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THE FLANNER BEACH FORMATION (MIDDLE PLEISTOCENE) IN EASTERN NORTH CAROLINA

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"If the entire Neogene section of southeastern North Carolina and northeastern South Carolina were exposed in the Grand Canyon, it would probably be assigned to one formation"

Wallace C. Fallaw, *in litt.*
5 May, 1983

CONTENTS

I. ABSTRACT

The Flanner Beach Formation was deposited along the Atlantic Coast of east-central North Carolina during a high stand of world sea-level about 200,000 years B.P. This major barrier-lagoon sequence can be divided into three members in its type area along the lower reaches of the Neuse River: 1) Smith Gut Member (new unit), deposited in early transgressive open-bay settings; 2) Arapahoe Sand Member (newly formalized unit), deposited in a barrier-island complex as the rate of sea-level rise decreased; and 3) Beard Creek Member (newly formalized unit), composed of sediments that accumulated in a spatial-temporal mosaic of bay and lagoonal environments. The barrier-sand lithosome is continued to the south of the Neuse valley as the Newport Sand Member (newly formalized unit).

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Time-equivalent deposits cropping out in the Pamlico River valley, 40 km north of the Flanner Beach type area, also are divisible into three units of member rank: 1) Hills Point Member (new unit), deposited in isolated lagoonal or river-estuary settings; succeeded vertically by 2) Mauls Point Member (new unit), deposited in more open lagoonal areas; and 3) a poorly exposed, unnamed member resembling the Beard Creek Member.

II. INTRODUCTION

The Flanner Beach Formation in particular and the lower Neuse River area in general have been the focus of many stratigraphic and paleontologic investigations. The purpose of this report is to provide an up-dated description of the Flanner Beach Formation, based upon both a review of recent studies and on field work undertaken in the Neuse and Pamlico River valleys in Summer, 1982, as a part of a dissertation completed recently at Tulane University.

The earliest of stratigraphic studies of Pleistocene beds cropping out along the Neuse River dates back to the early nineteenth century. Publications resulting from these studies were written by some of the more illustrious figures in the history of Atlantic Coastal Plain geology, including T.A. Conrad, W.H. Dall, and W.C. Mansfield. The interested reader should consult reviews of pre-1960's investigations appearing in Mansfield (1928), Richards (1950), Fallaw (1965), and DuBar *et al.* (1974). More recent literature is reviewed in the first part of this report.

Notwithstanding Professor Fallaw's admonition (epigraph), as a result of my field work, I recognize and describe new members within the Flanner Beach and identify time-equivalent deposits in the Pamlico River valley of Beaufort County. Informal members mapped and described by Mixon and Pilkey (1976) are promoted to the status of formal lithostratigraphic units and the environmental history of the Flanner Beach Formation is reconstructed using lithologic characteristics, physical and biogenic sedimentary structures, lateral and vertical facies relationships, relationship of deposits to surface morphologic features and to disconformities (where applicable), paleontologic data, and results of a limited number of oxygen-isotope analyses.

III. ACKNOWLEDGMENTS

This study was part of a doctoral dissertation completed at Tulane University, under the supervision of Emily H. Vokes. Field work was supported by grants from the Geological Society of America and the Society of the Sigma Xi (Tulane University Chapter). Funds for oxygen-isotope ratio analyses were provided by the Graduate School, Tulane University. Thomas M. Cronin provided important, unpublished information on time-correlation and age of the Flanner Beach Formation. Doc Brown and Clay Carter provided motorboat transportation to several study sites that would have been otherwise inaccessible. Laura Leitch patiently prepared the photographs and Darren Trotter carefully typed the manuscript. To all these individuals and institutions I express my sincere gratitude. My special thanks go to Drs. Jules R. DuBar, Wallace C. Fallaw, and Walter H. Wheeler for providing thoughtful, thorough reviews of this paper. Naturally, the observations and interpretations expressed herein are my own and I take full responsibility for them.

IV. METHODS

Eleven stratigraphic sections were measured and described from bluff-line exposures: four from the bluff-line extending along the north shore of the Neuse, four from the south shore of the Neuse and three from bluffs that surround Blounts Bay on the south shore of the Pamlico River (Figure 1). Beds were traced between bluff-line localities by directly walking out exposures or by making frequent landfalls using a motorboat. Field descriptions of lithostratigraphic units appear in the Appendix. Bulk fossiliferous sediment samples were collected at Whisk Point and Smith Gut, in southern Pamlico County, and used in a detailed paleoecologic analysis of the formation (Miller, 1984, and in preparation). From these samples, specimens of *Mulinia lateralis* valves were selected at critical stratigraphic elevations for use in oxygen-isotope analyses.

V. REVIEW OF RECENT INVESTIGATIONS

Neuse River Valley Area

Dubar and Solliday (1963) restudied the Neuse River exposures and decided to abandon the older stratigraphic nomenclature in favor of formation names based on carefully described type sections. They argued that "Pamlico formation" was an inappropriate name because no type section was ever described by Stephenson (1912, p. 286-290) and because they wished to abandon the tradition of using the same name for both a coastwise terrace surface and for the sediments that underlie it (*i.e.*, the "terrace-formation" concept). They proposed the new name "Flanner Beach Formation" for the youngest deposits cropping out along the lower Neuse River, between Johnson Point and Hancock Creek, downstream from New Bern, Craven County. The type section was located at the Flanner Beach Recreation Area

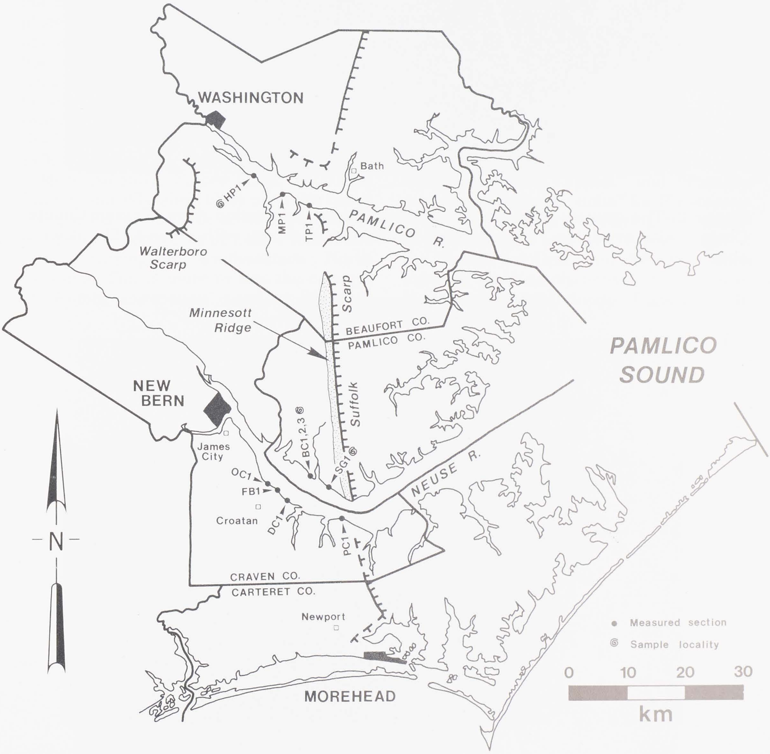

Figure 1. Map showing locations of measured sections along the Neuse and Pamlico Rivers in eastern North Carolina. Measured section numbers correspond to those used in Figures 5, 6, and 7, and in the Appendix.

Figure 2. The cypress-stump bed at Flanner Beach Recreation Area, Craven County. Contact with overlying Flanner Beach Formation is shown with arrows. The ruler is about 1 m long.

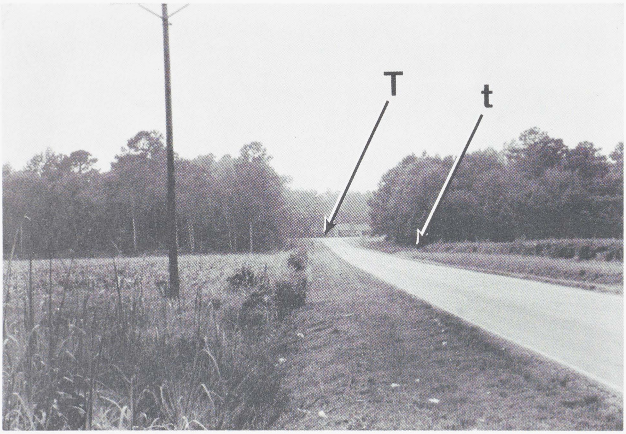

Figure 3. The Suffolk (or Grantsboro) Scarp just south of Arapahoe, Pamlico County. View is toward the west and the intersection of N.C. Highway 306 (in the distance) with County Road 1302 (foreground). *T*, edge of the Talbot geomorphic surface at +11.6 m MSL; *t*, toe of the scarp at about +8.0 m MSL

(DuBar and Solliday, 1963, p. 231-232; DuBar *et al.*, 1974, p. 121). The popular name "Croatan sand" was suppressed because no type section had been described by Dall (1892), who used the name "Croatan beds" informally; as originally delineated, the unit contained at least two formational units; and because Mansfield (1928) had later misidentified Pleistocene beds as Pliocene Croatan sand, owing to older fossils being reworked into a younger, superjacent unit. They proposed the name "James City Formation" to replace Croatan sand. The newer terminology applied by DuBar and Solliday (1963) has stood the test of time and subjective stratigraphic revision, and their formational nomenclature has been adopted essentially intact by the United States Geological Survey (Mixon and Pilkey, 1976; Blackwelder, 1981b).

More recently, Fallaw (1965, 1973) and Fallaw and Wheeler (1969) used the name "Neuse Formation" for all of the fossiliferous marine sediments of Late Pleistocene age occurring in southeastern North Carolina. This is more or less the concept of "Pamlico formation" used by Richards (1936, 1950, 1962, 1965). Although their detailed sedimentologic examinations of Pleistocene beds exposed along both sides of the Neuse River represent an important contribution, the stratigraphic labels employed by these workers have not been adopted. Their Neuse Formation in the Neuse Valley is equivalent to the Flanner Beach Formation, excluding sandy beds occurring near the surface in the Beard Creek area of Pamlico County, which they called "surficials," and the cypress-stump bed at Flanner Beach (Figure 2), for which they revived the name "Horry Clay." They also favored retaining the name "Croatan Formation" for subjacent fossiliferous beds, which they believed to be Pliocene in age.

