Sequence Stratigraphy and Foraminiferal Biostratigraphy for Selected Wells in the Albemarle Embayment, North Carolina

By

Larry Zarra

North Carolina Geological Survey

Open-File Report 89-5

Division of Land Resources

Department of Environment, Health, and Natural Resources

Raleigh

1989

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(Reprinted 1996)

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ABSTRACT

Twenty-six depositional sequences and 26 sequence boundaries are defined for the Lower Cretaceous to Quaternary subsurface section of the Albemarle embayment. Lower Cretaceous strata are divided into six sequences with resolution at the level of groups of stages. The seven Upper Cretaceous sequences have resolution to the stage or substage level. Most of the seven Paleogene and six Neogene/Quaternary sequences have resolution to the substage or planktic foraminiferal zone. Key new stratigraphic findings include revisions of the local Turonian to Campanian and Oligocene to Lower Pliocene sections. This report includes the first local documentation of Upper Eocene strata based on foraminiferal evidence.

Analysis of foraminiferal faunas in cuttings from five wells (33,670 feet) provided the basis for a local biostratigraphic framework which is effective for subdividing the section between the Middle Cenomanian and Early Pliocene. Eleven seismic sequence boundaries were recognized in the Cretaceous and Paleogene section based on interpretation of 414 line-miles of 12-fold CDPS reflection data. Synthesis of information from well logs, biostratigraphy, paleoecology, and synthetic seismograms resulted in the interpretation of 15 additional sequence boundaries. Systems tracts and condensed sections were identified for some of the sequences.

This study provides 10 more subdivisions than were defined in the previous local subsurface stratigraphic framework by identifying previously unrecognized units and subdividing recognized units. This higher resolution stratigraphic framework may enhance the accuracy of subsequent exploration models.

INTRODUCTION

This report presents results of research performed by the North Carolina Geological Survey for year four of the Continental Margins Agreement Number 14-12-0001-30316 between the Association of American State Geologists (AASG) and the U. S. Department of the Interior, Minerals Management Service (MMS), and was previously submitted to MMS as North Carolina Geological Survey Contractual Report 89-1. This stratigraphic framework study focuses on subsurface stratigraphy of the Pamlico and Albemarle Sound area of the Albemarle embayment, North Carolina.

Objectives

The purpose of this study was to provide a high-resolution subsurface stratigraphic framework for the study area by accomplishing a series of related objectives. A major part of this work was the development of a foraminiferal biostratigraphic framework. An independent line of investigation was the interpretation of available deep seismic data. Additional objectives were to refine and expand lithostratigraphic characterization of the section and develop paleoenvironmental interpretations. The final objective was to integrate all of this information to produce a sequence stratigraphic model. Petroleum potential was summarized in the context of this model.

Location and Geologic Setting

The year four research area is located in the Albemarle embayment (figure 1), and is centered on the Pamlico and Albemarle Sounds and adjacent coastal counties (figure 2). The Albemarle embayment is one of several east-

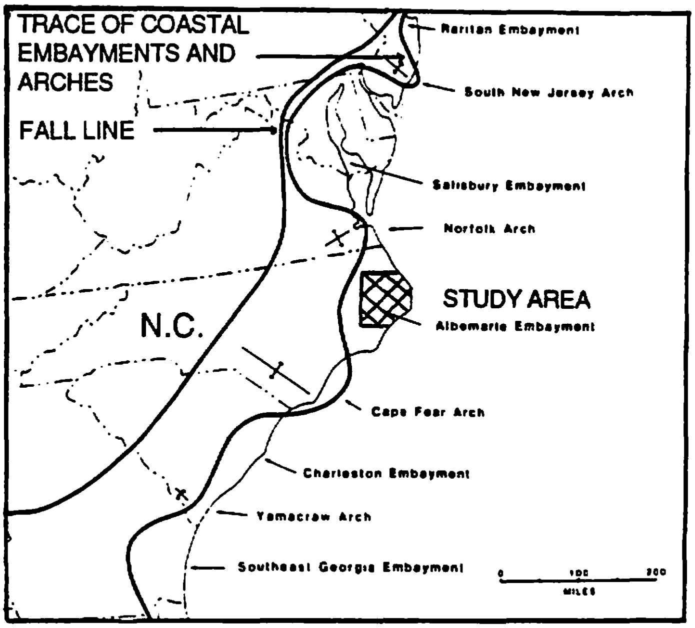


Figure 1. Map of embayments and arches of the Atlantic Coastal Plain (after Ward and Strickland, 1985).

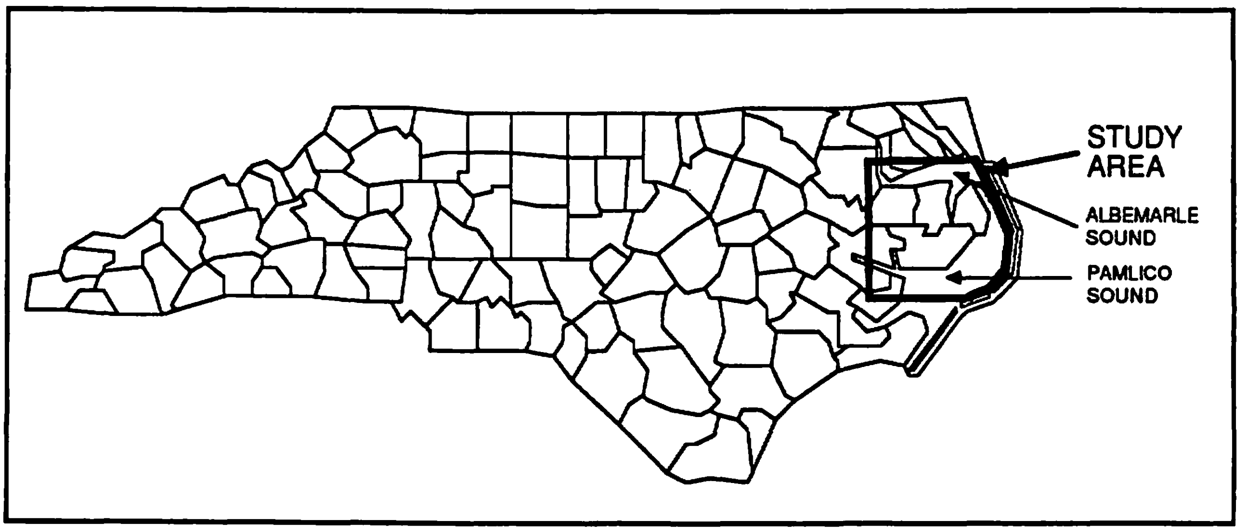


Figure 2. Map of North Carolina showing location of study area.

to southeast-trending semi-enclosed basins on the Atlantic Coastal Plain. It is flanked on the north and the south by east- to southeast-trending structural highs called the Norfolk arch and Cape Fear arch, respectively.

Primary data sources used to investigate the subsurface stratigraphy of the Albemarle embayment include well samples, well logs, and seismic reflection profiles. Well logs and seismic data are discussed below in the section on methods and material studied. Well samples consist of cuttings from five wells with a combined total depth of 33,670 feet. The Mobil #1 well was drilled in the Albemarle Sound; the Marshall Collins #1 well was drilled on Roanoke Island; and the Esso #2, Mobil #2, and Mobil #3 wells were drilled in the Pamlico Sound (figure 3). The Esso #2 well terminated in Lower Cretaceous strata and the remaining four wells terminated in basement. Samples from these wells are stored in the North Carolina Geological Survey sample repository. Basic information about the wells is given in Appendix A.

Regional dip of the Albemarle embayment is southeast (Brown and others, 1972). Proceeding from north to south, the Mobil #1, Marshall Collins #1, Esso #1, and Mobil #2 wells are oriented in an oblique dip direction. The Mobil #3 well is on strike with, and is slightly updip from the Mobil #2 well. The Mobil #2 well is the deepest and most downdip well examined, and generally has the most complete and best preserved stratigraphic section.

The Albemarle embayment has been a depocenter since the Late Jurassic(?) (Brown and others, 1972). The only report of Jurassic(?) strata for the North Carolina Coastal Plain is in the Hatteras Light (Esso #1) well, located on Cape Hatteras (Brown and others, 1972). The Esso #1 well was not examined, and strata of Jurassic age were not encountered in this study.

Lower Cretaceous strata primarily consist of sandstone and sandy claystone. Limestone is present but is less common. Strata in this interval were deposited in restricted marine to non-marine settings.

Upper Cretaceous and Paleocene strata primarily consist of silty claystone, glauconitic claystone, and fine grained sandstone. Most of the strata in this interval were deposited in open marine settings; non-marine strata are present but are not common. Outer shelf depositional settings are common in parts of the Senonian section.

Eocene and Oligocene strata primarily consist of limestone and sandy limestone with less common sand and silty clay. Lower and Middle Eocene strata consist of calcareous sandstone to sandy limestone, grading upward to a less sandy limestone. Upper Eocene strata consist of silty clays. Oligocene strata are mostly calcareous with some localized occurrences of sand and sandstone. This part of the section was deposited in an inner to middle shelf setting.

Lithology of Neogene strata is variable and reflects extremes in depositional settings. In the Miocene, calcareous strata were deposited in restricted marine or inner shelf settings, and clastic strata were deposited in inner shelf to upper slope settings. Post-Miocene strata primarily consist of sand and shelly sand, deposited in inner shelf to restricted marine settings. Intervals of sandy clay are less common, and reflect middle shelf depositional settings.

Previous work

General

Spangler (1950) outlined subsurface exploration in the North Carolina Coastal Plain, including a discussion of one of the wells examined for this study, the Esso #2 well. Most of Spangler's correlations were based on electric logs and lithology. He also noted a few species of foraminifera from the Upper Cretaceous.

Swain discussed subsurface stratigraphy of the North Carolina Coastal Plain in several publications (Swain, 1947, 1951, 1952; Swain and Brown, 1972). This work relied on ostracode biostratigraphy, well log correlations, and lithologic correlations.

Brown and others (1972) developed a subsurface stratigraphic model for the Atlantic Coastal Plain from North Carolina to Long Island. Seventeen chronostratigraphic units were defined, 16 of which were mapped in the Albemarle embayment. Pertinent aspects of their report are lithostratigraphic correlations and cross sections, lithologic descriptions, documentation of ostracode faunas, and limited documentation of foraminifera.

Owens and Gohn (1985) defined six depositional sequences for the Cretaceous of the Atlantic Coastal Plain, including the Albemarle embayment. Their compilation emphasized outcrop data and paleoenvironmental reconstructions. Pollen zonation was the primary biostratigraphic tool, but occurrences of other fossil taxa were cited.

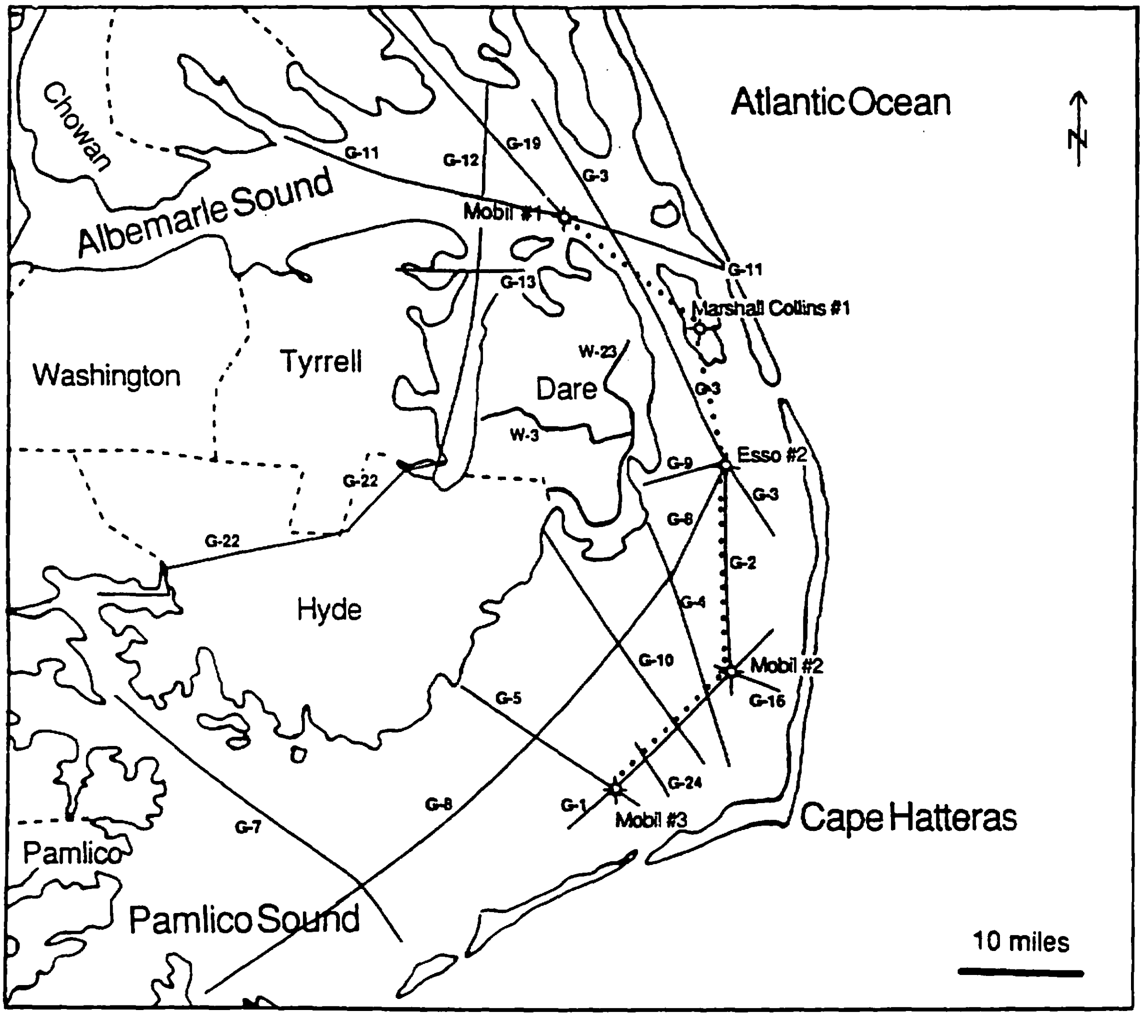
Popenoe (1985) detailed Cenozoic shelf and slope depositional history basinward of the study area. A grid of shallow seismic reflection data was correlated with existing well control. Popenoe's Croatan Sound line is located within the study area of this report, but this seismic line is not connected to the remainder of his seismic grid (Popenoe, 1985).

Poag and Valentine (1988) summarized the last decade of investigations of the U.S. Atlantic shelf and slope, including the area basinward of the Pamlico and Albemarle Sounds. They cited seismic and biostratigraphic studies which suggest the occurrence of a minimum of 32 Mesozoic to Cenozoic depositional sequences on the Atlantic margin.

Previous AASG/MMS research

Year one studies concentrated on lithostratigraphy and available geophysical data (Hoffman and others, 1985). Strata from Middle Eocene to Jurassic(?) or Lower Cretaceous were examined in eight wells. Eight lithologic packages were defined and correlated. Local ostracode biostratigraphy, structural geometry, and geophysical data were reviewed. The geophysical data included five synthetic seismograms and 153 line-miles of 12-fold common depth point stack (CDPS) seismic reflection data. Distinctive features from the synthetic seismograms were correlated with lithofacies in the wells and the seismic data were characterized. Control of depositional patterns was attributed to the basement wrench fault model proposed by Brown and others (1972).

Year two studies concentrated on examination and interpretation of well logs from 19 wells, 14 of which also had synthetic seismograms (Almy, 1987). Seismic reflection data examined by Hoffman and others (1985) was the subject



Cross Section ······ Well Location ⌖ Seismic Line G-11

Figure 3. Base map of the study area showing locations of the cross section, wells, and seismic lines.

of intensive interpretation. The Cretaceous was divided into five units for which average velocity, interval velocity, and structural maps were constructed. Biostratigraphic control followed Brown and others (1972) and Owens and Gohn (1985). Control of depositional patterns was attributed to basement topography and differential compaction (Almy, 1987).

The North Carolina Geological Survey did not participate in year three of the AASG/MMS Continental Margins program.

Methods and Material Studied

Cuttings samples from the wells examined in this study are available at 10-foot intervals. Samples from the Lower Cretaceous were examined at 30-foot intervals. Samples from the Upper Cretaceous and Cenozoic were examined at 20-foot intervals, although some were examined at 10-foot intervals to resolve specific lithologic relationships or stratigraphic boundaries. The samples were rinsed on a 75 micron sieve, dried, and floated to concentrate the microfossils. All of the floated fraction and float residue (non-floating fraction) were examined for each sample to document their lithology and contained faunas.

The lithology of each sample was examined and recorded. This usually resulted in more detailed information than the lithologic summaries provided by Brown and others (1972). Because washed cuttings samples were examined, individual grains less than 75 microns in diameter were not present. Samples which primarily consist of clay or poorly consolidated claystone were probably biased by the sample washing process.

