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SOUTHEASTERN GEOLOGY

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LATE-PLEISTOCENE PÉATS FROM LONG BEACH,

NORTH CAROLINA

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ABSTRACT

Two thin peat horizons are exposed in a cut along the Intracoastal Waterway near Long Beach, Brunswick County, North Carolina. The peats accumulated in shallow depressions (deflation hollows?) in a Pleistocene barrier complex. The lower peat is 20 cm thick, 2.8 m above m. s. l., and has a radiocarbon age of 36,000 years B. P. The upper peat is 40 cm thick, 3.8 m above m. s. l., and has a radiocarbon age of 35,800 years B. P. The peats are underlain and overlain by dune sands and a thin layer of dune sand separates them. The top of the section lies 7.2 m above m. s. l. Pollen analysis of the peats indicates a localized cypress-gum-shrub swamp with an interesting mixture of northern and southern species. Of the northern species, spruce is quite abundant and Sanguisorba canadensis, Arceuthobium pusillum and Schizaea pusilla occur. The southern species include cypress, Magnolia, Cyrilla and Diodia virginiana. The proximity of dune sand habitats is suggested by pollen of Polygonella, caryophylls, chenopods and Artemisia. The depressions were periodically inundated by dune movement.

Previously this barrier complex was assumed to be interglacial. However, the mixed pollen flora and the radiocarbon dates suggest a correlation with the mid-Wisconsin Port Talbot interstadial. It is tempting to suggest that the Long Beach barrier complex might have formed as a result of a marine transgression similar to that described recently from Sapelo Island, Georgia; but in the absence of critical geomorphological work, alternative explanations are possible.

INTRODUCTION

Concepts concerning the Pleistocene geology of the outer Coastal Plain of the Carolinas have undergone many revisions in the last few years. In the past, the various surface formations of the area were interpreted as terrace plains and scarps, each related to a separate high stand of the sea (Cooke, 1930; Flint, 1940). More recent work has demonstrated that the situation is decidedly more complex and that many different land forms and facies can be recognized (Oaks and Coch, 1963; Johnson and Du Bar, 1964; Thom, 1965 [and personal communication]). Deposits related to times of marine transgression include barrier sands, back-barrier silts and clays, near shore sediments and flood plain deposits. In many cases the relationships of the various sediment complexes have been determined and relative ages assigned. However, in most cases it is impossible to determine an absolute age and to ascertain the nature of the environmental conditions existing when the sediments accumulated.

Similarly, concepts concerning the nature of late-Pleistocene vegetational and environmental changes in the area have been modified extensively. Studies of pollen and other microfossils contained in organic sediments have led to a more precise reconstruction of full-glacial, late-glacial and post-glacial environmental changes in the Carolina Coastal Plain (Frey, 1951, 1953, 1955; Whitehead, 1963, 1964, 1965a, 1965b, 1967). However, comprehensive data are available for a relatively limited area and little is known concerning the nature of environmental changes prior to the Wisconsin maximum (ca. 20,000 yrs. B.P.).

Consequently, the occurrence of peat horizons in an exposure along the Intracoastal Waterway near Long Beach, Brunswick County, North Carolina is of extreme interest. The peats are associated with barrier sands assumed to date from an interglacial high stand of the sea, presumably the Sangamon. A study of the peats was undertaken in an attempt to determine their age and to ascertain the nature of the vegetation and environments existing when the sands and organic horizons were forming.

Acknowledgments

The writers wish to express their thanks to Arthur Cooper and Felton Nease who discovered the site, assisted with field work, and provided valuable discussion. We are especially grateful to Bruce G. Thom who visited the site at a later date and gave his impressions of the stratigraphy and the geomorphology of the region. Support has been provided by NSF Grants G-17277, GB-6059, and GB-6400.

GEOLOGY OF THE LONG BEACH AREA

The surficial sediments of the Long Beach area (Figure 1) have not been intensively studied, but the available evidence (Doering, 1960; Johnson and Du Bar, 1964; White, 1966; Thom, 1965 [and personal communication]) indicates that the surface formations range in age from

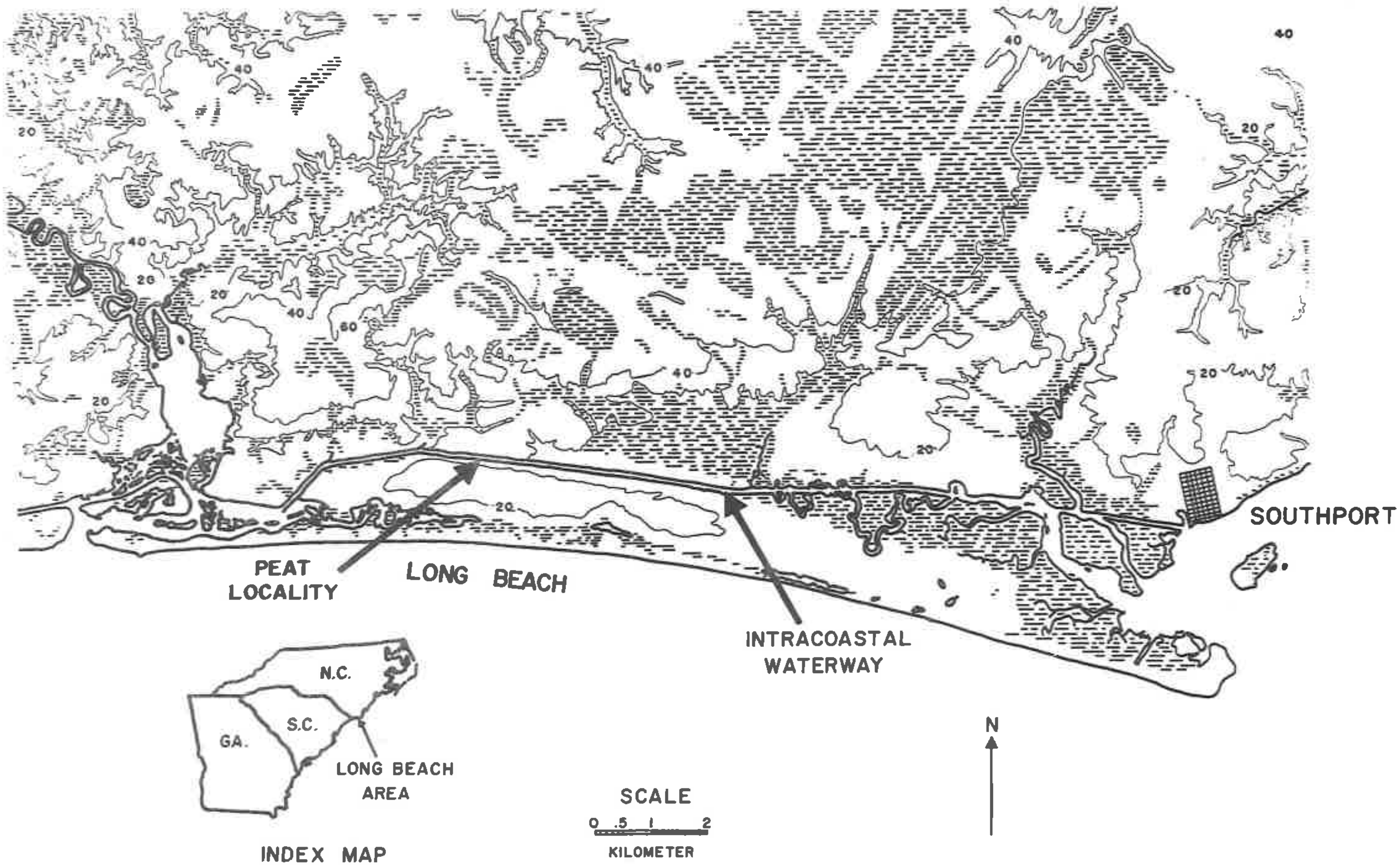

Figure 1. Map of the Long Beach area.

the Recent (along the coast) to mid-Pleistocene several kilometers inland. The landforms, involving both barrier and back-barrier facies, appear to relate to various high-stands of the sea.

A recent barrier exists as a narrow strip (100-400 meters wide) along the present coast. Surface elevations are low, rarely exceeding 3-5 meters above mean sea level. Directly behind this is a narrow back-barrier swale. Salt and brackish marshes are developed within this low area.

Contiguous with the recent barrier is the lowest of the Pleistocene barrier complexes, here referred to as the Long Beach barrier. This is a linear sand complex parallelling the present coast. It extends some 10 kilometers from Lockwood's Folly Inlet to the saltmarshes near Southport. The barrier is generally about one kilometer wide and has surface elevations between five and eight meters above mean sea level. The inner (northern margin) of the barrier is delimited by the Intracoastal Waterway, which follows a topographic low (probably the Long Beach back barrier) behind the barrier. The Waterway has cut through the barrier sediments in several places.

North of the Waterway is an extensive barrier surface with well developed linear beach ridges and swales and many clearly defined Carolina Bays. This barrier complex extends inland for many kilometers and attains surface elevations approaching 20 meters.

Although the relative ages of the various barrier and back barrier surfaces can be established readily enough, it is difficult to fix absolute ages. The Long Beach barrier appears to represent a northeasterly extension of the "Myrtle Beach bar" described by Johnson and Du Bar (1964) (Myrtle Beach barrier of Thom, 1965 [and personal communication]). A "Pamlico" (=Sangamon?) age has been suggested for the Myrtle Beach complex. The higher barrier has been given a similar age assignment by Johnson and Du Bar (1964), but the work of Horry County, South Carolina (Thom, 1965) suggests that the surface is pre-Sangamon.

The exposure from which the samples were collected is located on the south bank of the Intracoastal Waterway in the vicinity of Long Beach, Brunswick County, North Carolina (Figures 1 and 2). The coordinates of the site are 33° 55' 36" North Latitude, 78° 9' 30" West Longitude.

The section collected is described in Table 1. The sediments exposed in the cut are those of the Long Beach barrier. The sands of the complex are dune sands, some cross-bedded, some massive. Humate horizons are well developed at several levels in the profile, suggesting significant changes in the water table during deposition of the section. Two peats occur as thin bands extending approximately 200 meters along the face of the exposure. In places the peats are separated by a meter of sand, in other places they are virtually contiguous. The peats themselves contain fine sand lenses.

The peats were apparently deposited in shallow depressions

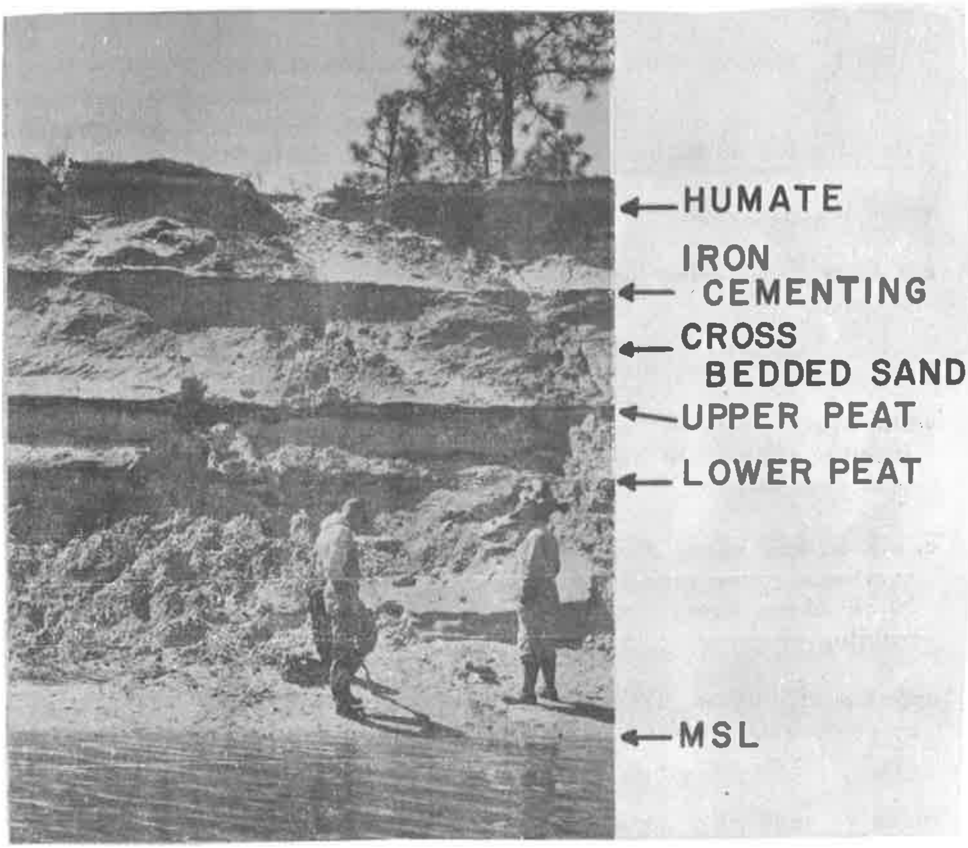

Figure 2. Photograph of the section collected.

(deflation hollows?) on the surface of the Long Beach barrier. The presence of humates suggests that water table was sufficiently high to permit formation of peat in the depressions. Burial of the peats was brought about by a renewed migration of dune sand.

VEGETATION OF THE LONG BEACH AREA

The vegetation of the Long Beach area, like that of most of the Coastal Plain, is complex. The patterns reflect the variety of surficial sediments that are present and hence the geomorphic history of the region.

The coarsest sands, found on the rims of the Carolina Bays and the "fossil" beach ridges of the barriers, are generally characterized by an open forest in which long-leaf pine (Pinus australis) and various scrub oaks are the most frequent trees. There is generally a sparse

Table 1. Stratigraphic Section - Long Beach Site.

Description of Sediment	Thickness (cm.)	Height above msl (cm.)
white leached sand	6	714-720
blackish clayey sand (humate horizon)	14	700-714
white leached sand, massive	10	690-700
white sand, massive, with iron-staining and cementing. Strongly cemented at base.	70	620-690
cross-bedded sand, dips towards northeast (dune sand). Humate 20 cm above base, cuts cross-bedding.	200	420-620
upper peat. black, irregular, clayey peat, sand lenses. C14 age = 35,800 yrs.	40	380-420
massive sand with humate banding	80	300-380
lower peat. black, irregular clayey peat with sand lenses. C14 age = 36,000 yrs.	20	280-300
brown sand, massive, extensive humate development. Some cross-bedded zones.	280	0-280

ground cover of xerophytic herbs and small shrubs (Wells, 1928; Wells and Shunk, 1931; Whitehead and Tan, 1968).