Another recent reinterpretation of stratigraphic relationships and nomenclature was made by Daniels *et al.* (1972), who used the names "Talbot" and "Pamlico morphostratigraphic units" for Pleistocene sediments directly underlying the extensive plains west and east, respectively, of the Suffolk (or Grantsboro) Scarp, which extends north-south across the Pamlico-Neuse interfluvial divide (Figures 1, 3).

Figure 4. The top of the Flanner Beach Formation (Talbot geomorphic surface) in south-central Beaufort County. View is toward south from N.C. Highway 33, about 11 km west of Edward.

They placed the cypress-stump bed and underlying shelly beds (= James City Formation) within their "Small sequence." Although these authors may have muddied the waters slightly by returning to the older terrace-formation terminology and by inventing the "Small sequence," they made an important contribution to the understanding of Quaternary stratigraphic relationships in the region by tracing, for the first time, units beneath the Pamlico-Neuse divide north of well-studied outcrops in the Neuse valley, and by describing stratigraphic cross-sections compiled from power-auger traverses across the Suffolk Scarp and Minnesott Ridge at several localities (Daniels *et al.*, 1972, figures 3, 5, 8, 9). The most recent version of this work is presented in Wheeler *et al.* (1983).

In 1974, DuBar *et al.*, presented a thorough account of the Quaternary stratigraphy in the Neuse valley, as currently understood, and listed fossils from the Flanner Beach and James City Formations. They reconstructed the post-Miocene environmental history of the area based on physical stratigraphy, relationship of lithologic units to landforms, and on general paleoecologic data. They used the informal name "Cherry Point unit" for sand cropping out at the Pine Cliff Recreation Area, Craven County, which they thought overlay and post-dated the Flanner Beach Formation (*cf.* "Arapahoe sand member" of the Flanner Beach Formation, Mixon and Pilkey, 1976).

The most recent series of studies relating to the Flanner Beach and James City Formations have dealt with the larger patterns of regional correlations and relationships between Atlantic Coastal Plain depositional cycles and changes in Late Cenozoic world climate (Akers, 1972; Liddicoat *et al.*, 1979; Cronin, 1980, Blackwelder, 1981a, b, c; Cronin *et al.*, 1981; McCartan *et al.*, 1982; Wehmiller and Belknap, 1982).

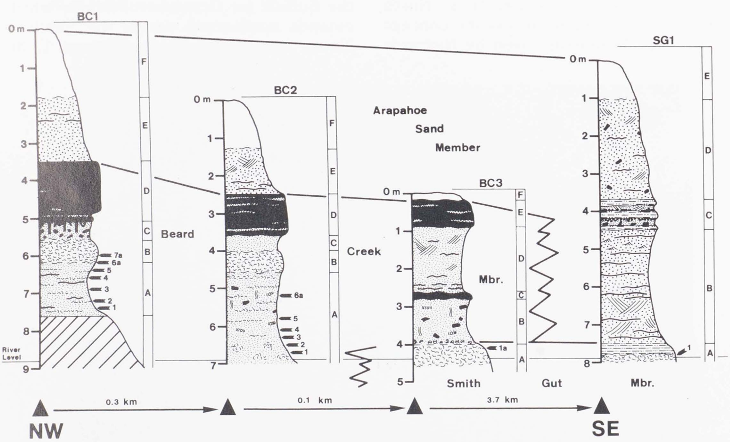

Figure 5. Stratigraphic panel-diagram of bluff-line exposures along north shore of Neuse River, Pamlico County, N.C. Exact locations of measured sections are shown in Figure 1 and described in Appendix. Bed letters are same as those used in Appendix, and arrows with numbers show stratigraphic levels from which bulk samples were collected for paleoecologic analyses. All symbols used in columns are explained in Figure 8.

Pamlico River Valley Area

Other than a reconnaissance of the stratigraphy of the bluffs along the south shore of the Pamlico River (Austin, 1973; Austin *et al.*, 1973), and an investigation of patterns of shoreline erosion in this area (Bellis *et al.*, 1975), the northern equivalents of the Flanner Beach Formation have remained essentially unstudied. My search for fossil deposits in the Pamlico valley provided the opportunity to examine and describe these bluff-line exposures (Miller, 1984).

A new description of the stratigraphy and paleontology of beds exposed in the Texasgulf, Inc., stripmine at Lee Creek in eastern Beaufort County (Ray, 1983) provides some of the latest information on units occurring to the east of, and on units situated stratigraphically below, the Flanner Beach deposits in the Pamlico-Neuse interfluvial divide. In this collection of papers, the contribution by Belt *et al.* (1983) includes a description of an environmental stratigraphic unit, their "current unit" of possible middle Pleistocene age, that may be a time-equivalent of the Flanner Beach Formation.

VI. STRATIGRAPHY OF THE FLANNER BEACH FORMATION

General Characteristics

The Flanner Beach Formation is the surface unit in the vicinity of the Neuse and Pamlico Rivers where elevations range from about +7 to +12 m MSL (Mean Sea Level). The top of the formation is typically a flat and poorly-drained plain known as the "Talbot geomorphic surface" (Daniels *et al.*, 1972), having an average elevation of about +11 m MSL (Figure 4). The main body of the formation appears to extend from the toe of the Walterboro Scarp in the west, to the crest of the Suffolk (or Grantsboro) Scarp in the east (Figure 1). Up-valley fluvial equivalents of the paralic Flanner Beach deposits no doubt are to be found occurring along the Tar, Trent, and upper Neuse Rivers west of the Walterboro Scarp; marine equivalents appear to occur in some instances in the shallow subsurface just east of the Suffolk Scarp (Daniels *et al.*, 1972, figure 9; Belt *et al.*, 1983; Wheeler *et al.*, 1983, figure 11; T.M. Cronin, *in litt.*, 9 May, 1983). This shows that the Flanner Beach is closely associated with the Talbot

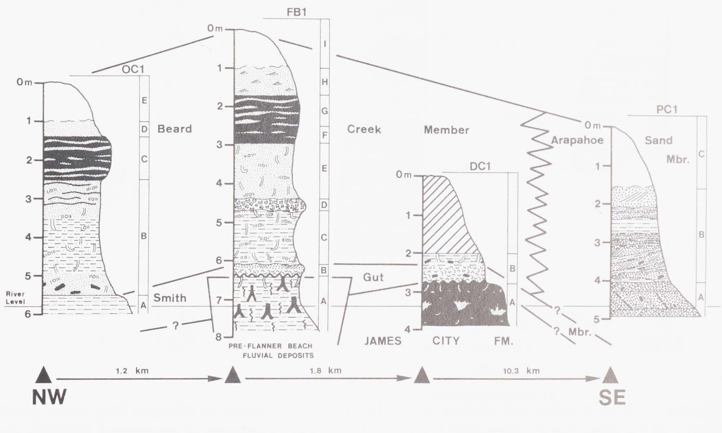

Figure 6. Stratigraphic panel-diagram of bluff-line exposures along south shore of Neuse River, Craven County, N.C. Exact locations of measured sections are shown in Figure 1 and described in Appendix. Bed letters are same as those used in Appendix. All symbols used in columns are explained in Figure 8.

surface, which appears to be the preserved surface of a sediment-filled lagoon, but is not exactly coextensive with it. Farther to the east, beneath the Outer Banks, subsurface evidence suggests that Flanner Beach equivalents in this area have either been removed by erosion or are lithostratigraphically unrecognizable (see Herbert, 1978; Susman and Heron, 1979). The Walterboro Scarp appears to be an abandoned mainland shoreline formed during deposition of at least part of the Flanner Beach Formation; whereas the Suffolk Scarp (Figure 3) in the vicinity of the Pamlico and Neuse Rivers is a regional landform post-dating the unit, and resulting from a complex history of shoreline reoccupation that eroded and truncated the eastern portion of the Flanner Beach Formation (Daniels *et al.*, 1972, 1977; Mixon and Pilkey, 1976).

The Flanner Beach Formation, in the vicinity of the Neuse River, can be subdivided into four members, three of which have been informally named and mapped by Mixon and Pilkey (1976, p. 9-18, Plate 1). The three named subdivisions are: 1) the Arapahoe Sand Member, comprising barrier-island deposits within the Flanner Beach on either side of the Neuse River; 2) the Newport Sand Member, consisting of similar, geographically disjunct barrier sands underlying ridge-and-swale topography just south of the Newport River in

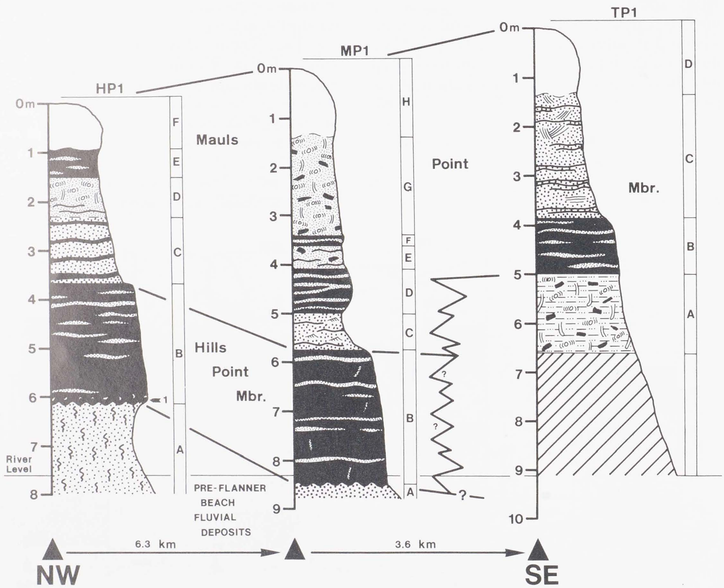

Figure 7. Stratigraphic panel-diagram of bluff-line exposures in Blounts Bay area, south shore of Pamlico River, Beaufort County, N.C. Exact locations of measured sections are shown in Figure 1 and described in Appendix. Bed letters are same as those used in Appendix, and arrow with number in column HP1 shows stratigraphic level from which bulk sample was collected for paleoecologic analysis. All symbols used in columns are explained in Figure 8.