The lithologic character of each sequence is summarized in the results section. Particular aspects of the lithology are emphasized only where they illustrate or help clarify specific stratigraphic relationships. For example, the presence of glauconite in a marginal marine setting may indicate the position of a condensed section, or the presence of iron stained sand grains may indicate an episode of subaerial exposure.

Sandstones in the local stratigraphic section range from poorly indurated to very indurated. Drilling and washing processes tend to partially disaggregate poorly consolidated sandstone cuttings, but the original lithology is partially preserved. Unconsolidated sands also occur throughout the stratigraphic section. Age and depth do not correlate to the degree of consolidation; loose sands occur in Lower Cretaceous strata and firmly cemented sandstones occur in upper Neogene strata.

Assemblages of foraminifera were documented to provide biostratigraphic and paleoecologic information. The resulting biostratigraphic framework is discussed in a separate section below. Initial paleoenvironmental estimates for each well were based on the occurrence of depth-restricted benthic genera and the abundance and diversity of planktic and benthic species (Bandy, 1954, 1956; Gernant and Kesling, 1966; Jones, 1983; Murray, 1973; Sliter and Baker, 1972). Initial paleoenvironmental estimates were reinterpreted for each sequence. Additional data sources used for this reinterpretation include lithology, well log character, occurrences of associated taxa, and sequence stratigraphic relationships.

Spontaneous potential, resistivity, and gamma-ray logs were used for stratigraphic correlation and to interpret depositional settings and systems tracts. General log features were described for some of the sequences to help characterize or define the lithology of that interval. Specific log signatures were described for sequences where they define stratigraphic boundaries or provide useful correlation points. The spontaneous potential and resistivity logs are shown on plate 1, but the gamma-ray logs were not reproduced in this report. Gamma-ray logs were cited and described only where they provide additional useful information. Well logs were not discussed for sequences where they do not provide additional useful information.

The North Carolina Geological Survey received 24 seismic lines consisting of 540 line-miles from Cities Service Oil Company. Eighteen lines (414 miles) of 12-fold CDPS data recorded to four seconds two-way time were selected for this study (figure 3). This includes six seismic lines (153 miles) which were used in the AASG/MMS year one and year two studies (Hoffman and others, 1985; Almy, 1987). A seismic consultant mapped the top of basement and four other seismic sequence boundaries throughout the study area (Underwood, 1988). The seismic report (Underwood, 1988) also includes brief discussions of methodology, reflector character, structure, and depositional setting. Tables of average velocities were calculated from sonic logs from the Mobil #1, Marshall Collins #1, Mobil #2, and Mobil #3 wells (Underwood, 1988). These were used to correlate seismic horizons to well depths. Relying on information from the seismic report (Underwood, 1988), in-house interpretation generated six additional seismic sequence boundaries. These additional seismic sequence boundaries were delineated on four seismic lines which approximately parallel the cross section. Descriptions of the shape of seismic packages in the results section refer to their geometry as viewed on these four seismic lines.

BIOSTRATIGRAPHIC FRAMEWORK

First down-hole occurrences of selected planktic and benthic foraminifera were used to construct a biostratigraphic framework (Appendix B). Planktic foraminifera were identified to the species level whenever possible. Almost all of the benthic foraminifera were identified to the genus level; but only distinct, abundant, biostratigraphically important, or paleoenvironmentally sensitive benthic foraminifera were identified to the species level. The biostratigraphic framework lists selected planktic and benthic foraminifera which are diagnostic of local fossiliferous units. Species are included because they are diagnostic of a local stratigraphic unit or because they were used in this study to correlate to standard biostratigraphic zonations. The significance of these species is discussed in the descriptions of the individual sequences.

Biostratigraphic control is fair to good throughout much of the Upper Cretaceous and Tertiary section. In most of this section, foraminiferal zonation provided resolution to the level of stage or zone for individual sequences. In the Lower Cretaceous section, planktic foraminifera are absent and benthic foraminifera are scarce. The ostracode-based zonation of Brown and others (1972) was adapted to provide approximate biostratigraphic control within parameters set by the global cycle chart of Haq and others (1987), for sequences defined in the Lower Cretaceous.

Biostratigraphic tops (first down-hole occurrences) do not necessarily equate to the tops of sequences. In basinward depositional settings a biostratigraphic top may coincide with the sequence boundary, but in shoreward depositional settings it is more likely to correlate with the condensed section. The positions of individual biostratigraphic tops are also dependent on a number of other factors, including lithology and differential preservation.

SEQUENCE STRATIGRAPHY

Sequence stratigraphy was initially introduced as a model for seismic stratigraphic interpretation applied to petroleum exploration (Vail and others, 1977), but concepts developed for this model can also be applied without seismic data. The basic unit of sequence stratigraphy is the depositional sequence, defined by Mitchum and others (1977) as "... a stratigraphic unit composed of a relatively conformable succession of genetically related strata, and bounded at its top and base by unconformities or their correlative conformities". Widespread testing and application of sequence stratigraphy led to the development of a series of global cycle charts (Vail and others, 1977; Haq and others, 1987). These global cycle charts were developed by interregional correlation of episodes of coastal onlap, and correlation of intervening, widespread unconformities termed sequence boundaries (Vail and others, 1977). The initial global cycle chart has been revised, and is correlated to biostratigraphic, chronostratigraphic, and magnetostratigraphic standards (Haq and others, 1987). Types of unconformities are defined according to relative magnitude of sea level falls (Vail and Todd, 1981). Genetically related lithofacies within depositional sequences are separated into systems tracts (Haq and others, 1987).

In the Cretaceous and Paleogene section of this study, several sequence boundaries were recognized by interpreting characteristic patterns of seismic reflector terminations (Mitchum and others, 1977). These seismic sequence boundary horizons were converted from time to depth, plotted on the well logs, and compared to sequence boundary horizons interpreted from the well logs. For individual sequences, calculated seismic sequence boundary horizons and well log sequence boundary picks are generally within 100 feet of one another.

Several types of information were used to delineate and correlate sequence boundaries which were not recognized on the seismic sections. Some sequence boundaries were identified at biostratigraphic gaps and others were identified by characteristic well log signatures. These interpretations were supported by lithologic and paleoecologic information. In reasonably well preserved sections, sequence boundaries were defined at a point where there is a basinward shift of coastal onlap (Vail and others, 1977). In shallow clastic depositional regimes sequence boundaries were interpreted at the base of a distinct sandstone. On spontaneous potential, resistivity, and gamma-ray logs this is expressed as a sharp-based log signature (Van Wagoner and others, 1988). Sequence boundaries were also recognized in well samples, where a more basinward lithofacies or biofacies was overlain by a more landward lithofacies or biofacies.

Systems tracts are three-dimensional genetically related lithofacies packages which make up depositional sequences (Van Wagoner and others, 1988). The transgressive systems tract is separated from the overlying highstand systems tract by the condensed section, which represents slow deposition at a time of maximum flooding (Posamentier and others, 1988; Posamentier and Vail, 1988). Systems tract interpretations are only presented for sequences where their identification and correlation are relatively unambiguous. For many of the sequences defined in this study not enough section is preserved, or too few wells have been examined to adequately identify systems tracts.

Age correlations and names for the sequence boundaries are from the oldest strata overlying the sequence boundary (Vail and Todd, 1981). In situations where sequence boundaries merge toward the basin margin, one is considered to be the major sequence boundary and the others are minor sequence boundaries. The major sequence boundary is the one which is at the base of the most areally restricted depositional sequence (Vail and others, 1980).

All available data were integrated to produce a local depositional model. Twenty-six sequence boundaries which divide the stratigraphic section from surface to basement into 26 depositional sequences were identified. The result is a preliminary sequence stratigraphic model for strata underlying the Pamlico-Albemarle Sound area. The sequences and sequence boundaries are displayed on a point-to-point well log cross section (plate 1). The depth of each sequence boundary in each well is listed in Appendix C. On the cross section the labels for the depositional sequences are placed between the Mobil #3 well and the Mobil #2 well. The labels for the sequence boundaries are placed between the Mobil #2 well and the Esso #2 well. Positions of sequence boundaries on the cross section are plotted on spontaneous potential and resistivity log curves. Well logs with a scale of 1 inch equals 100 feet were used to delineate and correlate sequences and sequence boundaries. Less distinct well log signatures are not evident on plate 1, which has a vertical scale of 1 inch equals 400 feet.

The local depositional model is compared to the global coastal onlap curves of and Haq and others (1987) to illustrate probable ages for the sequence boundaries (plate 2). Ages and positions of sequence boundaries below the lower Middle Cenomanian sequence boundary are approximate. Ages and positions of sequence boundaries in the Upper Cretaceous and Cenozoic section are more accurate because they are based on higher resolution biostratigraphic control. Subsurface stratigraphic columns from previous workers are provided on plate 2 for comparison. They are positioned relative to the standard chronostratigraphic column, but are not accurately placed relative to the ages of sequences defined in this study. A comparison of chronostratigraphic ages of sequences defined in this study with chronostratigraphic units of Brown and others (1972) for the Mobil #2 well is shown on plate 3.

RESULTS

Overview

The 26 sequences and 26 sequence boundaries identified in the study area are described in this section, from oldest to youngest. Descriptions include criteria used to identify and correlate the depositional sequences and sequence boundaries. Information about the lithology and paleontology of the sequences is summarized. Biostratigraphic zonations of sequences are presented and correlations of sequence boundaries to the global cycle chart of Haq and others (1987) are reviewed. Systems tracts are identified for those sequences from which they could be interpreted.

Sequence K-1

Sequence K-1 is present in the Mobil #2 and Mobil #3 wells. It overlies basement rocks, and is separated from basement by the K-1 sequence boundary. This sequence is a sheet-shaped unit where seen on the seismic sections. It falls below seismic resolution north of the Mobil #2 well at a small-scale basement fault identified by Underwood (1988). The K-1 sequence consists of a lower non-marine sandstone and an upper marginal marine section consisting of sandstone and silty shale. Thin limestone beds (10 feet) are present in the upper part of this sequence but are not common. The lower non-marine part of this sequence is the transgressive systems tract and the upper marginal marine part is the highstand systems tract. The K-1 sequence is capped by the K-2 sequence boundary. This horizon was picked at the base of a non-marine sandstone with a blocky, sharp- to moderately sharp-based spontaneous potential log signature. The K-2 sequence boundary was also correlated using seismic reflectors.

The benthic foraminifer Choffatella decipiens occurs in the Mobil #2 well at the transition between the transgressive and highstand systems tracts. The occurrence of a marine foraminifer at this point is consistent with the predicted position of a condensed section (Loutit and others, 1988). This species indicates an Aptian to Berriasian age for the K-1 sequence (Owens and Gohn, 1985). The K-2 sequence boundary falls within the Lower Zuni B supercycle set of Haq and others (1987).

Sequence K-2

This sequence is sheet- to wedge-shaped and thins north of the Marshall Collins #1 well. Toplap and downlap terminations of a sigmoid clinoform on seismic line G-1 near the Mobil #2 well help define the K-2 and K-3 sequence boundaries. The K-2 sequence occurs in four wells, but was not penetrated by the Esso #2 well. In the Mobil #3 and Mobil #2, wells the K-2 sequence overlies the K-1 sequence, and the intervening sequence boundary is the K-2. In the Marshall Collins #1 and Mobil #1 wells the K-2 sequence overlies basement, and the intervening sequence boundary is the K-1. Where the K-1 and K-2 sequence boundaries coalesce the K-1 is considered to be the major unconformity because the K-1 sequence is more areally restricted.

Interpretation of log signatures, lithology, and fauna indicate division of the K-2 sequence into an upper part and a lower part. The lower part consists of sandstone which has a blocky to moderately spiky spontaneous potential log signature. The presence of lignite and coarse-grained angular sand indicate a non-marine depositional setting. This lower sand and sandstone represent the transgressive systems tract. In the Mobil #3, Mobil #2, and Marshall Collins #1 wells the first occurrence of Choffatella decipiens in this sequence is in the sample immediately above the transgressive systems tract. These occurrences indicate the position of the condensed section. The upper part of this sequence consists of fine-grained sandstones and silty shales. Sparse benthic microfaunas in this upper lithofacies suggest turbid depositional conditions in marginal marine and shallow inner neritic paleoenvironments. The upper part of this sequence represents the highstand systems tract.

The K-3 sequence boundary was picked at the base of a sharp-based spontaneous potential log signature for the non-marine sandstone which overlies sandy to silty shales of the K-2 highstand systems tract. The horizon defined by the base of this sandstone agrees with the projected depth of the seismic sequence boundary.

The benthic foraminifer Choffatella decipiens, indicative of an Aptian to Berriasian Age (Owens and Gohn, 1985), occurs in three of the four wells which penetrated the K-2 sequence. The overlying K-3 sequence boundary falls within the Lower Zuni B supercycle set of Haq and others (1987).

Sequence K-3

The K-3 sequence is sheet-shaped to slightly wedge-shaped. It thickens to the south between the Esso #2 well and the Mobil #2 well. Internal seismic reflectors are distinct and essentially parallel. This sequence pinches out approximately 10 miles west of the Mobil #1 well, where it onlaps a mounded basement structure.

The basal part of the K-3 sequence is a thin (20-90 feet) sandstone which has a blocky, flat-based spontaneous potential log signature. The occurrence of coarse, angular, iron-stained sand grains and the absence of fossils indicate a non-marine depositional setting for this predominantly fine-grained sandstone. This lithofacies represents the transgressive systems tract. Sparse occurrences of glauconite immediately above this sandstone in the Mobil #1 and Mobil #2 wells indicate a condensed section at this horizon. Overlying the basal sandstone is a thick (150-470 feet) silty shale. This upper shaly interval was deposited in very shallow inner neritic to marginal marine conditions. Very sparse arenaceous and porcelaneous foraminifera occur in this section, along with mollusk fragments and ostracodes. Thin (10-20 feet) beds of biogenic limestone also occur in this interval, but are rare. This upper lithofacies represents the highstand systems tract.

The K-4 sequence boundary is interpreted by correlation of seismic reflectors with well log and lithologic data. The seismic correlation for this sequence boundary ranges from 30 feet below to 100 feet above the well log correlation for this horizon. On the well logs, the K-4 sequence boundary represents an abrupt transition between silty shales from the highstand systems tract of the K-3 sequence and basal sandstones of the transgressive systems tract of the K-4 sequence. The K-4 sequence boundary was observed in all five wells, but only the uppermost portion of the K-3 sequence was penetrated in the Esso #2 well.

<u>Choffatella</u> <u>decipiens</u> occurs in this sequence in the Mobil #3 well. This species indicates an Aptian to Berriasian age for the K-3 sequence (Owens and Gohn, 1985). The K-4 sequence boundary coincides with the local top of Unit H of Brown and others (1972), and falls within the Lower Zuni B supercycle set of Haq and others (1987).

Sequence K-4

On the cross section (plate 1) the K-4 sequence is a wedge-shaped package which thickens substantially in a basinward direction. The lower part of the K-4 sequence is a thin (60-100 feet) sandstone which generally has a sharp-based, blocky to slightly serrate spontaneous potential log signature. This generally fine-grained sandstone was deposited in a non-marine or possibly a marginal marine setting. In the Mobil #2 well, iron-stained sand grains cemented to abraded shell fragments suggest subaerial exposure and proximity to marginal marine conditions for this interval. Other accessory rocks and minerals present in trace quantities in this sandstone include mica, pyrite, and green shale. This interval represents the transgressive systems tract of the K-4 sequence.

In the Mobil #2 well, a sparse occurrence of glauconite, which indicates the position of the condensed section, was observed at the top of the transgressive systems tract. The upper part of the K-4 sequence is composed of a thick (200-1,000 feet) series of sandstones and shales with several interspersed thin (10-20 feet) limestone beds. These strata were deposited in a marginal marine to very shallow inner neritic setting. This interpretation is based on the occurrence of ostracodes, mollusks, biogenic limestones, and very sparse occurrences of agglutinated foraminifera. The upper part of the K-4 sequence represents the highstand systems tract.

The K-5 sequence boundary was delineated by correlating well log signatures, lithology, and paleoenvironmental trends. In the Mobil #1 and Marshall Collins #1 wells, the K-5 sequence boundary is distinct. It is positioned at an abrupt transition from sandy clays of the K-4 highstand systems tract to overlying non-marine sandstones of the K-5 transgressive systems tract. The basal K-5 sandstone in these two wells has a sharp-based, blocky spontaneous potential log signature. In the three downdip wells the K-5 sequence boundary is less distinct. In these wells, the basal K-5 sandstone has a less sharp-based and slightly serrate spontaneous potential log signature and there is little difference in depositional setting above and below the K-5 sequence boundary.

Brown and others (1972) reported an occurrence of Choffatella decipiens in the Mobil #2 well, in the lower part of their Unit G. The lower half of Unit G approximately corresponds to sequence K-4. The ostracode based zonation of Swain and Brown (1972) and Brown and others 1972) provides a Late Aptian to Early Albian age for their Unit G, which falls within the Lower Zuni B-4 and Upper Zuni A-1 supercycles of Haq and others (1987).

