

BIOSTRATIGRAPHY, PALEOGEOGRAPHY, AND PALEOENVIRONMENTS
OF THE UPPER CRETACEOUS (CAMPANIAN)
NORTHERN MISSISSIPPI EMBAYMENT

by

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A DISSERTATION

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ABSTRACT

Most paleogeographic and paleoenvironmental reconstructions of the northern Mississippi Embayment during the Late Campanian (Late Cretaceous) illustrate a generalized gulf between central Mississippi and Arkansas stretching northward into southern Illinois. The most detailed reconstruction shows a large river flowing from the Appalachians to the northeastern edge of the gulf with a river delta covering most of the northern embayment and stretching from southern Illinois to west-central Alabama. Lack of age constraints, incorrect stratigraphic correlations, paucity of detailed geologic maps and subsurface data, and misunderstanding of the basin geometry have led to inaccurate or vague paleogeographic interpretations of the Upper Cretaceous northern Mississippi Embayment.

This project correlates the marine and nonmarine biostratigraphy, identifies the upper Campanian lithofacies, interprets the paleoenvironment of each lithofacies, and maps these interpretations to create a paleogeographic model of the northern Mississippi Embayment during the Late Campanian. Biostratigraphic indicators used in this project include foraminifera, calcareous nannoplankton, palynomorphs, ammonites, and other mollusks. Uppermost Campanian units correlated in this project include the uppermost Demopolis Chalk and lowermost Ripley Formation in Alabama and Mississippi; a basal volcanoclastic deposit of the subsurface Demopolis Chalk in Mississippi; the Coon Creek Formation lower facies in Tennessee; the Coffee Sand in northern Tennessee, Kentucky, Illinois, and Missouri; the smectite clays (proposed name of Glenallen Clay) in Missouri; the lower Nacatoch Sand and

upper Saratoga Chalk in Arkansas; and the Saratoga and Demopolis Chalks undifferentiated calcareous clay in the central embayment subsurface. Paleoenvironments identified in the study area include molluscan-rich clastic shelf; barrier bar complex; carbonate shelf; estuaries and tidal flats; depression marshes and lakes; and volcanoes with clastic and carbonate rims.

LIST OF ABBREVIATIONS AND SYMBOLS

<i>AL</i>	Alabama
<i>AR</i>	Arkansas
<i>CCTS</i>	Coon Creek type section
<i>CIMAS</i>	Cooperative Institute for Marine and Atmospheric Studies
<i>Co.</i>	County
<i>FL</i>	Florida
<i>Fm</i>	Formation
<i>FO</i>	First occurrence (of a biostratigraphic indicator)
<i>GBIF</i>	Global Biodiversity Information Facility
<i>GIS</i>	Geographic Information System
<i>GSSP</i>	Global Boundary Stratotype Section and Point
<i>ICS</i>	International Commission on Stratigraphy
<i>IL</i>	Illinois
<i>ISGS</i>	Illinois State Geological Survey
<i>ITIS</i>	Integrated Taxonomic Information System
<i>km</i>	Kilometers
<i>KY</i>	Kentucky
<i>LO</i>	Last occurrence (of a biostratigraphic indicator)
<i>m</i>	Meters

<i>Ma</i>	Mega-annum (millions of years)
<i>Mbr</i>	Member
<i>MERAS</i>	Mississippi Embayment Regional Aquifer Study
<i>MEOW</i>	Marine Ecoregions Of the World
<i>MO</i>	Missouri
<i>MS</i>	Mississippi
<i>NGDC</i>	National Geophysical Data Center
<i>NOAA</i>	National Oceanic and Atmospheric Administration
<i>PaleoDB</i>	Paleobiology Database
<i>SST</i>	Sea surface temperature
<i>SSV</i>	Sea surface velocity
<i>TN</i>	Tennessee
<i>USA</i>	United States of America
<i>USGS</i>	United States Geological Survey
<	Less than
>	Greater than
=	Equal to

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CONTENTS

ABSTRACT.....	ii
LIST OF ABBREVIATIONS AND SYMBOLS	iv
ACKNOWLEDGMENTS	vi
LIST OF TABLES	x
LIST OF FIGURES	xii
1. INTRODUCTION	1
2. BIOSTRATIGRAPHIC CORRELAION OF UPPER CAMPANIAN UNITS IN THE NORTHERN MISSISSIPPI EMBAYMENT	9
3. PALEOENVIRONMENTAL INTERPRETATION OF THE LOWER FACIES OF THE COON CREEK FORMATION.....	78
4. PALEOGEOGRAPHY AND PALEOENVIRONMENTS OF THE LATEST CAMPANIAN MISSISSIPPI EMBAYMENT GULF	113
5. CONCLUSIONS.....	166
REFERENCES	171

LIST OF TABLES

2.1 Upper Cretaceous palynomorphs and their upper Campanian and lower Maastrichtian ranges	21
2.2 Lithologic descriptions of the upper Campanian and lower Maastrichtian lithofacies in the study area, in alphabetical order by formation.....	25
2.3 Cores, well cuttings, and outcrops biostratigraphically correlated to the lower Coon Creek lithofacies.....	31
3.1 Bivalves present in the Coon Creek type section.....	83
3.2 Gastropods present in the Coon Creek type section	85
3.3 Vertebrate genera present in the Coon Creek type section.....	88
3.4 Foraminiferans present in the Coon Creek type section	89
3.5 Abiotic characteristics of locations identified in the biogeographic analysis as potential modern analog environments to the CCTS.....	101
4.1 Lithologic descriptions of the uppermost Campanian lithofacies (Coon Creek lower lithofacies age equivalent) in the northern Mississippi Embayment study area.....	123
4.2 Molluscan genera in the uppermost Campanian lithofacies in the Mississippian Embayment and range of water depth (shallowest to deepest) inhabited by the same modern genera	124

4.3 Subsurface samples from uppermost Campanian lithofacies in the
northern Mississippi Embayment used in this study.....137

LIST OF FIGURES

1.1 The Mississippi Embayment and immediate area	2
1.1 Geology and topography of the region	3
1.2 Structural geology of the Mississippi Embayment	4
2.1 The study area: northern Mississippi Embayment and the immediate surrounding area.....	11
2.2 Late Campanian and early Maastrichtian biostratigraphic ranges of palynomorph zones, calcareous nannoplankton, foraminifera, and ammonites	14
2.3 Upper Campanian and lower Maastrichtian outcrop belts in Tennessee, Kentucky, Illinois, and Missouri with points showing locations of surface and subsurface data used in this project	24
2.4 Upper Campanian and lower Maastrichtian outcrop belts in Alabama, Mississippi, and Tennessee with points showing locations of surface and subsurface data used in this project.....	27
2.5 Upper Campanian and lower Maastrichtian outcrop belts in Missouri and Arkansas with points showing locations of surface and subsurface data used in this project.....	28
2.6 The upper Campanian and lower Maastrichtian outcrop belt in the northern Mississippi Embayment study area	56