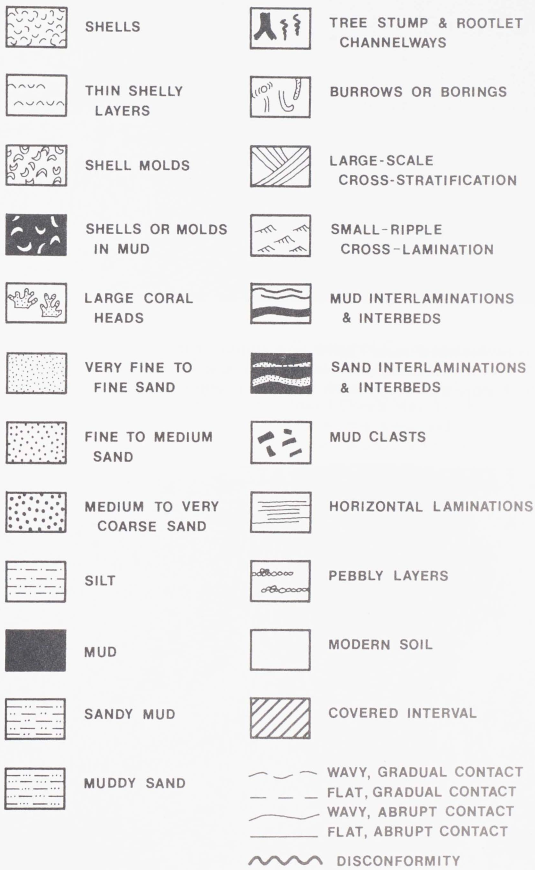

Figure 8. Explanation of symbols used in Figures 5, 6, and 7.

Figure 9. Cross-stratified sand (light) and muddy sand (dark) in the Arapahoe Sand Member at Pine Cliff Recreation Area, Craven County, N.C. (This is bed B, measured section PC1 in Figure 6 and Appendix.) Trowel is approximately 25 cm long.

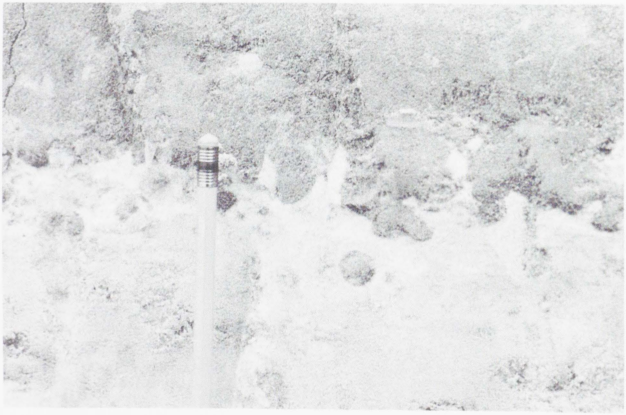

Figure 10. Close-up view of contact between a muddy sand (dark) and a clean sand (light) layer in the Arapahoe Sand Member (same location as Figure 9). Note burrows filled with muddy sand near the contact; other, less distinct burrows can be seen in the sand near bottom of photograph.

Figure 11. Bluff-line at Whisk Point, Pamlico County, N.C., immediately west of Beard Creek. Darker, lower portions of bluff correspond to exposures of the Beard Creek Member and lighter upper portions correspond to exposures of the Arapahoe Sand Member. A gradual facies change within the Beard Creek Member begins near the center of the photograph, where muddy sand beds to the west (left) start to give way to cleaner sand beds with fewer silt-clay interbeds and laminations to the east (right).

Figure 12. Exposure of Flanner Beach Formation at Whisk Point, Pamlico County, N.C. (near measured section BC3 in Figure 5). Head of digging tool rests on top of Smith Gut Member.

Figure 13. Shelly lenses composed almost entirely of the mactrid clam *Mulinia lateralis*, Beard Creek Member, Whisk Point, Pamlico County, N.C. (This is typical of upper part of bed A, measured sections BC1 and BC2, in Figure 5 and Appendix.) Ruler is 15 cm long.

Figure 14. Thick shell-bed within the Beard Creek Member (bed B, measured sections BC1 and BC2, Figure 5 and Appendix), Whisk Point, Pamlico County, N.C. Most of the shells are *Mulinia lateralis* and *Ensis directus*. Ruler is about 3 cm wide.

Carteret County; and 3) correlative, fossiliferous, muddy sand and mud backbarrier deposits of the Beard Creek Member. It is proposed here to raise these informal units to the status of formal lithostratigraphic subdivisions of the Flanner Beach Formation. Only the Beard Creek and Arapahoe Sand Members are well exposed along the Neuse River (Figures 5, 6, 8). A fourth, previously unnamed, subunit cropping out beneath the Newport Sand Member 1.6 km north of the village of Broad Creek, Carteret County, consisting of shelly, muddy sand and representing the basal beds of the formation, also crops out on the Neuse near Smith Gut, Pamlico County (Mixon and Pilkey, 1976, pp. 13, 15). This distinctly different lithologic subdivision of the Flanner Beach Formation is herein named the "Smith Gut Member," and bluffs located 0.3 km northwest (upstream) of Smith Gut (measured section SG1, Figure 1) are designated as the type locality. The type section is described in the Appendix and illustrated in Figure 5. The locality labeled SP-1 near Broad Creek, Carteret County, by Mixon and Pilkey (1976, figure 3) can be regarded as a reference section for the Smith Gut Member.

Based upon my field work along the south shore of the Pamlico River in the vicinity of Blounts Bay, and on subsurface mapping by Daniels *et al.* (1972, 1977) across the Suffolk Scarp in the Pamlico-Neuse interfluve, it appears that beds equivalent to the Flanner Beach Formation also crop out in the Pamlico valley (Figures 7, 8). The Blounts Bay exposures were described by Austin *et al.* (1973), but no lithostratigraphic units were formally named and delineated. I propose here that sands and muds, which crop out in the bluff-line between Chocowinity Bay and Tripp Point, south shore of the Pamlico River, Beaufort County (see Hackney and Blounts Bay 7.5′ quadrangles), be assigned to the Flanner Beach Formation of DuBar and Solliday (1963), and Mixon and Pilkey (1976). This assignment is based on comparable lithologies, elevations, and stratigraphic relationships with other units.

The Flanner Beach Formation in the Pamlico valley also is divisible into members, two of which are well exposed and can be traced throughout the Blounts Bay area (Figure 7). The upper portion of the Flanner Beach in this area is a sandy subunit with silt-clay interbeds, herein named the "Mauls Point Member." The bluffs located 1.2 km southwest of Mauls Point on the southeastern shore of Blounts Bay, Beaufort County, are designated as the type locality (measured section MP1, Figure 1). The type section is described in the Appendix and illustrated in Figure 7. Clayey-silt to silty-clay beds that conformably underlie the Mauls Point Member are herein named the "Hills Point Member." Bluffs located 0.2 km upstream from Camp Hardee near Hills Point, south shore of the Pamlico River, Beaufort County, are designated as the type locality (measured section HP1, Figure 1). The type section is described in the Appendix and illustrated in Figure 7. A thick burrow-mottled, muddy-sand unit, poorly exposed in the lower parts of bluff-faces between Tripp Point and Nevil Creek is another distinct lithologic subdivision (measured section TP1; Figures 1, 7).

Depositional Environments – Neuse River Valley

Most of the Flanner Beach Formation was deposited in a patchwork of nearshore environments of a major barrier-lagoon coastal complex. My interpretations of the depositional environments for each member of the formation are given below.

Smith Gut Member. – Pebbly, shelly, muddy sand, in places lying directly on the James City-Flanner Beach disconformity, appears to be a basal transgressive deposit of the Flanner Beach Formation. Bulk samples from the two best exposures of the Smith Gut Member on the northshore of the Neuse River (measured sections BC3, SG1; Figures 1, 5) contained many exotic, normal marine mollusks and older shells reworked from the subjacent James City Formation, as well as an indigenous, polyhaline association of mollusks (Miller, 1984). Exposed thickness of the Smith Gut is not more than about 0.5 m, and it appears that the unit is an irregular blanket-shaped deposit that becomes thicker in paleotopographic low areas and at the base of the southeastern extent of the formation. The Smith Gut would seem to represent the rapid flooding of coastal rivers and adjacent lowlands in the region of the Neuse and Newport River valleys at the beginning of a major episode of interglacial coastal inundation. The Smith Gut Member grades upward into barrier-sands of the Arapahoe Sand Member east of Beard Creek at its type locality: West of Beard Creek and near the Flanner Beach Recreation Area, the Smith Gut grades upward and landward (?) into backbarrier muddy sands of the Beard Creek Member (Figures 5, 6).

Newport Sand Member. – This subdivision of the Flanner Beach, originally proposed as an informal unit by Mixon and Pilkey (1976, p. 9-11), was not examined in the course of my field study. These authors regarded it as a barrier-sand lithosome associated with ridge-and-swale landforms in Carteret County. The Newport Sand Member ranges in thickness from about 3 m in the northwestern part of its outcrop area to about 12 m near the village of Broad Creek in the south, and is geometrically a thin wedge that tapers to the northwest where it intertongues with the Beard Creek Member. At least the upper part of the unit, associated with convex-landward beach ridge topography, represents a local progradation of the Flanner Beach shoreline late in the depositional cycle of the formation (Mixon and Pilkey, 1976).

Arapahoe Sand Member – Cross-stratified, fine to coarse sand, with subordinate muddy sand interbeds, pebbly layers, and small cylindrical burrows, cropping out near Smith Gut and at the Pine Cliff Recreation Area (SG1, Figure 5; PC1, Figures 6, 9), is typical of the Arapahoe Sand Member. This barrier sand unit is also a thin, wedge-shaped deposit that is probably truncated on the east by the Suffolk (or Grantsboro) Scarp and intertongues to the west with the Beard Creek Member. At Whisk Point, Pamlico County (measured sections BC1 and BC2, Figure 5), the Beard Creek Member grades upward into a fine sand, about 3 m thick with occasional cross-laminations and discontinuous clay laminations, that appears to be either distal flood tidal-delta or backbarrier sandflat deposits within the Arapahoe Sand Member. The member is up to 7.5 m thick along its eastern margin near the Suffolk Scarp (Mixon and Pilkey, 1976, p. 13).