On somewhat finer sediment types (silty sands of the barriers, sandy clays and silts of the back-barrier flats) loblolly pine (Pinus taeda) grows with occasional long-leafs and a variety of oaks. On favorable sites one can find sweet gum, (Liquidambar), pond pine (P. serotina) and various shrubs more typical of pocosins (Magnolia, Gordonia, Persea, Cyrilla, Clethra, and many ericaceous species).

The lows between the linear beach ridges generally possess an interesting combination of plants of the sandy sites and species more typical of moist soils. The latter include many of the shrubs alluded to above and cypress (Taxodium), black gum (Nyssa sylvatica) and cedar (Chamaecyparis).

Within the Carolina Bays, where the soil is moist and peaty, typical "bay" or pocosin vegetation occurs. The vegetation of such sites is dominated by closely spaced shrubs, including the "bays" (Gordonia, Magnolia and Persea), many ericaceous species, Cyrilla, Clethra, Myrica, Ilex and Itea. A number of tree species occur within pocosins as well. These include red maple (Acer rubrum), black gum, cypress, sweet gum, cedar, pond pine and loblolly pine.

The proximity of the present coast is indicated by the abundance of live oak (Quercus virginiana), yaupon (Ilex vomitoria), juniper and wax myrtle (Myrica cerifera). These often form an extremely distinctive assemblage near the active beach dunes. In the Long Beach area this vegetation can be seen best in the low between the Long Beach barrier and the recent barrier. The distribution of these species seems to be controlled as much by vagaries of the extreme maritime environment (e.g., wind and salt spray) as by edaphic factors (Wells, 1928; Wells and Shunk, 1938; Ooosting and Billings, 1942).

The vegetation of the active dunes along the recent barrier is also quite distinctive. Sea oats (Uniola paniculata) is especially abundant, with occasional sea elders (Iva imbricata). Interdune lows and old deflation hollows often have a characteristic shrub vegetation, with Myrica, Ilex, "bay" shrubs, etc.

Salt marshes are well developed on the fine-grained back barrier sediments of the region. Along the river courses the salt marshes grade imperceptibly into fresh water marshes and eventually into rich bottomland forests (with cypress, gum, cottonwood, sycamore, etc.).

METHODS

Samples for pollen analysis and radiocarbon dating were collected from the section described previously. A clean face was prepared by digging back approximately 1.5 meters from the exposed surface. Pollen samples were collected at close intervals in the two peat horizons and bulk samples for C14 dating were cut out using carefully cleaned implements. The pollen samples were stored in sealed one dram vials and the C14 samples were wrapped first in aluminum foil, then in mylar.

Pollen samples were prepared by boiling in 10 percent KOH; demineralizing first in cold 10 percent HCl, then in boiling concentrated HF; acetolyzing for one minute; staining in basic fushsin; and mounting in silicone oil (12,500 centistokes). All counts were made with a Wild M 11 microscope at a magnification of 400 diameters. Critical identifications were carried out using oil immersion (bright field) and the phase contrast optics of a Wild M 20 microscope. A minimum of three slides were counted for each level, and a minimum of 2,000 grains tabulated. Percentages were calculated based on a pollen sum that included tree, shrub and herb pollen. Grains of pteridophytes and aquatics were excluded from the sum.

RADIOCARBON DATES

Material was collected from both peat horizons for radiocarbon dating. It was necessary to dig back between one and two meters from the face of the exposure to eliminate the possibility of root contamination. The samples were submitted to Isotopes, Inc. for dating and the results were as follows:

	- 3000
Upper peat (I-1746)	35, 800 + 4200
	- 2600
Lower peat (I-745)	36, 000 + 3700

Both of the dates are finite, but approaching the limits of the method, hence must be interpreted cautiously. If the dates can be accepted, then a mid-Wisconsin rather than a Sangamon correlation is indicated. However, there are several potential sources of contamination. First of all, the exposed surface of the peat was permeated with modern root material, making it necessary to dig back more than one meter from the face. Although the samples collected did not appear to contain any root material, one can not be absolutely certain that the samples were in fact root free. Secondly, the development of humates throughout the profile suggests a second potential source of younger material--downward percolation of organic molecules from the surface. The writers deem this unlikely, as most of the humate horizons appear to have formed as the sands and peats of the Long Beach complex were accumulating. Thus organic materials from the surface and sands lower down would be more or less contemporaneous. In addition, the modern humate, located just beneath the present surface, would probably serve as an effective barrier preventing further downward movement of organic complexes.

THE POLLEN DIAGRAM

The microfossil data are presented in Figure 3 and Tables 2-4. The pollen spectra of the upper peat are characterized by a predominance of tree types (particularly "Cupressaceae", *Nyssa*, *Quercus*, *Pinus* and *Picea*) with herbs and shrubs less frequent. Composites, grasses, sedges and chenopods are the most abundant herb types, and *Ilex*, *Sambucus*, *Viburnum* and *Rhus* the most common shrub. Spores of *Isoetes* are especially frequent in the uppermost level. Less abundant tree types which are of importance include *Tsuga*, *Abies*, *Juglans nigra*, *J. cinerea*, *Fagus*, *Acer saccharum*, *Magnolia* and *Taxodium*.

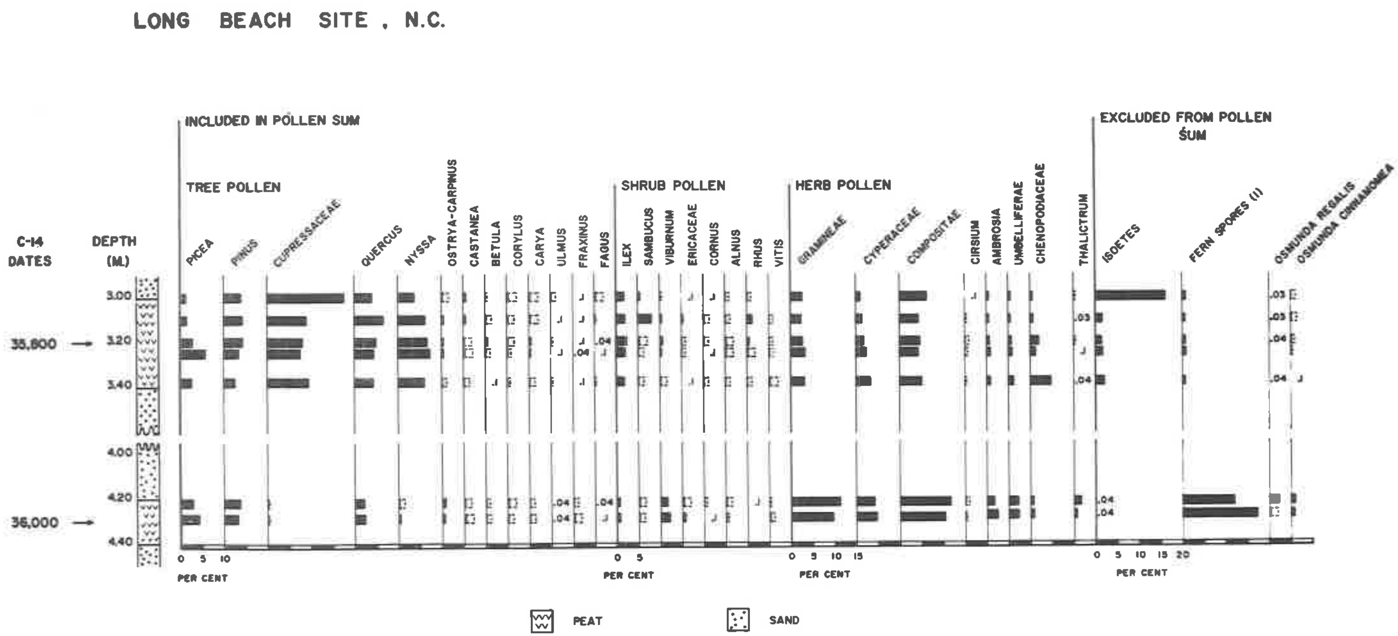

Figure 3. Pollen diagram from the Long Beach section.

Table 2. Tree and Shrub Pollen Types Not Included in Diagram.

Depth (cm.)	Tilia	Acer rubrum	Acer saccharum	Liquidambar	Tsuga	Magnolia	Taxodium	Juglans nigra
420	0.1	.03	.03	0.2	0.1	0.1	0.2	0.1
410	0.1	---	.03	---	.03	0.1	0.1	---
400	0.1	---	0.1	.04	.04	.04	0.1	0.1
396	.04	---	---	0.1	---	0.1	0.1	---
382	---	---	---	0.1	0.1	.04	0.1	---
298	---	---	0.1	0.1	.04	0.1	---	---
291	---	---	0.1	.04	.04	.04	---	---

Depth (cm.)	Juglans cinerea	Abies	Myrica	Cephalanthus	Cyrilla	Parthenocissus	Lonicera	Arceuthobium
420	0.1	--	.03	0.1	--	--	--	--
410	--	.03	--	--	.03	.03	--	.03
400	--	.04	--	.04	--	--	--	--
396	--	0.1	--	--	--	.04	--	--
382	--	0.1	--	--	--	--	.04	--
298	.04	.04	.04	0.3	--	0.1	.04	.04
291	--	--	--	0.1	--	0.1	0.1	--

Table 3. Herb Types Not Included in Pollen Diagram.

Depth (cm.)	Caryophyllaceae	Cruciferae	Polygonella	Plantago	Impatiens	Artemisia	Ranunculus	Liguliflorae
420	0.1	.03	.03	.03	0.1	0.1	0.3	.03
410	0.1	--	--	.03	--	.03	0.3	.03
400	0.1	--	--	--	.04	.04	0.3	.04
396	0.2	--	--	--	--	.04	0.2	.04
382	0.1	--	--	--	--	--	0.2	0.1
298	0.1	--	0.1	--	--	.04	0.1	0.4
291	.04	--	0.1	--	--	0.1	0.1	0.3

Depth (cm.)	Rumex	Labiatae	Potentilla	Liliaceae	Scrophulariaceae	Leguminosae	Urtica	Gaura	Hypericum
420	--	--	--	--	--	--	--	--	--
410	--	.03	.03	0.2	.03	0.2	.03	.03	--
400	--	--	--	--	--	0.1	--	--	.04
396	.04	.04	--	0.1	--	0.1	--	--	--
382	--	--	--	.04	--	--	--	--	--
298	--	.04	--	0.1	--	--	--	.04	--
291	--	.04	--	0.2	--	--	--	0.1	--

Depth (cm.)	Sanguisorba Canadensis	Primula	Diodia Virginiana	Rosaceae	Saxifraga	Allium	Gentiana
420	--	--	--	--	--	--	--
410	--	--	--	--	--	--	--
400	.04	.04	--	--	--	--	--
396	.04	--	--	--	--	--	--
382	.04	--	0.1	--	--	--	--
298	--	--	.04	0.3	0.1	.04	--
291	--	--	--	0.2	.04	--	.04

Among the herbs and shrubs, grains of Arceuthobium, Sanguisorba canadensis, caryophylls, Polygonella, Plantago, Artemisia, Impatiens and Diodia virginiana also occur.

The pollen spectra from the lower peat differ in that herbaceous

Table 4. Miscellaneous Microfossils Not Included in Pollen Diagram.

Depth (cm.)	Fern Spores(3)	Dinoflagellates	Myriophyllum	Sagittaria	Proserpinaca	Lycopodium	Nuphar	Polypodium	Polygonum Persicaria
420	1.0	1.0	--	--	--	--	--	--	0.3
410	0.1	--	+	+	.03	--	0.3	--	0.3
400	0.2	--	--	--	--	.04	0.4	.04	0.3
396	0.3	--	--	--	--	.04	0.4	--	0.4
382	0.4	.04	--	--	--	.04	0.4	--	0.4
298	1.4	--	--	--	--	0.6	0.4	0.1	0.4
291	0.4	--	--	--	--	0.2	--	0.1	0.1

pollen and fern spores are far more frequent than in the upper peat horizon. Also, "Cupressaceae" and Nyssa grains are less common. The most abundant grains are less common. The most abundant grains types are fern spores, composites, grasses and sedges. Pine, spruce and oak are common, as well as Viburnum, Ilex and Ericaceae. Other significant but less frequent types include Acer saccharum, Fagus, Tsuga, Abies, J. cinerea, Magnolia, Arceuthobium, caryphylls, Polygonella, Artemisia and Diodia virginiana.

ENVIRONMENTAL RECONSTRUCTIONS

As indicated, there are appreciable differences between the two peat horizons. However, it is unlikely that this connotes profound environmental differences. It is more reasonable to assume that both peat horizons accumulated under essentially the same climatic conditions, and that the dissimilarity in pollen spectra reflect instead variation in the vegetation growing on the surface of the peat or proximate to the depression. It is well established that plants growing in the immediate vicinity exert an influence on the character of the pollen rain incorporated into peat (Janssen, 1966).

The pollen spectra of the lower peat abound in herbaceous types, while the upper peat spectra are dominated by tree types, especially cypress and gum. Grains of various swamp shrubs are common in both horizons. Grains of aquatics are more common in the upper peat. This suggests that while the lower organic horizon was accumulating, grasses, sedges, composites and ferns were abundant on the surface of the peat (or at least, directly over the point where the sample was taken). While the upper peat was developing, cypress and gum were apparently growing in and around the depression. The relative abundance of aquatics in the upper peat suggests that the water table was higher or the hydroperiod was longer during that time.

The pollen spectra contain an interesting admixture of "northern" and "southern" pollen types. Of the northern types, spruce is the most common (attaining a maximum of over 6 percent) and grains of the dwarf mistletoe (Arceuthobium), burnet (Sanguisorba canadensis), fir (Abies) and hemlock (Tsuga) occur occasionally. A few grains of white walnut (Juglans cinerea) were also encountered, and this species does not occur on the Coastal Plain at present. Spores of the curly grass fern, Schizaea pusilla, also occur, but they were not encountered during the actual counts and their stratigraphic position in the section is uncertain, since they were found in bulk peat samples sent to the senior author previously by Felton Neese. The "southern" elements include "Cupressaceae" (probably mostly Taxodium), Magnolia, Cyrilla and Diodia virginiana.

There are also indicators of the peat-forming environment itself and the uncolonized sand of the adjacent dune habitats. In the former category are such entities as cypress, gum, ericaceous shrubs, Cyrilla, and Diodia virginiana. In the latter group are chenopods, Artemisia, Polygonella, and caryophylls. It is thus apparent that dunes were in close proximity to the peat.