2.7	Examples of subsurface Upper Campanian and lower Maastrichtian stratigraphy in the northern Mississippi Embayment study area	57
2.8	The uppermost Campanian lithofacies in the subsurface of the northern Mississippi Embayment study area	58
3.1	The Coon Creek Formation type section in McNairy County, Tennessee and one of the well preserved fossils from the type section	82
3.2	Distribution of molluscan classes at the CCTS and their status as extinct or extant.....	92
3.3	Flow chart illustrating biogeographical modeling compiling species ranges to produce a biogeographic genus raster	94
3.4	Flow chart illustrating summation of biogeographical genus rasters to produce a faunal assemblage raster	94
3.5	The four areas identified in the biogeographic geospatial analysis identifying potential modern analog environments	95
3.6	Average realized niche depth ranges of extant bivalve genera for which depth ranges could be found in publications.....	99
3.7	Average realized niche depth ranges of extant gastropod genera for which depth ranges could be found in publications.....	99
3.8	A west-to-east cross section depicted the interpreted environment for the lower Coon Creek facies and Coon Creek type section environments.....	104
4.1	Geology of the study area and Gulf Coastal Plain	116
4.2	The Reelfoot Rift within the Mississippi Embayment.....	118

4.3 The upper Campanian and lower Maastrichtian outcrop belt in the northern Mississippi Embayment study area	122
4.4 Fossils in clayey sand matrix at the Coon Creek type section, Coon Creek lower lithofacies	126
4.5 Outcrop of the Coffee Sand near Camden, Tennessee	128
4.6 Photos of ISGS core #15204 from Pulaski County for depths 63-66 m, 66-71 m, 64.5 m, and 69 m	131
4.7 Photos from Woodruff County Craig Williams core MW No. 6 from 254.8-257.6 m	135
4.8 Depression lakes and marshes in a section of the Marianna 1:100,000-scale topographic map in Washington County, Florida, north of Greenhead	145
4.9 Molluscan biogeographic and bathymetric ranges	147
4.10 Spatial extent of the outcrop belt of regional bedrock units containing heavy minerals	149
4.11 Estimated paleobathymetry and surface sediments of the gulf in the latest Campanian Mississippi Embayment	151

CHAPTER 1

INTRODUCTION

The Problem

During the Late Cretaceous, sea levels were much higher than today, and waters of what would become today's Gulf of Mexico flooded much of the southeastern United States, with an inlet of the ocean stretching from Louisiana up into southern Illinois. This large inlet was underlain by a southwesterly dipping trough-like basin known today as the Mississippi Embayment. The Cretaceous units deposited in this embayment can be seen today as a curved outcrop belt in the Gulf Coastal Plain (Fig. 1) with Cretaceous formations cropping out on both the eastern and western rim of the embayment in Alabama, Mississippi, Tennessee, Kentucky, Illinois, Missouri, and Arkansas. Although research has been published on lithostratigraphy and paleontology of sites and formations in the Mississippi Embayment, previous reconstructions of embayment paleogeography and paleoenvironments of the embayment have been constructed without appropriate age-constraint of correlated formations or without consideration of the underlying structural controls. This project biostratigraphically correlates the upper Campanian and lower Maastrichtian (uppermost Cretaceous) marine and nonmarine deposits in the northern embayment and interprets the paleoenvironments of the uppermost Campanian (~71-72 Ma) facies around the embayment to produce a paleogeographic and paleoenvironmental map of the northern Mississippi Embayment.

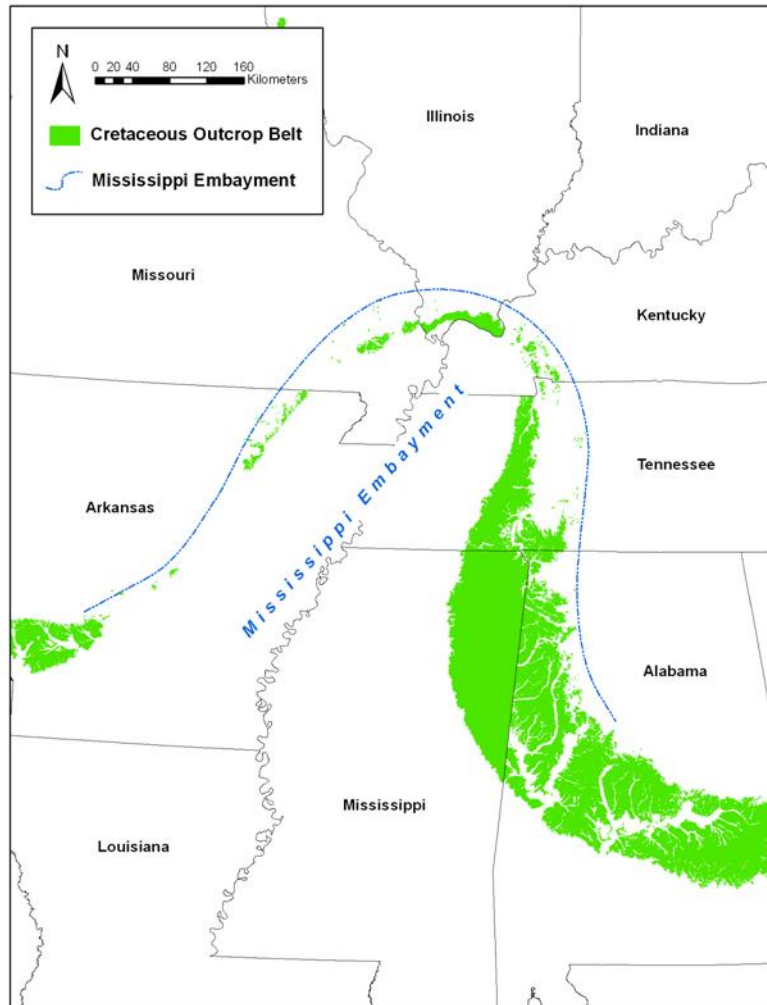


Figure 1. The Mississippi Embayment and immediate area. Geospatial data used to create this map in ArcGIS were downloaded from Alabama Metadata Portal (2006), Kentucky Geological Survey (2002), Source Water Assessment Program (1992), Tennessee Spatial Data Server (2000), Illinois Natural Resources Geospatial Data Clearinghouse (1996), and Missouri Spatial Data Information System (1998).

Geologic Setting

The Mississippi Embayment lies within the central U.S. in the lower Mississippi Valley, and can be seen on a national geologic map (Fig. 2) as a sedimentary basin striking north-northeast across northeastern Arkansas, southeastern Missouri, southern Illinois, western Kentucky, western Tennessee, northern Mississippi, and the northwestern corner of Alabama. The structure is filled mainly with Cretaceous marine sediments and Tertiary alluvium that are exposed at the surface, showing a curve in the Cretaceous coastal plain sediments in the lowlands of the Mississippi Valley. The embayment’s northernmost extent includes the confluence of the

Ohio and Mississippi Rivers and stretches southward cutting across the Ouachita and Appalachian Orogen (Fig. 2).

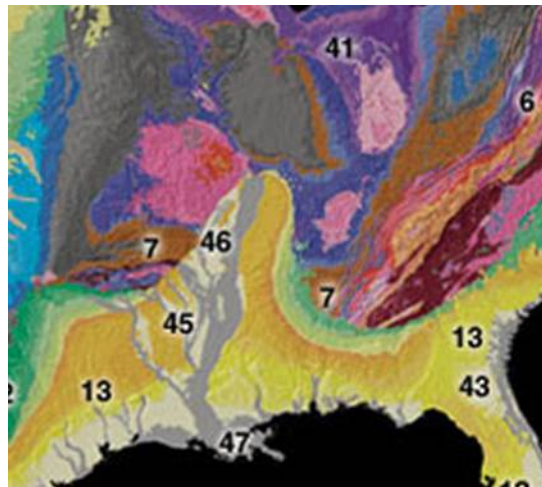


Figure 2. Geology and topography of the region. Numerical labels represent different physiographic regions: 7 (reddish brown) – Ouachita Mountains; 46 – Crowley’s Ridge, a highland area striking parallel to the Mississippi River; 45 (light tan) – alluvial plain; 13 (orange-yellow) – the coastal plain; 47 (gray) – the Mississippi Delta and River deposits. Modified from Barton et al., 2003.