At the Smith Gut section (SG1, Figure 5),

Figure 15. Ichnofossil *Teichichnus* in the Beard Creek Member at Otter Creek, Craven County, N.C. (bed B, measured section OC1, Figure 6 and Appendix). Ruler is graduated in centimeters and millimeters.

the Arapahoe Sand consists of three beds: 1) a lower medium to coarse sand with megaripple cross-laminations in the lower half, small-ripple cross-laminations in the upper half, and clay interlaminations throughout; 2) a middle bed consisting of interbedded sandy mud and cross-laminated, pebbly sand; and 3) an upper fine to medium sand with megaripple cross-laminations, discontinuous clay laminations, and clay clasts. The sequence seems to represent shallow channel tidal-delta sands, situated above and below a thin interval of sandflat deposits. At Pine Cliff Recreation Area (measured section PC1, Figure 6), two well defined beds are exposed: 1) a lower fine to coarse sand with wedge-shaped cross-stratification sets, pebbly layers (with flat, discoid quartz pebbles up to 1 cm in diameter), and large clay clasts; grading upward into 2) a thicker sequence of interbedded fine to medium sand and muddy sand, with abundant bivalve burrows (Figure 10), large scale cross-bedding in the lower and upper parts (Figure 9), and horizontal bedding in the middle part. These beds appear to represent a succession of deep to shallow channel settings within a tidal-delta depositional environment, together with possible tidal-flat areas. The lateral facies change from barrier complex sands of the Arapahoe Sand to the backbarrier deposits of the Beard Creek Member takes place over a broad area beginning near measured section BC3 (Figures 5, 11, 12) at what is now the mouth of Beard Creek.

Beard Creek Member. – Landward of the Newport Sand and Arapahoe Sand Members, shelly, muddy sands with minor silt-clay interbeds crop out along both sides of the Neuse River valley. The Beard Creek Member is up to 6 m thick near the Flanner Beach Recreation Area (measured section FB1, Figure 6) and 4 m thick at Whisk Point (BC1 and BC2, Figure 5), forming a fairly regular blanket-shaped deposit beneath the Talbot geomorphic surface. The Beard Creek could be up to 15 m thick along the axial portion of the ancestral Neuse River paleochannel (see Mixon and Pilkey, 1976, p. 18), but the basal part of these deposits may actually include beds of the Smith Gut Member, as defined herein.

Beard Creek Member exposures at the type locality at Whisk Point consist of four beds, resting conformably on the Smith Gut Member (BC1, BC2; Figure 5): 1) a lower, thick bed consisting of fine sand to muddy sand with pods, stringers, and flat lenses of mollusk shells (consisting overwhelmingly of the valves of *Mulinia lateralis;* Figure 13); overlain by 2) a very shelly, very fine to fine sand packed with *M. lateralis* (Figure 14); grading upward into 3) a thin bed of fine to medium sand, in places with burrows, clay clasts, and *Cyrtopleura* sp. in living positions; capped by 4) a laminated mud with sand interlaminations and lenses, and lacking fossil shells. This sequence of beds records first an environmental mosaic of polyhaline to mesohaline, sandy bottom settings near the seaward margins of a bay or lagoon; followed by shelly, lagoon-floor areas that received little net sediment accumulation owing to by-passing or winnowing when local inlets were active; then sandy lagoonal firm-grounds; and finally the very fine-grained floor of a lagoon center or mainland lagoon-margin bay at the top of the sequence. As the Arapahoe Sand Member outcrop area is approached from the west, Beard Creek Member environ-

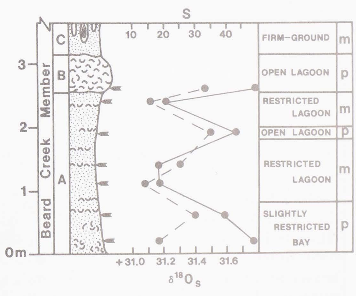

Figure 16. Oxygen-isotope stratigraphy of the Beard Creek Member at Whisk Point, Pamlico County, N.C. Species richness, S (solid line), and $\delta^{18}O_s$ (dashed line) are plotted together against stratigraphic elevation. Fossil associations recognized in bulk samples listed along right side of diagram with inferred average relative salinity (m = mesohaline, p = polyhaline).

ments become largely sandy bottom, outer lagoonal settings with sand derived from sandflats, wash-over fans, and flood tidal-deltas of the adjacent barrier complex (see measured section BC3, Figure 5; also Figures 11, 12).

The Beard Creek Member along the south shore of the Neuse River is generally finer-grained or contains more fine-grained beds, and lacks shelly beds upstream from the Flanner Beach Recreation Area. The stratigraphy of the Flanner Beach Formation at its type locality has been discussed by DuBar and Solliday (1963), and DuBar *et al.* (1974). The exposures at the type locality are now so deeply weathered and overgrown that only the shelly lower portions of the formation are well exposed, and these deposits may form part of the Smith Gut Member rather than the Beard Creek. The exposures at Otter Creek (measured section OC1, Figure 6) have not been previously described, and consist for the most part of two thick beds: 1) a lower sand – silt – sand sequence that is thoroughly bioturbated, with a well-preserved final generation of traces including *Thalassinoides* and *Teichichnus* (Figure 15); overlain by 2) laminated mud with wavy, discontinuous sand interlaminations, lacking trace fossils. This succession of beds represents sandy to silty lagoonal deposits overlain by lagoon-margin muds. A thin, fine sand bed caps the Otter Creek and Flanner Beach Recreation Area sections (Figure 6), and could represent progradational river-estuary deposits.

Depositional Environments – Blounts Bay Area

Hills Point Member. – The lowest bed in the Flanner Beach Formation in the Blounts Bay area of Beaufort County is a laminated silty-clay to clayey-silt with sand lenses and interlaminations, few *Planolites* burrow systems, and carbonized wood fragments. The only body fossils that were collected *in situ* from Flanner Beach equivalents in the Pamlico River valley were molds of *Rangia cuneata*, an oligohaline clam, from the base of the Hills Point Member at its type section (HP1, Figure 7). The Hills Point is about 2.5 m thick and seems to have a blanket-like or tabular geometry. It intertongues with, and grades upward into, the Mauls Point Member, which in places is rather heavily burrow-mottled, suggesting an environmental succession from slightly brackish to possibly mesohaline or even polyhaline conditions. The Hills Point Member probably accumulated as very fine-grained sediments and/or fecal pellets in a well-protected, low salinity lagoonal or river-estuary setting.

Mauls Point Member. – The deposits conformably overlying the Hills Point Member in the bluffs along the margins of Blounts Bay consist of a complex of interbedded sands, muds, and biogenically homogenized units. The Mauls Point Member is about 4 m thick at the type locality (MP1, Figure 7) and also appears to be a blanket-shaped unit. The type section consists of a sequence of five beds: 1) a basal fine to medium sand, with wavy clay interlaminations and small-ripple cross-laminations; 2) a thick bed of interbedded sand and mud; 3) followed by another fine sand bed like the basal layer; 4) a thin mud-sand bed, like the one above the basal sand; and finally, at the top, 5) a thick, burrow-mottled, fine sand with disrupted clay interlaminations. The lower cyclic portion of the sequence seems to represent alternating periods of abundant sand supply and/or higher hydraulic energy levels, and periods of at least intermittently lowered sand supply and/or increased protection from waves and currents. The upper burrow-disrupted bed suggests higher salinity levels allowing larger populations and greater varieties of trace-makers to rework bottom sediments. Mauls Point beds appear to have been deposited in more open lagoonal settings compared with the muds of the Hills Point Member.

Unnamed member. – The Hills Point Member appears to grade eastward into a heavily burrow-mottled, very fine to fine sand containing clay clasts (Figure 7). This unit was probably deposited in the sandy bottom, polyhaline, outer portions of a lagoon. Austin *et al.* (1973) reported abundant molds of bivalves from these deposits. This unit bears the closest resemblance to the typical Flanner Beach Formation deposits of the Neuse River valley of any time-equivalent units examined in the Pamlico valley. It could represent the environmental (facies) equivalent of the lower Beard Creek Member, as exposed at Whisk Point, Pamlico County, and Flanner

Beach Recreation Area, Craven County (Figures 5, 6).

Oxygen-Isotope Stratigraphy

Oxygen-isotope ratio analyses were performed on seven subsamples of *Mulinia lateralis* valves from bulk samples collected from the Beard Creek Member at Whisk Point, Pamlico County (BC1 and BC2; Figures 1, 5). The results are plotted with overall species-richness values of the fossils against stratigraphic elevation in Figure 16, and are expressed in terms of $\delta^{18}O_s$, where

$$\delta^{18}O_s = \left(\frac{^{18}O/^{16}O_{sample}}{^{18}O/^{16}O_{SMOW}} - 1 \right) \times 1000.$$

Deviations are given with respect to the SMOW (Standard Mean Ocean Water) standard (see Anderson and Arthur, 1983).

The $\delta^{18}O$ values from the Beard Creek Member have a mean of +31.29‰ and range between +31.08 and +31.50‰. All samples were rather rich in the heavier isotope, yet the fossils, sediments, and environmental stratigraphic profile of the Beard Creek Member do not suggest unusually high average salinity levels or low growth temperatures for mollusks in original backbarrier habitats (see Miller, 1984). Tan and Hudson (1974) analyzed stable isotopic compositions of mollusks from the Jurassic Great Estuarine Series of Scotland, a marginal marine paleoenvironmental patchwork not unlike the Flanner Beach Formation, and discovered some freshwater and brackish-water mollusks with unaccountably heavy oxygen-isotope values. Lloyd (1964, 1969) suggested that meteoric water precipitated in marsh and mudflat areas marginal to open bodies of water may become enriched in ^{18}O during seasonal dry periods, then are flushed into the adjacent well-mixed waters, with the heavier isotope eventually incorporated into calcareous skeletons of resident invertebrates. Another possibility is that *M.*

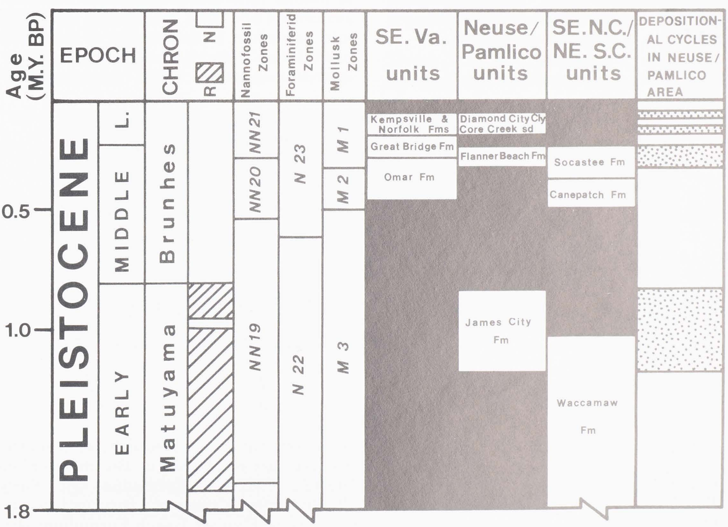

Figure 17. Time-correlation of the Flanner Beach Formation, based on unpublished information provided by Dr. Thomas M. Cronin, U. S. Geological Survey (*in litt.*, 9 May, 1983). Column at right shows depositional cycles in east-central North Carolina.

lateralis may preferentially incorporate the heavier isotope into its skeleton as a result of some sort of "vital effect," or physiologically-mediated non-equilibrium precipitation of $CaCO_3$ as aragonite (see Urey *et al.*, 1951). Perhaps a combination of the flushing of marginal marshes containing waters rich in $\delta^{18}O$, together with the growth of *M. lateralis* shells during spring months in seasonally cool estuarine waters that became mixed with this isotopically heavy runoff, would explain the systematically high $\delta^{18}O_s$ values of carbonate skeletons that grew during a major interglacial high-stand of sea level linked to global warming.