The pollen spectra from the peats are quite different from modern pollen spectra in the region (Whitehead and Tan, 1968), suggesting the possibility that the vegetation and climate were unlike the present. Northern elements are not represented in modern sediments in nearby Bladen County (occasional hemlock grains do occur, but these could be derived from trees cultivated locally), pine is more abundant, and grains of herbs and shrubs are less common. Caution is necessary, however, because some of the differences could reflect the fact that the Long Beach spectra are from a localized peat, though the modern spectra alluded to are from large lakes.

It is interesting to compare the Long Beach peat spectra with samples from both interglacial and interstadial horizons in the Southeast. Interglacial spectra are available from two Horry clay sections, one just south of Long Beach, in Horry County, South Carolina (Frey, 1952), the other further north along the Neuse River near New Bern, North Carolina (Whitehead and Davis, in press). Apparent interstadial spectra are present in the sediments of the Bay lakes in Bladen County (Frey, 1951, 1953, 1955; Whitehead, 1963, 1964, 1965a, 1965b, 1967).

The Long Beach spectra differ from the interglacial ones in having considerably less pine and a much stronger representation of "northern" types. The interglacial spectra are quite similar to modern samples from the Bay lakes. There are interesting similarities between the Long Beach spectra and those from the "middle organic horizon" from the Bay lakes. Representative of many tree, shrub and herb types is similar. Present evidence suggests that the middle organic horizon dates from a mid-Wisconsin interstadial (Whitehead, 1967).

The generalization that emerges from these comparisons is that the vegetation contemporaneous with the deposition of the Long Beach peats was similar to that existing in Bladen County during a mid-Wisconsin interstadial. The logical extension of this is that the peats might be mid-Wisconsin in age rather than interglacial.

A precise vegetational and climatic reconstruction is difficult, especially since there are no modern spectra that correspond well with those from the peats. It would appear that the vegetation was "unnatural" by modern standards; especially, that it contained a distinctly "azonal" mixture of northern and southern species. One might speculate that environmental conditions were similar to those existing in areas where the various taxa come closest to coexisting at the present time. The general area where most of the southern and northern species overlap is southern New Jersey. Cypress, Diodia, and Magnolia are distributed north to New Jersey (Cyrilla only as far as southeastern Virginia), while Schizaea, Arceuthobium, and spruce extend south into New Jersey. A climatic comparison of southeastern North Carolina and southern New Jersey suggests that while the peat horizons were accumulating the annual temperature was approximately 9°C cooler than at present.

DISCUSSION

The data from the Long Beach section have interesting implications. As mentioned previously, it was assumed that the barrier, like all other Pleistocene barriers in the Southeast, dated from an interglacial high stand of the sea. However, the radiocarbon dates are mid-Wisconsin and the pollen spectra are more similar to interstadial than to interglacial horizons. Thus, two lines of evidence suggest the possibility that the barrier complex dates from a mid-Wisconsin interstadial. This, in turn, indicates that marine transgression which formed the barrier might have been mid-Wisconsin.

In this context it is interesting that there are several other lines of evidence pointing to a significant mid-Wisconsin interstadial. Investigations within the area of the Erie lobe have suggested an appreciable withdrawal of ice lasting from 48,000 to 24,000 years B.P. (Dreimanis et al., 1966). This interval has been called the Port Talbot Interstadial. Paleotemperature studies of cores from the Carribbean seem to indicate a warming of surface waters during the same time span (Emiliani, 1966). Pollen analytical studies of sediments from the Bay lakes in Bladen County indicate lower lake levels and a greater abundance of temperate species prior to the classical Wisconsin advances (Frey, 1953; Whitehead, 1964, 1967). Lastly, there are indications of a mid-Wisconsin transgression from Georgia, Florida, and the Gulf of Mexico (Hoyt et al., 1967; Schnable and Goodell, 1967; Curray, 1961).

It is tempting to present the Long Beach data as further evidence of an interstadial and a marine transgression. However, it is premature to make such a suggestion. An interglacial age can not be ruled out completely, as there is a finite possibility that the radiocarbon dates are in error. Furthermore, considering the paucity of pollen-analytical data from interglacial horizons, one can not state unequivocally that spectra of the Long Beach type are characteristic of a mid-Wisconsin interstadial and not of the Sangamon interglacial. Lastly, detailed geomorphological studies are needed to fix the relationships of the various barrier complexes in the area.

CONCLUSIONS

The peats exposed in the Long Beach section formed in shallow depressions, probably deflation hollows, in a Pleistocene barrier complex. Water table was sufficiently close to the surface to permit peat formation. Open dunes were in close proximity to the peat surface, as indicated by the occurrence of pollen from xerophytes. The peats supported a localized cypress-gum-shrub vegetation which varied considerably through time. The local vegetation was azonal in the sense that a striking admixture of northern and southern species occurred. The climate may have been similar to that presently existing in southern New Jersey, an area where the boreal and austral species come closest to overlapping at present. The peats were occasionally inundated by renewed cycles of dune migration.

Both the radiocarbon dates and pollen spectra suggest that the barrier complex is mid-Wisconsin rather than Sangamon in age. A Port Talbot Interstadial correlation seems indicated. These data correlate with other information on sea level from Georgia, Florida and the Gulf of Mexico and indicate the possibility of a high stand of the sea during Port Talbot time. However, caution is indicated, as critical geomorphological studies have not been carried out and the dates and pollen data can not be considered unequivocal.

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BARITE NODULES IN THE ATHENS SHALE IN NORTHEASTERN TENNESSEE AND SOUTHWEST VIRGINIA

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ABSTRACT

Barite nodules have been identified in carbonaceous beds of the Athens Shale (Middle Ordovician) at seven localities in northeastern Tennessee and southwest Virginia. The nodules are spheroidal to ellipsoidal in shape and the size varies from less than 0.5 inch to more than a foot in diameter. Typically, the nodules contain barite crystals up to 1.0 mm. in size disseminated in a black shale matrix together with variable amounts of pyrite.

The nodules are comparable in chemical composition, mineralogy, form, and size with those of recent origin occurring on the floor of the Pacific Ocean. According to Revelle and Emery (1951), occurrences of barite concretions in the Pacific Ocean appear to be coincident with prominent faults and the concretions formed during diagenesis by the interaction of ascending barium chloride solutions with sulfate-bearing interstitial sea water in the sediment. The same mechanism is believed to be applicable for the nodules in the Athens Shale. Ascending solutions traversing the Shady Dolomite (Lower Cambrian) and the Knox Dolomite (Upper Cambrian and Lower Ordovician) may have deposited the observed concentrations of epigenetic barite in these formations simultaneous with the diagenetic formation of the barite nodules in the euxinic muds of the Athens Shale in Middle Ordovician time. The widespread distribution of the nodules is interpreted to indicate regional hydrothermal activity.

INTRODUCTION

Barite-bearing nodules have been identified at seven localities in northeastern Tennessee and southwest Virginia over a distance of 75 miles. All known occurrences are in the basal beds of the Athens Shale. This paper describes the field occurrence, chemical composition, and petrography of these nodules and attempts to explain their origin. In addition, the possible relationship between barite nodules in the Athens Shale and Mississippi Valley-type barite deposits in East Tennessee is evaluated.

The authors are grateful to C. W. Blount, J. H. Davis, R. C. Hale, L. D. Harris, V. J. Hurst, R. W. Johnson, Jr., R. A. Laurence, S. W. Maher, and Helmuth Wedow, Jr. for their critical review of the manuscript. This paper is published with the permission of the Tennessee Valley Authority.

GENERAL GEOLOGY

The area under consideration is in the Appalachian Valley and Ridge province. The rock units which comprise the area are: the Conasauga Group (Middle and Upper Cambrian); the Knox Group (Upper Cambrian and Lower Ordovician); and the Chickamauga Group (Middle and Upper Ordovician). A major unconformity occurs at the top of the Knox Group (Figure 1).

The dominant structural elements are northeast-trending folds and thrust faults. The major thrust fault in the area is the Pulaski fault system. Both folds and thrust faults are locally offset by later east-west cross faults.

The Chickamauga Group is the dominant unit west of the Pulaski fault and is extensively exposed in the Bays Mountain synclinorium. Locally, Knox dolomite occurs in broad anticlines. In contrast, the area southeast of the Pulaski fault is characterized by extensive exposures of dolomites of the Knox Group, and Middle Ordovician shales are confined to synclinal belts.

The Athens Shale generally overlies the Lenoir Limestone which is the basal formation of the Chickamauga Group. In the study area the Athens Shale is a dark gray to black, carbonaceous, pyritic shale. Graptolites are locally abundant. In general, it is less calcareous and more siliceous than the shale exposed at the type locality near Athens, Tennessee, which is 75 miles southwest of the study area. Nodular beds of black, dense limestone locally interbedded with the basal beds of the Athens Shale were named the Whitesburg Limestone by Ulrich (1930). Following the usage by Brokaw et al., (1966) the basa limestone beds are included in the Athens Shale in this paper. According to Decker (1952), the underlying Lenoir Limestone is absent at some localities near Greeneville, Tennessee, and the Athens Shale rests directly on the Mascot Dolomite (Knox Group). The Athens Shale grades upward into a calcareous, blue-gray shale which is referred to as the Sevier Shale in the study area.

The Athens Shale is generally considered to be a typical example of a euxinic, marine shale, forming under anaerobic conditions

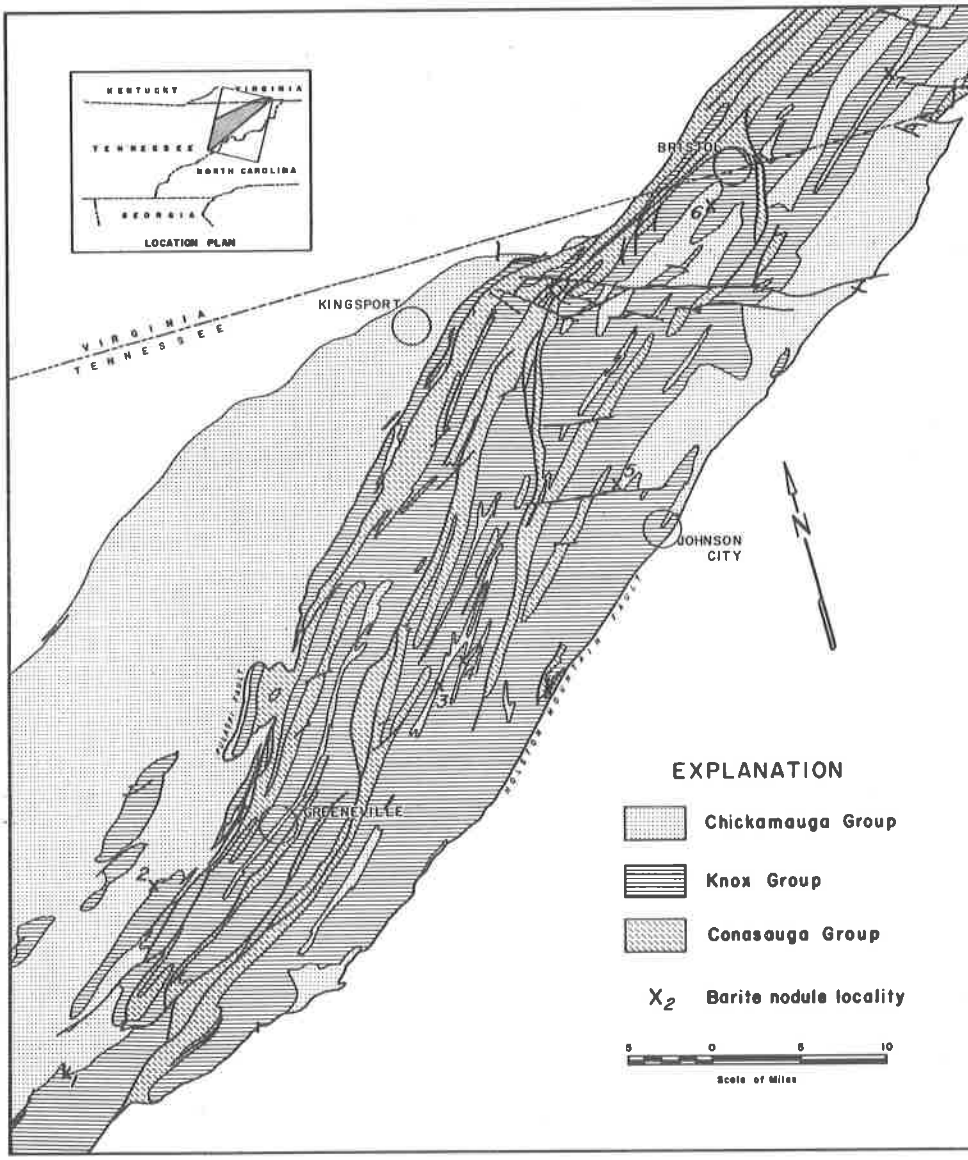

Figure 1. Map showing general geology and locations of barite nodules in Northeast Tennessee and Southwest Virginia. Geology taken from Hardeman (1966).

in fairly deep water. Most of the organisms identified in these rocks are pelagic forms.

Barite nodules occur in the lower 50 feet of the Athens Shale. The locations of known occurrences are shown in Figure 1 and precise

Table 1. Coordinate Locations of Barite Nodules.

Locality Number	Quadrangle	State Coordinate Location	
1	Parrotsville, Tenn.	613,900N	2,863,350E
2	Mosheim, Tenn.	652,900N	2,903,900E
3	Telford, Tenn.	690,400N	2,996,500E
4	Leesburg, Tenn.	718,400N	3,017,825E
5	Jonesboro, Tenn.	736,700N	3,092,100E
6	Bristol, Tenn.-Va.	817,775N	3,116,550E
7	Abingdon, Va.	129,100N	974,050E

locations by state coordinates are given in Table 1. Nodules appear to be most abundant at localities 2, 3, and 6. Non-baritiferous nodules of pyrite, phosphate, and calcite also occur in this zone.

DESCRIPTION OF BARITE NODULES

Megascopic Description

Although baritiferous nodules are probably abundant in the Athens Shale, they are not easily distinguished from other types of concretions on cursory examination. For this reason, they have not been identified by most geologists who have studied this formation.

The nodules are gray to black, spheroidal to ellipsoidal masses (Figure 2). A high density is not sensibly apparent unless the barite concentration exceeds approximately 20 percent (by weight). The observed size-range varies from less than 0.5 inch to more than a foot in diameter. The surfaces of some nodules show faint spiny projections of tabular barite crystals which stand in relief above the black shale matrix. Barite crystals are easily discerned in slabs trimmed with a diamond saw but are difficult to recognize on a broken surface. Variable amounts of pyrite are contained in the nodules.