The Mississippi Embayment first underwent extension in the late Precambrian as Laurentia pulled apart from Gondwana and was reactivated by rifting during the Mesozoic (Braile et al., 1986). At the end of the Triassic, Pangaea was breaking up and the Atlantic Ocean was forming as North America, Europe, Africa, and South America were rifting apart. During the Jurassic, the Mississippi Valley Graben underwent extension again (Braile et al., 1986; Hildenbrand, et al., 1982), and developed new, large fractures in the graben with igneous intrusions (Fig. 3; Hildenbrand et al., 1982; Cox and Van Arsdale, 2002). Igneous intrusions and faulting continued into the Cretaceous with further extension of the Reelfoot Rift. The downwarping, paired with a late Campanian eustatic sea-level high (Braile et al., 1986), allowed this area to flood with seawater from the Western Interior Seaway and northern Gulf of Mexico, forming the Mississippi Embayment. Due to the low elevation of this graben basin and relatively high surrounding topography, thick layers of sediment eroded from the southern Appalachians

(Pryor, 1960), the Nashville Dome (Harrison and Litwin, 1997), Pascola Arch (Cox and Van Arsdale, 2002), and Ouachita Mountains (Harrison and Litwin, 1997; Cox and Van Arsdale, 2002) and were deposited in the embayment as marine sediments. The Reelfoot Rift remains tectonically active today, with swarms of microseismic activity delineating the Reelfoot Rift and New Madrid Seismic Zone (Fig. 3; Cox and Van Arsdale, 2002).

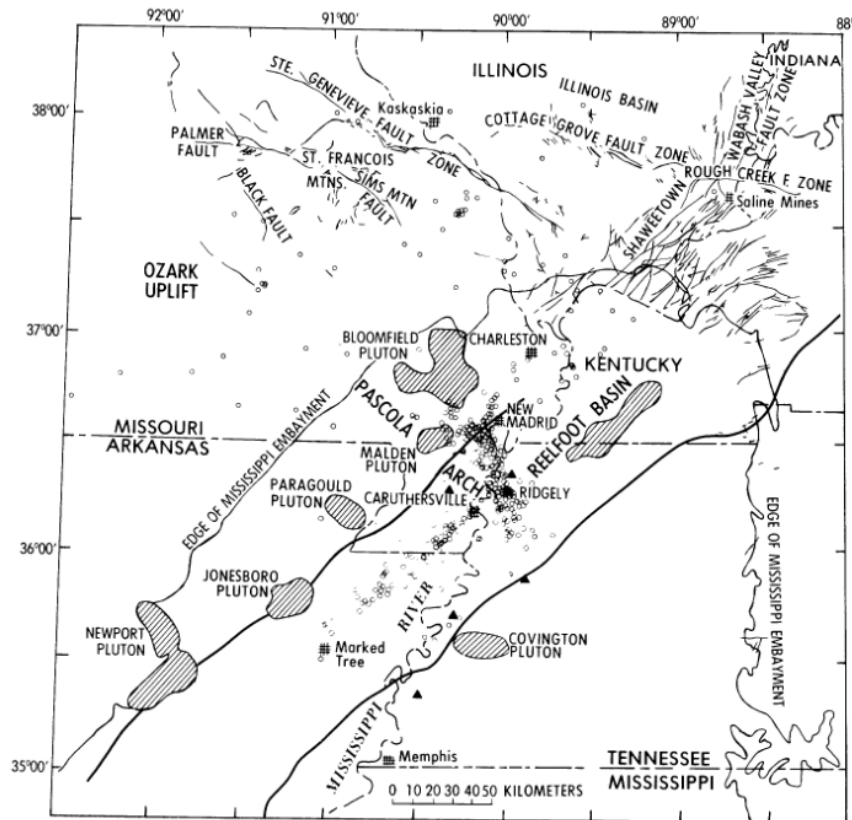


Figure 3. Structural geology of the Mississippi Embayment. Points are historic earthquake epicenters of the New Madrid Seismic Zone, delineating the faults of the Reelfoot Rift. Gray areas are igneous intrusions. Figure is from McKeown, 1982.

During the Late Cretaceous, the planet’s climate underwent a thermal maximum (Bice et al., 2002; Poulsen et al., 2003; Skelton, et al., 2003), with average global temperatures as much as 6 degrees Celcius higher than those today (Norris and Bice, 2002), and little to no ice capped the poles (Stoll and Schrag, 1996; 2000; Miller et al., 1999; Skelton, et al., 2003). During this

global greenhouse, sea level was over 100 m above the current position, and the ocean flooded large portions of North America (Skelton, et al., 2003). There are four main peaks in eustatic sea level that have been identified in the Campanian and Maastrichtian (Hancock, 1993). The first peak occurred in the earliest Campanian, about 83 Ma; the second occurred in the middle Campanian around 79 Ma; the third peak, considered to be the highest of the four, occurred during the late Campanian about 73 Ma; and the last peak occurred later in the middle Maastrichtian around 68 Ma (Russell and Parks, 1975; Hancock, 1993). These peaks have been identified in sequence stratigraphy and, more recently, with paleoclimate evidence from foraminiferal oxygen isotope analyses (Barerra, et al., 1997). Transgressive-regressive cycles seen in the Gulf Coastal Plain strata show thickening deposits of chalks during these estimated peaks. In the coastal plain sediments, according to Hancock (1993), Peak 1 is associated with the Arcola Limestone Member, the upper member of the overlying the Mooreville Chalk; Peak 2 is estimated at a nondescript point within the lower portion of the Demopolis (Tupelo Tongue); Peak 3 is well associated with the thick chalks of the lower and middle Demopolis Chalk; and Peak 4 is interpreted as being represented by the Prairie Bluff Chalk. The time period for which this project focuses, the latest Campanian, is between peaks 3 and 4.

Mississippi Embayment Stratigraphy

The Campanian and Maastrichtian lithology of the embayment includes both sedimentary and igneous rocks. Subsurface plutons have been inferred from magnetic and gravity mapping (Hildenbrand et al., 1982; Hildenbrand et al., 2001) and mid- and Late Cretaceous dikes and sills have also been located (Crone and Schweig, 1994). From mid-Cretaceous to early Tertiary, the embayment crossed over a superplume, the Bermuda Hot Spot (Cox and Van Arsdale, 2002), creating a southeastern trending line of volcanic intrusions (now-subsurface) from central

Arkansas to central Mississippi. Cretaceous igneous rock exposed at the surface in the northern embayment exists in only northeastern Arkansas and is approximately 87 to 105 Ma (Haley et al., 1993).

Cretaceous formations in the outcrop belt range in age from the Cenomanian Tuscaloosa Group (Woodbinian Stage according to Russell and Parks, 1975) to the late Maastrichtian Owl Creek Formation (Navarroan Stage according to Russell and Parks, 1975). Campanian and Maastrichtian sedimentary deposits in the outcrop belt within the northern Mississippi Embayment include the Eutaw Formation, Coffee Sand, Sardis Formation, Demopolis Chalk, Coon Creek Formation, Ripley Formation, McNairy Sand, Nacatoch Sand, Owl Creek Formation, Post Creek Formation, and unnamed coal units and fossiliferous nonmarine clay.