Sequence K-5

The K-5 sequence has a generally sheet-shaped geometry, but thickens slightly to the northwest. Sequence K-5 consists of a thin (15-75 feet) basal sandstone, and a thick (500-700 feet) overlying section which consists of alternating sandstones (10- 50 feet thick) and silty shales (10-250 feet thick). Thin (10-30 foot) biogenic limestone beds also occur in the upper section, but are not common. The lower sandstone represents the transgressive systems tract. In the two northern wells the transgressive systems tract is non-marine and in the two southern wells it is marginal marine. In the Esso #2 well it may be either non-marine or marginal marine. The medium- to fine-grained sandstones of the non-marine intervals of this systems tract contain oxidized, coarse-grained sand (approximately 10 percent) and trace quantities of mica. The fine-grained sandstones of the marginal marine intervals of this systems tract contain ostracodes and mollusk shells.

The upper part of this sequence represents a thick highstand systems tract. In the Mobil #1 well, this section reflects a non-marine depositional setting. In the Marshall Collins #1 well the highstand systems tract is divided into a lower marginal marine part and an upper non-marine part. Downdip this systems tract represents deposition in a marginal marine to very shallow inner neritic setting. Marine intervals in this systems tract contain ostracodes, mollusks, and rare benthic foraminifera. Specimens of Ammobaculites, Textularia and a several other genera occur in clastic sections, and unidentified quinqueloculine forms occur in the limestones.

The K-6 sequence boundary was correlated and mapped throughout the seismic network by Underwood (1988). This seismic reflector represents one of the more distinct seismic sequence boundaries in the study area. In the Mobil #2 and Mobil #3 wells the seismic and log correlations for the K-6 sequence boundary are within 30 feet of each other. In the Marshall Collins #1 and Mobil #1 wells the seismic correlation is 100 and 250 feet (respectively) above the well log correlation for this sequence boundary. This log correlation is at the base of a sandstone with a blocky, sharp-based spontaneous potential log signature. This horizon separates silty shales and sandstones below the sequence boundary from a more sandstone dominated section above. Spontaneous potential log signatures of sandstones from the K-5 sequence are generally more serrate, while those of sandstones in the overlying K-6 sequence are generally more blocky.

No time diagnostic foraminifera were observed in this sequence. The K-5 sequence is approximately equivalent to the upper half of Unit G of Brown and others (1972) and Swain and Brown (1972). Their ostracode zonation provides a Late Aptian or Early Albian age for Unit G. This falls within the Lower Zuni B-4 and Upper Zuni A-1 supercycles of Haq and others (1987).

Sequence K-6

The K-6 sequence is a thick (900-1,130 feet) wedge-shaped unit which thins slightly downdip. In the Mobil #2 well the transgressive systems tract consists of a thin (30 feet) basal non-marine micaceous sandstone, and a thicker (250 feet) sandy to silty claystone with a serrate spontaneous potential log signature. Benthic foraminifera and associated fossils from this claystone are representative of a marginal marine to shallow inner neritic paleoenvironment. The transgressive systems tract in this well is overlain by a thin (40 foot) condensed section which consists of glauconitic sandstone and biogenic limestone. The long ranging planktic species <u>Hedbergella</u> <u>delrioensis</u> occurs in this thin open marine interval. The remainder of this sequence in this well consists of a thick (580 feet) highstand systems tract. This interval contains sparsely fossiliferous fine-grained sandstones and silty claystones which were deposited in a marginal marine setting. Systems tracts are not as clearly defined in the other wells.

In the three northern wells this sequence consists of thin (30-60 feet) sandstones with slightly serrate, blocky spontaneous potential log signatures, interspersed with slightly thicker (30-100 feet) silty claystones. The paleoenvironment of this sequence in the Mobil #1 well is predominantly non-marine. The Marshall Collins #1 well contains marginal marine and non-marine intervals in approximately equal amounts. The Esso #2 and Mobil #3 wells exhibit predominantly marginal marine paleoenvironments in this sequence. The marginal marine intervals exhibit sparse occurrences of various agglutinated foraminifera.

The lower Middle Cenomanian sequence boundary was correlated and mapped by Underwood (1988). Truncation of several reflectors by the lower Middle Cenomanian sequence boundary indicate erosion of the upper part of the K-6 sequence near the Mobil #2 and Mobil #3 wells. This explains why this sequence is 1,110 to 1,130 feet thick in the three updip wells and 900 to 1010 feet thick in the two downdip wells. Internal reflectors of this sequence are generally even and parallel, and have good continuity (Underwood, 1988).

The seismic correlation for the lower Middle Cenomanian sequence boundary is between 120 and 150 feet above the well log correlation for this horizon. This log correlation is at the base of a thin sandstone with a spiky spontaneous potential log signature. This sandstone is less distinct than the sandstones with blocky spontaneous potential log characters which are typical of sequence K-6. The lower Middle Cenomanian sequence boundary represents a division between generally non-marine and marginal marine paleoenvironments below, and predominantly open marine paleoenvironments above.

Unit F of Brown and others (1972) comprises the majority of sequence K-6. Swain and Brown (1972) and Brown and others (1972) correlated their Unit F with the Fredericksburg and Washita Stages, undifferentiated. This falls within the Upper Zuni A-1 and A-2 supercycles of Haq and others (1987).

Middle to Upper Cenomanian Sequence

The Middle to Upper Cenomanian sequence is comprised of silty shales with thin (10-30 feet) beds of fine-grained sandstone. This sequence was deposited in a marine setting, except for the basal 20 feet of the most updip well. In each well a condensed section separates the transgressive systems tract from the highstand systems tract. The condensed section is in a thin (approximately 10 feet) marine clay which is characterized by a deflection toward baseline on the spontaneous potential logs and resistivity logs. The condensed section is also characterized by the presence of glauconite, and maximum paleobathymetry. Several species of planktic foraminifera occur in proximity to the condensed section. In the two downdip wells, a second transgressive event was interpreted for the highstand interval, based on paleobathymetric trends. This may represent a parasequence, or possibly a separate, less well defined sequence, also of Middle to Late Cenomanian age.

The Middle to Upper Cenomanian sequence is capped by the Lower to Middle Turonian 1 sequence boundary. This sequence boundary was correlated on well log, lithologic, and paleoecologic data. In each well, the sequence boundary is at the base of a sandstone with a sharp-based, blocky to serrate-blocky spontaneous potential log signature. This transition defines an abrupt shift from silty shales below to coarse-grained sandstones above, and illustrates a basinward shift of coastal onlap. In all but the most basinward well, the sequence boundary represents a shift from a marginal marine paleoenvironment below to a non-marine paleoenvironment above. In the Mobil #2 well the sequence boundary represents a shift from a middle neritic paleoenvironment below to a shallow inner neritic paleoenvironment above.

Rotalipora cushmani occurs in the Esso #2 well near the condensed section. Praeglobotruncana delrioensis and P. stephani occur near the condensed section in the Marshall Collins #1, Esso #2, and Mobil #2 wells. Also, Praeglobotruncana delrioensis and P. stephani occur in the upper part of the highstand systems tract in the Mobil #2 well.

Praeglobotruncana delrioensis is known from the Late Albian and Cenomanian, and became extinct in the Rotalipora cushmani Zone (Caron, 1985). Rotalipora cushmani is limited to the Rotalipora cushmani Zone (Caron, 1985). This zone correlates with the upper part of the Middle Cenomanian and the lower part of the Upper Cenomanian, and falls within the Upper Zuni A-2.3 and 2.4 third-order cycles of Haq and others (1987). Biostratigraphic zonations for the Middle to Upper Cenomanian sequence and the Lower to Middle Turonian sequence 1 suggest correlation of the Lower to Middle Turonian 1 sequence boundary to the 93 m.y. global unconformity of Haq and others (1987).

Lower to Middle Turonian Sequence 1

The Lower to Middle Turonian sequence 1 was established and correlated using well log, lithologic, and paleontologic data. In the Mobil #1 and Marshall Collins #1 wells, this sequence consists of a thin (30-70 feet) interval of coarse-grained angular sand overlain by a series of thin (10-30 feet) fine-grained sandstones and light brown silty shales. The lower sand was deposited in a non-marine setting, and the upper interval, which contains oyster shell fragments, was deposited in a marginal marine setting. This sequence is similar in the Esso #2 well except that the upper part contains a discrete, 100-feet-thick inner shelf biofacies containing a few planktic foraminifera. A more fully developed foraminiferal assemblage occurs in the Mobil #2 well, where this sequence is entirely marine. In this well the resistivity log indicates a predominantly shaly section with a few thin (10 feet) sandstones. In the Mobil #3 well this sequence is sand-prone and represents a predominantly marginal marine paleoenvironment.

The Lower to Middle Turonian 2 sequence boundary overlies the Lower to Middle Turonian sequence 1. This sequence boundary was recognized by lithologic relationships and well log signatures which indicate a basinward shift of coastal onlap. In the Mobil #1 well this sequence boundary is at a transition from a restricted marine silty clay to an overlying non-marine sandstone which has a blocky, sharp-based spontaneous potential log signature. This log signature indicates the position of the sequence boundary in the Marshall Collins #1, Esso #2, and Mobil #3 wells. The correlative horizon in the Mobil #2 well is at a transition from middle shelf clays to overlying shallow shelf sands. In this well this sequence boundary is at the base of a negative deflection on the gamma-ray log, and at the base of a positive deflection on the resistivity log. The spontaneous potential log is unreliable in this well above this point.

Planktic foraminifera in the Marshall Collins #1 and Mobil #2 wells indicate an early to Middle Turonian age for this sequence. Dicarinella algeriana occurs in both of these wells. This species became extinct at the end of the Helvetoglobotruncana helvetica Zone (Caron, 1985). Other planktic species which locally have tops in this sequence are Whiteinella brittonensis and Whiteinella hoelzli.

Planktic foraminiferal zonation suggests that the Lower to Middle Turonian sequence 1 correlates with the Upper Zuni A-2.5 or 2.6 third-order cycles of Haq and others (1987). Age and stratigraphic position of the overlying sequence suggests that the Lower to Middle Turonian 2 sequence boundary is correlative with either the 91 m.y. or the 90.5 m.y. global unconformities of Haq and others (1987).

Lower to Middle Turonian Sequence 2

The Lower to Middle Turonian sequence 2 is a 170- to 300-feet-thick, generally sheet-shaped unit which thickens to the south between the Esso #2 and Mobil #2 wells. In the four northern wells the depositional setting is predominantly marginal marine to shallow shelf. Here the rocks are mostly fine-grained sandstones, silty sandstones, and silty clays. A similar lithologic section occurs in the lower three-fourths of this sequence in the Mobil #3 well; but, in the upper part a thin middle neritic clay is preserved. Paleobathymetry is unchanged across the overlying basal Santonian sequence boundary in the Mobil #3 well, but is deeper above this horizon in the other four wells. In the Marshall Collins #1, Esso #2 and Mobil #3 wells this sequence boundary separates shallow inner shelf paleoenvironments from overlying deep middle shelf paleoenvironments. Also, a biostratigraphic gap from Middle Turonian to Early Santonian occurs at this horizon. This hiatus supports seismic evidence for widespread erosion of the top of the Lower to Middle Turonian sequence.

The basal Santonian sequence boundary was also recognized and defined using seismic and well log correlations. The log correlation for this sequence boundary is subtle. In the four northern wells this horizon is at the base of a very thin (10 feet or less) sandstone which is represented by a small positive deflection on the resistivity logs. In the two southern wells this sandstone was recognized on the gamma-ray logs. Seismic correlations for this sequence boundary fall within 50 feet of the log correlations for this horizon. The seismic reflector which represents the basal Santonian sequence boundary truncates several subadjacent reflectors. This provides evidence for erosion of the top of the Lower to Middle Turonian sequence 2.

The fauna is similar to that of the underlying sequence, and contains Dicarinella algeriana and Whiteinella brittonensis. These species indicate an Early to Middle Turonian age for this sequence (Caron, 1985; Loeblich and Tappan, 1961). This biostratigraphic range correlates with the Upper Zuni A-2.6 or 2.7 third-order cycles of Haq and others (1987). Zonation of the overlying Lower Santonian sequence suggests that the basal Santonian sequence boundary is correlative with the 87.5 m.y. global unconformity of Haq and others (1987).

Lower Santonian Sequence

The Lower Santonian sequence is a thin (190-290 feet) slightly wedge-shaped unit which thickens to the south. Seismic structure of this unit consists of parallel, high-amplitude, continuous reflectors. In addition to truncation of subadjacent reflectors, the basal Santonian sequence boundary was identified by onlapping reflectors which occur between the Marshall Collins #1 and Mobil #1 wells.

Lithology, well logs, and foraminiferal assemblages indicate that this sequence was deposited entirely under open marine conditions. Strata in this sequence are primarily silty shales and claystones, with thin (10 feet or less) intervals of fine-grained sandstone. Glauconite pellets comprise up to one-half of the volume of washed cuttings in some samples from this interval. Resistivity log characters indicate a predominantly shaly interval with a few thin sandstones, and gamma-ray log characters reflect concentrations of glauconite. Foraminiferal faunas are abundant and diverse, and indicate deep middle neritic and outer neritic paleoenvironments.

The Lower Santonian sequence is capped by the Lower Campanian sequence boundary, which was delineated and correlated on log, seismic, and paleontologic data. The seismic correlation for this sequence boundary is within 30 feet of the resistivity log correlation. This resistivity log signature is expressed as a low, sharp-based positive deflection. This horizon is also coincident with the biostratigraphic top of the Early Santonian.

An Early Santonian Age was assigned to this sequence by zonation of planktic foraminifera. Marginotruncana renzi and Dicarinella primitiva occur at the top of this stratigraphic interval. Both of these species became extinct at the top of the Dicarinella concavata Zone (Caron, 1985), which spans the Late Coniacian and Early Santonian (Haq and others, 1987). No species which are limited to the Coniacian were observed. Other planktic species which commonly occur in this interval include Marginotruncana marginata, M. sinuosa, and Dicarinella concavata.

The Santonian portion of the Dicarinella concavata Zone correlates with the upper part of the Upper Zuni A-3.2 and the lower part of the Upper Zuni A-3.3 third-order cycles of Haq and others (1987), or the interval between the 88 m.y. and 86 m.y. downlap surfaces. The Lower Santonian sequence is capped by the Lower Campanian sequence boundary, which is correlated to the 80 m.y. global unconformity of Haq and others (1987).

Lower Campanian Sequence

The Lower Campanian sequence is uniformly thin (40-90 feet). This sequence was recognized and correlated by its well log character and faunal content. In the three northern wells, interpretations of resistivity log signatures indicate a thin (10 feet or less) basal sandstone overlain by a clay with silty to slightly sandy intervals. In the two southern wells the resistivity log character of this sequence indicates a more sandy interval with a generally fining-upward trend. Samples from this sequence contain silty to slightly sandy clay, with abundant glauconite pellets. The Upper Campanian sequence boundary overlies this sequence, and is placed at the base of a silty to sandy bed which is more visible on large-scale logs. This subtle resistivity log signature coincides with the first down-hole occurrence of the benthic index species Kyphopyxa christneri.

Abundance and diversity of foraminifera indicate a middle to outer shelf setting for this sequence. Planktic foraminifera are common, but all are long ranging Early Campanian to Early Maastrichtian species. In the Gulf Coast stratigraphic section, the extinction of the benthic species Kyphopyxa christneri is considered to be diagnostic of the top of the lower part of the Taylor Stage. Locally, this species is consistent in occurrence, and its first down-hole occurrence is used to approximate the top of the Lower Campanian (Owens and Gohn, 1985).

Biostratigraphic zonation of this sequence and adjacent units, and information provided on the global cycle chart, suggest this sequence is correlative to the Upper Zuni A-4.1 or Upper Zuni A-4.2 third-order cycles of Haq and others (1987). This sequence is capped by the Upper Campanian sequence boundary, which is correlated to the 77.5 m.y. global unconformity of Haq and others (1987).

Upper Campanian Sequence

The Upper Campanian sequence is very thin (50-70 feet) updip, and is substantially thicker (190-220 feet) south of the Esso #2 well. This sequence was recognized and correlated by its log character and faunal content.

The Upper Campanian sequence and overlying basal Upper Maastrichtian sequence boundary are clearly defined in the Marshall Collins #1 and Esso #2 wells. Samples from this interval consist of soft silty clays with fine- to very fine-grained sands and abundant (50-70 percent) glauconite pellets. Abundant foraminiferal faunas indicate an outer neritic paleoenvironment. The biostratigraphic top for this sequence coincides with a very thin (less than 10 feet) peak on the resistivity logs, which represents a basal transgressive sand or sandstone associated with the basal Upper Maastrichtian sequence boundary. In the Mobil #1 well this sequence contains a lower, inner neritic biofacies and an upper, middle neritic biofacies, but biostratigraphic markers are absent. Overlying the middle neritic biofacies is an inner neritic biofacies which contains coarse- to fine-grained sands with several iron-stained grains. This upper transition suggests a basinward shift of coastal onlap, and correlates with a very subtle peak on the resistivity log. In the Mobil #2 and Mobil #3 wells this sequence consists of a thin (60 feet), very fossiliferous, middle to outer neritic clay overlain by a thicker (120-190 feet) poorly fossiliferous very silty clay. The lower part of this interval is similar to the outer neritic biofacies which occurs in the two wells to the north. The upper part of this interval may represent a highstand systems tract which was eroded from the section to the north. The sequence boundary overlying this silty clay is at the base of a thin (10-15 feet) sand or sandstone which is recognized at the base of a low-amplitude positive deflection on the resistivity log.