Considering the estuarine paleoenvironmental setting of the Beard Creek Member, oscillations in $\delta^{18}O_s$ probably reflect the effects of dilution of isotopically rather heavy lagoonal waters by lighter freshwater from rivers and streams. Variation of $\delta^{18}O_s$ values with salinity levels in estuaries can be nearly linear (Dodd and Stanton, 1981, figure 3.28), and several studies have successfully employed oxygen-isotope ratio analyses of marginal marine fossils to determine paleosalinities (*e.g.* Tan and Hudson, 1974; Dodd and Stanton, 1975). In most Beard Creek Member samples, highest values of $\delta^{18}O_s$ for *M. lateralis* valves correspond to high values of overall species richness and molluscan diversity, and low values of $\delta^{18}O_s$ are usually matched by high values of molluscan dominance. Therefore, considered in unison with environmental stratigraphic and paleoecologic information, variations in $\delta^{18}O_s$ appear to reflect rhythmic, long-period changes in average salinity levels within the Beard Creek Member (Miller, 1984).

Age and Correlation of the Flanner Beach Formation

The determination of ages and coastwise correlations of Quaternary stratigraphic units in the Atlantic Coastal Plain have

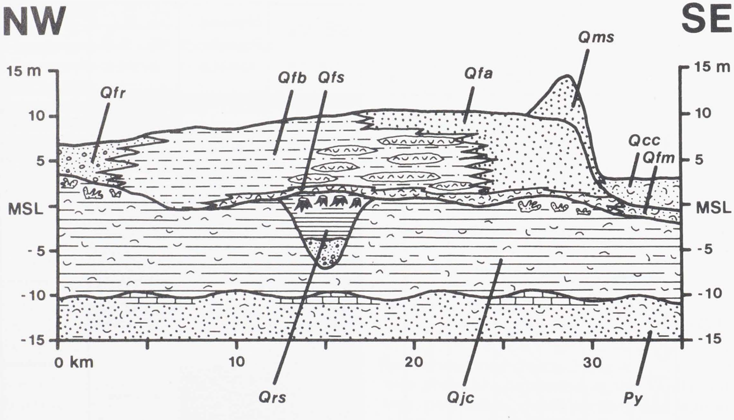

Figure 18. Schematic stratigraphic cross-section down the lower Neuse River from the vicinity of Johnson Point, Craven County, to just east of Minnesott Beach, Pamlico County. Lithostratigraphic units are: *Py*, Pliocene Yorktown Formation; *Qjc*, Early Pleistocene James City Formation; *Qrs*, pre-Flanner Beach river and swamp deposits; *Qfr*, up-valley fluvial equivalents of Middle Pleistocene Flanner Beach Formation; *Qfs*, Smith Gut Member of Flanner Beach Formation; *Qfb*, Beard Creek Member of Flanner Beach Formation; *Qfa*, Arapahoe Sand Member of Flanner Beach Formation; *Qfm*, marine equivalents of Flanner Beach Formation; *Qms*, Late Pleistocene Minnesott sand; *Qcc*, Late Pleistocene Core Creek sand.

been based largely on three properties: 1) elevation and lateral continuity of tops of units forming surface formations [extension of the terrace-formation concept employed by Shattuck (1906), and Stephenson (1912), and many subsequent workers]; 2) vertical relationships of units separated by unconformities (*e.g.* Mansfield, 1928); and 3) identity and relative ages of macroinvertebrate fossil assemblages, mainly mollusks (*e.g.*, Richards' 1936 and 1965 criterion for recognition of "Pamlico Formation" deposits). Newer methods involve the study of smaller areas in greater detail, use of subsurface borings to trace units in the shallow subsurface, and utilization of various paleontologic, geochemical, and geophysical innovations. These innovations include: 1) the use of microfossils, such as foraminiferids and ostracodes, to establish worldwide and intrabasinal correlations (Akers, 1972; Cronin and Hazel, 1976; Cronin, 1980); 2) employment of ostracodes and pollen to reconstruct ancient climates and geographies (*e.g.* Cronin *et al.*, 1981; Whitehead, 1983, and references therein); 3) refinement of molluscan biostratigraphy in the Atlantic Coastal Plain (Blackwelder, 1981a); 4) magnetostratigraphic techniques used to relate onshore Coastal Plain units to a worldwide magnetic time scale (Liddicoat *et al.*, 1979; Liddicoat and Mixon, 1980; Liddicoat *et al.*, 1981); and 5) geochronometric applications of amino acid and radiometric methods (Colquhoun and Blanchard, 1971; Bender, 1973; Belknap *et al.*, 1977; Moslow and Heron, 1979; Blackwelder, 1981a, 1981b; Cronin, 1981; McCartan *et al.*, 1983; Wehmiller and Belknap, 1983). Owing to recent developments in Quaternary oceanic stratigraphy involving the application of stable light-isotope analyses, radiometric and magnetic geochronometry, and biostratigraphic zonations employing planktonic foraminiferids and calcareous nannofossils (see Berggren and van Couvering, 1974; van Donk, 1976), correlations with a more or less continuous and well documented Atlantic Ocean Basin record are now potentially possible for Pleistocene coastal formations.

In the Quaternary section of the Neuse River area, four major transgressive-regressive depositional cycles are preserved as unconformity-bounded sequences. These are, from oldest to youngest: 1) James City Formation (early Pleistocene);

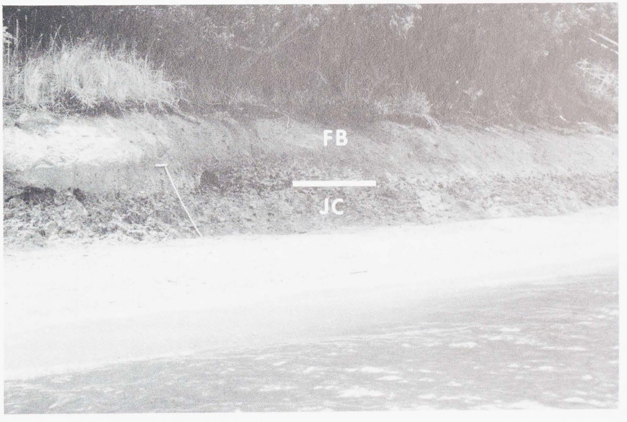

Figure 19. Disconformity separating James City (JC) and Flanner Beach (FB) Formations at private beach 0.7 km southeast of Dam Creek, Craven County, N.C. (measured section DC1 in Figure 6 and Appendix). Ruler is about 1 m long.

2) Flanner Beach Formation (middle Pleistocene); 3) Core Creek sand (late Pleistocene); and Diamond City Clay – Atlantic sand (also late Pleistocene) (DuBar *et al.*, 1974; Mixon and Pilkey, 1976; McCartan *et al.*, 1982). Each depositional cycle should correspond to at least one period of global warming, diminution of continental ice sheets, and rise in world sea-level.

Based on uranium-series and amino acid dating of fossils, the Flanner Beach Formation is now thought to be about 200,000 years old. It is disconformably underlain by an older Pleistocene unit (James City Formation) dating to about 700,000 to 1,000,000 years B.P., and is bordered on the east by younger Pleistocene coastal-margin deposits (Core Creek Sand) dating to about 75,000 to 130,000 years B.P. (McCartan *et al.*, 1982; Thomas M. Cronin, U.S. Geol. Surv., *in litt.*, 9 May, 1983). The Diamond City – Atlantic cycle is apparently Wisconsinian. Liddicoat *et al.* (1979) have shown that the Flanner Beach was deposited during a period of normal magnetic polarity, whereas the underlying James City appears to have been deposited during an earlier period of reversed polarity. They place the Brunhes-Matuyama magnetostratigraphic boundary (dating to about 730,000 years B.P.) in the gap separating the two formations.

If dating of the Flanner Beach is accurate, the unit is correlative with van Donk's (1976) oxygen-isotope stage 7 in the Western Atlantic Basin. In the southeastern Atlantic Coastal Plan, the Flanner Beach Formation is contemporary with the Great Bridge Formation in southeastern Virginia and with the Socastee Formation in southeastern North Carolina – northeastern South Carolina. The formation is within Cronin's (1980, figure 5) ostracode Zone C and Blackwelder's (1981a) mollusk zone M1 (lower Yongesian Substage of the Longian Stage). Figure 17 summarizes the time-correlation of the Flanner Beach and related units as currently understood.

Flanner Beach Depositional Cycle

The sediments and fossils of the Flanner Beach Formation were deposited during a high stand of world sea-level about 200,000 years B.P., corresponding to a major interglacial period reflected in oxygen-isotope stratigraphy of deep oceanic cores (van Donk, 1976, figure 5). Estimated maximum sea-level at this time was +8 (±4.0) m MSL (Cronin *et al.*, 1981). The Flanner Beach can be considered an allostratigraphic unit (see North American Commission on Stratigraphic Nomenclature, 1983, p. 865-867), separated from older (James City) and younger (Core Creek) unconformity-bounded sequences by stratigraphic discontinuities that record low stands of sea-level, which correspond to periods of global cooling, continental glaciation, and coastal emergence (Figures 18, 19).