Preserved faunas and floras have allowed age estimates of the embayment deposits. Dating Campanian and Maastrichtian deposits within the Mississippi Embayment is based mainly on relative dating of first and last occurrences of key index species and assemblages of species. Biostratigraphic indicators used for relative dating of upper Campanian and lower Maastrichtian deposits include foraminifera (Burnett et al., 1992; Mancini et al., 1996), calcareous nannoplankton (Smith, 1975; Burnett et al., 1992), ammonites (Cobban and Kennedy, 1991; Larson et al., 1997), palynomorphs (Hower et al., 1990; Harrison and Litwin, 1997), and bivalves and gastropods (Stephenson, 1914). Because index taxa are often facies-dependent, a lithofacies may not necessarily contain each of these taxa, or may contain only marine or only nonmarine taxa, making correlation difficult. One Upper Cretaceous lithofacies that does contain both marine and nonmarine index taxa is the lower facies of the Coon Creek in Tennessee. Because this lithofacies contains index nannoplankton, ammonites, and palynomorphs, it was chosen in this project to help join the upper Campanian and lower Maastrichtian marine and

nonmarine biostratigraphic record, allowing correlation of the uppermost Campanian lithofacies in the northern Mississippi Embayment.

Literature Review of Biostratigraphy

The Late Cretaceous biostratigraphy of the northern Mississippi Embayment has remained a large uncorrelated section of Gulf Coastal Plain geology due in part to the lack of marine biostratigraphic indicators in many of the clastic units. This, combined with the fact that the true structure of the embayment was not known until the mid 1980s, when the Reelfoot Rift was discovered to underlie the northern embayment, has complicated attempts at interpreting paleoenvironments within the embayment. Previous paleomaps have shown multiple interpretations and estimations (Pryor, 1960; Williams and Stelck, 1975; Cobban et al., 1994; Schwimmer, 2002; Scotese, 2003) of the coastline of the Late Cretaceous embayment, but these maps are produced on the continental scale, and focus mainly on generalized lithostratigraphy without consideration of paleoecology and tectonic variables within the embayment. Pryor (1960) conducted an in-depth study of the embayment and produced a Cretaceous paleogeographic map of the embayment. His paleomap, however, was constructed and published prior to the mapping of all Cretaceous embayment formations (Russell and Parks, 1975; Harrison and Litwin, 1997) and prior to defining the structural controls of the Reelfoot Rift on sedimentation within the embayment. Since Pryor's research, the embayment formations have been studied in pieces and compared within selected regions of the embayment, but the holistic picture of the upper Campanian Mississippi Embayment remains unclear.

Significance of This Research

This research ties together the upper Campanian marine and nonmarine biostratigraphy in the Gulf Coastal Plain; correlates the upper Campanian and lower Maastrichtian lithofacies in the

northern embayment; and clarifies the paleogeography and paleoenvironments of the northern Mississippi Embayment during the late Campanian. Results of this research contribute to Late Cretaceous biostratigraphy, lithostratigraphy, paleogeography, and paleoenvironment of a significant portion of the Gulf Coastal Plain. Not only does this contribute more to the understanding of Gulf Coastal Plain stratigraphy, but age correlations also provide a same-age surface and dated lithofacies, which can in turn be used in future tectonic analyses associated with tectonic uplift and subsidence in the New Madrid Seismic Zone region in the northern embayment.

CHAPTER 2

BIOSTRATIGRAPHIC CORRELATION OF THE UPPER CAMPANIAN UNITS IN THE NORTHERN MISSISSIPPI EMBAYMENT

Abstract

Biostratigraphic correlation of uppermost Campanian units in the northern Mississippi Embayment was performed, and includes marine, nonmarine, clastic, and carbonate lithofacies in western Alabama, Mississippi, Tennessee, Kentucky, Illinois, Missouri, and northeastern Arkansas. Correlations are based on current biostratigraphic definitions of the Campanian-Maastrichtian boundary, and upper Campanian total range zones and assemblage zones most commonly applied in Gulf Coastal Plain biostratigraphy. Biostratigraphically useful taxa include ammonites, bivalves, gastropods, calcareous nannoplankton assemblage zones, and palynomorph assemblages. Samples were collected from outcrops, cores, and well cuttings across the study area, and were analyzed for macrofossils, foraminifera, and calcareous nannoplankton. Biostratigraphic data were also collected from publications, museums, and geological surveys. Of all lithofacies analyzed, the lower lithofacies of the Coon Creek Formation in Tennessee contains the most taxa useful for age constraint, including both marine and nonmarine indicators. Northern Mississippi Embayment lithofacies in the study area that were found to be age-equivalent to the Coon Creek lower lithofacies in Tennessee, based on correlated taxa, include the following: the upper Demopolis Chalk and lower Ripley Formation in Mississippi and western Alabama; the Coffee Sand in Kentucky, southern Illinois, and southeastern Missouri;

unnamed nonmarine clays in Missouri; the lower Nacatoch Sand in northeastern Arkansas; and the Saratoga Chalk in the subsurface of northeastern Arkansas.

1. Introduction

The northernmost reach of the Late Cretaceous Gulf of Mexico is represented in the Mississippi Embayment, a trough of thick sediment stretching from southern Illinois southward toward northern Louisiana (Fig. 1). With the exception of a few igneous plutons and thin ash layers in the southern part of the embayment (Merrill, 1983), the majority of the Cretaceous sedimentary lithofacies contain no igneous material, and require stratigraphic position or biostratigraphic indicators for age estimation. Biostratigraphic correlation of upper Campanian units in the Mississippi Embayment has been met with several challenges, including poor preservation of marine index fossils, lithofacies dependence of index taxa, and apparent differences in late Campanian and early Maastrichtian index species' biostratigraphic ranges. Late Campanian biostratigraphic correlation of embayment units would contribute to comprehension of regional geology in several ways. First, it would match multiple biostratigraphic zonations for carbonates and clastics as well as for marine and non-marine facies. Secondly, it would help identify time-equivalent lithofacies to help in reconstruction of a late Campanian paleoecologic reconstruction. And finally, it would provide an estimated chronostratigraphic surface from which to compare and measure other stratigraphic and tectonic surfaces and sequences.

