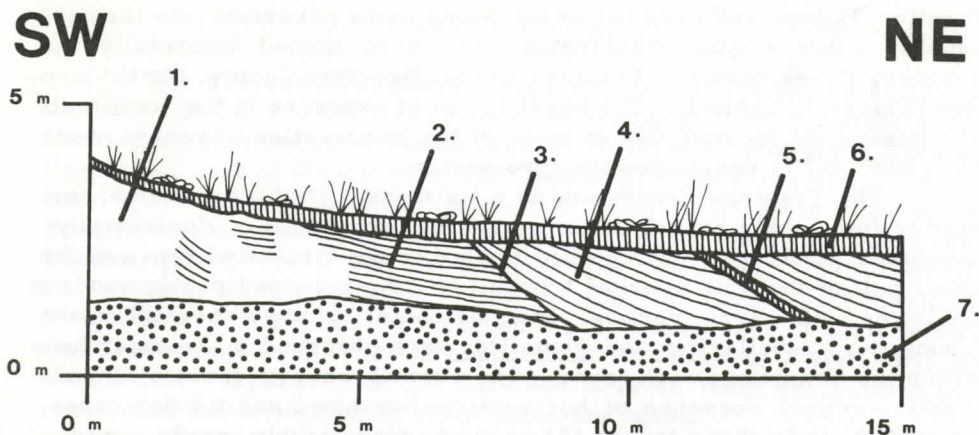


Figure 4. Sketch of eolian sand cropping out in northwest face of borrow pit located 600 m west of intersection of county roads 1440 and 1427. The features illustrated are: 1) massive sand, 2) low angle cross-bedded sand, 3) truncation surface, 4) high angle cross-bedded sand, 5) buried soil A₁ horizon, 6) modern A₁ horizon with grasses and prickly pears rooted in the top, and 7) pit wall talus.

dune sands to other stratigraphic units in the area is shown in Figure 5.

DEPOSITIONAL HISTORY OF THE WHARTON STATION DUNES

Origin

A minimum of three environmental conditions must coexist before valley dunes can be generated: 1) a source of loose sand, 2) absence of vegetative cover at source area, and 3) winds with sufficient energy and duration to move source sands into the areas of deposition (Cooper, 1958; Daniels and others, 1969; Bigarella, 1972).

Three possible source areas are available in the Tar-Pamlico Valley. Modern sand bars along the Tar River and Tranters Creek could have been deflated and their sand transported to the northeast by winds blowing across the valley. However, the vast majority of recent deposits along the river and creeks are wet, fine-grained, organic-rich sediments that are not susceptible to eolian transport. The Tranters Creek sand is also a possible source, but the outcrop area of this stratigraphic unit is limited to a very narrow, discontinuous band along the sides of Tranters Creek. The most likely source of sand is the widespread soil A₂ horizon occurring at the top of the Tranters Creek sand. The lowering of water tables during even short-lived arid

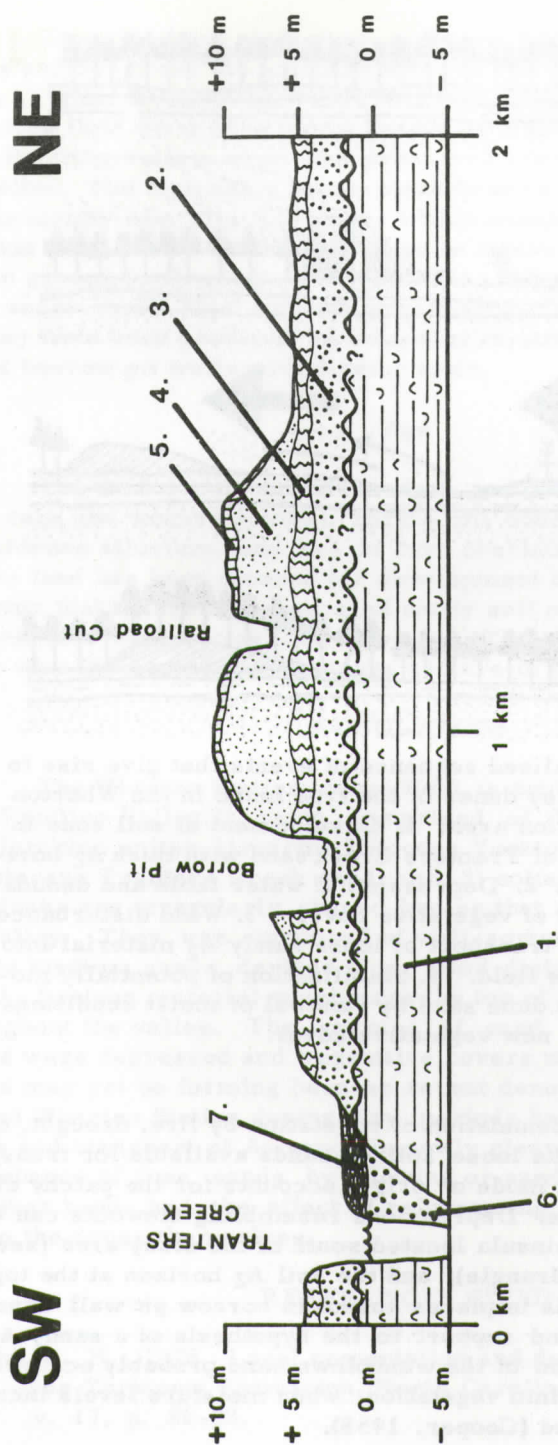


Figure 5. Schematic cross-section through the Wharton Station dune field. Stratigraphic units include: 1) Pliocene Yorktown Formation, 2) Pleistocene Tranter's Creek sand, 3) soil zone in top of Tranter's Creek sand, 4) Holocene eolian dune sand, 5) soil zone in top of eolian sand, 6) Holocene alluvial sand, and 7) Holocene floodplain deposits along Tranter's Creek.