Planktic foraminifera are abundant in this sequence, but they are mostly species which range through the Campanian and Early Maastrichtian. Several benthic foraminifera were used to recognize this sequence. The extinctions of Globorotalites conicus and Lituola taylorensis are considered to be diagnostic of the Upper Campanian (Cushman, 1946). Van Hinte (1976) cited an extinction point for Bolivinoides decorata within the Upper Campanian but below the Globotruncanita calcarata Zone. The consistent occurrence of these three benthic species in this sequence indicates an upper, but not uppermost, Campanian stratigraphic position.

Most of the Upper Campanian coincides with the Upper Zuni A-4.3 third-order cycle of Haq and others (1987). This sequence is capped by the basal Upper Maastrichtian sequence boundary, which correlates to the 71 m.y. global unconformity of Haq and others (1987).

Upper Maastrichtian Sequence

The Upper Maastrichtian sequence is thin (100 feet) in the northern part of the the section and thickens (160 feet) slightly toward the south. This sequence and the overlying upper Lower Paleocene sequence boundary were recognized and correlated using lithologic, log, and paleontologic data.

In the Mobil #1 well this sequence contains a mixture of silty glauconitic clay and medium- to fine-grained sand. In the Marshall Collins #1 and Esso #2, wells the lithology of this sequence is predominantly a fossiliferous silty clay with abundant glauconite. The uppermost glauconitic sample in these wells commonly has a small amount of oxidized glauconite pellets. In the Mobil #2 and Mobil #3 wells this sequence primarily consists of indurated silty claystone. In these two wells, foraminifera are rare and glauconite is absent. The Upper Maastrichtian sequence in each of these wells is overlain by a thin (10-15 feet) layer of medium- to coarse-grained subangular sand. This sand is represented as a distinct sharp-based positive deflection on the resistivity logs for several wells. The base of this sand marks the upper Lower Paleocene sequence boundary.

Planktic foraminifera are common in the Marshall Collins #1 and Esso #2 wells, and scarce in the three Mobil wells. Two species from this section, Globotruncana ventricosa and Rosita fornicata, became extinct in the Gansserina gansseri Zone (Caron, 1985). Rosita contusa and Gansserina gansseri, which range no lower than this zone (Caron, 1985), also occur in this section. The latter two of these taxa are believed to be in-place because species limited to the overlying Abathomphalus mayaroensis Zone were not observed. Thus, a zonation within the G. gansseri Zone is indicated.

The Globotruncana gansseri Zone is in the upper, but not uppermost, Maastrichtian and correlates with the Upper Zuni A-4.5 third-order cycle of Haq and others (1987). This sequence is capped by the upper Lower Paleocene sequence boundary, which approximately correlates to the 63 m.y. global unconformity.

Lower Paleocene Sequence

The Lower Paleocene sequence is of uniform thickness (130-190 feet) except for in the Mobil #1 well, where it is substantially thinner (40 feet). Rocks of this sequence are predominantly clastic, and generally firmly indurated. In the Mobil #2 and Mobil #3 wells, this section is a slightly glauconitic, very fine-grained sandstone to sandy siltstone with calcareous cement. Silty shales are common in the Esso #2 and Marshall Collins #1 wells. The thin Lower Paleocene section in the Mobil #1 well is a slightly glauconitic, medium- to fine-grained sandstone. Most of the samples from this sequence contain limited foraminiferal assemblages because of poor preservational characteristics of the rocks and the fragile nature of planktic fossils.

The Lower Paleocene sequence is capped by the middle Upper Paleocene sequence boundary. A distinctive reflector which represents this sequence boundary was identified and mapped throughout the seismic network by Underwood (1988). It truncates underlying reflectors, and is onlapped by overlying reflectors. This seismic sequence boundary is within 80 feet of the log correlations which represent this horizon on the cross section. On the resistivity logs, this sequence boundary is at the base of a peak which indicates a thin sandstone overlying the Lower Paleocene sequence. Gamma-ray logs generally support the resistivity log correlations for this sequence boundary, but are complicated by localized limestone and glauconite concentrations.

The depositional environment for this unit was entirely neritic, but determination of paleoecologic zones is hampered by poor faunal preservation, especially in the Mobil #2 and Mobil #3 wells. Zonation of this sequence is based on a sparse but well preserved planktic fauna in the Marshall Collins #1 well, where Morozovella trinidadensis and M. inconstans occur. These species became extinct at the end of planktic Zone P2 (Toumarkine and Luterbacher, 1985; Stainforth and others, 1975). The absence of species limited to Zone P1 suggests a zonation of Zone P2 for this interval. Associated planktic species in this interval include Subbotina triloculinoides, Morozovella uncinata, and M. pseudobulloides.

Planktic Zone P2 correlates with the upper part of the Tejas A1.2 third-order cycle of Haq and others (1987). The Lower Paleocene sequence is capped by the middle Upper Paleocene sequence boundary, which is correlated to the 58.5 m.y. global unconformity of Haq and others (1987).

Upper Paleocene Sequence

The Upper Paleocene sequence was recognized and correlated using logs, lithology, and paleontologic data. This sequence is thickest in the Esso #2 well (130 feet) from which it thins slightly (120-100 feet) to the south and substantially (70-50 feet) to the north. Lithology of this sequence is uniform. The lower part is a thin (10-25 feet) sand bed which is coarse-grained and subangular updip in the Mobil #1 well and is medium- to coarse-grained and subrounded downdip in the Mobil #2 well. Resistivity log signatures which represent this basal sand are apparent in all of the wells, but the spontaneous potential log signature which represents this basal sand is clearly defined only in the three northern wells. The spontaneous potential logs in the Mobil #2 and Mobil #3 wells are not effective above this point. The basal sand is overlain by an interval of silty clay to very fine-grained sandstone.

The Upper Paleocene sequence is capped by the uppermost Paleocene or Lower Eocene sequence boundary. In the Mobil #1 well this sequence boundary is at the base of a sandy limestone which is characterized on the resistivity and gamma-ray logs by an abrupt deflection to relatively low values. In the other wells, this sequence boundary is at the base of a coarse- to fine-grained sand bed. This bed is characterized by a positive deflection on spontaneous potential and resistivity logs for the three northern wells and by a negative deflection on the gamma-ray logs for the two southern wells. This lithologic break is also evident in the cuttings.

Foraminiferal abundance is low but evenly distributed in the Upper Paleocene sequence. Subbotina triloculinoides is common and occurs at the top of this sequence in several wells. This species became extinct in Zone P4 (Toumarkine and Luterbacher, 1985; Stainforth and others, 1975) and provides an upper age limit for this sequence. This limit is supported by the occurrence of Morozovella angulata and M. conicotruncata, which also became extinct in Zone P4 (Toumarkine and Luterbacher, 1985; Stainforth and others, 1975). The longer ranging species Acarinina mckannai is also common in this sequence. Foraminifera which are limited to zones earlier than P4 were not observed in this interval, which suggests a zonation of planktic Zone P4 for this sequence. Benthic foraminifera which have a first down-hole occurrence in this unit include Gyroidina subangulata and Marginulina tuberculata.

Planktic Zone P4 correlates with the Tejas A2.1 third-order cycle of Haq and others (1987). The Upper Paleocene sequence is capped by the uppermost Paleocene or Lower Eocene sequence boundary. Limited biostratigraphic information from the superadjacent sequence precludes precise age determination for this sequence boundary. It is potentially correlative with any of eight unconformities between the 54.5 m.y. and 49.5 m.y. global unconformities of Haq and others (1987).

Uppermost Paleocene to Lower Eocene Sequence

The uppermost Paleocene to Lower Eocene sequence is a very thin (20-100 feet) wedge-shaped unit which is thickest to the south and thins northward. It pinches out northward of the Marshall Collins #1 well as a result of either lapout or truncation.

In the Esso #2 and Marshall Collins #1 wells the uppermost Paleocene to Lower Eocene sequence consists of a thin (10 feet) medium-grained sand overlain by a thin (10-30 feet) silty clay. In the Mobil #2 and Mobil #3 wells, the same thin (10-20 feet) sand layer is overlain by a thicker (80-90 feet) silty clay. In the two southern wells, resistivity log signatures for the silty clay show a fining-upward trend to a point of lowest resistivity, where traces of glauconite were observed. Above this, the silty clay coarsens-upward to the overlying Middle Eocene sequence boundary. This sequence boundary occurs at the base of a fine-grained, very calcareous sandstone.

Foraminifera are rare in this sequence. Benthic foraminiferal assemblages indicate inner neritic to shallow middle neritic paleoenvironments. The only planktic foraminifera observed in this sequence occur in the Marshall Collins #1 well. A latest Paleocene or Early Eocene age is suggested by the occurrence of Subbotina soldadoensis soldadoensis, which ranges from planktic Zone P5 to P9 (Toumarkine and Luterbacher, 1985; Stainforth and others, 1975).

Haq and others (1987) documented eight third-order cycles in the uppermost Paleocene to Lower Eocene: Tejas A2.2 to Tejas A2.9. These are capped by the 54.5 m.y. to 49.5 m.y. global unconformities, respectively. The uppermost Paleocene to Lower Eocene sequence correlates with this range of cycles, but further refinement is not possible without additional data.

Middle Eocene Sequence

The Middle Eocene sequence is a thick (370-520 feet), predominantly calcareous unit which thins slightly to the north. Underwood (1988) correlated and mapped a reflector throughout the seismic network which represents the seismic sequence boundary at the top of this unit. This seismic sequence boundary is within 30 to 50 feet of the lithologic and well log picks for the top of this sequence.

The lower half of this sequence consists of a very calcareous, fine-grained sandstone. This calcareous sandstone grades upward to a sandy bioclast limestone with bryozoan fragments. Glauconite is common at the top of this sequence, either as medium- to coarse-grained pellets, or as fine grains within the limestone matrix.

The depositional setting for the majority of this sequence is inner neritic, but some middle neritic intervals were also recognized. Foraminiferal assemblages are generally sparse and poorly preserved. The long-ranging planktic species Subbotina linaperta occurs in several wells, and the shorter ranging "Globigerinoides" higginsi was observed in the Esso #2 well. The latter of these species ranges from planktic Zone P9 to P11 (Stainforth and others, 1975) and possibly into Zone P12 (Toumarkine and Luterbacher, 1985). Benthic foraminifera which occur in several wells include Gyroidina orbicularis planata, G. octocamerata, and Melonis planata.

The Middle Eocene age for this sequence is corroborated from published data. Jones (1983) documented foraminiferal assemblages from outcrop and shallow subsurface samples located southwest of the study area, which are probably correlative with this sequence. Planktic foraminiferal zonation of this unit was limited to Zones P12 to P13 (Jones, 1983).

Planktic Zones P12 to P13 correlate with the Tejas A3.4 and lower part of the Tejas A3.5 third-order cycles of Haq and others (1987). In the Mobil #2 well the Middle Eocene sequence is overlain by the Upper Eocene sequence, and the intervening sequence boundary is the basal Upper Eocene sequence boundary. In the Mobil #3, Esso #2, and Marshall Collins #1 wells the Middle Eocene sequence is overlain by the Lower Oligocene sequence and in the Mobil #1 well it is overlain by the Lower Miocene sequence (plate 1). The basal Upper Eocene sequence boundary correlates to the 39.5 m.y. global unconformity of Haq and others (1987).

Upper Eocene Sequence

The Upper Eocene sequence is a thin (50 feet) unit which occurs only in the Mobil #2 well, the most downdip well examined. This sequence is represented on seismic lines G-1 and G-2 as a reflector centered on the Mobil #2 well. This reflector falls below seismic resolution two to three miles north and south of this well.

Lithology of the Upper Eocene sequence is a silty clay. Glauconite is abundant in the upper part and reworked limestone fragments occur in the lower part. The Upper Eocene sequence is capped by the Lower Oligocene sequence boundary. The gamma-ray log and cuttings indicate that this sequence boundary is at the base of a sandstone. This thin sequence may represent an incised valley fill facies or a stranded erosional remnant.

Benthic foraminifera are abundant and diverse in this sequence. Common species include Nonionella jacksonensis, Bulimina jacksonensis, B. ovata, and Valvulina sp. The depositional setting of this sequence is outer neritic. This unit is faunally distinct from middle neritic assemblages immediately overlying and underlying this sequence.

A Late Eocene age for this sequence is indicated by the occurrence of Globigerinatheca semiinvoluta, which is limited in range to the Globigerinatheca semiinvoluta Zone (Stainforth and others, 1975). Other planktic species which occur in this sequence include Globorotalia cerroazulensis cerroazulensis, Hantkenina longispina, and Globigerinatheca tropicalis. This zone correlates with the Tejas A4.1 third-order cycle of Haq and others (1987). The Upper Eocene sequence is capped by the Lower Oligocene sequence boundary. This horizon may correlate to either the 36 m.y. or 33 m.y. global unconformity of Haq and others (1987).

Lower Oligocene Sequence

The Lower Oligocene sequence is a thin wedge-shaped unit. It is thickest in the Esso #2 well (120 feet), and is thinner to the north (70 feet) and south (70-90 feet). This unit was not observed in the Mobil #1 well.

This sequence was identified by its stratigraphic position between two distinct features. It overlies lithologically distinct Middle Eocene limestones or faunally distinct Upper Eocene clays; and underlies the Upper Oligocene sequence which has a very distinct basal lithology of medium- to very coarse-grained sand with locally abundant phosphate pellets. In the Mobil #2, Mobil #3, and Marshall Collins #1 wells the base of the transgressive systems tract of the Upper Oligocene sequence is identified at the base of a high-amplitude spike on the gamma-ray log. In the Esso #2 well, spontaneous potential and resistivity logs indicate a sandstone at this horizon.

In stratigraphic literature, the Lower Oligocene usually refers to the Cassigerinella chipolensis/Pseudohastigerina micra Zone, or upper Zone P17 and Zone P18 (Stainforth and others, 1975). This is equivalent to the Gulf Coast Vicksburg Stage. Haq and others (1987) placed the boundary between the Upper and Lower Oligocene at the 30 m.y. global unconformity, which they correlate to the boundary between the Rupelian and Chattian European stratotypes. This boundary is in the middle of Zone P21, or the Globorotalia opima opima Zone (Stainforth and others, 1975). The designated boundary of Haq and others (1987) is used in this study.

Foraminifera are sparse in this interval because of dilution by caved sands from the overlying sequence. A deep inner to middle neritic paleoenvironment was interpreted for this sequence. The occurrence of Globigerina ampliapertura and Globorotalia increbescens indicate a zonation no higher than the Globigerina ampliapertura Zone, or lower P20/P19 (Stainforth and others, 1975). The absence of Pseudohastigerina micra suggests that this sequence does not represent a Vicksburg Stage equivalent. Exact placement of the top of the Globigerina ampliapertura Zone is not firmly established (Haq and others, 1987; Stainforth and others, 1975). The ranges of Globigerina ampliapertura and Globorotalia opima opima overlap locally in outcrop (Zarra, 1983, 1988), on the slope offshore from North Carolina (Stainforth and Lamb, 1981), and elsewhere worldwide (Stainforth and others, 1975). Globigerina ciperoensis, Globorotalia opima nana, Cassigerinella chipolensis, and Globorotalia postcretacea are associated faunal constituents in this sequence. These species are typical of the Globigerina ampliapertura Zone in the North Carolina Coastal Plain (Zarra, 1983, 1988; Reilly-Fletcher, 1986).

The Globigerina ampliapertura Zone correlates with the upper part of the Tejas A4.4 third-order cycle of Haq and others (1987). This interval is capped by the Upper Oligocene sequence boundary, which is correlated to the 28.4 m.y. global unconformity of Haq and others (1987).

Upper Oligocene Sequence

Shape and distribution of the Upper Oligocene sequence are similar to the underlying sequence. The Upper Oligocene sequence is a thin wedge-shaped unit which is thickest (220 feet) in the Mobil #2 well and thins to the north (90-170 feet) and south (90 feet). This sequence does not occur in the Mobil #1 well.

In the Marshall Collins #1, Esso #2, and Mobil #2 wells the lower part of this unit is a very coarse- to medium-grained subangular to subrounded quartz sand. In the Marshall Collins #1 and Esso #2 wells this basal sand contains up to 50 percent phosphate grains, and phosphate coated ichthyoliths are common. In the Mobil #2 well, phosphate grains are evenly distributed throughout the lower part of this sequence, and are not concentrated within the basal sand. In the Mobil #3 well and the upper part of the Mobil #2 well this sequence consists of sandy, moldic limestone and barnacle-shell hash. In the Esso #2 and Marshall Collins #1 wells, the upper part of this sequence is predominantly a silty clay.