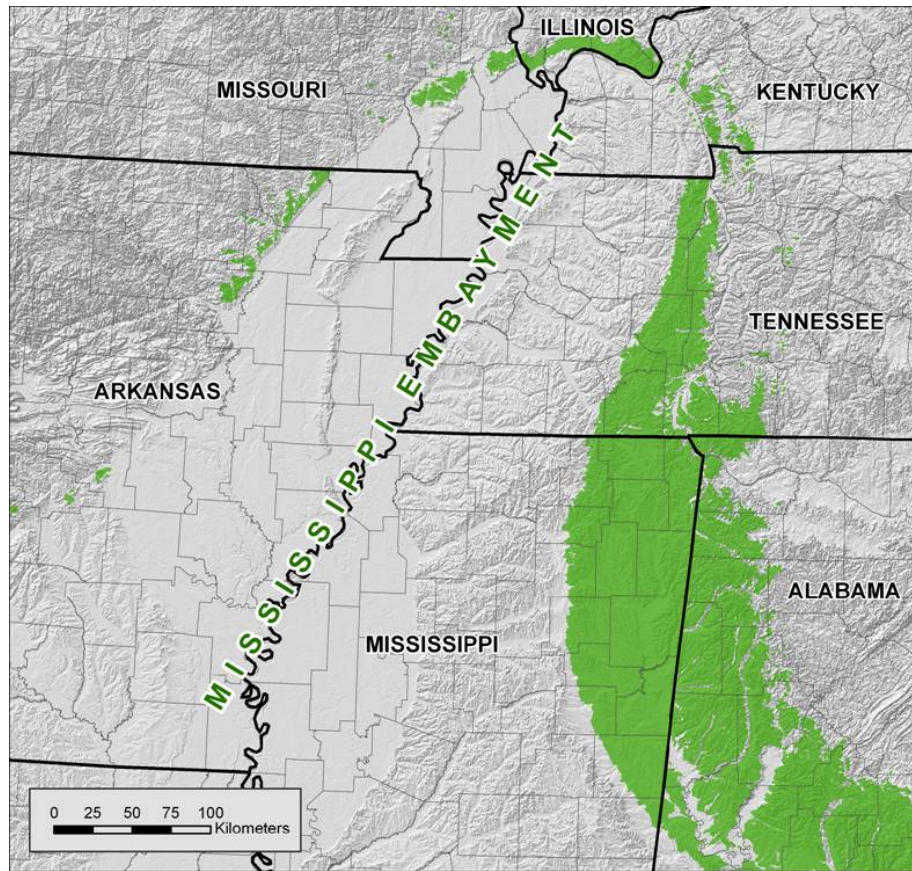


Fig. 1. The study area: northern Mississippi Embayment and the immediate surrounding area. Green shows the Cretaceous outcrop belt.

Most biostratigraphic correlations performed in the Gulf Coastal Plain have been based on marine index fossils such as calcareous nannoplankton, foraminifera, ammonites, and bivalves. These index fossils may not be present in all units, however, as presence or absence of taxa is often dependent on facies (e.g., different depositional environments have different ecologies), as well as preservation (clastic units with higher porosity allow more dissolution of shell material). Nannoplankton and foraminifera tend to be most abundant in carbonate units (Puckett, 1995), whereas ammonites and bivalves tend to be more abundant in clastic units (Mancini et al., 1996). Nearshore, deltaic, and fluvial clastic units can be void of marine index fossils, but often have higher pollen and spore content. Facies having different combinations of

index taxa must be used to aide in biostratigraphic correlations within the embayment. One specific upper Campanian unit is used in this project for biostratigraphic correlations: the lower lithofacies of the Coon Creek Formation. The lower lithofacies of the Coon Creek Formation in Tennessee is an upper Campanian glauconitic silty sand that contains multiple marine and nonmarine index species and assemblages used in biostratigraphy in the Gulf Coastal Plain. By using index fossils present in this lithofacies with other biostratigraphic markers commonly used in the Gulf Coastal Plain, biostratigraphic correlations of the lower Coon Creek age-equivalent lithofacies in outcrops, wells, and cores around the northern Mississippi Embayment can be made.

2. Study Area and Geologic Setting of the Northern Mississippi Embayment

During the Cretaceous thermal maximum, global temperatures and eustatic sea levels were higher than those of today (Skelton, et al., 2003). Shallow tropical seas covered much of central North America, and the northern Gulf of Mexico flooded part of the central United States, forming the Mississippi Embayment (Cox and Van Arsdale, 2002). During the middle Late Cretaceous, the embayment area underwent thermal uplift and extensional stress (Cox and Van Arsdale, 2002); cooling, combined with sediment loading, contributed to subsidence of the area beginning in the late Late Cretaceous, based on radiometric dates of subsurface igneous material (Baksi, 1997; Dockery et al., 1997; Cox and Van Arsdale, 2002). The Mississippi Embayment can be identified on geologic maps as a curved outcrop belt of Cretaceous units stretching across western Alabama, Mississippi, western Tennessee, western Kentucky, southern Illinois, southeastern Missouri, and eastern Arkansas (Fig. 1). Of the embayment units, portions of the following formations were deposited during the late Campanian regression: Coon Creek Formation, Coffee Sand Formation, Demopolis Chalk Formation, Ripley Formation (Russell and

Parks, 1975; Smith, 1975; Hancock, 1993; Mancini et al., 1996; Harrison and Litwin, 1997), McNairy Sand Formation, Nacatoch Sand Formation, Saratoga Chalk Formation (Stephenson and Crider, 1916; Russell and Parks, 1975; Harrison et al., 1996), lignitic coal units in western Kentucky, Post Creek Formation (Roberts, 1929; Hower et al., 1990; Harrison and Litwin, 1997), and unnamed units in northeastern Arkansas (Stephenson and Crider, 1916). These units were deposited after the Campanian's maximum eustatic peak, which is associated with the thickest and purest chalk interval in the Demopolis (Hancock, 1993; Mancini et al., 1996; Mancini and Puckett, 2002).

3. Upper Campanian Biostratigraphy

3.1 Overview of Late Campanian Biostratigraphy

The Campanian-Maastrichtian boundary, like most stage boundaries, has changed over the decades as new index taxa or guide events have been proposed, and applied to different units in regions around the world. Before the Global Boundary Stratotype Section and Point (GSSP) for the base of the Maastrichtian was ratified by the Commission on Stratigraphy (ICS) in 2000, at least seven other boundaries were proposed, all based on different index taxa in different regions (Gradstein et al., 2005). Because variations in stratigraphic boundaries change over time, it is important to define on which index species the boundary is based. The paragraphs in the following sections further define the index taxa used in distinguishing upper Campanian from lower Maastrichtian, and the species and assemblages used in the biostratigraphic correlations within this work (Fig. 2).