Microscopic Description

The nodules are composed of barite and pyrite in a black shale matrix. The textural variations exhibited by the nodules are a function of the barite content. In nodules containing less than about 50 percent barite, euhedral to subhedral, randomly oriented crystals of barite averaging about 1.0 mm. show a fairly uniform distribution through the concretion (Figure 3). The central portions of the crystals show optical continuity under crossed nicols, whereas a thin outer rim is comprised of a finely crystalline mosaic with a semi-random orientation of the

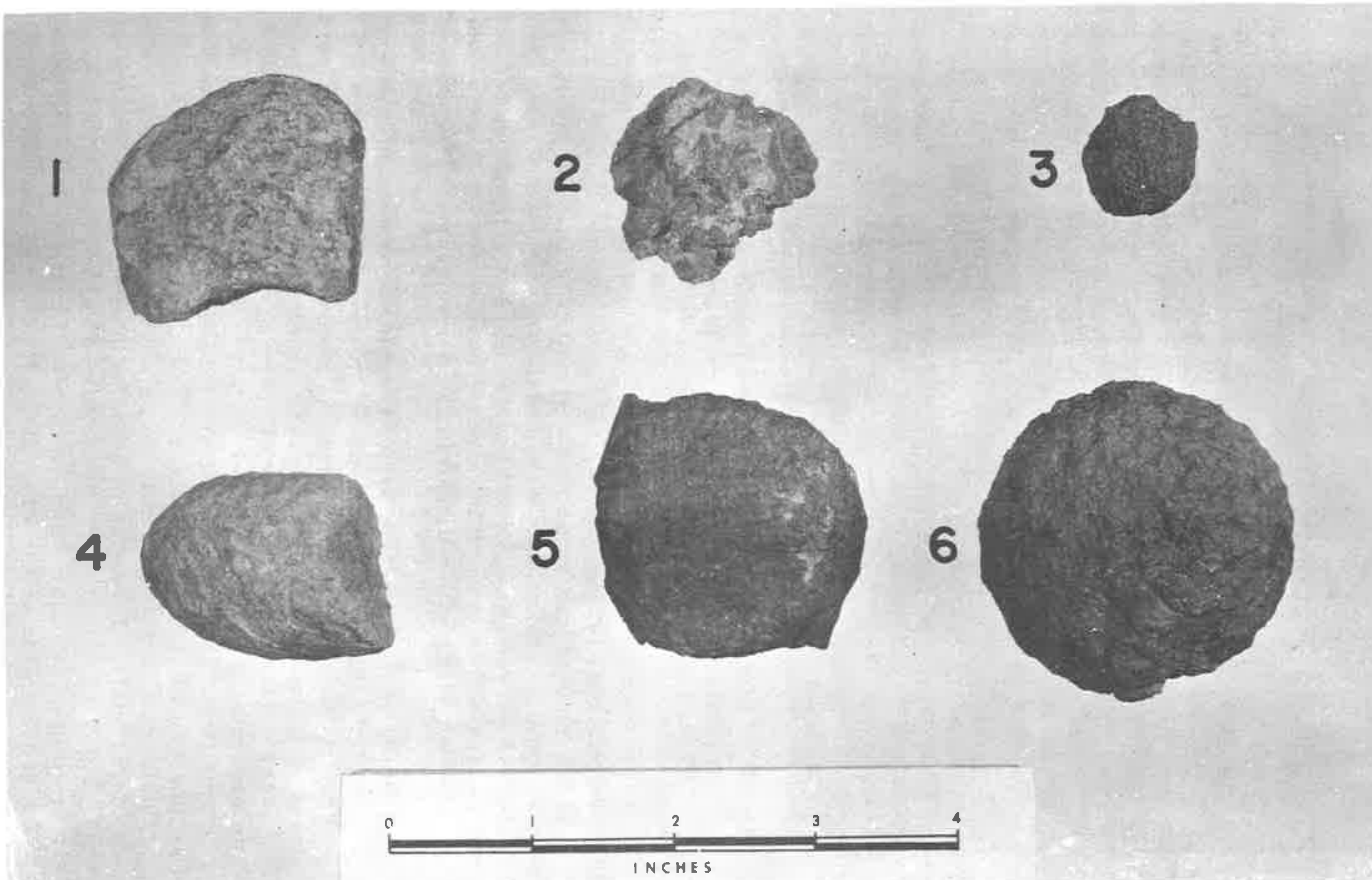

Figure 2. Photograph of barite nodules found at localities 1, 2, 3, 4, 5, and 6 shown in Figure 1.

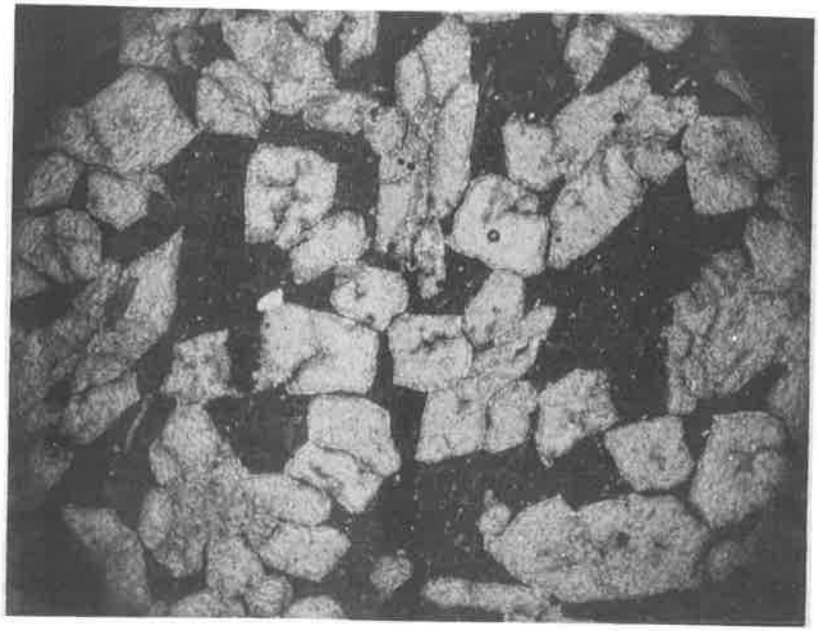

Figure 3. Photomicrograph of barite nodule showing barite crystals (light) disseminated in black shaly matrix. Plane light.

individual crystallites (Figure 4).

Some nodules are composed entirely of barite and pyrite with no shaly matrix. Texturally, these nodules are quite different from those described above. The central portion of each concretion consists of a coarse-crystalline mosaic of anhedral barite crystals grading outward into radial laths which extend to the outer margin of the concretion.

Nodules of intermediate barite concentration contain clustered aggregates of lath-shaped crystals and single crystals of barite.

The interstitial shaly material is comprised of quartz, sericite(?), and organic matter with lesser amounts of calcite. In some nodules, dense concentrations of sericite(?) and quartz are included in the barite crystals, whereas in other nodules, crystals are relatively free of impurities. Laminations in the shale matrix are commonly flexed around apices of barite crystals.

Pyrite is characteristically more abundant in the nodules than in the enclosing shale. It occurs in both the interstitial black shale and the barite grains as irregularly disseminated cubic crystals. In some concretions, a thin circular band of pyrite crystals, oriented in the plane of the bedding, forms the central portion of the nodules. Cubic-shaped barite overgrowths, conforming to the outline of the enclosed pyrite crystals, were observed in thin-sections of some of the nodules.

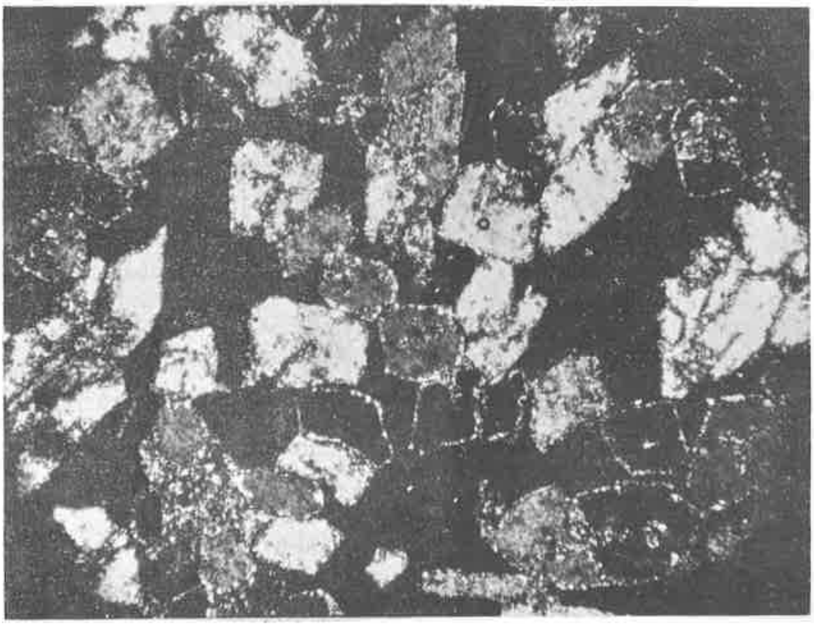

Figure 4. Photomicrograph of same area shown in Figure 3 under crossed nicols. Rims of barite crystals are characterized by finely crystalline barite.

The birefringence and extinction positions of these overgrowths contrast with the surrounding barite.

CHEMICAL COMPOSITION OF THE BARITE NODULES

Chemical analyses of nodules from localities 2 and 6 are presented in Table 2 together with published analyses for geologically recent barite concretions collected from the sea floor. Some of the nodules at locality 2 are compositionally similar to those collected from the Pacific Ocean. However, the silica content of some of the nodules in the Athens Shale is quite high (locality 6). According to Revelle and Emery (1951) barite concretions near the California coast contain over one percent strontium oxide. Localities 2 and 6 contain only 0.13 and 0.05 percent SrO respectively.

Three sets of samples were collected at localities 3, 6, and 7. Each set includes one or more nodules and a sample of the enclosing shale. Spectrographic analyses of these samples are presented in Table 3. Barium and iron are significantly enriched in the nodules relative to the enclosing shale reflecting the greater abundance of barite and pyrite. The concentrations of aluminum, calcium, copper, potassium, magnesium, sodium, titanium, and vanadium are significantly

Table 2. Chemical Analyses of Barite Concretions.

	Concretions in the Athens Shale[5]		Concretions from the floor of the Pacific Ocean	
	Locality #2	Locality #6	California[1]	Kai Islands[2]
SiO_2	9.1	46.3	10.81	6.42
Al_2O_3	1.9	3.4	4,39	2.32
BaO	48.6	27.0	40.91	53.85
Fe_2O_3	11.0	3.5	3.67	1.67
SrO	0.13	0.05	+1[4]	---
PbO	n.d.	n.d.	n.d.	---
SO_3	25.2	13.5	21.33[3]	28.56

1. Revelle and Emery (1951). Smooth rounded barite nodules.
2. Bøggild (1916).
3. SO3 computed from percent BaO.
4. Strontium (Sr) determination based on spectrographic analysis.
5. Constituents analyzed by wet chemical methods except for strontium and lead which were analyzed spectrographically.

Table 3. Spectrographic Analyses of Barite Nodules (column B) and the enclosing shale (column A). Values are in percent.

	Locality No. 3		Locality No. 6		Locality No. 7	
	A	B	A	B	A	B
Al	17	3	15	5	16	4
Ba	0.3	+10	0.3	+10	0.3	+10
Ca	15	7	7	5	10	3.5
Cu	0.007	-0.005	0.015	0.005	0.02	0.01
Fe	8	15	5	3	5	+20
K	3.5	0.3	2.5	1.5	1.5	0.6
Mg	4	0.6	3.5	1.2	3.5	1.2
Mn	0.08	0.04	0.08	0.04	0.04	-0.005
Na	2.5	0.3	2	0.6	2	0.8
Ni	0.015	0.015	0.015	0.01	0.015	0.02
Pb	0.012	-0.01	-0.01	-0.01	-0.01	-0.01
Ti	1.2	0.15	0.6	0.2	0.5	0.15
V	0.03	0.005	0.04	0.012	0.035	-0.005

lower in the nodules. In general, the decrease appears to be roughly proportional to the amount of interstitial shale present and inversely proportional to the combined pyrite-barite content. Hence, the composition of the interstitial black shale matrix of the nodules is probably comparable to that of the enclosing shale.

The concentration of barium in the shale is 0.3 percent in each of the samples cited in Table 3. The average concentration of barium in 17 samples collected from the Athens Shale is 0.24 percent (Carpenter, in preparation). Precambrian black shales in the Ocoee Series of eastern Tennessee and western North Carolina average 0.19 percent barium. According to Turekian and Wedepohl (1961) the average barium content for all types of shale is 0.058 percent. Pelagic sediment from the eastern Pacific Ocean is reported to average 0.39 percent barium (Goldberg and Arrhenius, 1958). Mud enclosing barite concretions off the California coast contains less than 0.1 percent barium (Revelle and Emery, 1951). The barium content of the Athens Shale is, therefore, greater than that characteristic of shales in general, but is within the range of normal pelagic sediment and certain black shales. The occurrence of barite concretions in shales is judged to be largely independent of the "background" concentration. Barite-bearing concretions occur in some sediments which contain less barium than the Athens Shale, yet are not known to occur in sediments containing more barium than this formation.

SOME GEOCHEMICAL CONSIDERATIONS BEARING ON THE ORIGIN OF BARITE CONCRETIONS

Because of the limited solubility of barium sulfate, high concentrations of barite in sedimentary rocks can develop only under a unique set of conditions in the sedimentary environment. The solubility of barium sulfate in water at standard conditions is 2,460 ug/liter (Hodgman, 1952). Chow and Goldberg (1960) have estimated that the solubility of barium sulfate in sea water is only 52 ug/liter as a result of the high concentration of sulfate ions. At depths of 1,000 meters, the solubility may reach 70 ug/liter because of the effect of pressure on solubility. Analyses of water samples collected at different depths in the ocean indicate that sea water is slightly under-saturated in barium sulfate (Chow and Goldberg, 1960). There is no evidence that the barium content of sea water throughout the Paleozoic was substantially different from its present value. Shales, for example, do not show time dependent variations in the concentration of barium.

Notwithstanding the small concentration of dissolved barium sulfate in sea water, Puchelt (1967) advocates that barium sulfate may precipitate directly during evaporation. Theoretically, barite should precipitate when the volume of sea water is reduced between 1/3 and

1/5 of the original volume corresponding to the last stages of carbonate deposition and the initial stages of calcium sulfate precipitation. Under extremely uniform conditions of evaporation, several feet of relatively pure barite may form. According to Puchelt (1967), an example of this type of barite deposit is a barite-rich bed 0.75 meters thick lying between the Haupt Dolomite (below) and the Basal Anhydrite (above) in the Zechstein Series of Germany. Barite of this origin characteristically contains several percent strontium.