The position of the overlying basal Miocene sequence boundary was determined from log correlation and lithology. In the southern two wells, this sequence boundary is at the base of calcareous and slightly phosphatic sandstones of the Lower Miocene sequence 1. This lithologic boundary is represented by a negative deflection on the gamma-ray logs and a positive deflection on the resistivity logs. In the Marshall Collins #1 and Esso #2 wells the basal Miocene sequence boundary separates the Upper Oligocene sequence from the Lower Miocene sequence 2. Here the sequence boundary is at the base of a thin (10 feet) medium- to coarse-grained sand which is represented by a small-scale negative deflection on the gamma-ray log from the Marshall Collins #1 well and by a very small-scale positive deflection on the resistivity log from the Esso #1 well.

Distribution and preservation of foraminifera is variable. Foraminifera are very rare in the Mobil #3 well. The Esso #2 well has a good benthic assemblage, but planktic foraminifera are scarce. Planktic assemblages are common in the Marshall Collins #1 and Mobil #2 wells. Time diagnostic species with a first down-hole occurrence in this interval include Globigerina ciperoensis, Globorotalia opima nana, and Globigerina anguliofficinalis. These species, along with longer ranging associated planktic species, are locally diagnostic of the Globigerina ciperoensis Zone, or Zone P22 (Stainforth and Lamb, 1981; Zarra, 1983, 1988; Reilly-Fletcher, 1986).

The Globigerina ciperoensis Zone correlates with the Tejas B1.2 and Tejas B1.3 third-order cycles of Haq and others (1987). This sequence is capped by the basal Miocene sequence boundary, which correlates to the 25.5 m.y. global unconformity of Haq and others (1987).

Lower Miocene Sequence 1

The Lower Miocene sequence 1 is a thin (50-60 feet) unit which occurs in the Mobil #2 and Mobil #3 wells, but not in the three northern wells. This sequence consists of a slightly phosphatic calcareous sandstone which is overlain by a thin (10 feet) sand in the Mobil #3 well and is overlain by a thicker (30 feet) clay in the Mobil #2 well. The upper sand and clay part of this sequence also contains small quantities of phosphate grains. In these two wells the correlation for the overlying sequence boundary is evident on the gamma-ray logs at the base of a limestone.

Foraminifera are not preserved in the calcareous sandstone lithofacies of this sequence. In the upper sandy lithofacies of the Mobil #3 well, foraminifera are rare. The Mobil #2 well contains a diverse foraminiferal assemblage in the upper phosphatic clay. This assemblage includes Globorotalia kugleri, which became extinct at the top of planktic Zone N4 (Kennett and Srinivasan, 1983). The absence of species limited to the Oligocene Zone P22 indicates this sequence is correlated to Zone N4.

Zone N4 is correlated to part of the Tejas B1.4 third-order cycle of Haq and others (1987). This sequence is capped by the Lower Miocene 2 sequence boundary. Exact correlation of this of this sequence boundary is uncertain. It may be correlated to the 21 m.y. global unconformity of Haq and others (1987), or one of the local fourth-order seismic sequences of Snyder and others (1988).

Lower Miocene Sequence 2

The Lower Miocene sequence 2 is thickest (410 feet) in the Mobil #2 well and thins to the north (240-330 feet) and south (340 feet). In the Mobil #3 well, this unit is predominantly a sandy limestone overlain by a thin (30 feet), fine-grained sand. In the Mobil #2 well the lower quarter of this sequence is calcareous, the middle half is a slightly silty clay, and the upper quarter is a slightly sandy to silty clay. In the three northern wells there is a thin (10 feet), distinct, medium-grained sand at the base of this unit, overlain by clays, silty clays, and fine-grained sands.

Lower Miocene sequence 2 is overlain by Lower Miocene sequence 3. These sequences are separated by the upper Lower Miocene sequence boundary. This horizon was correlated using gamma-ray logs from the Mobil #3, Mobil #2, Marshall Collins #1, and Mobil #1 wells and with spontaneous potential and resistivity logs from the Esso #2 well. This sequence boundary is at the base of a medium- to fine-grained sand.

Preservation of foraminifera in this sequence is variable, and ranges from poor to excellent. The most abundant and diverse faunas in this sequence occur in the upper half of the Marshall Collins #1 well and in the middle half of the Mobil #2 well. In these intervals the paleoenvironment is deep outer neritic to shallow upper bathyal. A few of the more abundant species of benthic foraminifera are Uvigerina calvertensis, Lenticulina americana, and Hanzawaia concentrica. Planktic faunas are diverse, and contain many long ranging species. Short ranging planktic species in this sequence include Catapsydrax unicavus, C. dissimilis, and Globoquadrinia praedehiscens, all of which became extinct in planktic Zone N6 (Kennett and Srinivasan, 1983).

Foraminiferal faunas documented herein do not provide sufficient resolution to discriminate between planktic Zones N5 and N6. Comparison with a study of planktic foraminiferal biostratigraphy by Waters and Snyder (1986) 100 miles to the southwest suggests that planktic Zone P6 best represents this depositional sequence. Zone N6 correlates with the upper part of the Tejas B2.1 third-order cycle of Haq and others (1987). This interval is capped by the upper Lower Miocene sequence boundary, which correlates to the 17.5 m.y. global unconformity of Haq and others (1987).

Lower Miocene Sequence 3

Lower Miocene sequence 3 is a thin (110-150 feet) unit which is distributed evenly across the study area. In the Mobil #3, Mobil #2, Marshall Collins #1, and Mobil #1 wells, the gamma-ray log signatures are similar and indicate uniform deposition. A thin (20-30 feet) basal sand is overlain by a section comprised of alternating sand and clay beds. A similar section is interpreted from electric log signatures from the Esso #2 well.

This unit is moderately fossiliferous, with foraminiferal faunas representing deep inner neritic to middle neritic paleoenvironments. Preservation of foraminifera is poor in the Mobil #1, Esso #2, and Mobil #3 wells. In the Mobil #2 and Marshall Collins #1 wells, sparse planktic faunas contain Globigerina euapertura. This species became extinct in Zone N7 (Waters and Snyder, 1986) and is used herein to separate Zone N7 from the underlying Zone N6.

Except for the lowermost part, Zone N7 correlates with the Tejas B2.2 third-order cycle of Haq and others (1987). In the three southern wells the lower Miocene sequence 3 is overlain by the Middle Miocene sequence, and the intervening sequence boundary is the lower Middle Miocene sequence boundary. In the two northern wells the lower Miocene sequence 3 is overlain by the Lower Pliocene sequence. The lower Middle Miocene sequence boundary is correlated to the 15.5 m.y. global unconformity of Haq and others (1987).

Middle Miocene Sequence

The Middle Miocene sequence is thickest in the Mobil #2 and Mobil #3 wells (70-80 feet), thins substantially in the Esso #2 well (30 feet), and is absent to the north. This unit was recognized by its faunal content and correlated by paleoenvironmental trends and log signatures. Its lithology, often masked in cuttings by caved shell fragments and sand, is a sandy to silty clay. The base of the overlying Lower Pliocene sequence is marked by a coarse-grained subrounded sand.

Planktic foraminifera of the Praeorbulina bioseries provide excellent biostratigraphic resolution for this sequence. The occurrence of Globigerinoides sicanus, Praeorbulina transitoria, P. glomerosa curva, P. glomerosa circularis and Orbulina universa limit the biostratigraphic range of this interval to Zone N9 (Kennett and Srinivasan, 1983). Orbulina universa is an extant species which evolved in Zone N9 (Kennett and Srinivasan, 1983) and was not observed above the Middle Miocene sequence in any of the wells.

Zone N9 correlates with the middle of the Tejas B2.4 third-order cycle of Haq and others (1987). This sequence is capped by the Lower Pliocene sequence boundary, which is correlated to the 5.5 m.y. global unconformity of Haq and others (1987).

Lower Pliocene Sequence

Lithofacies in this sequence are variable. In the southern two wells, a basal sand is overlain by a lower pecten bioherm and an upper sandy limestone. In the Mobil #2 well the sandy limestone is overlain by a middle neritic biofacies. In the northern three wells, inner neritic and middle neritic biofacies consisting of fine-grained sand, fine-grained sandstone, siltstone, and clay predominate.

The post-Lower Pliocene sequence boundary caps the Lower Pliocene sequence. This horizon was delineated and correlated using well log signatures and paleontologic data. In wells with gamma-ray logs (all except Esso #2), the sequence boundary is at an abrupt transition from an underlying clay to an overlying sand. This feature is also seen on the resistivity log from the Esso #2 well. Coincident with this horizon is a transition from deep inner neritic or middle neritic paleoenvironments below, to marginal marine and very shallow inner neritic paleoenvironments above.

Foraminiferal representation is poor in the shelly and calcareous lithofacies and fair to good elsewhere. An Early Pliocene age is indicated as an upper limit by the planktic species Neogloboquadrina acostaensis, Pulleniatina primalis, and Dentoglobigerina altispira globosa. Of these, the two former species became extinct in Zone N19-20 and the latter became extinct in Zone N19 (Kennett and Srinivasan, 1983), or Early Pliocene. This sequence overlies units of either Early Miocene or early Middle Miocene age. Later Middle Miocene and Late Miocene strata were not recognized.

Zone N19 correlates with the Tejas B3.4 third-order cycle of Haq and others (1987). The Lower Pliocene sequence is capped by the post-Lower Pliocene sequence boundary. Exact correlation of this sequence boundary to the global cycle chart is uncertain, because biostratigraphic control for the overlying sequence is absent.

Upper Pliocene to Recent Sequence

This sequence consists of undifferentiated shallow marine sediments. It overlies the Lower Pliocene sequence, and its upper limit is the modern depositional surface. This unit is thickest (350 feet) in the Esso #2 well, and thins to the north (210-230 feet) and south (180-210 feet).

The resistivity log from the Esso #2 well and the gamma-ray logs from the other wells indicate a predominantly sandy section with a few silty intervals. Cuttings from this interval contain variable proportions of shell fragments and coarse- to fine-grained sand.

Foraminifera are absent in the Mobil #3 well and scarce to abundant in the other wells. These assemblages are dominated by Elphidium ssp. and Quinqueloculina ssp. and are similar to modern assemblages documented in this area by Grossman (1967). Samples in this interval also contain benthic species which are characteristic of shallow open marine conditions, as well as a few planktic specimens. Paleoenvironments in this interval range from marginal marine to shallow inner neritic.

DISCUSSION AND CORRELATION OF SEQUENCES

Overview

For convenience of discussion, the 26 sequences defined in this report are divided into eight sets. These include three sets of Cretaceous sequences which reflect similarities in depositional setting, and five sets of Tertiary/Quaternary sequences that generally correspond to series chronostratigraphic boundaries.

Biostratigraphic correlations for the Lower Cretaceous are approximate. They generally conform to parameters set by the ostracode zonation of Brown and others (1972) and the global cycle chart of Haq and others (1987). Ages for the Upper Cretaceous and Tertiary sequences are from foraminiferal biostratigraphy. In most cases this provides resolution to the level of stage or zone.

Sequences K-1 to K-6

The lower six sequences account for approximately half of the stratigraphic section. These sequences are provisionally designated K-1 through K-6 (in ascending order), because current data do not allow correlation of individual sequences to individual stratotypes. Sequence boundaries in this interval were defined using seismic and log correlations and were supported by lithologic and paleoenvironmental trends.

Seismic reflectors are continuous to semi-continuous and predominantly parallel (Underwood, 1988). Occasional small-scale channels and prograding clinoforms are present. Based on the overall seismic character, Underwood (1988) suggested that this interval was deposited in a low energy littoral to near-shore setting.

A very shallow inner neritic to non-marine depositional setting is indicated by lithology, well logs, and paleontologic data. This section is predominantly clastic, consisting of sandstone and sandy claystone. Sandstone beds are generally less than 100 feet thick. Thin biogenic limestones are also present, but are not abundant.

Time diagnostic planktic foraminifera are absent and benthic foraminifera are rare. Choffatella decipiens, which indicates an Aptian to Berriasian age (Owens and Gohn, 1985), occurs in sequences K-1 to lower K-4. Non-marine paleoenvironments were interpreted for intervals of sandstone and sand which are generally medium- to coarse-grained and have blocky spontaneous potential log signatures. Samples from these intervals commonly contain iron-stained sand grains and mica. Marginal marine paleoenvironments are indicated by fossiliferous intervals which contain ostracodes, mollusk fragments, and benthic foraminifera.

Each sequence in this interval consists of a lower non-marine sandstone and an upper marginal marine section consisting of sandstone, shale or claystone, and occasional occurrences of biogenic limestone. The lower non-marine intervals are interpreted to represent transgressive systems tracts and the upper marginal marine intervals are interpreted to represent highstand systems tracts. In a few cases, the transition between these systems tracts is indicated by the presence of glauconite.

This set of Lower Cretaceous and lowermost Upper Cretaceous sequences is equivalent to depositional sequence 1 of Owens and Gohn (1985). Correlation of their predominantly outcrop based pollen zonation for their depositional sequence 1 to rocks from this study area is not clear.

Sequences K-1, K-2, and K-3 are equivalent to Unit H of Brown and others (1972), sequences K-4 and K-5 are equivalent to Unit G of Brown and others (1972), and sequence K-6 is equivalent to Unit F of Brown and others (1972). The ostracode based biostratigraphic subdivision of Brown and others (1972) provides biostratigraphic ages for this part of the section. It does not, however, provide resolution finer than the level of groups of supercycles on the global cycle chart. On the correlation chart (plate 2), positions of the K-1 through K-6 sequence boundaries are estimated from the global cycle chart of Haq and others (1987) within biostratigraphic constraints provided by Brown and others (1972).

Cenomanian and Turonian Sequences

This set of three sequences includes the Middle to Upper Cenomanian sequence, the Lower to Middle Turonian sequence 1 and the Lower to Middle Turonian sequence 2. This set is differentiated from underlying and overlying sets of sequences by seismic character, depositional setting, and biostratigraphy. This interval is between the lower Middle Cenomanian sequence boundary and the basal Santonian sequence boundary. On the seismic sections this package is characterized by parallel reflectors. Continuity is good in the lower part of this package, and moderately good in the upper part.

Sequence boundaries in this interval were delineated by log correlation, lithology, and paleobathymetric trends. Sequence boundaries overlying the lower two sequences are at horizons where biofacies and lithofacies indicate a basinward shift of coastal onlap. The upper sequence boundary was defined using seismic data. It was picked at a reflector which terminates several underlying reflectors, indicating widespread erosion. There is a distinct faunal and lithologic discontinuity at this horizon, with the overlying unit representing deposition in a more basinward setting.

The Cenomanian and Turonian sequences represent a more basinward depositional setting than the underlying strata, but they were deposited in a shallower setting than the overlying set of sequences. Lithology consists of silty sandstones and claystones. Limestones are rare, and occur only in the Cenomanian sequence.

Paleoenvironments range from thin, non-marine transgressive systems tracts in the Lower to Middle Turonian sequence 1, to middle neritic parts of highstand systems tracts in each sequence. Assemblages of planktic foraminifera in the middle neritic intervals are sparse, but do provide good biostratigraphic resolution.

Depositional sequence 2 of Owens and Gohn (1985) approximately correlates with the Upper Cenomanian and Lower Turonian Stages. Precise correlation of the Cenomanian and Turonian sequences of this study to depositional sequence 2 of Owens and Gohn (1985) is hampered by a lack of common reference points.

Direct comparison of the chronostratigraphic units of Brown and others (1972) to sequences from this study is possible because their units are delineated in wells used in this study. Locally, the top of Unit E of Brown and others (1972) occurs at a horizon which is 50 to 150 feet below the Lower to Middle Turonian 1 sequence boundary. The top of Unit D of Brown and others (1972) is in the upper half of the Lower to Middle Turonian sequence 1. The top of Unit C of Brown and others (1972) occurs at a horizon which is approximately 50 feet below the basal Santonian sequence boundary.

The Middle to Upper Cenomanian sequence was deposited during the time represented by the Rotalipora cushmani Zone, which spans most of the Middle and Upper Cenomanian. This sequence is a chronostratigraphic equivalent to the lower part of depositional sequence 2 of Owens and Gohn (1985). The Middle to Upper Cenomanian sequence is also approximately equivalent to Unit E of Brown and others (1972).

The two Lower to Middle Turonian sequences have similar foraminiferal faunas. Their age is limited to no later than Middle Turonian by the occurrence of Dicarinella algeriana and Whiteinella brittonensis (Caron, 1985; Loeblich and Tappan, 1961). The age of these sequences is also constrained by the age of the underlying sequence. These sequences are partially correlative to depositional sequence 2 of Owens and Gohn (1985).

Strata assigned to the Lower to Middle Turonian sequence 1 encompass most of Unit D and the lower part of Unit C of Brown and others (1972). Strata assigned to the Lower to Middle Turonian sequence 2 are equivalent to the remainder of Unit C. Brown and others (1972) correlated Unit D to the Eagleford Stage, which is approximately equivalent to the Turonian Stage. Unit C of Brown and others (1972) was correlated to the Austin Stage, which is equivalent to the Coniacian, Santonian, and lowermost Campanian Stages.