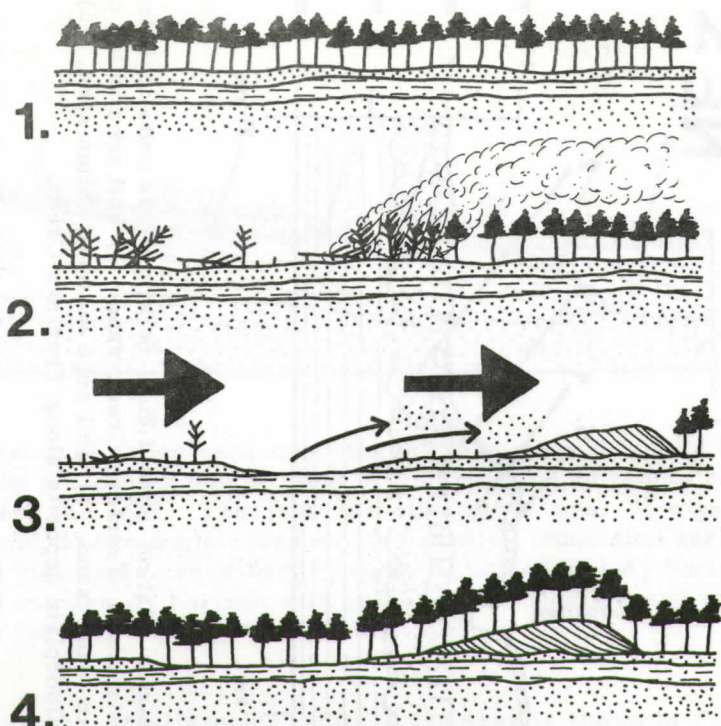


Figure 6. Idealized sequence of events that give rise to valley dunes of the type found in the Wharton Station area: 1. Development of soil zone in top of Tranters Creek sand with thick A_2 horizon. 2. Depression of water table and denudation of vegetative cover. 3. Wind disturbance and transport of loose sandy A_2 material into dune field. 4. Stabilization of potentially mobile dune sand by renewal of moist conditions and new vegetative cover.

periods and the local denudation of vegetation by fire, drought, or plowing would together make loose soil A_2 sands available for transport by wind (Figure 6). This mode of origin accounts for the patchy distribution of the valley dunes. Depressions resembling blowouts can be seen on the River View Peninsula located south of the study area (see Washington 7.5 minute quadrangle), and the soil A_2 horizon at the top of the Tranters Creek sand is in places absent in borrow pit wall exposures. These observations lend support to the hypothesis of a sandy A_2 horizon source. Deposition of the wind blown sand probably occurred when sand was transported into vegetation, when moisture levels increased, or when winds subsided (Cooper, 1958).

Cross-bedding observed in borrow pit walls dips consistently to the northeast and the northeastern sides of dunes are composite slip faces (Figure 4, 5). The winds that moved sand into the Wharton Station dune field must have blown generally from the southwest across the Tar-Pamlico Valley when the preserved cross-stratified sands were deposited. The high angle cross-stratification resulted from deposition in dominantly dry, slip face areas within dunes; low angle cross-stratification may reflect either deposition in moist dune areas or deposition within grassy baffles (Steidtmann, 1974; Goldsmith, 1973). Massive dune sands could also indicate precipitation in and around vegetation, or may have been produced by smearing of structures during the scraping of borrow pit walls with digging tools.

Age

The dune sands contain modern and aboriginal artifacts (e. g. , beer cans and worked stones), bury a soil zone in the top of subjacent Pleistocene alluvium, and are in turn overlain by a modern soil zone. Where land has been cleared for development or recently plowed in the Wharton Station area, the exposed sandy soil material is disturbed and reworked by wind during dry periods. The dune sands, then, are no older than the buried soil horizons and are in part modern.

CONCLUSIONS

The Wharton Station dune field is typical of dune fields in the Tar-Pamlico Valley in being comprised of three shallow subsurface stratigraphic units: 1) marine Pliocene Yorktown Formation, 2) fluvial Pleistocene Tranter's Creek sand, and 3) eolian sands of Holocene age. The dunes are irregularly shaped bodies that are scattered throughout the valley. They are composed of well-sorted, trough cross-bedded, fine to medium sands derived from wind disturbance and transport of soil A₂ horizon material which caps the top of the Tranter's Creek sand throughout the valley. The sources of sand originated when water tables were depressed and vegetative covers were temporarily absent. Dunes may yet be forming because recent denudation of vegetative cover around Wharton Station during dry periods has promoted wind disturbance and transport of A₂ sands in newly cleared or plowed areas. The disturbance of dune sands by plowing or sand pit excavation has, on the other hand, had the effect of rejuvenating potentially mobile sands within the dunes themselves.

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