The evaporation mechanism may be applicable to strontium-bearing barite interlayered with evaporitic sediment as Puchelt (1967) suggests. However, it does not easily explain barite concretions in pelagic sediment which formed beneath the sedimentary interface during diagenesis. A concretion containing 500 grams of barite represents the entire amount of barium sulfate contained in 10,000,000 liters of sea water (at 50 ug/liter). The implied amount of water circulation in the bottom sediments required to provide the requisite quantity of barium would seem to preclude sea water, at normal salinities, as a source of barium, assuming a circulation mechanism.

Diffusion of barium from sea water into the bottom muds might also serve as a means of barium enrichment. A diffusion mechanism may account for high concentrations of manganese and phosphorus in concretions, and may also account for abnormal concentrations of barium in oceanic sediment. However, unlike phosphate and manganese nodules, known barite nodules are restricted to areas overlying shear zones in the ocean floor (Revelle and Emery, 1951). Unless future studies show different distribution trends for these concretions, this diffusion mechanism has little applicability in explaining their origin.

Another possible source of barium contained in concretions is organic matter which concentrates barium in skeletal material or fecal matter in amounts commonly exceeding 0.1 percent but generally less than 1 or 2 percent. Bowen (1956) has reported that organisms including brown, red, and green algae, chiton shells, cephalopod bone, and corals contain 450 to 4,400 times the barium concentration of sea water. Arrhenius (1959) reports concentrations of several percent barite in equatorial pelagic sediment below areas of high organic productivity. Higher concentrations were identified in fecal matter. Xenophyophora, a rhizopod widely distributed in tropical waters, is known to contain barite granules in the skeletal material (Samoilov, 1917).

For organically deposited concentrations of barium to serve as a source for barite in concretions, chemical migration of barium through interstitial water in sediment is required. Owing to the high concentration of $SO_4^{=}$, sea water cannot dissolve or transport appreciable quantities of barium.

Barium chloride has much greater solubility than barium sulfate, and some hot springs are known to contain appreciable quantities of dissolved barium chloride. Seidl (1958) reports that 105 mg.

(105,000 ug) of barium sulfate dissolves in 1 liter of water containing 100 grams of NaCl. Barite crustations have formed around brine springs in Germany (Latterman, 1888), Great Britain (Dunn, 1877), and Colorado (Headden, 1905). Studies of the constituents of fluid inclusions in Mississippi Valley-type deposits by Newhouse (1932) and Roedder (1963) indicate that the ore solutions contain appreciable quantities of salts (up to 20 percent), sodium chloride being the most abundant.

Revelle and Emery (1951) conclude that barite concretions on the ocean floor off the coast of California were deposited by the reaction between barium chloride in juvenile water and the interstitial sea water of the sediments. These nodules, as well as those discovered in oceanic sediment near Ceylon and the Kai Islands are interpreted to be located on prominent faults of considerable magnitude. These faults are presumed to be channelways for hypogene waters containing dissolved barium chloride (Revelle and Emery, 1951).

ORIGIN OF BARITE NODULES IN THE ATHENS SHALE

The indicated paragenetic sequence for the nodules is black mud-pyrite-barite. Following deposition on the bottom muds, concentrations of pyrite developed locally in the sediment. Later, barite was deposited at many of these sites and the interstitial muds were largely displaced and compressed by crystal growth. In addition, chemical replacement of the mud by barite is evidenced by inclusions of clay minerals in the barite crystals. In the process of crystal growth, barite formed overgrowths on earlier pyrite cubes.

The present sites of barite nodules in the shale are interpreted to indicate localized conditions of supersaturation of barium sulfate. The temporal and spatial relationships between pyrite and barite suggest that the same conditions prompted nucleation and growth of each mineral. The degree and types of biochemical activity in the bottom muds may have determined sites of supersaturation.

Barite nodules in the Athens Shale show striking similarities to those described by Revelle and Emery (1951) which were dredged from the Pacific Ocean off the California coast. The size and shapes of the concretions are similar and both contain a clay matrix. Furthermore, the chemical composition of the nodules are comparable. The present writers believe that the interpretation of Revelle and Emery (1951) is applicable for the nodules in the Athens Shale and conclude that barium was introduced into the bottom sediments, probably as barium chloride, in highly saline, hypogene solutions. Barite was deposited by reaction between these solutions and sulfate-bearing interstitial sea water at sites of supersaturation. The widespread distribution of the nodules is interpreted to represent regional hydrothermal activity.

BARITE NODULES AND MISSISSIPPI VALLEY-TYPE DEPOSITS

IN EAST TENNESSEE

Barite and zinc deposits in the Appalachian Valley and Ridge province are considered to be representative of the Mississippi Valley-type deposits whose general characteristics have been summarized by Ohle (1959). In the study area barite and zinc mineralization has been described in the Fall Branch district (Secrist, 1924) and in the Mosheim and Johnson anticlines (Brokaw et al., 1966). Mineralization consists of veins and breccia orebodies in the Kingsport Formation and the Mascot Dolomite (Knox Group). Most geologists in the area subscribe to the views of Kendall (1960) and Hoagland, Hill and Fulweiler (1965) who advocate that mineralization occurred while the beds were essentially flat-lying prior to late Paleozoic folding and thrust faulting. The primary evidence is that mineralized breccias show little, if any, relation to these later structures, and that stratification in the matrix of the mineralized breccia conforms to that of adjacent beds.

The time of ore emplacement is generally considered to be during the time interval of the unconformity at the top of the Mascot Dolomite. However, the widespread hydrothermal activity deduced from the occurrence of barite concretions suggests that mineralization may have occurred as late as Athens time.

Continued study of the Athens Shale and equivalent units to the west is recommended to determine the pattern of hydrothermal activity manifested by the barite concretions. If a defineable pattern can be determined, exploration target areas in the underlying Kingsport Formation and Mascot Dolomite may be defined.

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ROCKBRIDGEITE IN IRON PHOSPHATE NODULES FROM POLK COUNTY, FLORIDA

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ABSTRACT

Rockbridgeite has been found in nodules from the phosphatic sediments of the Pliocene Bone Valley Formation of central Florida. The rockbridgeite is formed as a result of weathering of the original phosphatic sediments and it is associated with other secondary iron phosphate minerals including vivianite, beraunite, and cacoxenite.

INTRODUCTION

The rare mineral rockbridgeite (Frondel, 1949), $Fe^{+2}Fe^{+3}_4(PO4)_3(OH)_5$, has been identified as a major constituent of secondary iron phosphate nodules contained in the phosphatic sediments of the Pliocene Bone Valley Formation of central Florida. Blanchard and Denahan (in press) have reported the occurrence of nodules, from the same general location, which are composed of quartz grains with beraunite; with beraunite and very small amounts of vivianite; and with cacoxenite, beraunite, and goethite. In view of the discovery of rockbridgeite in similar material, the original nodules have been reexamined to see if they also contain rockbridgeite, but none was found. A new group of iron phosphate nodules has been acquired from the waste rock at a phosphate mine southwest of Brewster, Polk County, Florida.

These nodules contain rockbridgeite associated with hydrated and basic hydrated iron phosphate minerals, including vivianite, beraunite, and cacoxenite, and with goethite, detrital quartz, and traces of kaolinite, crandallite, wavellite, and a rhombohedral carbonate. As far as I am aware the presence of rockbridgeite has not previously been recognized in the rocks of Florida.

Acknowledgment

I am grateful to Mr. John Waldrop (Florida State Museum) for supplying me with the iron phosphate nodules.

DESCRIPTION

Rockbridgeite occurs in irregularly shaped nodules which are variously colored brown, reddish brown and yellow-brown (limonite), black (rockbridgeite with goethite), yellow (cacoxenite), dark greenish blue (beraunite), and deep blue (vivianite), and are yellowish brown, green, blue-green and white on the weathered surface. Microcrystalline rockbridgeite occurs in intimate mixtures with microcrystalline goethite and it is probable that this material has been considered as simply a mixture of iron oxide minerals. The rockbridgeite-goethite mixture is dark reddish to dark gray to black (dark olive when powdered), has a hardness between 4 and 5, and has a bulk specific gravity between 3.0 and 3.3. On the weathered surface of the nodules rockbridgeite occurs as a soft greenish material relatively free from admixed goethite.

In thin section the species rockbridgeite normally shows extreme pleochroism in green and yellow-brown colors (e.g., rockbridgeite from Rockbridge County, Va.). The material from Florida is also pleochroic in yellow-brown to green colors, but in standard thin sections the pleochroism is not obvious (except at the very thin edges of the section) because of the very small crystal size and because of aggregate effects. In most parts of a thin section the rockbridgeite simply shows yellow-brown or greenish absorption colors. Under crossed polars the interference colors are yellowish to reddish brown and the material does not go to extinction; the appearance under crossed polars is due to the combined effects of high birefringence, strong dispersion, strong absorption and aggregate structure.

IDENTIFICATION

Identification of rockbridgeite was accomplished by X-ray analysis of hand-picked portions of the iron phosphate nodules. All of the samples contained enough impurities (chiefly goethite, quartz and vivianite, or beraunite) to show up in the X-ray diffractometer patterns, however by discounting the lines of the impurities it was possible to obtain good values for d-spacings of the rockbridgeite and these correspond very closely to those obtained from rockbridgeite from Rockbridge County, Virginia (the type locality for the species) and to those recorded by Frondel (1949), on A.S.T.M. card #8-159, and by Vorma (1961). Optical properties and differential thermal analysis were of little use in identification of rockbridgeite.

Representative diffractometer patterns are given in Figure 1. These were made with Ni-filtered Cu radiation (40 kv., 15 ma.), pulse height selection to reduce background, a scanning speed of 0.4° 2 θ per minute, and a 0.2° detector slit. Close correspondence of d-spacings and intensities between the diffractometer patterns of Florida

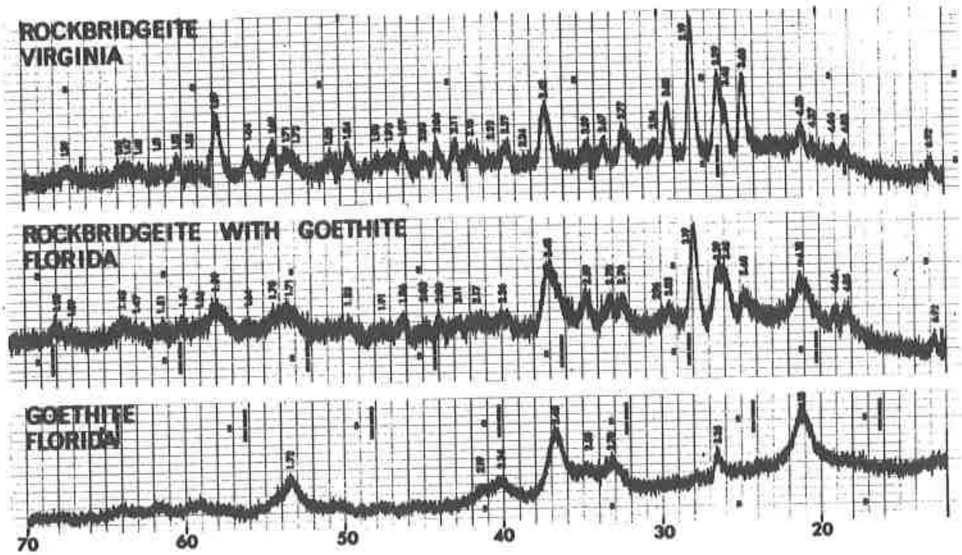

Figure 1. X-ray diffractometer patterns for rockbridgeite and goethite.

rockbridgeite (Figure 1 center) and rockbridgeite from Rockbridge County, Virginia (Figure 1 top), the type locality, was not obtained. Rather, certain peaks for the material from Florida were anomalously high and the d-spacings for these anomalous peaks closely match those for goethite. For this reason a diffractometer pattern is included for goethite (Figure 1 bottom) which was concentrated from limonitic nodules found in the same general area as the rockbridgeite-goethite mixture, and it is evident that all of the strong reflections for goethite interfer with those of rockbridgeite.

If the pattern for goethite is subtracted from the Florida rockbridgeite-goethite mixture both the intensities and d-spacings closely correspond to those obtained from pure rockbridgeite (Virginia).

DISCUSSION

Original minerals in the phosphorites of the Bone Valley Formation include apatite, montmorillonite, quartz, and minor accessories. Weathering of these sediments in post-Bone Valley time has resulted in the development of a bleached zone containing such minerals as quartz wavellite, crandallite, millisite, kaolinite, and secondary apatite (Altschuler et al., 1956). During the weathering process phosphate is liberated from the apatite and iron is liberated from the montmorillonite. Under certain conditions iron and phosphate have combined to form various hydrated and basic hydrated iron phosphate minerals, including vivianite, beraunite, cacoxenite, and rockbridgeite. The genetic relationship between the iron phosphate minerals is complex and consideration of the paragenesis of the iron phosphate nodules awaits collection of more material.

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MARINE FOSSILIFEROUS PLEISTOCENE DEPOSITS IN SOUTHEASTERN NORTH CAROLINA

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ABSTRACT

The term "Neuse Formation" is proposed for marine fossiliferous Pleistocene deposits in southeastern North Carolina. The "Pamlico Formation" and the "Flanner Beach Formation" have previously included these deposits. The Pamlico Formation was defined topographically and not as a distinct lithologic unit. The Flanner Beach Formation includes deposits of the non-marine Horry Clay, marine fossiliferous sediments, and unfossiliferous surficial sands, and it is not a distinct lithologic unit. The type locality of the Neuse Formation is in Pamlico County on the north bank of the Neuse River Estuary. The Neuse Formation occurs east and west of the Pamlico terrace scarp and does not seem to be directly related to the scarp.

The Neuse Formation consists of four facies: (1) very fine-grained quartz sand, silt, and clay; fossiliferous, moderately to very poorly sorted; (2) fine-grained quartz sand; fossiliferous, moderately sorted; (3) sand-silt-clay and very fine-grained quartz sand; fossiliferous, poorly to very poorly sorted; and (4) coquina.

INTRODUCTION

Study Area and Purpose of Investigation

The sediments and fauna of marine fossiliferous Pleistocene deposits in southeastern North Carolina were studied to determine stratigraphic relationships and environments of deposition. This report is

1/ Research for this paper done while the senior author was a graduate student at the University of North Carolina at Chapel Hill.