Internally the Flanner Beach cycle consists of a basal typically thin, pebbly muddy sand (Smith Gut Member) that represents the early and perhaps very rapid inundation of the eastern and southern parts of the Pamlico-Neuse area. This unit contains an environmentally and temporally mixed fossil assemblage that accumulated during the initial submergence of the ancestral Neuse River valley, estuarine lowlands and bordering swamps (*e.g.* cypress-stump bed at Flanner Beach Recreation Area), and seaward areas of low relief (locality SP-1, in Mixon and Pilkey,

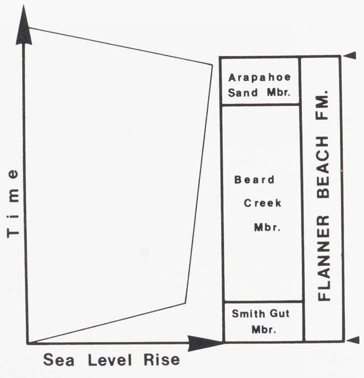

Figure 20. Eustatic model of Flanner Beach Formation as exposed at Whisk Point, Pamlico County, N.C. This is very similar to Hallam's (1981, p. 124) eustatic model E, with rapid rise and lowering of sea level interrupted by a prolonged period of very gradual rise in sea level.

1976, Plate 1). Following the initial flooding of the Neuse River area it appears that barrier islands, possibly prograding southward from a headland in the vicinity of the Pamlico River, began the isolation of a coastal compartment that was to become the depositional center for shelly, muddy sand of the Beard Creek Member to the south, and for sediments of the Hills Point and Mauls Point Members to the north. Communication with the adjacent ocean through migrating inlets was more open in the southern portion of this estuarine basin, as shown by stratigraphic evidence and presence of polyhaline fossil associations (Miller, 1984). The gap between the Arapahoe Sand and Newport Sand outcrop areas (Mixon and Pilkey, 1976, Plate 1) may indicate the former position of a large bay-mouth that originally separated these two barrier segments. This baymouth would have allowed open circulation between a backbarrier bay or sound and the adjacent Atlantic Ocean. The Flanner Beach Formation sediments cropping out in the Pamlico River valley would have been deposited in a shallow, protected part of the basin farthest from the bay mouth and probably close to the mouth of the ancestral Tar River, as shown by facies relationships, lithologies, and the presence of few trace fossils and oligohaline clams. Within the Beard Creek Member, a succession of beds with mesohaline to polyhaline fossil associations, with varying $\delta^{18}O$ values (Figure 16), records changes in circulation patterns within the basin caused by modifications in coastal geomorphology (establishment of the Arapahoe barrier, opening and closing of inlets, in-filling of the basin). This is a second-order cycle developed within the primary glacio-eustatic depositional cycle represented by the entire formation.

After deposition of the Smith Gut Member, the rate of sea-level rise apparently decreased, as during the ongoing post-Wisconsinian eustatic rise of sea-level (see Milliman and Emery, 1968; Bloom, 1970). During this interval the Arapahoe-Newport barrier was constructed; inlet formation and migration, and backbarrier basin infilling were probably the dominant depositional processes. Landward building of washover fans and development of extensive flood tidal-deltas helped to complete the filling of the Flanner Beach estuarine basin (*cf.* Moslow and Heron, 1979, p. 229-233), as indicated by the facies onlap of Arapahoe Sand onto Beard Creek Member deposits at Whisk Point, Pamlico County (Figure 5, 11). At about the same time, the Newport barrier segment to the south was prograding seaward, as indicated by the development of curved, convex-landward beach ridges in Carteret County. Laminated mud beds, which lack fossils or burrows, occurring near the top of the Beard Creek Member at Otter Creek and Flanner Beach Recreation Area, Craven County, and at Hills Point, Beaufort County, in the top of the Mauls Point Member (Figures 6, 7), could represent the final stage of in-filling of the backbarrier basin by fine-grained lacustrine (?) or river-estuary sediments. A rapid lowering of sea-level left the Flanner Beach Formation emergent, and susceptible to fluvial erosion by down-cutting of river channels and to pedogenic alteration as the marine shoreline retreated across the continental shelf to the east (see Figure 20).

VII. FUTURE WORK ON THE FLANNER BEACH FORMATION AND RELATED UNITS

The U. S. Geological Survey continues to show a great amount of interest in the Flanner Beach and related units in the Atlantic Coastal Plain. New reports on paleoclimatology and sea-level history of coastal formations (Thomas M. Cronin), and on new uranium-series dates from this area (Barney J. Szabo) are being prepared. The paleoecologic findings from my study of Flanner Beach Formation fossils will be published within about a year. The present report is intended to provide an update on the stratigraphy of the Flanner Beach Formation and indicates that much is now known about the geologic history of this interesting unit.

In the future, researchers might consider examining the following unsolved problems:

1) Can marine equivalents of the Flanner Beach be recognized east of the Suffolk Scarp, and what is the nature and age of these deposits?

2) Few studies have attempted to relate Quaternary, up-valley fluvial units in the Atlantic Coastal Plain to the better known estuarine and marine deposits of the outer Coastal Plain (see Miller, 1979). Researchers interested in fluvial processes and landforms of coastal rivers can rightly regard this as a completely open field for study in North Carolina.

3) More needs to be known about the latest Pleistocene history of the Pamlico-Neuse area. Units such as the "Atlantic sand" of Mixon and Pilkey (1976) need to be investigated in more detail, and related to older and younger depositional cycles.

4) Is there a distinct depositional cycle represented by the "intermediate terrace" lying between the Pinetown and Union Chapel scarps, with a surface elevation of about +10 m MSL, described briefly by Mixon and Pilkey (1976, p. 36) from the Albermarle Sound – Pamlico River interfluvial plain? Or, alternatively, is this surface related to emplacement of the Flanner Beach Formation or Core Creek Sand?

5) Is the Walterboro Scarp the western boundary of Flanner Beach estuarine beds, or do Flanner Beach deposits extend beneath the scarp to the west, with the scarp representing a temporary stillstand of a retreating Flanner Beach sea (see Daniels *et al.*, 1972, figure 3 and p. 16)?

6) To my knowledge, stable light isotopes have not been used to any great extent to characterize paleotemperatures and paleosalinities in the outer Coastal Plain of North Carolina. My use of fluctuations in $\delta^{18}O$ values in the Beard Creek Member to corroborate faunal inferences of local changes in relative salinity levels during the development of the Flanner Beach estuarine basin has convinced me of the great potential that this approach holds. With careful paleoecologic studies, isotope-ratio analyses should yield valuable data that will enable more accurate, detailed reconstructions of paleoenvironments.

7) Although much has been written about occurrences of macroinvertebrate fossils in the Neuse River area, little useful paleoecologic information has ever been published. The units in this area are no less interesting paleontologically because they are so geologically young; the fauna contained in the James City, Flanner Beach, and Core Creek sequences can be very rich in species and/or numbers of individuals and records an extraordinary history of changing climates and sea-levels in the region. The study of the faunal and floral history of these Quaternary units has just begun.

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IX. APPENDIX

Measured sections in the Flanner Beach Formation in its type area (Neuse River valley) and in the Blounts Bay area (Pamlico River valley), eastern North Carolina.

All sections measured and described in Summer, 1982. Measured section numbers and bed letters are keyed to the stratigraphic panel diagrams (Figures 5, 6, 7, 8). Location of sections is shown in Figure 1, and described in detail at the beginning of each entry below. *Section SG1 is the type section of the Smith Gut Member, section HP1 is the type section of the Hills Point Member, and section MP1 is the type section of the Mauls Point Member.*

NORTH SHORE OF NEUSE RIVER, FIGURE 5

I. *MEASURED SECTION BC1*

Bluffs 0.6 km northwest of center of mouth of Beard Creek, at end of jeep trail about 0.3 km upstream from Whisk Point; north shore Neuse River, Pamlico County, N. C.; southeast corner Upper Broad Creek 7.5 ′ quadrangle.

FLANNER BEACH FORMATION

ARAPAHOE SAND MEMBER

F. Soil . . . . 1.8 m

E. Sand, fine, well-sorted, angular to subangular, loose, light pinkish-gray (5 YR 9/1); few slightly indurated muddy sand interlaminations; traces of heavy minerals and mica; no fossils observed; heavily burrow-mottled (?) gradational contact with top of bed D . . 1.7

BEARD CREEK MEMBER

D. Mud with sand interlaminations and lenses; sticky, slightly indurated; dark greenish-gray (5 G 4/1) with moderate brown (5 R 4/4 – 3/4) color mottles; sand partings up to 10 mm thick near top and bottom, 2 to 3 mm thick near middle; no fossils observed; top grades into unit E, bottom intertongues with unit C 1.6

C. Sand, fine, moderately sorted, subangular, moderately indurated; dark bluish-gray (5B 4/1); top heavily burrowed, with small curved-cylindrical burrows about 5 mm in diameter and larger straight-cylindrical burrows 4 to 5 cm in diameter; some larger burrows contain *Cyrtopleura* sp. in living positions, molds of other bivalves near bottom; clay clasts (= disrupted clay interlaminations) scattered throughout; top intertongues with unit D, bottom undulatory and grades into unit B 0.5

B. Shelly sand; sand very fine to fine, poorly sorted, subangular to angular, trace of heavy minerals; dark greenish-gray (5 G 3/1); abundant *Mulinia lateralis*, *Ensis directus*, *Polinices duplicatus*, *Busycon* spp., bivalves mostly disarticulated and randomly oriented; slightly muddy in places; top and bottom undulatory and gradational with units C and A 0.6

A. Sand, fine, subangular to subround, moderately sorted, slightly indurated; medium bluish-gray (5B 5/1); discontinuous clay interlaminations up to 2 cm thick with burrow perforations; shelly sand lenses up to 5 cm thick with abundant *Mulinia lateralis*, surrounded by sparsely fossiliferous, bioturbated sand; bivalve shells oriented randomly near bottom and with convex-sides-up near top; trace of heavy minerals; top grades into unit B and base is covered . . . . 1.4+

Covered interval 1.2

Total: 8.8 m

II. *MEASURED SECTION BC2*

Bluffs about 0.3 km southeast of BC1 and 0.4 km northwest of center of mouth of Beard Creek, at Whisk Point, north shore Neuse River, Pamlico County, N.C.; southwest corner Arapahoe 7.5′ quadrangle.