The Lower to Middle Turonian sequence 1 is a chronostratigraphic equivalent of Unit D. The Lower to Middle Turonian sequence 2 is also a chronostratigraphic equivalent of Unit D, not Unit C. The reason for different interpretations of the age of these rocks is that planktic foraminiferal zonation provides a definitive top for the Lower Santonian at a horizon which is 300 to 400 feet above the top of Unit C, which Brown and others (1972) defined as an Austin Stage equivalent.

Santonian to Maastrichtian Sequences

This set of sequences includes the Lower Santonian sequence, the Lower Campanian sequence, the Upper Campanian sequence, and the lower Upper Maastrichtian sequence. This set of sequences is differentiated from subadjacent and superadjacent strata by its generally more basinward depositional setting. Sequences in this set are characterized by fine-grained clastic rocks and abundant foraminiferal assemblages.

The Lower Campanian sequence boundary was delineated by seismic correlation, biostratigraphy, and log correlation. In the Lower Santonian sequence, seismic reflectors are continuous and parallel, with good continuity.

This seismic sequence boundary correlates with a thin sand on the resistivity log, and a definitive biostratigraphic top. The upper three sequence boundaries in this set were recognized and correlated using logs and biostratigraphy.

Paleoenvironments of the more fossiliferous parts of the section are deep middle neritic to outer neritic. Preservation of foraminifera varies from poor to excellent. Intervals with sparse foraminiferal assemblages may represent inner neritic paleoenvironments, or possibly more basinward depositional conditions. Lithology consists primarily of clays and silty clays, with localized high concentrations of glauconite pellets.

Each sequence boundary in this set is characterized by the extinction of planktic or benthic foraminiferal index species. Planktic taxa provide a reliable top for the Lower Santonian sequence. Tops for the Campanian sequences depend on benthic foraminiferal species which are widely accepted as zonal indices for the the Gulf Coast section. The top of the lower Upper Maastrichtian sequence was recognized at the first down-hole occurrence of several planktic or benthic species.

In this set, correlations between the sequences and unconformities of Owens and Gohn (1985) and the sequences and sequence boundaries of this study are relatively good. The Lower Santonian sequence is a partial chronostratigraphic equivalent of depositional sequence 3 of Owens and Gohn (1985), which was assigned an age of Santonian to earliest Campanian. Depositional sequence 4 of Owens and Gohn (1985) comprises the remainder of the early Campanian, and is a chronostratigraphic equivalent of the Lower Campanian sequence of this study. Depositional sequence 5 of Owens and Gohn (1985) spans the late Campanian and part of the early Maastrichtian. The Upper Campanian sequence of this study spans the upper but not uppermost Campanian, so this sequence is a chronostratigraphic equivalent of the lower part of depositional sequence 5 of Owens and Gohn (1985). Depositional sequence 6 of Owens and Gohn (1985) covers the remainder of the Maastrichtian. The lower Upper Maastrichtian sequence of this study (Gansserina gansseri Zone of Caron, 1985) is a chronostratigraphic equivalent to the middle part of depositional sequence 6 of Owens and Gohn (1985).

Unit B of Brown and others (1972) is a lithostratigraphic equivalent of the lower three sequences in this set. Brown and others (1972) correlated Unit B to to the Taylor stage, which is equivalent to the Upper Campanian and the upper part of the Lower Campanian. The lower three sequences in this set make up parts of the Lower Santonian to Upper Campanian. The reason for this discrepancy is that the top of the Lower Santonian is 300 to 400 feet above the top of the Santonian Stage equivalent of Brown and others (1972).

The lower Upper Maastrichtian sequence of this study is limited to the lower part of the Upper Maastrichtian. This correlates with part of Unit A of Brown and others (1972). Their Unit A represents the entire Maastrichtian.

The Lower Maastrichtian sequence is partially equivalent to the local Deflandrea dartmooria - Alterbia minor Assemblage Zone of Coblentz (1985). This dinoflagellate zone spans the late Early Maastrichtian and early Late Maastrichtian, and is based on data from several core holes located in Lenoir and Brunswick counties, North Carolina (Coblentz, 1985).

Paleocene Sequences

Two sequences of Paleocene age occur in the study area, a Lower Paleocene sequence and an Upper Paleocene sequence. These thin units represent marine depositional settings and occur in each of the wells.

The middle Upper Paleocene sequence boundary was delineated throughout the study area on the seismic network (Underwood, 1988). This sequence boundary was also recognized on resistivity and gamma-ray logs and occurs at the base of a thin sandstone which separates the Paleocene sequences. The overlying uppermost Paleocene or Lower Eocene sequence boundary was recognized on spontaneous potential and resistivity logs in the northern three wells and on gamma-ray logs in the southern two wells.

The Paleocene sequences each consist of a thin, lower, fine-grained sandstone overlain by sandy siltstones and silty shales and claystones. In the lower sequence glauconite is locally abundant. Depositional setting of these sequences ranges from inner neritic to outer neritic. Variable preservation of microfaunas hampered more precise paleoenvironmental interpretations.

Outcropping and shallow subsurface strata of Paleocene age in the North Carolina Coastal Plain are assigned to the Beaufort Formation, which is divided into the Jericho Run Member and an upper unnamed member. A planktic zonation of P1 has been cited for the Jericho Run Member based on sparse foraminiferal control (Brown and others, 1977). If the Jericho Run Member is an updip equivalent of the lower Paleocene sequence of this study, a zonation of P2 may be indicated for this member.

The Upper Paleocene sequence correlates to planktic Zone P4. Outcrop and shallow subsurface samples of the upper member of the Beaufort Formation have been assigned to the same zone (Harris and Baum, 1977; Brown and others, 1977). In outcrop, this member contains an abundant and diverse outer neritic foraminiferal fauna.

Strata of the Lower Paleocene sequence are equivalent to the Midwayan chronostratigraphic unit of Brown and others (1972), which correlates to the Lower Paleocene and lowermost part of the Upper Paleocene. Strata of the Upper Paleocene sequence are equivalent to the lower part of the Sabinian chronostratigraphic unit of Brown and others (1972), which correlates to the upper part of the Upper Paleocene and the Lower Eocene.

Regional studies have subdivided the local Cenozoic section into unconformity bounded units. Poag and Valentine (1988) suggested a single sequence spanning the upper part of the Lower Paleocene and the lower part of the Upper Paleocene for the Atlantic shelf and slope. Popenoe (1985) indicated a single sequence represented by Paleocene rocks on the North Carolina shelf. Poag and Ward (1987) identified two episodes of coastal onlap for Paleocene strata of the Albemarle embayment, one in the Lower Paleocene and one in the Upper Paleocene. More precise comparisons to these regional studies are difficult because they are not tied to a foraminiferal zonation or local well section.

Eocene Sequences

Sequences of Eocene age in the study area include the uppermost Paleocene or Lower Eocene sequence, the Middle Eocene sequence, and the

Upper Eocene sequence. Strata of these sequences were deposited under fully marine shelfal conditions, but otherwise are dissimilar. These sequences are grouped together because of their stratigraphic position.

The Uppermost Paleocene or Lower Eocene sequence occurs in the four southern wells. It is a thin unit consisting of a lower sandstone overlain by a very silty clay, and was deposited in an inner shelf to shallow middle shelf setting. The overlying Middle Eocene sequence boundary was correlated using resistivity logs downdip and resistivity and spontaneous potential logs updip.

Foraminifera are sparse in this sequence because of shallow paleoenvironments and poor preservation. The occurrence of Subbotina soldadoensis soldadoensis suggests a possible range of planktic zones P5 to P9, or uppermost Paleocene through Lower Eocene.

Brown and others (1972) did not differentiate strata which in this study comprise the uppermost Paleocene or Lower Eocene sequence and the Upper Paleocene sequence. Instead they grouped them together as their Sabinian chronostratigraphic unit. Poag and Valentine (1988) indicated a Lower Eocene sequence on their Atlantic margin composite section. Popenoe (1985) indicated the presence of an upper Ypresian to lower Lutetian sequence for the subsurface of the North Carolina shelf. This is a partial chronostratigraphic equivalent of the uppermost Paleocene to Lower Eocene sequence. Poag and Ward (1987) identified a correlative coastal onlap event for strata of Early Eocene age in the Albemarle embayment.

The Middle Eocene sequence is a thick unit which extends across the study area. The overlying basal Upper Eocene sequence boundary was correlated using well logs and seismic reflection data. This sequence boundary reflector is most distinct in eastern Pamlico Sound, but is less distinct toward the north and west, where this horizon becomes progressively shallower in the stratigraphic section.

The Middle Eocene sequence consists of a lower calcareous fine-grained sandstone, which grades into an upper very sandy limestone. Glauconite is commonly present in the uppermost part of this sequence. The lithology of this sequence is most distinct on gamma-ray logs, and in cuttings.

Preservation of foraminifera in this interval is poor. Most specimens exhibit calcite overgrowths, and planktic species are rare. The paleoenvironment of this interval was interpreted as predominantly inner neritic. This interpretation may be artificially shallow because of poor preservation of microfaunas.

The Middle Eocene sequence probably correlates with the Castle Hayne Formation of Ward and others (1978) and the Claibornian chronostratigraphic unit of Brown and others (1972). Zullo and Harris (1987) subdivided rocks of the Castle Hayne Formation into five separate depositional sequences.

The Upper Eocene sequence occurs only in the Mobil #2 well. This thin unit consists of a lower sandstone, and an upper silty glauconitic clay which was deposited in an outer neritic paleoenvironment. The foraminiferal fauna in this interval is abundant and diverse. Planktic foraminifera indicate a zonation within the Globigerinatheca semiinvoluta Zone, which correlates with planktic Zones P15 and lowermost P16. This sequence was also recognized as a discrete unit on seismic reflection data and on the gamma-ray log.

There has been considerable controversy as to whether there are strata of Late Eocene age in outcrop or shallow subsurface of the North Carolina Coastal Plain. Baum and others (1978) proposed a Late Eocene age for their New Bern Formation. This is supported by Zullo (1979) based on zonation of barnacles, and Worsley and Turco (1979) based on calcareous nannofossils. Ward and others (1978) referred to the same strata as the Spring Garden Member of the Castle Hayne Formation and assigned a Middle Eocene age to them based on correlations of mollusk assemblages. Working with foraminiferal assemblages from outcrop and shallow subsurface, Jones (1983) assigned these strata to planktic Zones P12 to P13, and found no foraminiferal evidence for the Late Eocene. Brown and others (1972) and Poag and Ward (1987) also found no evidence for Upper Eocene strata in North Carolina. Upper Eocene strata occur in a slope core (ASP 5/5B) off the coast of southernmost North Carolina (Stainforth and Lamb, 1981), but these strata have not been correlated onto the shelf. This study constitutes the first documentation of planktic foraminiferal evidence for Late Eocene age strata in North Carolina. Additional work remains to determine whether this sequence can be correlated updip.

Oligocene and Lowermost Miocene Sequences

The three sequences in this set are the Lower Oligocene sequence, the Upper Oligocene sequence, and the Lower Miocene sequence 1. The two Oligocene sequences occur in the four southern wells, and the lowermost Miocene sequence occurs in the two southernmost wells. These sequences were deposited in shallow to deep neritic paleoenvironments, and contain varying amounts of clastic and carbonate rocks. Sequence boundaries in this set were correlated using lithologic characteristics and well log character, but were not delineated on the seismic sections.

Lithology of the Lower Oligocene sequence is a silty clay. The overlying Upper Oligocene sequence boundary is at the base of a coarse-grained sand which commonly contains abundant phosphatic pellets. This sand represents the transgressive systems tract of the overlying sequence and is evident on the gamma-ray log and in cuttings.

Foraminiferal faunas in samples from the Lower Oligocene sequence are sparse because of sand caved from the overlying unit. The presence of Globigerina ampliapertura and Globorotalia increbescens, and the absence of Globorotalia opima opima and Pseudohastigerina micra indicate placement within the Globigerina ampliapertura Zone.

The Oligocene chronostratigraphic unit of Brown and others (1972) was defined as containing Vicksburgian and Chickasawhayan age strata. No Vicksburg age equivalents were observed in this study. Strata mapped as the Oligocene chronostratigraphic unit of Brown and others (1972) include the Upper Eocene sequence, the Lower Oligocene sequence, and the lower part of the Upper Oligocene sequence. Poag and Ward (1987) indicated coastal onlap in the Albemarle embayment above the Vicksburg Stage, but below the 30 m.y. global unconformity of Haq and others (1987). This interval is a partial chronostratigraphic equivalent of the Lower Oligocene sequence of this study. Strata referable to the Globigerina ampliapertura Zone were recognized in outcrop (Zarra, 1983, 1988) and shallow subsurface (Reilly-Fletcher, 1986) samples from the North Carolina Coastal Plain, but the older Pseudohastigerina micra Zone and younger Globorotalia opima opima Zone were absent. In Atlantic Slope Project core 5/5B, Stainforth and Lamb (1981) recognized a complete Rupelian, Chattian, and lower Aquitanian section.

The Upper Oligocene sequence consists of a lower coarse-grained sand or phosphatic sand, overlain by silty clay, limestone, or barnacle shell hash. The overlying basal Miocene sequence boundary was recognized and correlated with gamma-ray logs, and lithofacies interpreted from cuttings. In the two southern wells, this sequence boundary was picked at the base of an overlying carbonate unit which comprises the lower part of the Lower Miocene sequence 1. This sequence boundary horizon correlates with the base of a thin sand in the Esso #2 and Marshall Collins #1 wells, which is at the base of the Lower Miocene sequence 2.

The depositional setting for the Upper Oligocene sequence is inner shelf to outer shelf. Occurrence and preservation of foraminifera is uneven, with planktic faunas restricted to the silty clays. Planktic foraminifera from this interval indicate correlation to the Globigerina ciperoensis Zone.

Brown and others (1972) did not recognize Lower Miocene strata in the subsurface of North Carolina. Strata of the Upper Oligocene sequence of this study are equivalent to part of the Oligocene chronostratigraphic unit and part of the Middle Miocene chronostratigraphic unit of Brown and others (1972). In the study area, the division between their Oligocene and Middle Miocene chronostratigraphic units coincides with the top of the transgressive systems tract of the Upper Oligocene sequence.

Planktic foraminiferal faunas from the Upper Oligocene sequence are similar to those documented in outcrop (Zarra, 1983, 1988) and shallow subsurface (Reilly-Fletcher, 1986) samples from the Globigerina ciperoensis Zone in North Carolina. Planktic faunas from this sequence are also similar to those from the Globigerina ciperoensis Zone in Atlantic Slope Project well 5/5B (Stainforth and Lamb, 1981), and the Chickasawhay Formation of the Gulf Coast (Poag, 1972).

The Lower Miocene Sequence 1 occurs in the Mobil #2 and Mobil #3 wells. It consists of a lower sandy limestone overlain by an upper phosphatic sand or clay. The occurrence of Globorotalia kugleri in the upper silty clay of the Mobil #2 well indicates a zonation of planktic Zone N4, which is equivalent to the Globorotalia kugleri Zone (Stainforth and others, 1975).

Brown and others (1972) included strata of the Lower Miocene sequence 1 in their Middle Miocene chronostratigraphic unit. Based on sparse planktic foraminiferal faunas Zarra (1983, 1988) suggested a zonation of the Globorotalia kugleri Zone for a few outcrop samples in eastern North Carolina. Abundant and diverse time equivalent faunas were documented by Stainforth and Lamb (1981) in Atlantic Slope Project 5/5B cores. Waters and Snyder (1986) recognized planktic Zone N4 in vibracores from southern Onslow Bay, southwest of the study area.

Lower and Middle Miocene Sequences

This set of sequences includes the Lower Miocene sequence 2, the Lower Miocene sequence 3, and the lower Middle Miocene sequence. These sequences are grouped together because of similarities in age, depositional setting, and seismic character. The two Lower Miocene sequences extend across the study area, but the Middle Miocene sequence occurs only in the three southern wells. Lithology of this sequence primarily consists of fine-grained sands, silts, and clays. This set of sequences represents a more basinward depositional setting than the overlying strata, with a range of paleoenvironments from inner neritic to shallow upper bathyal.

Seismic data also suggest a wide range of paleoenvironments for this set. On seismic line G-2, between the Mobil #2 and Esso #2 wells, several prograding clinoforms occur. These features either do not occur, or are too shallow in the stratigraphic section to be observed on the other seismic lines. These clinoforms indicate a considerable range of paleobathymetry at the time of deposition. A similar depositional style is seen on a shallow, high-resolution seismic line of Popenoe (1985, Fig. 4-7), which extends from the Esso #2 well to north of the Marshall Collins #1 well. Popenoe (1985) documented erosional and depositional episodes on the North Carolina shelf associated with sea level and gulf stream positions during the Miocene.

Lithology and depositional settings of the Lower Miocene sequence 2 are variable. The lower part of this sequence in the Mobil #2 and Mobil #3 wells is a sandy limestone, deposited in an inner neritic setting. In the Mobil #2 well this is overlain by a deep outer neritic to shallow upper bathyal clay. To the north, this sequence consists of shelf sands and silty clays. The overlying upper Lower Miocene sequence boundary is at the base of a thin sand bed, which was correlated using gamma-ray logs. This coincides with a biostratigraphic horizon and a distinct upward shoaling event which indicates a basinward shift of coastal onlap.