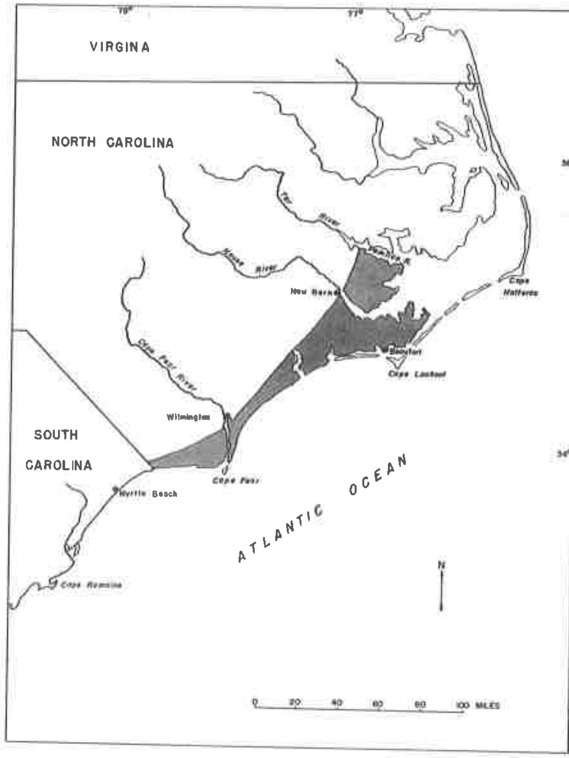

Figure 1. Index map of southeastern North Carolina. Area studied is shaded.

concerned with definition and stratigraphic description of the Neuse Formation. A description of the fauna and of inferred environments of deposition is in preparation.

The study area extends along the coast from the North Carolina-South Carolina boundary (33° 52' N) northeast to the Pamlico River in central eastern North Carolina (35° 30' N), a distance of approximately 150 miles (Figure 1). The strata which were examined occur up to 35 miles inland.

Acknowledgments

The authors wish to thank Roy L. Ingram and William A. White of the University of North Carolina for their interest and assistance. Financial aid was provided by the University of North Carolina's Smith Fund.

Previous Work

The first detailed study of Pleistocene sediments of North Carolina was done by Stephenson (1912). He divided them into five formations:

	Feet above sea level
Coharie	160-235
Sunderland	110-150
Wicomico	50-110
Chowan	25-50
Pamlico	0-25

Stephenson believed that the sediments were shallow marine, estuarine, and floodplain deposits. He mentioned the occurrence of marine fossils at one locality in the Chowan Formation (Stephenson, 1912), but most workers have assigned all marine fossiliferous Pleistocene in North Carolina to the Pamlico Formation.

Stephenson named the Pamlico Formation for Pamlico Sound in eastern North Carolina. The formation was defined as those Pleistocene sediments to the east of the escarpment at the seaward edge of the Chowan Formation and including sediments in the terrace re-entrants in the principal river valleys (Stephenson, 1912). Stephenson described the formation as consisting of "fine sandy loams, sands and clays, and to a limited extent of gravels" (Stephenson, 1912). He noted the coquina deposits in the Cape Fear area, the fossiliferous beds along the Neuse River Estuary, and a few other fossiliferous localities (Stephenson, 1912). One Pamlico outcrop, in northern North Carolina, was described (Stephenson, 1912), but no type locality was designated.

Richards has done extensive work on the marine fossiliferous Pleistocene of the Atlantic coast. His most complete publication (Richards, 1962) summarizes many of his observations, among them being: (1) the Pamlico Formation, into which he placed the marine fossiliferous Pleistocene deposits of North Carolina, and its equivalents are present from Massachusetts into Mexico; and (2) the deposits are probably Sangamon. Richards (1966) noted five marine Pleistocene localities in northeastern North Carolina, all of which he placed in the Pamlico Formation.

Cooke (1937) proposed the term "Horry Clay" for a bed containing cypress stumps below marine Pleistocene deposits near Myrtle Beach, South Carolina. Richards (1950) extended this stratigraphic name to similar beds at Flanner Beach along the Neuse River Estuary in North Carolina, where they are overlain by marine Pleistocene beds.

Dall (1892) described molluscan fossils from the south bank of the Neuse estuary, 13 to 15 miles downstream from New Bern. These fossils seemed to be Pliocene to Dall. He named the strata from which the fauna came the "Croatan beds" (Dall, 1892), but no type section was designated. His Croatan samples contained 83 percent living species

(Dall, 1892).

Mansfield (1928) found that Dall's collection appeared to contain both Pliocene and Pleistocene molluscan species. He investigated the area along the south bank of the Neuse estuary and reported an unconformity separating fossiliferous Pliocene and Pleistocene beds at localities 11 and 15 miles downstream from New Bern. The Pliocene sediments, which he assigned to the Croatan Formation, were described by Mansfield as coarse sand and gravel.

Mansfield (1936) extended the Croatan Formation to include fossiliferous strata farther up river near James City, about 2 to 5 miles downstream from New Bern.

Du Bar and Solliday (1963) questioned the desirability of using the name "Pamlico Formation" and recommended its suppression as a name for a lithologic unit. They noted (Du Bar and Solliday, 1963) that: (1) Stephenson (1912) described the type area as a terrace-plain, a geomorphic rather than a lithologic concept; (2) only one outcrop of typical Pamlico Formation was described and no type section was designated; (3) Stephenson did not consider marine fossils to be characteristic of the Pamlico Formation; (4) Stephenson did not adequately describe the formation; and (5) use of the term for both geomorphic and lithologic features is undesirable.

Du Bar and Solliday (1963) rejected the term "Pamlico Formation" and used "Flanner Beach Formation" for Neogene deposits near Flanner Beach. They included in the formation the marine fossiliferous Pleistocene beds, the cypress-bearing Horry Clay strata, and unfossiliferous surficials. They found no Pliocene beds near Flanner Beach. They did find some Pliocene fossils but thought their presence could be explained by their having been reworked into Pleistocene beds (Du Bar and Solliday, 1963). Since they found no Pliocene strata in the type area of the Croatan Formation, they dropped the term "Croatan" and named the fossiliferous beds near James City, which they regarded as questionably Pliocene, the James City Formation.

Du Bar (1962) published radiocarbon dates ranging from older than 35,000 years BP to older than 42,000 years BP from marine Pleistocene in South Carolina. Arnold and Libby (1951) reported a date of about 20,000 years BP from the Horry Clay near Myrtle Beach, South Carolina.

Lithologic Terminology

Size terms used to name the sediments were derived by plotting sand-silt-clay percentages on a triangular diagram (Shepard, 1954). The class term for the modal size was added to descriptions of sands. Phi percentile parameters are those of Folk and Ward (1957). Roundness was determined by the Powers' (1953) method. Cross-stratification terminology is that of McKee and Weir (1953).

Localities

The localities described below are plotted on Figure 2.

1. Hobucken, Pamlico County; spoil piles from a drainage ditch 20 feet west of Hobucken School.

2. One mile north of Alliance, Pamlico County; spoil piles from a drainage ditch along County Road 1203, 1.0 mile north of the point where the road crosses the Norfolk and Southern railroad.

3. Alliance, Pamlico County; outcrop in a creek crossed by County Road 1200 in the village.

4. Beard Creek, Pamlico County; outcrop on the north bank of the Neuse River Estuary immediately west of the mouth of Beard Creek; 2.0 miles southeast of the center of the village of Kendall Beach and 0.4 mile south of the end of County Road 1101; type locality of the Neuse Formation.

5. Riverdale, Craven County; outcrop on the south bank of the Neuse River Estuary, 1.2 miles east of the village of Riverdale.

6. Flanner Beach, Craven County; outcrop on the south bank of the Neuse River Estuary at the Flanner Beach Recreation Area, approximately 10 miles downstream from the southeastern edge of New Bern.

7. One and one-tenth miles southeast of Flanner Beach, Craven County; outcrop on the south bank of the Neuse River Estuary.

8. One and four-tenths miles southeast of Flanner Beach, Craven County; outcrop on the south bank of the Neuse River Estuary.

9. Carolina Beach bridge, New Hanover County; spoil piles from excavation for Highway 421 bridge over the Intracoastal Waterway, 1.5 miles north of the center of the town of Carolina Beach.

10. Open Grounds, Carteret County; spoil piles from a drainage ditch near the northeastern end of the ditch system on the Open Grounds farm; County Road 1300 passes immediately west of the farm. The locality is 5.3 miles east-southeast of the point where County Road 1300 crosses Back Creek.

11. Open Grounds, Carteret County; spoil piles from near the center of the ditch system on the Open Grounds farm; 3.5 miles southeast of the point where County Road 1300 crosses Back Creek.

12. Adams Creek, Carteret County; spoil piles from the Adams Creek Canal section of the Intracoastal Waterway, one mile north of Highway 101.

13. Newport River, Carteret County; outcrop in roadside ditch 0.4 mile north of Newport River and 0.3 mile north of the intersection of County Roads 1155 and 1154; 6.2 miles east of the center of the town of Newport.

14. Channel Haven, New Hanover County; outcrop in a canal in the Channel Haven housing development, 1.2 miles north of the center of the village of Myrtle Grove; County Road 1148 passes immediately west of the housing development.

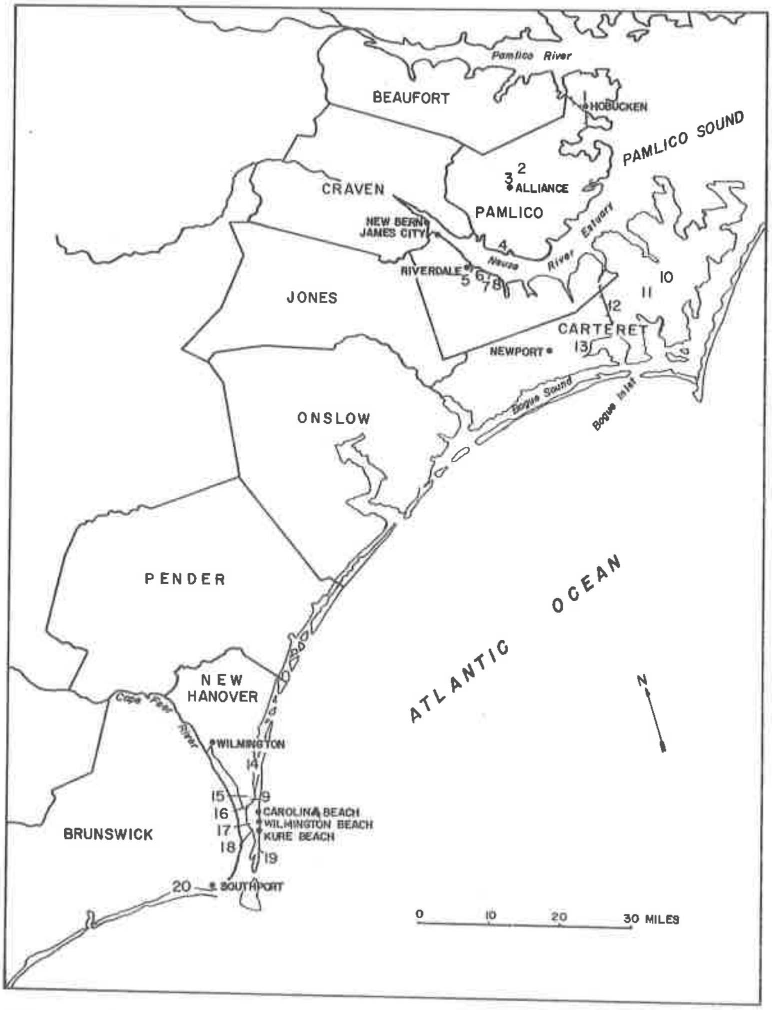

Figure 2. Neuse Formation localities.

15. One mile north of Snow's Cut, New Hanover County; outcrop in a sand pit 300 feet west of Highway 421, 1.0 mile north of the Intracoastal Waterway bridge.

16. Snow's Cut, New Hanover County; outcrop along the Intracoastal Waterway, extending about 600 feet west of the Highway 421 bridge; the canal here passes through Snow's Cut.

17. Wilmington Beach, New Hanover County; outcrop in a drainage ditch 0.7 mile northwest of the center of the village of Wilmington Beach, 20 feet south of a paved road going west from the village.

18. Kure Beach, New Hanover County; outcrop at water level on the east bank of the Cape Fear Estuary, 1.0 mile northwest of the

center of Kure Beach; at an abandoned military installation.

19. Fort Fisher, New Hanover County; outcrop along the beach 0.2 mile north of the Fort Fisher monument.

20. Long Beach, Brunswick County; outcrop along the north bank of the Intracoastal Waterway, 1.1 miles northwest of the center of the town of Southport.

THE NEUSE FORMATION--A DEFINITION

Problems of Terminology

Several different names have been applied to marine fossiliferous Pleistocene deposits in the Atlantic and Gulf Coastal Plains. Cape May Formation in New Jersey and Anastasia Formation in Florida are examples. The term "Pamlico" has been commonly used from Maryland to Georgia.

Although proliferation of stratigraphic names is undesirable, the authors believe that a more reasonable terminology for the marine fossiliferous Pleistocene strata on the Atlantic Coastal Plain is needed. Previously, both the unfossiliferous surficial sediments and the marine fossiliferous Pleistocene deposits underlying them have been assigned to the same formation because they occur at a certain altitude and are Pleistocene. Actually, the unfossiliferous surficial "Pamlico" sediments are quite distinct from the marine fossiliferous sediments and are much more similar to other surficial deposits which occur at higher elevations. The fossiliferous deposits are lithologically more similar to underlying Pliocene and Miocene beds than they are to the surficials. It seems also that the fossiliferous Pleistocene beds are not directly related to the Pamlico terrace scarp, as will be discussed later.

The "Flanner Beach Formation," as defined by Du Bar and Solliday (1963) is undesirable because it includes the unfossiliferous surficials, marine fossiliferous Pleistocene beds, and strata assigned to the Horry Clay, all of which are distinct lithologic units.

Description and Stratigraphic Relations

The term "Neuse Formation" is here proposed for marine fossiliferous Pleistocene deposits in North Carolina. The name is taken from the Neuse River Estuary along whose banks good outcrops occur. The type section is in Pamlico County on the north bank of the Neuse River Estuary (locality 4, Figure 2). It is 11 miles southeast of the southeastern edge of New Bern and immediately west of the mouth of Beard Creek. The outcrop extends for approximately 300 yards along the bank of the estuary. The measured section described below is near the eastern edge of the outcrop (Plate 1, Figure 1).