FLANNER BEACH FORMATION

ARAPAHOE SAND MEMBER

F. Soil . . . . 1.2 m

E. Sand, fine, well-sorted, subangular, loose; light pinkish-gray (5 YR 9/1); faint trough cross-laminations and few clay interlaminations near base; trace of heavy minerals; no fossils observed; top gradational with unit F, bottom intertongues with unit D 1.2

BEARD CREEK MEMBER

D. Mud with sand interlaminations and lenses; sticky, slightly indurated; dark greenish-gray (5 G 4/1) with moderate brown (5 YR 4/4) color mottles; sand interlaminations more common, thicker near top and bottom; no fossils observed; top and bottom intertongue with units C and E 1.1

C. Sand, fine to medium, moderately sorted, subangular to angular, moderately indurated; dark bluish-gray (5 B 4/1); slightly muddy, structureless (bioturbated?); no fossils observed; top intertongues with unit D, bottom undulatory and grades into B 0.4

B. Shelly sand; sand very fine to fine, poorly sorted, subangular to angular, trace of heavy minerals; dark greenish-gray (5 G 3/1); abundant *Mulinia lateralis*, *Ensis directus*, *Polinices duplicatus*, *Busycon* spp., bivalves mostly disarticulated and randomly oriented; slightly muddy in places; top and bottom undulatory and gradational with units C and A 0.6

A. Sand, fine, well-sorted, subangular to angular, slightly indurated; medium bluish-gray (5 B 5/1); clay clasts and burrow systems referrable to *Thalassinoides;* slightly muddy near base; shelly lenses near top and irregularly shaped pods near bottom with abundant *Mulinia lateralis,* surrounded by sparsely fossiliferous bioturbated sand; bivalve shells in lenses near top of unit frequently oriented convex-sides-up, more often randomly oriented near base of unit; trace of heavy minerals; top grades into unit B, bottom not exposed . . . . . 2.4+

Total: 6.9 m

III. *MEASURED SECTION BC3*

Bluffs about 0.1 km east of BC2 and 0.3 km northwest of center of mouth of Beard Creek, at Whisk Point, north shore Neuse River, Pamlico County, N. C.; southwest corner Arapahoe 7.5′ quadrangle.

FLANNER BEACH FORMATION

BEARD CREEK MEMBER

F. Soil . . . . . 0.2 m

E. Mud with sand interlaminations and lenses, pedogenically altered and moderately indurated; dark yellowish-orange (10 YR 6/6) to grayish orange (10 YR 7/4); no fossils observed; top grades into unit F, bottom grades abruptly into unit D 0.7

D. Sand, fine to very fine, moderately sorted, subangular, loose with slightly indurated limonitic layers, very pale orange (10 YR 8/2), limonite-cemented zones light brown (5 YR 5/6); ripple cross-laminated, few clay flasers in ripple troughs, clay interlaminations near base 9 to 14 cm thick; no fossils observed; top and bottom grade abruptly into units E and C 1.7

C. Interlaminated clay and sand; clay dark greenish-gray (5 G 4/1), sand same as in unit D; no fossils observed; top and bottom grade abruptly into units D and B 0.2

B. Sand, fine, moderately to well sorted, subangular, slightly indurated; light olive-gray (5 Y 6/1) in upper two-thirds changing to dark bluish-gray (5 B 4/1) in lower third; heavily bioturbated, clay clasts and biogenically distrupted clay laminations; few bivalve molds near base; becomes slightly silty near bottom; top grades abruptly into unit C, bottom grades gradually into unit A 1.2

SMITH GUT MEMBER

A. Shelly sand; sand very fine to fine, poorly sorted, subround, moderately indurated; dark greenish-gray (5 G 4/1); silty and contains abundant shells of *Mulinia lateralis*, some of which are oriented convex-sides-up but most are arranged randomly in bed; contains some reworked James City Formation fossils and forms limonite-cemented ledge at toe of bluff, so could be mistaken for top of older formation; top grades into unit B, bottom not exposed . . . . . 0.6+

Total: 4.6 m

IV. *MEASURED SECTION SG1*

Bluffs 3.4 km southeast of center of mouth of Beard Creek and 0.3 km northwest of Smith Gut, north shore of Neuse River, Pamlico County, N. C.; northwest part of Cherry Point 7.5′ quadrangle. *Type section of Smith Gut Member.*

FLANNER BEACH FORMATION

ARAPAHOE SAND MEMBER

E. Soil . . . . . 1.0 m

D. Sand, fine to medium, moderately sorted, subangular to angular, loose; yellowish-gray (5 Y 8/1); trough cross-laminated, with occasional wavy clay interlaminations and clay clasts; heavy mineral content and size of clay clasts increase toward base; no fossils observed; contact with unit E gradational, contact with unit C wavy, sharp 2.6

C. Interbedded sandy mud and sand; mud layers laminated to massive, soft, pale red (10 R 6/2) to pale yellowish brown (10 YR 6/2); sand fine, well sorted, subround to subangular, loose, very pale orange (10 YR 8/2); sand interbeds contain burrows, discontinuous to continuous pebble layers (quartz pebbles up to 1 cm in longest dimension), clay clasts, and ripple cross-laminations; no fossils observed; top contact sharp with unit D, bottom undulatory, grading into unit B 0.8

B. Sand; near top – medium, moderately sorted, subround to subangular, loose, white (N9); near bottom – medium to coarse, poorly sorted, round to subangular, loose, dark yellowish-orange (10 YR 6/6); clay interlaminations throughout, with ripple cross-laminations and clay drapes in upper part and trough cross-laminations in lower part; no fossils observed; top grades into unit C, bottom grades abruptly into unit A 3.0

SMITH GUT MEMBER

A. Muddy sand with shells; upper 3 cm sand-mud mixture with sand fine to medium, subround to subangular, poorly sorted as a shole, slightly indurated, light olive-brown (5 Y 5/6); bottom part slightly less muddy with abundant shells of *Mulinia lateralis*, slightly indurated, dark greenish-gray (5 GY 4/1); top grades abruptly into unit B, base not exposed . . . . 0.5 +

Total: 7.9 m

SOUTH SHORE OF NEUSE RIVER, FIGURE 6

V. *MEASURED SECTION OC1*

Bluffs 0.3 km southeast of center of mouth of Otter Creek and 0.7 km northwest of Flanner Beach Recreation Area, south shore Neuse River, Craven County, N. C.; north-central part of Havelock 7.5′ quadrangle.

FLANNER BEACH FORMATION

BEARD CREEK MEMBER

E. Soil . . . . 0.9 m

D. Sand, fine, poorly sorted, subangular to angular, moderately indurated, grayish-orange (10 YR 7/4); pedogenically altered, apparently structureless, slightly silty; no fossils observed; top and bottom grade into units E and C 0.4

C. Mud, slightly sandy, light gray (N7); with discontinuous wavy sand interlaminations up to 4 cm thick near top and bottom; sand very fine to fine, moderately sorted, subround to subangular, yellowish gray (5 Y 8/1); no fossils observed; top and bottom grade into units D and B 1.2

B. Sand and silt; top 1 m is sand, very fine to fine, moderately sorted, subangular, very light gray (N8) to white (N9), thoroughly burrow-mottled, with discontinuous clay interlaminations and a few clay clasts; middle 1.2 m is coarse silt to very fine sand, light gray (N7), burrow-mottled; bottom 0.8 m is sand, fine, moderately sorted, subangular, light gray (N7), with clay clasts and burrows; lastest generation of burrow systems include *Thalassinoides* and *Teichichnus;* unit slightly to moderately indurated; no skeletal fossils observed; top grades into unit C, bottom grades abruptly into unit A 3.0

SMITH GUT MEMBER (?)

A. Muddy sandstone to sandy mudstone; laminated to thickly bedded, limonite-cemented, light brown (5 YR 5/6); indurated, ledge-forming unit poorly exposed; no fossils observed; top grades abruptly into unit B, base not exposed . . . . 0.5 +

Total: 6.0

VI. *MEASURED SECTION FB1*

Bluffs 0.5 km southeast of Flanner Beach Recreation Area, south shore Neuse River, Craven County, N. C.; Havelock 7.5′ quadrangle. *This is type locality of Flanner Beach Formation of DuBar and Solliday (1963).*

FLANNER BEACH FORMATION

BEACH CREEK MEMBER

I. Soil . . . . 1.0 m

H. Sand, fine, moderately to well sorted, subangular to angular, slightly indurated; very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4) with dark yellowish-orange (10 YR 6/6) bands; ripple cross-laminated, faint larger-scale cross-stratification; no fossils observed; top and bottom grade into units I and G 0.7

G. Interbedded mud and sand; mud layers up to 5 cm thick, sticky, medium gray (N5), with discontinuous interlaminations of coarse silt; sand interbeds and flat lenses up to 2 cm thick, with low-angle cross-laminations; sand very fine to fine, moderately sorted, subangular to angular, dark yellowish-orange (10 YR 6/6); no fossils observed; top and bottom grade into units H and F 0.8

F. Mud, sticky, slightly sandy; medium gray (N5); few sand interlaminations; sand very fine, moderately sorted, subangular to angular, very light gray (N8); no fossils observed; top and bottom grade into units G and E 0.4

E. Sand, fine to medium, moderately to poorly sorted, subangular to angular, slightly indurated; light olive gray (5 Y 6/1); heavily burrow-mottled with light brown (5 YR 5/6) color mottles coinciding with burrows; slightly muddy near top, disrupted laminations to thin beds of sand throughout; no skeletal fossils observed; top grades into unit F, bottom sharp, but conformable with unit D 1.5

D. Shell-mold bed; sand, silty, fine to medium, poorly sorted, subangular, limonite-cemented and moderately indurated; light brown (5 YR 5/6) with very light gray (N8) color mottles; abundant molds of bivalves throughout; top and bottom sharp, but conformable with units E and C 0.3

C. Muddy sand; sand fine, poorly sorted, subangular; light olive gray (5 Y 6/1); heavily burrow-mottled, some disrupted clay interlaminations; slightly indurated; no skeletal fossils observed; top sharp, conformable with unit D, bottom undulatory, gradational with B . 1.4

SMITH GUT MEMBER (?)