In the Lower Miocene sequence 2, foraminifera from the Mobil #2 and Marshall Collins #1 wells indicate planktic zone N6. Onshore, Reilly-Fletcher (1986) found Zone N6 overlying the late Oligocene Zone P22 (N3) in the shallow subsurface. To the south, in Onslow Bay, Waters and Snyder (1986) found Zone N6 overlying Zone N4. Planktic Zone N5 is absent, or is not represented by diagnostic foraminifera.

The Lower Miocene sequence 3 consists of thin sand and silty clay beds which were deposited in deep inner neritic to middle neritic paleoenvironments. In the three southern wells this sequence is overlain by the Middle Miocene sequence; in the two northern wells it is overlain by the Lower Pliocene sequence. In each well the overlying Middle Miocene sequence boundary is at the base of a thin sand bed observed in cuttings and on well logs.

Sparse planktic faunas from the Lower Miocene sequence 3 contain Globigerina euapertura, indicating a zonation no younger than N7 (Waters and Snyder, 1986). In shallow subsurface samples onshore, Reilly-Fletcher (1986) found Zone N7 overlying Zone N6. The same stratigraphic succession was documented in vibracores from Onslow Bay by Waters and Snyder (1986).

The Middle Miocene sequence occurs in the three southern wells. The Lower Pliocene sequence boundary is at the base of a coarse-grained sand which overlies the sandy to silty clays of the Middle Miocene sequence. This horizon coincides with an upward shoaling event, and divides open marine biofacies below from shallow marine to marginal marine biofacies above.

Planktic foraminifera from the Middle Miocene sequence indicate planktic Zone N9. Gibson (1983) documented Zone N8 at the Lee Creek Mine in Beaufort County, but not Zone N9, based on the absence of Orbulina universa. This species occurs in the Middle Miocene sequence. In two shallow wells northeast of the Lee Creek Mine, Abbott and Ernissee (1983) documented diatom assemblages equivalent to planktic zones N8 to N9, and N11.

Lower Pliocene to Recent Sequences

This set includes a Lower Pliocene sequence and an Upper Pliocene to Recent sequence. The Lower Pliocene sequence consists of marginal marine to shallow inner neritic shelly sands overlain by a thin inner shelf to middle shelf silty clay. The overlying Upper Pliocene to Recent sequence boundary is at the base of a medium- to coarse-grained sand which overlies the Lower Pliocene middle neritic biofacies.

Foraminifera from the middle neritic biofacies suggest Lower Pliocene Zone N19 based on the presence of species which became extinct in Zone N19 or N19/20, and the absence of strictly Miocene species. Foraminiferal faunas from this unit correlate reasonably well with those described from the Yorktown Formation at Lee Creek Mine by Snyder and others (1983). The lower shelly sand interval of this sequence may contain Upper Miocene strata which were not recognized because of the absence of time diagnostic foraminifera. Strata of Upper Miocene age crop out northwest of the study area.

The uppermost sequence consists of undifferentiated post-Lower Pliocene sands. This inner neritic to restricted marine unit is bounded by a sequence boundary below and the modern depositional surface above. No additional resolution or subdivision of this unit is possible with available data.

HYDROCARBON POTENTIAL

Including the wells examined for this study, 15 petroleum exploration wells have been drilled in Dare and Hyde Counties. All of these wells were dry and abandoned. The deepest well in North Carolina is the Hatteras Light (Esso #1) in Dare County, which penetrated basement at 9,853 feet. The closest offshore well is the Shell Baltimore Rise 93-1, which is located 250 miles northeast of the study area in 5,070 feet of water (Amato, 1987). In this well the top of the oil generation window is at 16,500 feet (Amato, 1987). This suggests that the stratigraphic section in the study area is not deep enough to have generated hydrocarbons.

In Lower Cretaceous strata of the study area the predominance of oxidized sandstones and sands, and red and green shales and claystones suggests that commercial source rocks are not present (Hunt, 1979). However, many of these sandstones may constitute good reservoirs, and the thin limestones and shales in this section may provide good seals, given appropriate structure. Lower Cretaceous sections basinward (east) of the study area are less likely to have been exposed to oxidizing conditions, and may contain adequate source rocks at sufficient depth to have generated hydrocarbons. Migration of hydrocarbons into the study area should not be ruled out.

Mobil Oil Company has announced plans to drill a 14,000 foot (projected depth) well on South Atlantic OCS block #467, about 50 miles east of Cape Hatteras. The primary objective of this well is the Jurassic shelf-edge reef trend, a play which has received considerable attention from the petroleum industry in the last decade.

This study provides two specific contributions which may facilitate future petroleum exploration efforts. First is a high-resolution biostratigraphic framework which can assist in the construction of more accurate exploration models. Second is a sequence stratigraphic model. With additional offshore seismic data this model could be extended basinward to predict source rocks and reservoir rocks at a depth sufficient to ensure thermal maturity.

CONCLUSIONS

Application of sequence stratigraphic concepts has resulted in a format for subdividing the stratigraphic section into sets of genetically related strata bounded by unconformities. Twenty-six depositional sequences were identified and correlated. This study represents a more accurate and higher resolution stratigraphic framework than previous work in the study area.

The lower six sequences, K-1 to K-6, represent marginal marine to non-marine depositional settings. In this part of the section an integrated sequence stratigraphic approach emphasizing seismic reflection data, log interpretation and correlation, and paleoenvironmental analysis was used. Sequence boundaries at the base of the K-4, K-6, and Middle to Upper Cenomanian sequences approximate the tops of Units H, G, and F, respectively, of Brown and others (1972). Validity of the K-2 to lower Middle Cenomanian sequence boundaries can be tested by determining their extent outside of the study area.

The Upper Cretaceous and Tertiary sequences generally represent open marine depositional settings. In this section an integrated sequence stratigraphic approach stressing foraminiferal biostratigraphy was used. This study documents and correlates previously unrecognized or poorly described foraminiferal assemblages for the Upper Cretaceous and Tertiary section of the study area. Stratigraphic findings for this part of the section are summarized below.

1) In the Middle to Upper Cenomanian sequence the occurrence of Rotalipora cushmani and Praeglobotruncana delrioensis confirms Brown and others' (1972) Woodbine Stage correlation for their Unit E, which comprises a majority of this sequence.

2) In the Lower to Middle Turonian sequence 1 the occurrence of Dicarinella algeriana, Whiteinella brittonensis, and Whiteinella hoelzli supports Brown and others' (1972) Eagle Ford Stage correlation for their Unit D, which comprises the lower part of this sequence. Results of this study do not agree with Brown and others (1972) Austin Stage correlation for the lower part of their Unit C, which comprises the upper part of this sequence.

3) In the Lower to Middle Turonian sequence 2 the occurrence of Dicarinella algeriana and Whiteinella brittonensis indicates an Early to Middle Turonian age. This does not agree with Brown and others' (1972) Austin Stage correlation for the upper part of their Unit C, which comprises a majority of this sequence.

4) In the Lower Santonian sequence the occurrence of Dicarinella primitiva and Marginotruncana renzi indicates an Early Santonian age. This does not agree with Brown and others' (1972) Taylor Stage correlation for the lower part of their Unit B, which comprises this sequence.

5) In the Lower Campanian and Upper Campanian sequences, benthic foraminiferal assemblages confirm Brown and others' (1972) Taylor stage correlation for the upper part of their Unit B, which comprises these sequences.

6) In the lower Upper Maastrichtian sequence the occurrence of Globotruncana ventricosa and Rosita fornicata with Rosita contusa and Gansserina gansseri indicates an early Late Maastrichtian age. This agrees with, and further refines Brown and others' (1972) Navarro Stage correlation for their Unit A, which comprises this sequence.

7) In the Lower Paleocene sequence the occurrence of Morozovella trinidadensis and M. inconstans and the absence of species limited to Zone P1 indicates zone P2. This agrees with and further refines Brown and others' (1972) Midway Stage correlation for strata in this sequence.

8) In the Upper Paleocene sequence the occurrence of Subbotina triloculinoides, Morozovella angulata, and M. conicotruncata, and the absence of species limited to Zone P3 indicate Zone P4. This agrees with Brown and others' (1972) Sabine Stage correlation for strata in this sequence and further refines this correlation to the lowermost part of the Sabine Stage.

9) In the uppermost Paleocene or Lower Eocene sequence the occurrence of Subbotina soldadoensis soldadoensis suggests a zonation of P5 to P9. This agrees with Brown and others' (1972) Sabine Stage correlation for these strata, but represents a separate unit from the Upper Paleocene sequence. Brown and others (1972) did not differentiate the strata which represent these sequences.

10) The Middle Eocene sequence is correlated to the Castle Hayne Formation, for which Jones (1983) provided a zonation of P12 to P13. This agrees with and further refines Brown and others' (1972) Claiborne Stage correlation.

11) In the Upper Eocene sequence the occurrence of Globigerinatheca semiinvoluta indicates a zonation of P15. Rocks of Upper Eocene age have not been previously documented in the deep subsurface of North Carolina.

12) The Lower Oligocene sequence was deposited during the time represented by the Globigerina ampliapertura Zone. This zone correlates, in part, with Brown and others' (1972) undifferentiated Vicksburgian-Chickasawhayan Oligocene Unit, and provides more precise biostratigraphic resolution.

13) The Upper Oligocene sequence was deposited during the time represented by the Globigerina ciperoensis Zone. Brown and others (1972) placed the lower part of this sequence in their undifferentiated Vicksburgian-Chickasawhayan unit, and the upper part in their Middle Miocene unit.

14) In the Lower Miocene sequence 1 the occurrence of Globorotalia kugleri and the absence of species limited to Zone P22 or older indicates Zone N4. Brown and others (1972) placed strata in this sequence in their Middle Miocene unit.

15) The Lower Miocene sequence 2 was deposited during the time represented by Zone N6. Brown and others (1972) placed the strata in this sequence in the upper part of their Middle Miocene unit.

16) The Lower Miocene sequence 3 was deposited during the time represented by Zone N7. Brown and others (1972) placed strata in this sequence in their Middle Miocene and Upper Miocene units.

17) The Middle Miocene sequence was deposited during the time represented by Zone N9. Brown and others (1972) placed strata in this sequence in their Middle Miocene and Late Miocene units.

18) In the Lower Pliocene sequence the occurrence of Dentoglobigerina altispira globosa, and the absence of Miocene species suggests a zonation of N19. Brown and others (1972) placed strata in this sequence in their Middle Miocene and Late Miocene units.

ACKNOWLEDGEMENTS

Partial support for this project was provided by the Continental Margins Cooperative Agreement No. 14-12-0001-30316-NC between the Minerals Management Service of the U. S. Department of the Interior and the Association of American State Geologists. Cities Service Oil Company donated 261 line-miles of seismic data for our year four research. Contract seismic interpretation and seismic mapping was performed by William D. Underwood, University of Tulsa, under sub-contract with the North Carolina Geological Survey.

The author is grateful to Charles W. Hoffman and Jeffrey C. Reid for their assistance in the design and supervision of this project. Most of the well samples were processed by John G. Nickerson and Scott Pearce. Some graphics were prepared by Roger Duke and Christopher Long. The author profited from discussions on local and regional geology with Patricia E. Gallagher, Charles W. Hoffman, John W. Jengo, and Scott W. Snyder. The organization and clarity of this report were significantly improved as a result of review comments provided by Charles W. Hoffman and Jeffrey C. Reid.

REFERENCES CITED

Abbot, W. H., and Ernissee, J. J., 1983, Biostratigraphy and paleoecology of a diatomaceous clay unit in the Miocene Pungo River Formation of Beaufort County, North Carolina, in Ray, C. E., Geology and paleontology of the Lee Creek Mine, North Carolina,I: Smithsonian Contributions to Paleobiology, n. 53, p. 287-353.

Almy, C. C., Jr., 1987, Lithostratigraphic-seismic evaluation of hydrocarbon potential, North Carolina coastal and continental margins: Interim report, Year 2, North Carolina Geological Survey interim administrative report, Cooperative program of the Association of American State Geologists and the U.S. Department of the Interior's Minerals Management Service for studies related to continental margins, 18 p.

Amato, R. V., editor, 1987, Shell Baltimore Rise 93-1 well: U.S. Minerals Management Service OCS Report MMS 86-0128, 55p.

Bandy, O. L., 1954, Distribution of some shallow-water foraminifera in the Gulf of Mexico: U. S. Geological Survey Professional Paper 254-F, p. 125-140.

Bandy, O. L., 1956, Ecology of foraminifera in northeastern Gulf of Mexico: U. S. Geological Survey Professional Paper 274-G, p. 179-204.

Baum, G. R., Harris, W. B., and Zullo, V. A., 1978, Stratigraphic revision of the exposed Middle Eocene to Lower Miocene formations of North Carolina: Southeastern Geology, v. 20, p. 1-19.

Brown, P. M., Brown, D. L., Shufflebarger, T. E. Jr., and Sampair, J. L., 1977, Wrench-style deformation in rocks of Cretaceous and Paleocene Age, North Carolina Coastal Plain: North Carolina Division of Earth Resources Special Publication 5, 47 p.

Brown, P. M., Miller, J. A., and Swain, F. M., 1972, Structural and stratigraphic framework and spatial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U. S. Geological Survey Professional Paper 796, 79 p.

Caron, M., 1985, Cretaceous planktic foraminifera, in Bolli, H. M., Saunders, J. B., and Perch-Nielson, K., editors, Plankton Stratigraphy: New York, Cambridge University Press, p. 17-86.

Coblentz, A. C., 1985, Taxonomy, biostratigraphy, and paleoecology of Upper Cretaceous dinoflagellates of North Carolina [M.S. thesis]: Newark, University of Delaware, 254 p.

Cushman, J. A., 1946, Upper Cretaceous foraminifera of the Gulf Coastal region of the United States and adjacent areas: U. S. Geological Survey Professional Paper 206, 241 p.

Gernant, R. E., and Kesling, R. V., 1966, Foraminiferal paleoecology and paleoenvironmental reconstruction of the Oligocene middle Frio in Chambers County, Texas: Transactions - Gulf Coast Association of Geological Societies, v. 16, p. 131-158.

Gibson, T. G., 1983, Stratigraphy of Miocene through Lower Pliocene strata of the United States Central Atlantic Coastal Plain, in Ray, C. E., editor, Geology and paleontology of the Lee Creek Mine, North Carolina, I: Smithsonian Contributions to Paleobiology, n. 53, p. 287-353.

Grossman, S., 1967, Ecology of Rhizopodea and Ostracoda of southern Pamlico Sound region, North Carolina: Part 1 living and fossil Rhizopod and Ostracode populations: University of Kansas Paleontological Contributions, serial number 44, p. 7-82.

Haq, B. U., Hardenbol, J., and Vail, P. R., 1987, Chronology of fluctuating sea levels since the Triassic: Science, v. 235, p. 1156-1167.

Harris, W. B., and Baum, G. R., 1977, Foraminifera and Rb-Sr glauconite ages of a Paleocene Beaufort Formation outcrop in North Carolina: Geological Society of America Bulletin, v. 88, n. 6, p. 869-872.

Hoffman, C. W., Almy, C. C., Jr, and Brown, P. M., 1985, Elements of the subsurface geologic framework of a segment of the North Carolina outer Coastal Plain and adjacent continental shelf: North Carolina Geological Survey interim administrative report, AASG/MMS Project R-84-1, 55 p.

Hunt, J. M., 1979, Petroleum geology and geochemistry: W. H. Freeman and Company, San Francisco, California, 617 p.

Jones, G. D., 1983, Foraminiferal biostratigraphy and depositional history of the Middle Eocene rocks of the Coastal Plain of North Carolina: North Carolina Geological Survey Section Special Publication 8, 80 p.

Kennett, J, P., and Srinivasan, M. S., 1983, Neogene planktonic foraminifera: Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania, 265 p.

Loeblich, A. R., and Tappan, H., 1961, Cretaceous planktonic foraminifera: Part 1 - Cenomanian: Micropaleontology, v. 7, p. 257-304.

Loutit, T. S., Hardenbol, J., Vail, P. R., and Baum, G. R., 1988, Condensed sections: the key to age determination and correlation of continental margin sequences, in Wilgus, C. K., Hastings, B. S., Kendall, C. G. St. C., Posamentier, H. W., Ross, C. A., and Van Wagoner, J. C., 1988, Sea-level changes: an integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication n. 42, p. 183-213.

Mitchum, R. M., Jr., Vail, P. R., and Thompson, S., III, 1977, Seismic stratigraphy and global changes of sea level, Part 2: The depositional sequence as a basic unit for stratigraphic analysis, in Payton, C. E., editor, Seismic stratigraphy - applications to hydrocarbon exploration: Tulsa, American Association of Petroleum Geologists Memoir 26, 516 p.

Murray, J. W., 1973, Distribution and ecology of living benthic foraminiferids: London, Heinemann Educational Books Limited, 274 p.