Surficials	Thickness (feet)
6. Fine-grained quartz sand; well-sorted, unfossiliferous, light gray, loose........	6.3
Unconformity	
Neuse Formation	
5. Clayey silt; very poorly sorted, very light gray, moderately indurated; shell layers up to 0.5 feet thick in the lower part; Cyrtopleura in living position; parting in some places..................	4.2
4. Fine-grained quartz sand; poorly sorted, yellowish-gray, poorly indurated; molds of fossils accentuated by limonite........	1.4
3. Very fine-grained quartz sand; poorly sorted, light olive-gray, poorly indurated; abundant fossils.....................	1.8
2. Very fine-grained quartz sand; well-sorted, grayish-yellow, moderately indurated; a few fossils.............................	3.2
1. Very fine-grained quartz sand; poorly sorted, light olive-gray, moderately indurated; a few round quartz pebbles scattered throughout; many fossils; lower contact not visible...........................	3.4
	20.3

Contacts between beds are somewhat irregular. A few yards to the west, beds 1, 2, and 4 pinch out and the entire section appears to be composed of beds similar to units 3, 5, and 6. To the east, the deposits seem to become more sandy and less fossiliferous.

The lithologies described above are the most common in the Neuse Formation in southeastern North Carolina, but distinctly different types occur. Coquina is present in several places in the formation, and the section at Snow's Cut, New Hanover County (locality 16, Figure 2), described on page 50, this paper, is designated a reference section for the Neuse Formation (American Commission on Stratigraphic Nomenclature, 1961, p. 653). Beds of fossiliferous sand and fossiliferous sand-silt-clay also occur.

The upper boundary of the formation is an apparently unconformable contact between fossiliferious Neuse deposits and unfossiliferous surficial sediments of Pleistocene age. The lower boundary is an unconformity and was observed at Flanner Beach (locality 6, Figure 2), where the Neuse Formation overlies the Horry Clay, and one and one-tenth miles southeast of Flanner Beach (locality 7, Figure 2), where the Neuse overlies the Croatan Formation.

The term "Neuse Formation" could probably be used for similar marine fossiliferious Pleistocene beds along the Atlantic Coast from New Jersey to Florida.

Relation to Physiography

The region underlain by the Neuse Formation in southeastern North Carolina is characterized by two distinct types of physiography. One type is a flat plain less than about 20 feet in elevation that occupies the eastern part of the peninsula between the Neuse Estuary and the Pamlico River. This is the type area of the Pamlico Formation as defined by Stephenson. The Pamlico terrace scarp, roughly marked by the 25 foot contour line, lies along the western border of the plain. The second type of physiography is composed of sand hills and ridges with isolated swampy areas, and lies west of the Pamlico scarp.

Most workers on Pleistocene fossiliferous sediments in the Atlantic Coastal Plain believe that all such deposits lie seaward of the 25 foot scarp. This relation may be generally true, but it does not apply to the Neuse River Estuary area (Figure 3). The scarp is clearly shown on topographic maps of the area between the Pamlico River and the Neuse River Estuary. The scarp appears to cross the estuary at least 4 miles seaward of Pleistocene fossiliferous deposits at Beard Creek (locality 4, Figure 2), Riverdale (locality 5, Figure 2), Flanner Beach (locality 6, Figure 2), 1.1 miles southeast of Flanner Beach (locality 7, Figure 2), and 1.4 miles southeast of Flanner Beach (locality 8, Figure 2). Sediments and fossils at these places are similar to those at localities 1, 2, and 3, which lie east of the terrace scarp. It may be that the sea, which is thought by most workers to have formed the Pamlico scarp during a transgression, extended up the estuary, and so accounts for beds west of the scarp, but there is little physiographic evidence for this along the Neuse. A surface elevation of 40 feet occurs above Neuse Formation beds at Beard Creek. It is true, however, that no marine fossiliferous Pleistocene deposits were observed above 20 feet in elevation.

SEDIMENTS

Facies in the Neuse Formation

The Neuse Formation is composed of four facies, each with distinct sediments and fauna. These are described in order of general geographic pattern of outcrops from north to south, and are named according to dominant lithologic type: very fine-grained sand, fine-grained sand, sand-silt-clay, and coquina (Figure 4).

Very Fine-grained Sand Facies

Moderately to very poorly sorted quartz sand, and silt and clay are the most common sediments in the Neuse Formation and occur at localities 1 through 9. The sands are typically light olive gray or

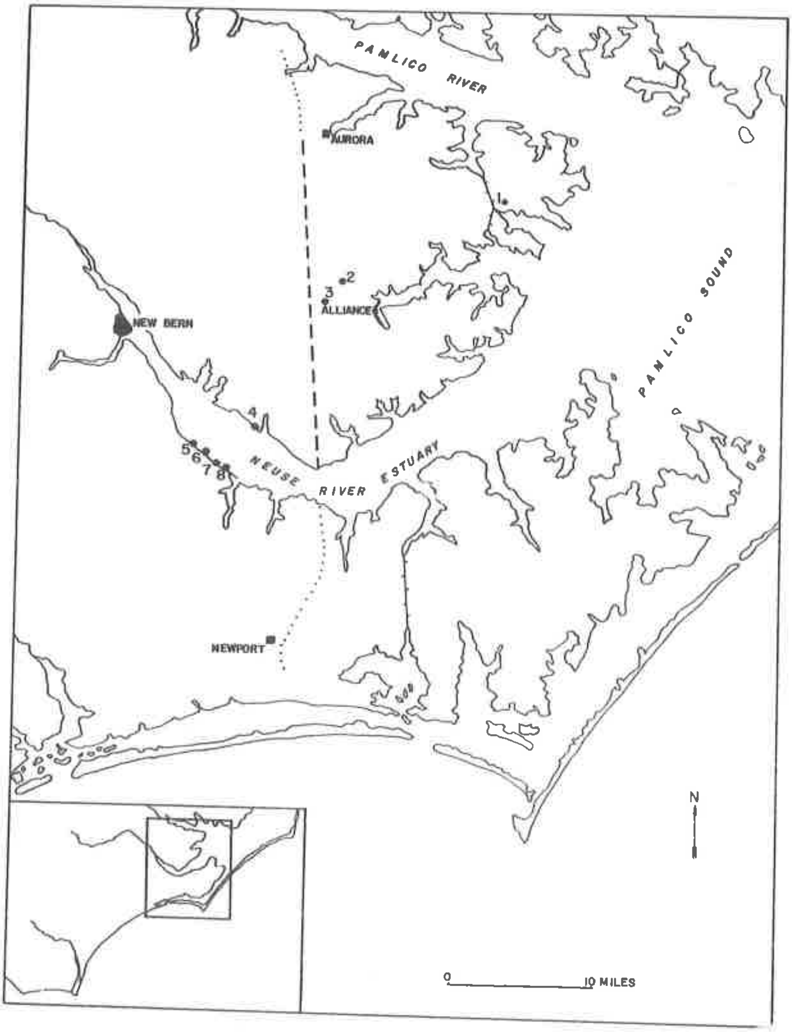

Figure 3. Location of the Pamlico terrace scarp in the Neuse River Estuary area. Scarp is definite along dashed line, vague along dotted portion. Neuse Formation localities are numbered.

yellowish gray, massive, and poorly indurated. Nine samples were analyzed for size distribution, and the results are shown in Table 1. Quartz composes at least 95 percent of the sand fraction, and heavy minerals, feldspar, and glauconite are rare. Some beds contain rounded, very fine-grained quartz pebbles widely scattered in the finer matrix. Roundness values are low, mean roundness being 0.24 (angular). Shells are generally scattered throughout the sediments, and carbonate

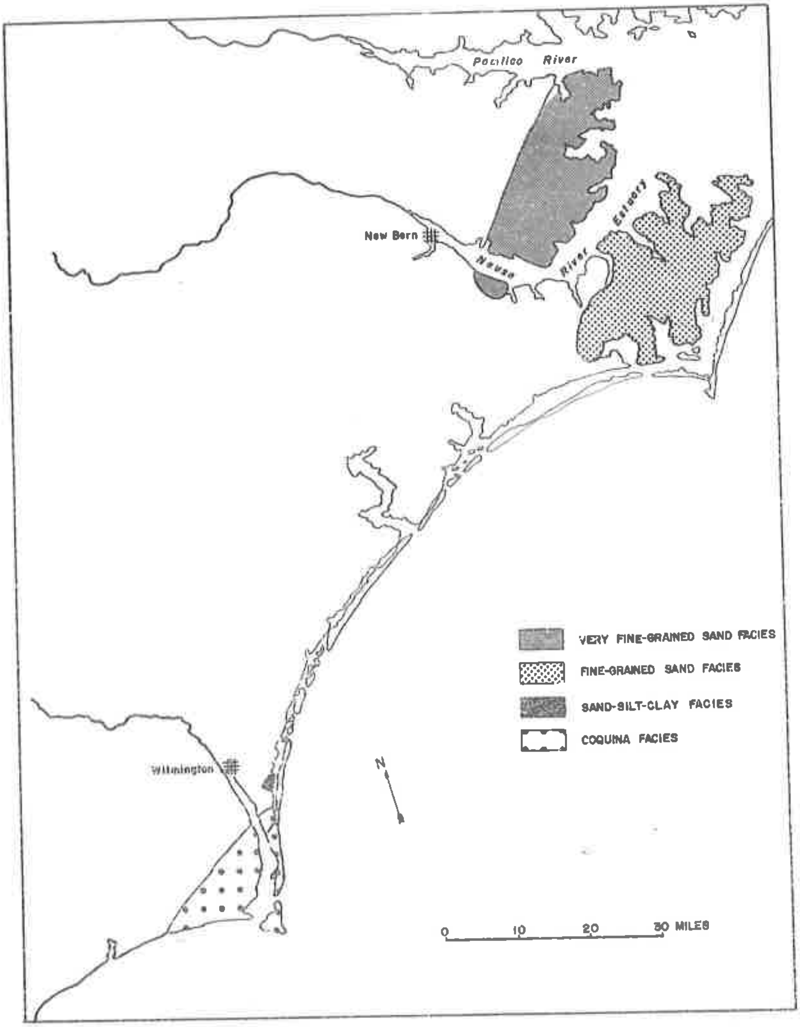

Figure 4. Areal relations of the Neuse facies, based on outcrops and spoil piles.

content has a mean value of 13 percent by weight.

Bedding at the Beard Creek outcrop is up to 4.2 feet thick. Thin shell layers occur here but are not typical of this facies (Plate 1, Figure 2).

The type section previously described is composed of this facies.

Histograms of size distribution of a sample from each facies are shown in Figure 5.

Table 1. Size Distribution Analysis of Very Fine-grained Sand Facies Samples.

Locality	M_z	σ_I	Sk_I	K_G	Maximum size	Pb	Sd	Si	Cl
3	2.8ϕ	1.5ϕ	0.28	2.9	v c sd		87%	7%	6%
4-1	3.5	1.7	0.41	7.9	f pb	1%	77	20	2
4-2	3.4	0.63	0.63	1.4	m sd		86	10	4
4-3	3.1	1.2	0.27	2.9	m sd		88	5	7
4-4	3.2	1.3	0.79	9.2	f sd		85	7	8
4-5	9.0	3.7	0.071	0.10	c sd		7	35	58
4A	3.1	1.3	0.57	3.3	c sd		87	5	8
6A	4.2	2.1	0.57	3.3	v c sd		59	32	9
6B	4.0	2.3	0.20	2.7	v c sd		75	16	9
Mean	4.0	1.8							

Fine-grained Sand Facies

Deposits of this facies occur at localities 10 through 13. The sediments are poorly indurated, pale yellowish brown, quartz sand. The Newport River outcrop (locality 13, Figure 2) was the only one analyzed in detail, because the others are spoil piles. The results of size distribution analysis are in Table 2.

Table 2. Size Distribution Analysis of Fine-grained Sand Facies Sample.

Locality	M_z	σ_I	Sk_I	K_G	Maximum size	Pb	Sd	Si	Cl
13	2.0ϕ	0.89ϕ	-0.12	1.1	f pb	1%	98%	1%	1%

Rounded quartz pebbles are more abundant here than in the very fine-grained sand facies. Heavy minerals, feldspar, glauconite, and mica constitute less than 5 percent of the rock. The particles are subangular, mean roundness value being 0.25. Shells are randomly scattered. Carbonate content is 14 percent by weight. Only about 2 feet of the deposit is exposed at the Newport River outcrop, where is is unconformably overlain by unfossiliferous sand.

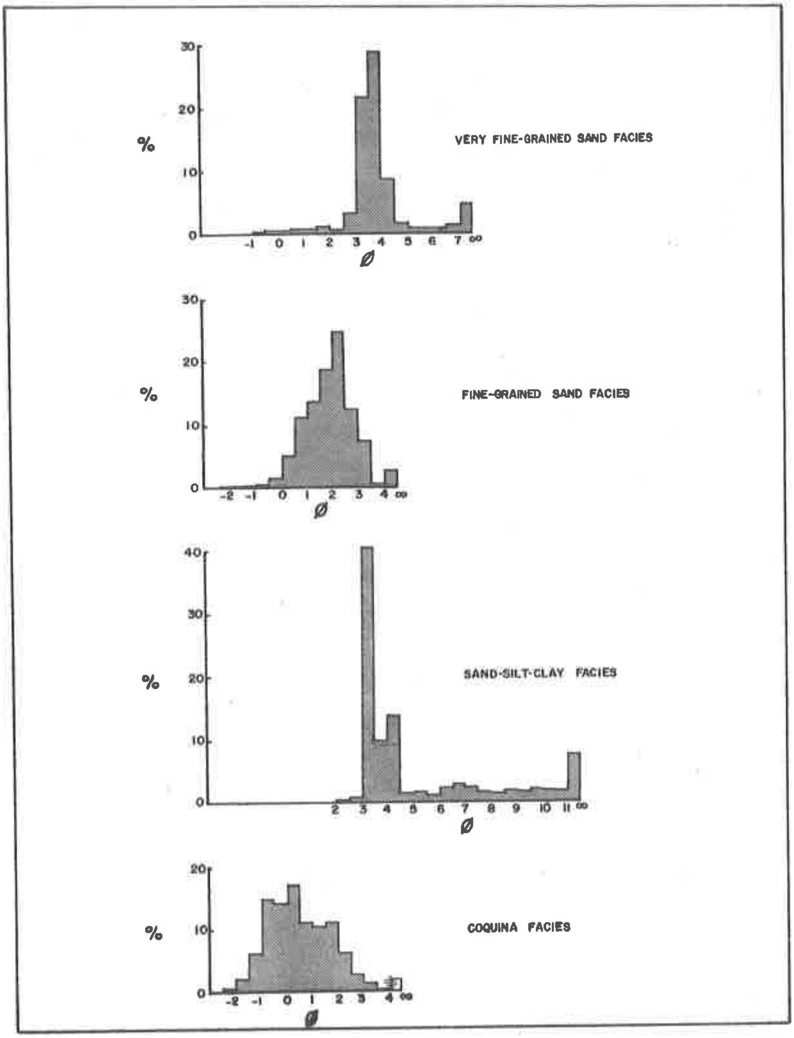

Figure 5. Sediment size distribution of a sample from each facies. The localities are, from top to bottom, Flanner Beach, near Newport River, Channel Haven, Snow's Cut.