B. Shelly sand; sand medium, well sorted, subround to subangular, shelly in bottom two-thirds, slightly to moderately indurated; olive gray (5 Y 4/1) where shelly, dark yellowish-orange (10 YR 6/6) in upper unfossiliferous portion of bed; faintly cross-laminated, with sand and clay clasts; abundant shells of *Mulinia lateralis* randomly oriented, some shells of *Dinocardium robustum* near base oriented convex-sides-up; becomes muddy sand upstream, laterally along the outcrop face; top wavy, grading into C, bottom is disconformable contact with unit A 0.3

UNCONFORMITY

PRE-FLANNER BEACH FLUVIAL DEPOSITS

A. Sandy mud; medium gray (N5) to medium dark gray (N4) with light brown (5 YR 5/6) color mottles associated with root channelways; some fossil trunks and roots of trees in living positions, larger root channelways just below contact filled with sand from above; top also with sand-filled burrow systems; moderately indurated; top disconformable contact with unit B, base not exposed . . . . 1.4+

Total: 7.8 m

VII. *MEASURED SECTION DC1*

Low banks 0.7 km southeast of Dam Creek and 2.2 km southeast of Flanner Beach Recreation Area, at private beach on south shore Neuse River, Craven County, N. C.; Havelock 7.5′ quadrangle.

FLANNER BEACH FORMATION

Covered interval . . . . approx. 2.0 m

C. Muddy sand to sandy mud; bluish-gray (5 B 4/1); fine, moderately sorted, subangular to angular; burrows near top, clay clasts throughout; occasional molds of bivalves; slightly indurated; top not exposed, bottom grades into B 0.3

B. Shelly muddy sand; same as unit C but with abundant shells of *Mulinia lateralis*, mostly randomly oriented; *Dinocardium robustum* shells oriented with convex-sides-up near base; top grades into unit C, bottom is disconformable contact with unit A 0.5

UNCONFORMITY

JAMES CITY FORMATION

A. Mud; medium bluish-gray (5 B 5/1); slightly shelly with *Nuculana acuta* common, *Septastrea* sp. coral heads up to 40 cm in diameter near base of unit apparently in living positions; burrows or borings near top filled with sand and shells from unit B; massive, moderately indurated; top is disconformable with unit B, base not exposed . . . . 1.0+

Total: 3.8 m

VIII. *MEASURED SECTION PC1*

Bluffs just east of beach at Pine Cliff Recreation Area, 0.2 km east of end of unpaved access road, at Cherry Point, south shore Neuse River, Craven County, N. C.; Cherry Point 7.5′ quadrangle.

FLANNER BEACH FORMATION

ARAPAHOE SAND MEMBER

C. Soil . . . . 1.3 m

B. Interbedded sand and muddy sand; sand fine to medium, moderately sorted, subangular, loose, pale yellowish-orange (10 YR 7/2) to very pale orange (10 YR 7/4) near top to light pinkish-gray (5 YR 9/1) near base of unit; muddy sand slightly indurated, limonitic, pale yellowish-brown (10 YR 6/2) to light brown (5 YR 5/6); major bedding units nearly horizontal in top one-third, inclined eastward (up to 28°) in lower two-thirds of unit; sand interbeds contain trough and planar cross-laminations, clay clasts and rare discontinuous interlaminations; abundant bivalve (?) burrows 5 to 10 mm in diameter that extend from bottoms of each layer into top of the subjacent layers; base of unit with discontinuous muddy sand lens, light olive gray (5 Y 6/1), non-limonitic; no skeletal fossils observed; top and bottom gradational with units C and A 2.5

A. Sand, fine to coarse, moderately to poorly sorted, subround to subangular, loose; very light gray (N8) to pale yellowish-orange (10 YR 8/6); large wedge-shaped cross-stratification sets with internal laminations dipping gently (5° to 10°) westward and more steeply (up to 35°) eastward; few burrows, clay clasts, limonitic bands, and pebbly laminations with flat quartz pebbles up to 1 cm in longest dimension; no skeletal fossils observed; top grades into unit B, bottom not exposed . . . . 0.8+

Total: 4.6 m

SOUTH SHORE OF PAMLICO RIVER, FIGURE 7

IX. *MEASURED SECTION HP1*

Bluffs 0.2 km upstream from Camp Hardee and about 1.2 km west of Hills Point, south shore Pamlico River, Beaufort County, N. C.; Blounts Bay 7.5′ quadrangle. *Type section of Hills Point Member.*

FLANNER BEACH FORMATION

MAULS POINT MEMBER

F. Soil . . . . 1.0 m

E. Interlaminated mud and sandy silt; mud medium gray (N5), silt very light gray (N8); top half pedogenically altered; slightly indurated; no fossils observed; top and bottom grade into units F and D 0.5

D. Silty sand; sand very fine (N8); heavily burrow-mottled in top half, few clay interlaminations in bottom half; no skeletal fossils observed; top grades into unit E, bottom grades very gradually into unit C 0.8

C. Sand, fine to medium, poorly sorted, subround to subangular, loose; very light gray (N8); clay interlaminations throughout but more common near bottom, medium light gray (N6), in places disrupted by burrows; faint ripple cross-laminations in sand; burrows 5 mm in diameter referrable to *Planolites*, few larger horizontal burrows up to 25 mm in diameter; no skeletal fossils observed; top and bottom very gradational to units D and B 1.4

HILLS POINT MEMBER

B. Mud; clay-silt mixture becoming clayeyer near base, medium dark gray (N4); with sand lenses and interlaminations, sand very fine, moderately sorted, subangular to angular, light olive gray (5 Y 6/1); interlaminations wavy, discontinuous, in bundles up to 5 cm thick, along with few laterally continuous bundles, both types more common near top; some interlaminations disrupted by burrows 5 to 20 mm in diameter; brownish black (5 YR 2/1) carbonized wood fragments up to 2 cm in longest dimension scattered throughout clay in basal 1 m; bottom marked by limonite-cemented mudstone layer, 1 to 3 cm thick, moderate brown (5 YR 3/4) to light brown (5 YR 5/6), with sparse molds of *Rangia cuneata;* unit sticky, soft except for indurated limonitic layer; top grades into unit C, bottom is disconformable contact with unit A 2.5

UNCONFORMITY

PRE-FLANNER BEACH FLUVIAL DEPOSITS

A. Sand, fine to medium, moderately to poorly sorted, subround to subangular, slightly indurated; pinkish gray (5 YR 8/1) to yellowish gray (5 Y 8/1) with light brown (5 YR 5/6) color mottles; color mottles coincide with root channelways, otherwise massive; slightly muddy; no skeletal fossils observed; top is disconformable contact with unit B, base not exposed . . . . 1.7+

Total: 7.9 m

X. ***MEASURED SECTION MP1***

Bluffs 1.2 km southwest of Mauls Point along southeastern shore of Blounts Bay, south shore Pamlico River, Beaufort County, N. C.; central part of Blounts Bay 7.5′ quadrangle. *Type section of Mauls Point Member.*

FLANNER BEACH FORMATION

MAULS POINT MEMBER

H. Soil . . . . 1.3 m

G. Sand, fine, well sorted, subround to subangular, loose; very light gray (N8); discontinuous mud interlaminations throughout, medium light gray (N6), up to 5 mm thick, becoming more numerous and thicker toward base, generally disrupted by burrows that coincide with dark yellowish-orange (10 YR 6/6) color mottles; no skeletal fossils observed; top and bottom grade into units H and F 2.1

F. Interlaminated mud and sand; mud and sand same as in unit G, but with much less bioturbated, wavy parallel layers; no skeletal fossils observed; top grades into unit G, bottom grades abruptly into unit E 0.2

E. Sand, fine, moderately to well-sorted, subangular, loose; very light gray (N8); with discontinuous clay interlaminations and clay clasts throughout; no fossils observed; top and bottom grade abruptly into units F and D 0.5

D. Interbedded sand and mud; sand fine, well sorted, subangular, loose, white (N9); mud medium light gray (N6), sticky, slightly sandy; sand layers up to 5 cm thick, mud layers up to 4 cm thick; no fossils observed; top and bottom grade abruptly into units E and C . 0.9

C. Sand, fine to medium, moderately sorted, subangular, loose; very light gray (N8); occasional discontinuous wavy clay interlaminations up to 5 mm thick, and ripple cross-laminations accented by heavy mineral-rich laminations; no fossils observed; top grades abruptly into unit D, bottom intertongues with unit B 0.8

HILLS POINT MEMBER

B. Mud, sticky, laminated, medium bluish-gray (5 B 5/1); with sand interbeds and interlaminations–sand very fine to fine, moderately sorted, subangular, slightly micaceous, same color as mud; interbeds with rippled tops and flat bottoms, interlaminations wavy-parallel, both becoming less common toward base; few *Planolites*-like horizontal burrows 1 to 2 cm in diameter, and brownish-black (5 YR 2/1) carbonized wood fragments in discontinuous laminations up to 2 mm thick; top intertongues with unit C, bottom is disconformable contact with unit A 2.7

UNCONFORMITY

PRE-FLANNER BEACH FLUVIAL DEPOSITS

A. Sandstone, medium to coarse, poorly sorted, hematite-cemented, indurated but friable; grayish-brown (5 YR 3/2); no structures observed at outcrop, but boulders of same lithology just offshore are trough cross-laminated with pebbly layers (graded?); no fossils observed; top is disconformable with unit B, base not exposed . . . . 0.3+

Total: 8.8 m

XI. *MEASURED SECTION TP1*

Bluffs 0.8 km northwest of Tripp Point and 0.7 km southeast of center of mouth of Nevil Creek, south shore Pamlico River, Beaufort County, N. C.; east-central part of Blounts Bay 7.5′quadrangle.

FLANNER BEACH FORMATION

MAULS POINT MEMBER (?)

D. Soil . . . . 1.4 m

C. Sand, fine to medium, moderately to well-sorted, subangular, loose; very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4); low-angle cross-laminations in wedge-shaped (?) sets, some faint horizontal sand laminations near base, and wavy-parallel clay interlaminations in bundles up to 4 cm thick; no fossils observed; top and bottom grade into units D and B 2.5

B. Mud, sticky, laminated, medium dark gray (N4); with wavy discontinuous sand interlaminations; sand very fine to fine, moderately sorted, subangular, very light gray (N8); some interlaminations disrupted by burrows; no skeletal fossils; top and bottom grade into units C and A 1.1

UNNAMED MEMBER

A. Sand, very fine to fine, moderately to poorly sorted, subround, very slightly indurated to loose; olive gray (5 Y 4/1); slightly muddy, with clay clasts (= disrupted clay layers); unit heavily burrow-mottled, with last generation of structures including many curved cylindrical sand-filled burrows 5 to 10 mm in diameter; no skeletal fossils observed; unit poorly exposed, with top grading into unit B and base covered by talus . . . . 1.6+

Covered interval . . . . approx. 2.5

Total: 9.1 m