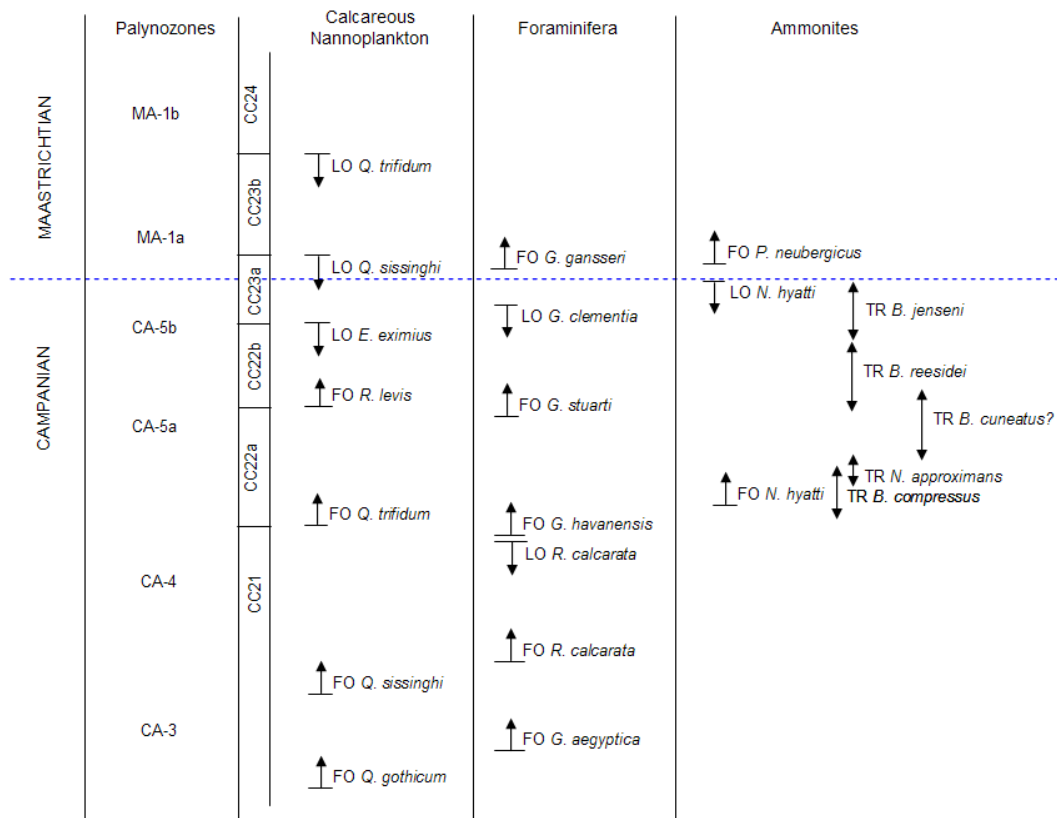


Fig. 2. Late Campanian and early Maastrichtian biostratigraphic ranges of palynomorph zones, calcareous nannoplankton, foraminifera, and ammonites. Blue dashed line represents the approximated Campanian-Maastrichtian boundary at 70.6 million years ago.

The GSSP for the Maastrichtian stage base is located in a limestone quarry in Tercis les Bains, France, on a bank of the Adour River (Odin, 2001; Odin and Lamaurelle, 2001a) and is estimated to be about 70.6 million years old (Kennedy et al., 1992; Gradstein et al., 1995; Odin and Lamaurelle, 2001a). Whereas the first occurrence (FO) of the ammonite *Pachydiscus neubergicus* is considered the guide-event for the base of the Maastrichtian Stage, 12 biohorizons together characterize the boundary interval and include the following: the FO of the ammonites *P. neubergicus* and *Didymoceras cylindraceum*; the last occurrence (LO) of the ammonite *Nostoceras hyatti*; the LO of the dinoflagellates *Corradinisphaeridium horridum*, *Raetiaedinium truncigerum*, and *Samlandia mayii*; the FO of the planktonic foraminiferans *Contusotruncana*

contuse and *Rugoglobigerina scotti*; the FO of the benthic foraminifera *Bolivinooides* with five lobes on last chamber, and the LO of *Gavelinella clementiana*; the FO of the inoceramid genus *Trochoceras*; and the LO of the calcareous nannofossil *Quadrum trifidum* (Odin and Lamaurelle, 2001a). In addition to these biohorizons originally described at the French section, an auxiliary section and point in Italy was also later described related to the GSSP section in France, assessing the planktonic foraminiferan biostratigraphy (Gardin et al., 2001). These foraminiferan biohorizons, along with correlated North American index fossils, have been used to help identify the Campanian-Maastrichtian boundary and upper Campanian lithofacies in the Gulf Coastal Plain.

In Gulf Coastal Plain units, the most commonly used index fossils for identification of Campanian and Maastrichtian strata include foraminiferans, calcareous nannoplankton (Smith, 1975; Eaton, 1987; Burnett et al., 1992; Hancock, 1993; Simmons et al., 1996; Mancini et al., 1996), and ammonites (Eaton, 1987; Hancock, 1993; Larson et al., 1997). Although less commonly used, palynomorph assemblages have also been used for biostratigraphy of upper Campanian nearshore and nonmarine clastic units (Wolfe, 1976; Harrison et al., 1996). Whereas there are limitations to each biostratigraphic method, these taxa have wide paleobiogeographic distributions, and have been found most useful in biostratigraphic correlations in North America, including the Western Interior Seaway and the Gulf and Atlantic Coastal Plains.

3.2 Upper Campanian Ammonites

Of the three species of ammonites used to identify the Campanian-Maastrichtian boundary at the GSSP, only two are present in North America: *P. neubergicus* and *N. hyatti* (Gardin et al., 2001; K uchler et al., 2001; Odin, 2001). *Pachydiscus neubergicus* has been

recovered from only one location in North America, the lower phosphatic zone of the Navesink Formation in New Jersey (Kennedy et al., 2000); however, because this is a condensed zone that also contains *N. hyatti*, the Campanian-Maastrichtian boundary of the section has not been pinpointed (Kennedy et al., 2000).

Whereas *P. neubergicus* is absent in the Gulf Coastal Plain (Odin, 1996; Puckett and Mancini, 1998), *N. hyatti* has been reported from units in southern Arkansas (Stephenson, 1941; Kennedy and Cobban, 1993), Tennessee (Coon Creek, Wade, 1926; Cobban and Kennedy, 1994), and Alabama (RMM-6993, RMM-6994, RMM-6995 - unpublished specimens from the Ripley in Wilcox County identified by Keith Young at the University of Texas, stored in scientific collections at the McWane Science Center; personal communication J. Ebersole, 2009). According to morphological descriptions by the authors, all specimens recovered from Gulf Coastal Plain units are of the subspecies *N. hyatti* Stephenson II, a biostratigraphically longer-ranging subspecies than that of the subspecies Stephenson I found at the Maastrichtian GSSP (Cobban and Kennedy, 1994; K uchler and Odin, 2001; Summesberger et al., 2007). The two subspecies of *N. hyatti* exhibit slight variation in morphology and biostratigraphic range, with Stephenson I no longer appearing after the end of the Campanian (Cobban and Kennedy, 1994; K uchler and Odin, 2001; Summesberger et al., 2007) and the LO of Stephenson II slightly before the end of the Campanian (Sugarman et al., 1995; Kennedy et al., 2000). The two subspecies vary morphologically with Stephenson I having distant ribbing on the body chamber and Stephenson II having coarser ribs and tubercles (Cobban and Kennedy, 1994; K uchler and Odin, 2001; Summesberger et al., 2007). Stephenson I is based on the fauna found at the Tercis section (Odin and Lamaurelle, 2001b); Stephenson II is based on Stephenson's (1941) holotype from Texas. Using radiometric dating of bentonite-bearing units with *N. hyatti* Stephenson II,

Kennedy et al. (1992) dated the last occurrence of *N. hyatti* Stephenson II in the Western Interior Province to be between 72.5 and 71 Ma (Kennedy et al., 1992; Odin and Lamaurelle, 2001a).

Other ammonites also used in biostratigraphy in North America that are present in the upper Campanian units of the Northern Mississippi Embayment include the upper Campanian baculite *Baculites undatus* and *Baculites claviformis* (Stephenson, 1941; Cobban and Kennedy, 1994; Larson et al., 1997). Whereas baculites are often used as stratigraphic indicators in the Western Interior Seaway units (Larson et al., 1997), baculites tend to be less common in the Gulf Coastal Plain units, and are rare in chalk facies (Mancini et al., 1996).