Sand-silt-clay Facies

Although this type of deposit, fossiliferous, poorly to very poorly sorted, sand-silt-clay to very fine-grained quartz sand, occurs only at Channel Haven (locality 14, Figure 2), it is distinct enough to be considered a separate facies. It is light olive gray, poorly indurated, and laminated in some places. The section (Plate 2, Figure 1) is:

	Thickness (feet)
Surficials	
3. Sand; poorly sorted, unfossiliferous......	5.4
Unconformity	
Neuse Formation	
2. Very fine-grained quartz sand; poorly sorted, poorly indurated, light olive-gray; numerous shells....................	1.7
1. Sand-silt-clay; very poorly sorted, poorly indurated, light olive-gray; shell layers; thin laminae; lower contact not visible......................	3.4
	10.5

The beds vary in thickness and the contact between beds 1 and 2 undulates. The results of size analyses of samples from the Channel Haven locality are shown in Table 3.

Table 3. Size Distribution Analysis of Sand-silt-clay Facies Samples.

Locality	M_z	σ_I	Sk_I	K_G	Maximum size	Pb	Sd	Si	Cl
14-1	5.5ϕ	2.8ϕ	0.78	1.0	f sd		52%	28%	30%
14-2	3.4	1.5	0.87	5.9	c sd		81	9	10

The grains are generally angular, mean roundness value being 0.20. Shell layers up to 0.4 feet thick occur in the lower bed, but most are much thinner. Carbonate content averages 15 percent by weight.

Coquina Facies

General Description. Coquina is exposed in the southern part of the area at localities 15 through 20 and has been found on the sea floor 30 miles southeast of Cape Fear, 46 feet below sea level (McClelland Engineers, Inc., 1963). Wells and Richards (1962) have reported coquina washed up on beaches near Capes Hatteras and Lookout on the North Carolina coast.

The coquina contains from about 50 to about 90 percent material by weight soluble in hydrocloric acid. This is nearly all carbonate in the form of fossils and sedimentary cement. Most of the shells are fragmented.

The rock is typically yellowish orange and porous. The insoluble residue is poorly sorted. Cross-stratification is well-developed at several outcrops (Plate 2, Figure 2). Round quartz pebbles up to 8 mm in diameter occur. Heavy minerals, glauconite, feldspar and mica constitute less than 5 percent of the sediment. The weathered surface of the coquina has a rough, crusty aspect owing to precipitation of small crystals of calcium carbonate. Table 4 shows results of analyses of insoluble residue of some coquina samples.

Table 4. Results of Size Distribution Analyses of Coquina Facies Samples.

Locality	M_z	σ_I	Sk_I	K_G	Maximum size	Pb	Sd	Si	Cl
15	0.23ϕ	1.4ϕ	0.03	0.88	f pb	19%	80%	1%	1%
16	0.47	1.2	0.20	0.91	f pb	10	90	1	1
19	2.0	0.86	-1.5	3.0	v f pb	3	92	1	1

The coquina facies exhibits the highest mean roundness values (0.31--sub-angular). Most shell material has been broken up, but many large shells are intact. Shells and shell fragments tend to have their largest dimensions horizontal, and most of the pelecypod shells lie convex upward.

Cross-stratification. Well-developed cross-stratification was observed at Snow's Cut (locality 16, Figure 2), Fort Fisher (locality 19, Figure 2), and at the Long Beach outcrop (locality 20, Figure 2). Both planar and trough types are present, and the sets are lenticular, wedge-shaped, and tabular. At locality 19, near Fort Fisher, cross-stratified coquina is exposed on the beach. Lenticular, trough-type sets are the most common here, and the sets are up to 8 feet wide and 12 feet long. The steepest dip measured was 35°, but most are much less, with an average dip around 15° to 20°. Most dips are to the south-southwest, but a few small sets, less than 10 percent of the total, dip to the northeast. Thickness of sets could not be accurately observed because of the thin outcrop, but larger sets appear to be at least 4 feet thick. Individual cross-strata appear to vary between 0.25 and 1.0 inches in thickness. The sets have erosional bounding surfaces and all are concave upward.

At Snow's Cut (locality 15, Figure 2) both planar and trough cross-stratification occur, and wedge, tabular, and lenticular sets are present. Most sets here dip to the south at about 20°, although approximately 30 percent dip to the north. Sets here average about 1 foot in thickness, and cross-strata are up to 1 inch thick.

Reference Section of the Neuse Formation. On the north side of the canal at Snow's Cut, at the western end of the bluff, a bed of poorly indurated coquina overlies a bed of well-indurated coquina. The section here is designated a reference section for the Neuse Formation (Plate 3, Figure 1).

		Thickness (feet)
3.	Loose, light-gray sand (insoluble residue?)............................	0.4
2.	Coquina; loose and poorly indurated, pale yellowish-orange; many well-preserved fossils and shell fragments................................	6.5
1.	Coquina; well-indurated, pale yellowish-orange; large shells concentrated in layers; lower contact not visible..........................	3.8
		10.7

The upper bed appears to grade laterally into well-indurated coquina about 10 feet to the east. Some of the shells and sand grains in bed 2 are cemented by carbonate. This bed could be the product of incomplete solution of carbonate cement or of incomplete cementation.

FOSSILS

The fauna of the Neuse Formation is dominated by pelecypods and gastropods. Foraminifera are numerous. Corals, bryozoans, barnacles, ostracodes, diatoms, fish teeth, and shark teeth were also found. The fossils are generally well-preserved. Many specimens of pelecypods were found with both valves together, and some occur in the position in which they lived. Specimens of Cyrtopleura, Tagelus, Ensis, and Labiosa commonly occur in the living position. Color patterns have been retained on a few specimens, particularly of Aequipecten, Mercenaria, and Olivella. A detailed report of the fauna is in preparation.

STRATIGRAPHIC RELATIONS

Lower Boundary of the Neuse Formation

Deposits near James City. About 2 to 5 miles downstream from New Bern, near the village of James City, light-gray, fossiliferous, argillaceous sands and sandy clays crop out. These beds were cursorily examined during this study. They appear to be Pliocene and can be assigned to the Croatan Formation, as was done by Mansfield (1936). The Neuse Formation was not observed near James City.

Deposits near Flanner Beach. The Neuse Formation crops out from about 9 to about 12 miles downstream from New Bern. Near Riverdale (locality 5, Figure 2) a bed of ferruginous sand with molluscan casts occurs. The recognizable species, Dinocardium robustum

(Solander) and Rangia cuneata (Gray), are characteristic of the Neuse Formation in this area.

At Flanner Beach (locality 6, Figure 2) the Neuse Formation overlies the Pleistocene Horry Clay. The Horry Clay here is composed of sand-silt-clay and contains tree remains that have been identified as Taxodium distichum (Linné) and Pinus serotina Miller (Berry, 1926) (Plate 3, Figure 2). Nonmarine deposits of this type underlying Pleistocene marine sediments have been reported from several places in the Atlantic Coastal Plain (Berry, 1909; Cooke, 1937).

The unconformable contact between the Neuse Formation and the Horry Clay at Flanner Beach is marked by a concentration of Rangia cuneata and Dinocardium robustum shells in the base of the Neuse Formation.

One and one-tenth miles downstream from Flanner Beach (locality 7, Figure 2), there is an outcrop exposing the Croatan-Neuse contact (Plate 4, Figure 1). The section is:

	Thickness (feet)
Surficials	
4. Silty sand; very poorly sorted, yellowish-gray, unfossiliferous..........	4.3
3. Sand-silt-clay; very poorly sorted; laminated in places; yellowish-gray; unfossiliferous........................	6.2
Unconformity	
Neuse Formation	
2. Silty sand; poorly sorted, light olive-gray (yellowish-orange where weathered); many fossils; Dinocardium shells at base.............................	1.7
Unconformity	
Croatan Formation	
1. Sandy silt; very poorly sorted, light olive-gray, fossiliferous; lower contact not visible........................	2.6
	14.8

Presence of the Croatan Formation

This study bears out the existence of the Croatan Formation near Flanner Beach. The following points are evident:

(1) At locality 7, 1.1 miles southeast of Flanner Beach, sediments of the lowest bed (Croatan Formation) are sandy silt. Neuse Formation deposits in this area are very fine sands and silty sands. The coarse sands of the Croatan Formation described by Mansfield (1928) were not observed, but these, too, are distinct from the Neuse Formation in this area. Dall (1892) mentioned a bluish, fossiliferous clay 13 miles downstream from New Bern in his original description

of the Croatan Formation. Apparently the sediments of the unit are quite variable.

(2) The Croatan bed 1.1 miles southeast of Flanner Beach contains the following molluscan species:

Abra aequalis (Say)
Aequipecten eboreus (Conrad)
Anadara transversa (Say)
Cardita arata (Conrad)
Chama cf. C. emmonsi Nicol
Corbula contracta Say
Crassinella lunulata (Conrad)
Lucina amiantus (Dall)
Lucina crenella Dall
Mulinia lateralis (Say)
Noetia limula (Conrad)
Plicatula marginata Say
Venericardia tridentata Say
Anachis avara Say
Crepidula convexa Say
Vermicularia spirata (Phillippi)

Of these, Noetia limula, Cardita arata, Plicatula marginata, and Aequipecten eboreus (Plate 5), apparently did not survive the Pliocene (22 percent of the species).

(3) The presence of well-preserved pelecypods, many with both valves together, in the lowest bed at locality 7 indicates that the Pliocene fossils were not reworked into Pleistocene beds. Especially significant are large, fragile shells of Aequipecten eboreus with the valves together in living position.

(4) The unconformity at the base of the Neuse Formation at Flanner Beach, where it overlies the Horry Clay, is marked by Dinocardium and Rangia shells. At locality 7, the base of the Neuse Formation is made conspicuous by a concentration of Dinocardium shells. These shell layers seem to mark the unconformable contact at the base of the marine Pleistocene in this area.

Upper Boundary of the Neuse Formation

Unfossiliferous surficial sediments occur throughout the Neuse Formation outcrop area, overlying and laterally adjacent to the Neuse Formation (Plate 4, Figure 2). They are highly variable and include sands, silty sands, pebbly sands, silts, and sand-silt-clays. Leaching probably has removed shell material from much of the Neuse Formation in some areas, leaving soils somewhat similar to the surficials. At most outcrops, however, the surficials appear to be distinctly different from the underlying beds.

The fact that the Neuse Formation is abundantly fossiliferous and the surficials are apparently devoid of marine fossils indicates that a significant change in depositional environment occurred after the Neuse was laid down. Neuse outcrops are scattered and separated by the surficials, suggesting that subaerial dissection occurred before deposition of the surficials.

Age of the Neuse Formation

Only 1 of the 81 molluscan species found in the Neuse Formation in this study is extinct. This species, Chama cf. C. emmonsi Nicol may have been reworked from Pliocene deposits. Richards (1962), who collected from many marine fossiliferous Pleistocene deposits in the Atlantic Coastal Plain, reported only three extinct species from among hundreds. The close similarity between the molluscan fauna in the Neuse Formation and the molluscan fauna now inhabiting the Carolina coast indicates that the Neuse Formation was deposited rather late in the Pleistocene.

CONCLUSIONS

(1) Marine fossiliferous Pleistocene deposits in southeastern North Carolina are a distinct lithologic unit and are herein defined and named the Neuse Formation. The term "Pamlico Formation" is undesirable for these beds because it was defined topographically, and the term "Flanner Beach Formation" was defined as including several distinct lithologic units. The Neuse Formation does not seem to be directly related to the Pamlico terrace scarp.

(2) The Neuse Formation consists of four facies, each lithologically and faunally distinct: very fine-grained quartz sand facies, fine-grained quartz sand facies, sand-silt-clay facies, and coquina facies.

(3) The similarity of Neuse Formation molluscan fauna to present fauna along the Carolina coast indicates that the Neuse beds were deposited late in the Pleistocene.

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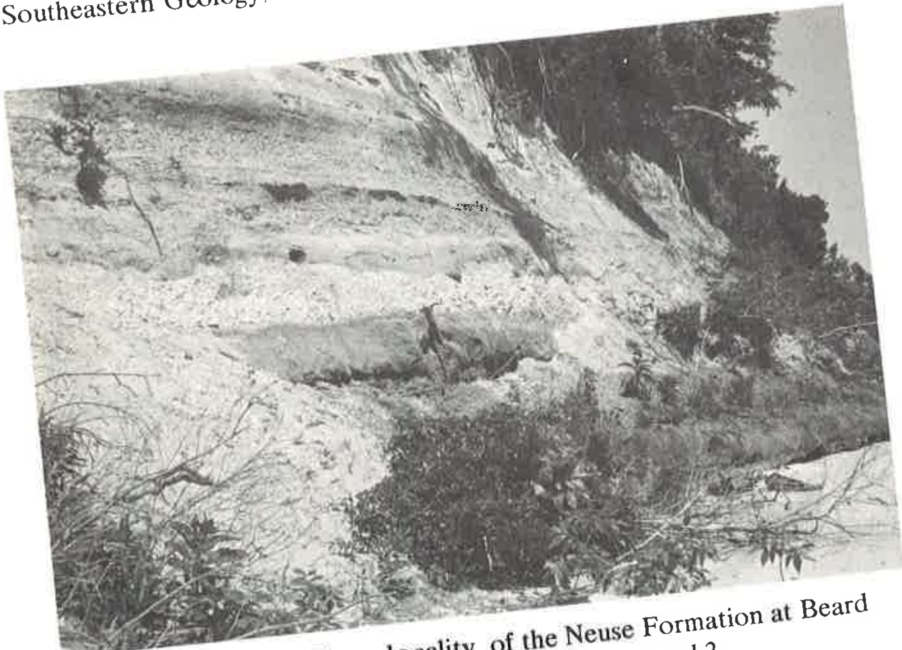

Plate 1, Fig. 1. – Type locality of the Neuse Formation at Beard Creek. Pick blade marks contact between beds 2 and 3.