Owens, J. P., and Gohn, G. S., 1985, Depositional history of the Cretaceous Series in the U. S. Atlantic Coastal Plain: stratigraphy, paleoenvironments, and tectonic controls of sedimentation: in Poag, C. W., editor, 1985, Geologic evolution of the United States Atlantic margin: New York, Van Nostrand Reinhold Company, Incorporated, p. 25-86.

Poag, C. W., 1972, Planktonic foraminifers of the Chickasawhay Formation, United States Gulf Coast: Micropaleontology, v. 18, p. 257-277.

Poag, C. W., and Valentine, P. C., 1988, Mesozoic and Cenozoic stratigraphy of the United States Atlantic continental shelf and slope: in Sheridan, R. E., and Grow, J. E., editors, The geology of North America, Volume I-2, The Atlantic continental margin, U. S.: Boulder, Colorado, Geological Society of America, p. 67-85.

Poag, C. W., and Ward, L. W., 1987, Cenozoic unconformities and depositional supersequences of North Atlantic continental margins: Testing the Vail model: Geology, v. 15, p. 159-162.

Popenoe, P., 1985, Cenozoic depositional and structural history of the North Carolina margin from seismic-stratigraphic analysis, in Poag, C.W. editor, 1985, Geologic evolution of the United States Atlantic margin: New York, Van Nostrand Reinhold Co., 383 p. and plates.

Posamentier, W. H., Jervey, M. T., and Vail, P. R., 1988, Eustatic controls on clastic deposition I - conceptual framework, in Wilgus, C. K., Hastings, B. S., Kendall, C. G. St. C., Posamentier, H. W., Ross, C. A., and Van Wagoner, J. C., Sea-level changes: an integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication 42, p. 109-124.

Posamentier, W. H., and Vail, P. R., 1988, Eustatic controls on clastic deposition II - sequence and systems tract models, in Wilgus, C. K., Hastings, B. S., Kendall, C. G. St. C., Posamentier, H. W., Ross, C. A., and Van Wagoner, J. C., Sea-level changes: an integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication 42, p. 125-154.

Reilly-Fletcher, R., 1986, Planktonic foraminifera from the Oligocene and Early Miocene of Jones and Onslow Counties, North Carolina [M.S. thesis]: Newark, University of Delaware, 417 p.

Sliter, W. V., and Baker, R. A., 1972, Cretaceous bathymetric distribution of benthic foraminifers: Journal of Foraminiferal Research, v. 2, p. 167-183.

Snyder, S. W., Mauger, L. L., and Akers, W. H., 1983, Planktonic foraminifera and biostratigraphy of the Yorktown Formation, Lee Creek Mine, in Ray, C. E., editor, Geology and paleontology of the Lee Creek Mine, North Carolina, I: Smithsonian Contributions to Paleobiology, n. 53, p. 455-481.

Snyder, S. W., Mallette. P. M., Snyder, S. W., Hine, A. C., and Riggs, S. R., 1988, Overview of seismic stratigraphy and lithofacies relationships in Pungo River Formation sediments of Onslow Bay, North Carolina Continental Shelf, in Snyder, S. W., editor, Micropaleontology of Miocene sediments in the shallow subsurface of Onslow Bay, North Carolina Continental Shelf: Cushman Foundation for Foraminiferal Research, Special Publication 25, p. 1-14.

Stainforth, R. M., and Lamb, J. L., 1981, An evaluation of planktonic foraminiferal zonation of the Oligocene: The University of Kansas Paleontological Contributions, Paper 104, 42 p.

Stainforth, R. M., Lamb, J. L., Luterbacher, H., Beard, J. H., and Jeffords, R. M., 1975, Cenozoic planktonic foraminiferal zonation and characteristics of index forms: The University of Kansas Paleontological Contributions, Article 62, 425 p.

Spangler, W. B., 1950, Subsurface geology of Atlantic Coastal Plain of North Carolina: American Association of Petroleum Geologists Bulletin, v. 34, p. 100-132.

Swain, F. M., 1947, Two recent wells in Coastal Plain of North Carolina: American Association of Petroleum Geologists Bulletin, v. 31, p. 2054-2060.

Swain, F. M., 1951, Ostracoda from wells in North Carolina Part 1, Cenozoic Ostracoda: U. S. Geological Survey Professional Paper 234-A, p. 1-58.

Swain, F. M., 1952, Ostracoda from wells in North Carolina Part 2, Mesozoic Ostracoda: U. S. Geological Survey Professional Paper 234-B, p. 59-93.

Swain, F. M., and Brown, P. M., 1972, Some Lower Cretaceous, Jurassic(?) and Triassic Ostracoda from the Atlantic Coastal region for use in hydrogeologic studies: U. S. Geological Survey Professional Paper 795, 55 p.

Toumarkine, M., and Luterbacher, H., 1985, Paleocene and Eocene planktic foraminifera, in Bolli, H. M., Saunders, J. B., and Perch-Nielson, K., editors, Plankton Stratigraphy: New York, Cambridge University Press, p. 87-154.

Underwood, W. D., 1988, North Carolina Geological Survey AASG/MMS phase 4 final report: unpublished contractual report to North Carolina Geological Survey, 14 p.

Vail, P. R., Mitchum, R. M., Jr., Shipley, T. H., and Buffler, R. T., 1980, Unconformities of the North Atlantic: Philosophical Transactions of the Royal Society of London, v. 294, p. 137-155.

Vail, P. R., Mitchum, R. M., Jr., Todd, R. G., Widmier, J. M., Thompson, S., III, Sangree, J. B., Bubb, J. N., and Hatlelid, W. D., 1977, Seismic stratigraphy and global changes of sea level, in Payton, C. E., editor, Seismic stratigraphy-applications to hydrocarbon exploration: Tulsa, American Association of Petroleum Geologists Memoir 26, p. 49-212.

Vail, P. R., and Todd, R. G., 1981, North Sea Jurassic unconformities, chronostratigraphy and sea-level changes from seismic stratigraphy, Petroleum Geology of the Continental Shelf of North-West Europe: London, Institute of Petroleum, p. 216-235.

Van Hinte, J. E., 1976, A Cretaceous time scale: American Association of Petroleum Geologists Bulletin, v. 60, plate 2.

Van Wagoner, J. C., Posamentier, H. W., Mitchum, R. M., Vail, P. R., Sarg, J. F., Loutit, T. S., and Hardenbol, J., 1988, An overview of the fundamentals of sequence stratigraphy and key definitions, in Wilgus, C. K., Hastings, B. S., Kendall, C. G. St. C., Posamentier, H. W., Ross, C. A., and Van Wagoner, J. C., Sea-level changes: an integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication 42, p. 39-45.

Ward, L. W., Lawrence, D. R., and Blackwelder, B. W., 1978, Stratigraphic revision of the Middle Eocene, Oligocene, and Lower Miocene - Atlantic Coastal Plain of North Carolina: U. S. Geological Survey Bulletin 1457-F, 23 p.

Ward, L. W., and Strickland, G. L., 1985, Outline of Tertiary stratigraphy and depositional history of the U.S. Atlantic Coastal Plain, in Poag, C. W. editor, 1985, Geologic evolution of the United States Atlantic margin: New York, Van Nostrand Reinhold Company, Incorporated, p. 87-123.

Waters, V. J., and Snyder, S. W., 1986, Planktonic foraminiferal biostratigraphy of the Pungo River Formation, southern Onslow Bay, North Carolina continental shelf: Journal of Foraminiferal Research, v. 16, p. 9-23.

Worsley, T. R., and Turco, K. P., 1979, Calcareous nannofossils from the Lower Tertiary of North Carolina, in Baum, G. R., Harris, W. B., and Zullo, V. A., editors, Structural and stratigraphic framework for the Coastal Plain of North Carolina: Field Trip Guidebook, Carolina Geological Society and Atlantic Coastal Plain Geological Association, p. 65-72.

Zarra, L., 1983, Biostratigraphy of planktonic foraminifera from Oligocene and lowermost Miocene rocks of the North Carolina Coastal Plain [abstract]: Geological Society of America, Abstracts with Programs, v. 15, p. 726.

Zarra, L, 1988, Biostratigraphy of planktonic foraminifera from Oligocene and lowermost Miocene rocks of the North Carolina Coastal Plain [M.S. thesis]: Newark, University of Delaware, 260 p.

Zullo, V. A., 1979, Biostratigraphy of Eocene through Miocene Cirripedia, North Carolina Coastal Plain, in Baum, G. R., Harris, W. B., and Zullo, V. A., editors, Structural and stratigraphic framework for the Coastal Plain of North Carolina: Field Trip Guidebook, Carolina Geological Society and Atlantic Coastal Plain Geological Association, p. 73-85.

Zullo, V. A., and Harris, W. B., 1987, Sequence stratigraphy, biostratigraphy, and correlation of Eocene through Lower Miocene strata in North Carolina: Cushman Foundation for Foraminiferal Research, Special Publication 24, p. 197-214.

APPENDIX A. WELL DATA

WELL NAME	OPERATOR	COUNTY	NCGS CODE	API #	TD	EL	LOGS
Esso #2 (Pamlico Sound)	Standard Oil of N.J.	Dare	DR-OT-1-47	32-055-00002	6410	21	SP, R
Mobil #1 (State of N.C #1)	Socony Mobil Oil Co.	Dare	DR-OT-1-65	32-055-00003	5269	24	SP, R, G, S, O
Mobil #2 (State of N.C #2)	Socony Mobil Oil Co.	Dare	DR-OT-2-65	32-055-00004	8386	24	SP, R, G, S, O
Marshall Collins #1	Edwin Blair and Assoc.	Dare	DR-OT-3-65	32-055-00005	6295	14	SP, R, G, S, O
Mobil #3 (State of N.C #3)	Socony Mobil Oil Co.	Hyde	HY-OT-1-65	32-095-00009	7309	24	SP, R, G, S, O

TD = Total Depth (in feet)
EL = Elevation of well datum above sea level (in feet)

SP = Spontaneous Potential
R = Resistivity
G = Gamma Ray
S = Sonic
O = Others

APPENDIX B. PRELIMINARY BIOSTRATIGRAPHIC FRAMEWORK

STRATIGRAPHIC INTERVALS	INDEX SPECIES	Depths to Index Species (in feet below sea level)				
		M #1	MC #1	E #2	M #2	M #3
Lower Pliocene	Neogloboquadrina acostaensis	196	316	459	216	--
	Dentoglobigerina altispira globosa	--	316	459	--	--
Middle Miocene	Globigerinoides sicanus	--	--	--	516	--
	Praeorbulina transitoria	--	--	--	516	--
	Praeorbulina glomerosa circularis	--	--	619	516	--
	Praeorbulina glomerosa curva	--	--	--	556	--
Lower Miocene-3	Globigerina euapertura	696	606	--	576	656
Lower Miocene-2	Globigerinoides altiapertura	--	--	--	576	696
	Catapsydrax unicavus	--	786	--	776	--
	Globigerinoides parawoodi	--	826	--	776	--
	Catapsydrax dissimilis	--	--	--	796	856
	Globoquadrina praedehiscens	--	--	--	816	--
Lower Miocene-1	Globorotalia kugleri	--	--	--	1136	--
Upper Oligocene	Globigerina anguliofficinalis	--	1006	--	1216	--
	Globigerina ciperoensis	--	1016	--	1226	--
	Globorotalia opima nana	--	1016	--	1226	--
Lower Oligocene	Globigerina ampliapertura	--	--	1319	--	--
	Globorotalia increbescens	--	1086	--	1426	--
Upper Eocene	Globigerinatheca semiinvoluta	--	--	--	1476	--
	Hanthenina longispina	--	--	--	1476	--
	Globorotalia cerroazulensis cerroazulensis	--	--	--	1496	--
Middle Eocene	Melonus planatus *	--	1146	--	--	--
	Gyroidina orbicularis planata *	--	1146	--	--	--
	Subbotina linaperta	--	1206	--	1536	--
	"Globigerinoides" higginsi	--	--	1419	--	--
Lower Eocene	Subbotina soldadoensis soldadoensis	--	1566	--	--	--
Upper Paleocene	Subbotina triloculinoides	1226	1586	1919	2156	--
	Robulus midwayensis *	--	1586	--	--	--
	Morozovella conicotruncata	--	--	1939	--	--
	Morozovella angulata	--	--	2179	2176	--
	Acarinina mckannai	1266	--	2179	2176	--

* = Benthic Foraminifera

M #1 = Mobil #1
MC #1 = Marshall Collins #1
E #2 = Esso #2
M #2 = Mobil #2
M #3 = Mobil #3

APPENDIX B. PRELIMINARY BIOSTRATIGRAPHIC FRAMEWORK (continued)

STRATIGRAPHIC INTERVALS	INDEX SPECIES	Depths to Index Species (in feet below sea level) M #1	MC #1	E #2	M #2	M #3
Lower Paleocene	Morozovella pseudobulloides	--	--	--	2236	--
	Morozovella uncinata	--	1726	--	--	--
	Morozovella inconstans	--	1746	--	--	--
	Morozovella trinidadensis	--	1746	--	--	--
	Vaginulina longiforma *	--	1766	--	--	--
Upper Maastrichtian	Robulus navarroensis *	1316	1786	--	--	--
	Anomalina pinguis *	1396	1786	--	--	--
	Dorothia bulletta *	1396	1806	--	--	--
	Globotruncana fornicata	--	1826	2339	2436	--
	Rugoglobigerina rugosa	1396	1846	2259	2476	--
	Globotruncana ventricosa	1396	1826	2258	--	--
Upper Campanian	Lituola taylorensis *	--	--	--	2716	--
	Bolivinoides decorata *	1456	1926	--	2716	--
	Globorotalites conicus *	1456	1926	2379	2736	2376
Lower Campanian	Kyphopyxa christneri *	1456	1986	2439	2776	--
	Planulina taylorensis *	--	1906	2359	2776	2376
Lower Santonian	Marginotruncata marginata	--	2026	2479	2836	2516
	Marginotruncana renzi	1776	2066	2459	2836	2516
	Dicarinella concavata	--	2106	2459	2836	--
	Dicarinella primitiva	--	--	--	2836	--
	Dicarinella imbricata	--	--	--	--	2516
	Marginotruncana pseudolinneiana	--	2266	2459	--	2536
	Marginotruncana sinuosa	--	2106	2479	2856	2576
	Whiteinella baltica	--	--	--	3076	--
	Dicarinella indica	--	--	--	3116	2616
Lower to Middle Turonian	Dicarinella algeriana	--		3059	3416	2816
	Whiteinella hoelzli	2256	2886	3019	3436	--
	Whiteinella brittonensis	--	2846	3039	3676	2816
Middle to Upper Cenomanian	Praeglobotruncana delrioensis	--	2926	3539	3876	--
	Guembelitria cenomana	--	2886	--	--	--
	Rotalipora cushmani	--	--	3659	--	--
Pre-Albian	Choffatella decipiens *	--	5806	--	8176	6376

* = Benthic Foraminifera

M #1 = Mobil #1
MC #1 = Marshall Collins #1
E #2 = Esso #2
M #2 = Mobil #2
M #3 = Mobil #3

APPENDIX C. DEPTHS BELOW SEA LEVEL OF SEQUENCE BOUNDARIES

SEQUENCE BOUNDARY	MOBIL #1	MARSHALL COLLINS #1	ESSO #2	MOBIL #2	MOBIL #3
POST-LOWER PLIOCENE	186	216	329	186	156
LOWER PLIOCENE	NA	NA	619	516	426
LOWER MIDDLE MIOCENE	396	606	649	586	516
UPPER LOWER MIOCENE	536	756	779	696	646
LOWER MIOCENE	NA	NA	NA	1106	986
BASAL MIOCENE	NA	996	1109	1166	1136
UPPER OLIGOCENE	NA	1086	1279	1386	1126
LOWER OLIGOCENE	NA	NA	NA	1456	NA
BASAL UPPER EOCENE	846	1156	1399	1506	1176
MIDDLE MIDDLE EOCENE	NA	1576	1909	2006	1696
UPPERMOST PALEOCENE OR LOWER EOCENE	1216	1596	1949	2106	1796
MID-UPPER PALEOCENE	1266	1666	2079	2226	1896
UPPER LOWER PALEOCENE	1306	1796	2229	2416	2076
BASAL UPPER MAASTRICHTIAN	1406	.1926	2359	2556	2236
UPPER CAMPANIAN	1456	1986	2439	2776	2436
LOWER CAMPANIAN	1516	2046	2479	2856	2536
BASAL SANTONIAN	1706	2256	2739	3106	2826
LOWER TO MIDDLE TURONIAN-2	1896	2446	2899	3396	3036
LOWER TO MIDDLE TURONIAN-1	2096	2736	3269	3896	3406
LOWER MIDDLE CENOMANIAN	2466	3246	3769	4346	3946
K-6	3586	4346	4899	5246	4956
K-5	4486	5146	5489	5996	5506
K-4	4656	5526	6219	6966	6116
K-3	4846	5806	NP	7506	6666
K-2	NA	NA	NP	7956	7046
K-1 (BASEMENT)	5231	6256	NP	8336	7198

NA = Not Applicable
NP = Not Penetrated