3.3 Upper Campanian Foraminiferans

Although more numerous in carbonate facies, foraminifera can also be found in clastic units, and in the fossil record, these protists appear mainly in marine or marginal marine deposits. The total range zone of *Globotruncana calcarata* (also known as *Globotruncanita calcarata* by those who separate keeled *Globotruncana* into the genus *Globotruncanita* (Reiss, 1957; Caron, 1985)) has been used widely for identification of the upper Campanian (Caron, 1985; Mancini et al., 1996; Puckett and Mancini, 1998) in the Gulf Coastal Plain, due to its wide distribution, short time interval (Obradovich et al., 1990), and common occurrence in carbonate units (Puckett and Mancini, 1998). However, the FO of *Pachydiscus neubergicus* is higher than the LO of *G. calcarata* (Puckett and Mancini, 1998). Because the lower part of the *G. calcarata* zone in North America has been dated at about 75.2 Ma from K-Ar dating of sanidine from a bentonite layer in the Annona Formation in southwestern Arkansas (Obradovich et al., 1990), Hancock et al. (1992) estimated the end of the *G. calcarata* total range zone to have been

approximately 74.2 Ma, about 4 million years before the currently defined Maastrichtian GSSP based on the first occurrence of *P. neubergicus* (Odin and Lamaurelle, 2001a).

Globotruncana calcarata is three foraminiferal zones below *Gansserina gansseri*, the foraminiferan zone occurring in association with *P. neubergicus* (Premoli Silva and Sliter, 1994; Puckett and Mancini, 1998). The two are separated by the zones of *Globotruncanella havanensis* (overlying *G. calcarata*) (Puckett and Mancini, 1998) and *Globotruncanca aegyptica* (underlying *G. gansseri*). Because many units in the Gulf Coastal Plain do not contain *G. gansseri*, *G. aegyptiaca*, or *G. havanensis* (Puckett and Mancini, 1998), the *G. calcarata* interval zone has most often been used for identification of the upper Campanian in the Gulf Coastal Plain (Taylor, 1985; Puckett, 1995).

3.4 Upper Campanian Calcareous Nannoplankton Assemblages

Calcareous nannoplankton are found mainly in carbonates, and it is calcium carbonate platelets of these phytoplankton that comprise the bulk of Cretaceous chalks (Skelton et al., 2003). Two calcareous nannoplankton assemblage zones, 22 and 23, are recognized as following the maximum transgressive surface in the late Campanian (Puckett, 1995; Mancini et al., 1996). Although these zonations have been redefined over the past several decades, the definitions for the zones used in this paper are based on the assemblages of taxa described by Perch-Nielson (1985), the most commonly used nanno assemblages in Cretaceous biostratigraphy in North America. According to Perch-Nielson (1985), the older of the nanno zones is the *Quadrum trifidum* zone, CC22, originally defined by Bukry and Bramlette (1970), and modified by Sissingh (1977). This zone is bounded by the first occurrence of *Q. trifidum* and the last occurrence of *Rheinhardtites anthophorus* and, according to Perch-Nielson (1985) includes the

following taxa: *Lithraphridites carniolensis*, *Stradneria crenulata*, *Chiastozygus platyrhethus*, *Rhagodiscus angustus*, *Tranolithus phacelosus*, *Corollithion signum*, *Eiffellithus turriseiffelii*, *Prediscosphaera ponticula*, *Microrhabdulus decoratus*, *Eiffellithus eximius*, *Micula decussate*, *Rheinhardtites anthophorus*, *Lithastrinus grillii* (CC22a only), *Micula concava*, *Lucianorhabdus cayeuxii*, *Calculites obscurus*, *Aspidolithus parvus constrictus*, *Ceratolithoides aculeus*, *Quadrum sissinghii*, *Q. trifidum*, *Rheinhardtites levis* (CC23b only), and *Arkhangelskiella cymbiformis*. The subdivision of Zone 22a and 22b is based on the first occurrence of *R. levis* (Sissingh, 1977). The higher upper Campanian calcareous nannozone, CC23, was defined by Sissingh (1977) and includes the following taxa: *L. carniolensis*, *S. crenulata*, *C. platyrhethus*, *R. angustus*, *T. phacelosus*, *C. signum*, *E. turriseiffelii*, *P. ponticula* (23a only), *M. decoratus*, *M. decussate*, *M. concava*, *L. cayeuxii*, *C. obscurus*, *A. parvus constrictus* (23a only), *C. aculeus*, *Q. sissinghii*, *Q. trifidum*, *R. levis* (CC23b only), and *A. cymbiformis*. Zone 23 is defined by the last occurrence of *R. anthophorus* and the last occurrence of *T. phacelosus* (Sissingh, 1977; Perch-Nielsen, 1985). Zone 23a is separated from 23b by the last occurrence of *A. parvus* (Sissingh, 1977). Incidentally, the oldest *Pachydiscus neubergicus* has been identified in rock containing a CC23b nanno assemblage (Wagreich, 1987; Burnett et al., 1992), suggesting that either the CC23b zone stretches across the uppermost Campanian and into the lowermost Maastrichtian, or that the first occurrence of *P. neubergicus* may reach down into the upper Campanian.

3.5 Upper Campanian Palynomorph Assemblages

In palynological research, the definition of palynomorph includes biological grains between 5 and 500 micrometers in diameter that can be extracted from rock and sediment

through a combination of wet sieving and strong acid treatments (Traverse, 2008). Consequently, palynomorphs include pollen, acritarchs, spores, dinoflagellates, and chitinozoans, but do not include diatoms, foraminiferans, or calcareous nannoplankton, because these bioclasts often are dissolved in the acid treatments (Traverse, 2008). Likewise, palynostratigraphy often includes biostratigraphic ranges of multiple taxa including angiosperm pollen, gymnosperm pollen, and dinoflagellates. This paper uses the above definitions when referring to palynomorphs and palynostratigraphy.

The majority of palynomorph research for Coastal Plain units was performed by Wolfe and Tschudy for biostratigraphic analyses to assist in mapping the Coastal Plain (Table 1; Tschudy, 1965a; 1965b; 1967; 1970a; 1970b; 1973a; 1973b; 1975; Wolfe, 1976). Although Wolfe's (1976) original work was based on palynomorph assemblages in units of the Atlantic Coastal Plain, a large percentage of his classifications and zonations are applicable to the Gulf Coastal Plain as well. Since Wolfe's research and analyses, there have also been a number of revisions to the Upper Cretaceous assemblages of the Gulf Coastal Plain (Tschudy, 1965a; 1965b; 1967; 1970a; 1970b; 1973a; 1973b; 1975; Gohn et al., 1982; Prowell et al., 1985; Owens, 1989; Sohl & Owens, 1991; Harrison et al., 1996; Christopher et al., 1999). Tschudy's (1965a; 1965b; 1967, 1970a, 1973b) works in particular, greatly contributed to the current knowledge of palynostratigraphy specific to the Northern Mississippi Embayment, and include palynomorph assemblage analysis of formation type sections. Tschudy's embayment research includes outcrops of many of the Cretaceous formations including upper Campanian and lower Maastrichtian units of the McNairy Sand, Coon Creek, and Coffee Sand. Further palynostratigraphy was also conducted in Illinois, helping to identify the Post Creek and Coffee Sand formations in southeastern Missouri, southern Illinois, and western Kentucky (Harrison et

al., 1966; Harrison and Litwin, 1997). Palynozones of the upper Campanian Gulf Coastal Plain palynomorph assemblages referred to in current literature thus include revisions of Wolfe's (1976) original zones, with the zonations being the same as Wolfe had originally named them: CA-5A, CA-5B, and CA-6/MA-1 (Fig. 2; Table 1).

Table 1. Upper Cretaceous palynomorphs and their upper Campanian (Ca) and lower Maastrichtian (Ma) ranges, modified from Frederiksen et al. (1982). Biostratigraphic range data compiled from Tschudy (1973b, 1975), Wolfe (1976), Harrison and Litwin (1997).

Late Campanian and Early Maastrichtian Palynomorphs	Late Campanian and Early Maastrichtian Palynozones						
	CA-3		CA-4	CA-5		MA-1	
	a	b		a	b	a	b
<i>Pseudoplicapollis serena</i> Tschudy, 1975 (NC-3)	x	x	x	x	x	x	
<i>Proteacidites</i> sp. A (PR-1)	x	x	x	x	x	x	x
<i>Holkopollenites</i> sp. C (CP3E-1)	x	x	x	x	x		
<i>Choanopollenites consanguineus</i> Tschudy, 1973	x	x	x	x	x	x	x
<i>Osculapollis aequalis</i> Tschudy 1975 (NO-1)		x	x	x	x		
<i>Choanopollenites</i> sp. E (NA-7)			x				
<i>Bohemiapollis</i> sp B (NI-2)			x				
aff. <i>Plicapollis</i> sp. A (NN-1)			x	x	x		
<i>Proteacidites</i> sp. G (PR-7)			x	x	x	x	x
<i>Choanopollenites</i> cf. <i>C. transitus</i> Tschudy, 1973 (NA-2)			x	x			
Triporate type A (NU-1)			x	x	x		
<i>Retitricolpites</i> sp. 1 (C3B-4)				x			
<i>Momipites</i> sp. A (NP-1)				x	x		
<i>Casuaripidites</i> sp. A (NO-2)				x	x		
<i>Semioculopollis</i> sp. A of Tschudy (1975)				x	x	x	
<i>Holkopollenites</i> cf. <i>H. chamardensis</i> Fairchild (CP3D-3)				x	x	x	x
<i>Interpollis</i> cf. <i>I. supplingensis</i> Pflug				x	x	x	x
<i>Baculostephanocolpites</i> sp. A (MPH-1)				x	x		
<i>Plicapollis usitatus</i> Tschudy, 1975 (NE-3)	x	x	x	x	x	x	x
<i>Choanopollenites</i> sp. A (NA-3)					x		
<i>Triatripollenites</i> sp. B (NP-2)					x	x	x
<i>Retitricolpites</i> sp. H (C3B-3)					x	x	x
<i>Proteacidites</i> sp. D (PR-4)					x		
<i>Psudovacuopollis involutus</i> Tschudy, 1975 (NT-1)	x	x	x	x	x	x	
<i>Choanopollenites</i> cf. <i>C. conspicuus</i> Tschudy, 1973 (NA-8)					x	x	x
<i>Casuarinidites</i> sp. B (NO-5)					x		
<i>Labrapollis</i> sp. A (NV-1)					x	x	
<i>Bravicolporites</i> sp. B (CP3F-2)					x	x	x
<i>Retitricolpites</i> sp. D (C3A-4)					x	x	
<i>Baculostephanocolpites</i> sp. B (MPH-2)						x	
<i>Vacuopollis munitus</i> Tschudy, 1975						x	
<i>Extremipollis vivus</i> Tschudy, 1975						x	
<i>Betulacaolpollenites</i> sp. A (NO-3)						x	x

biostratigraphic correlation. Core facilities at geological surveys were also visited, and cores and well cuttings were photographed, described, and sampled for subsurface correlation. Field and core samples were analyzed for nannofossils and microfossils. Nannofossil analyses were performed by Dr. Charles Smith at the Geological Survey of Alabama, to identify nannofossil assemblages and zones. Microfossil sediment samples were washed and sieved through very fine sand- and silt-size wire mesh sieves, dried, and analyzed by the author for foraminiferal analysis. Macrofossils helpful in age determination were photographed and identified. Macro-, micro-, and nannofossils identified in field work, lab analysis, and literature review were compared to index species used in current standards set by the ICS and current North American biostratigraphic correlations. Following age estimations based on biostratigraphic data, data points (including surface and subsurface sample points, well logs, auger holes, cores, and well cuttings) were mapped together.

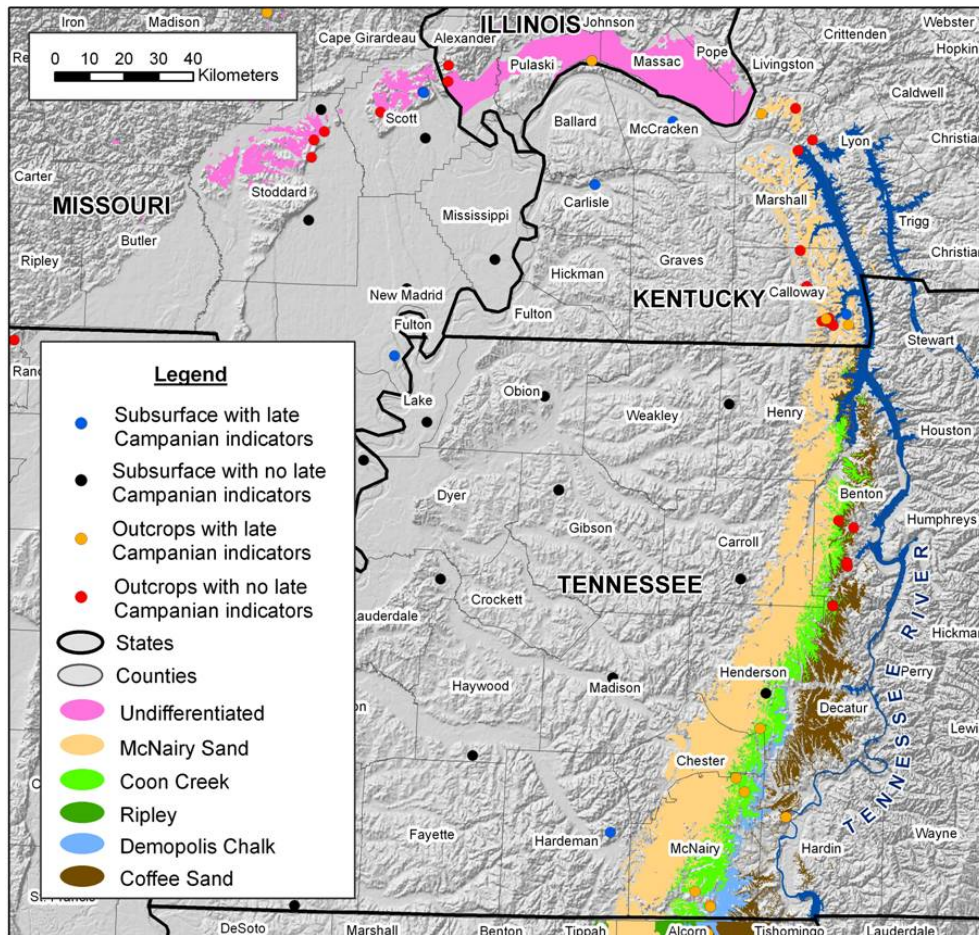


Fig. 3. Upper Campanian and lower Maastrichtian outcrop belts in Tennessee, Kentucky, Illinois, and Missouri with points showing locations of surface and subsurface data used in this project.

5. Correlating Lower Coon Creek Age-Equivalent Lithofacies in the Northern Mississippi Embayment

Upper Campanian and lower Maastrichtian lithofacies used in correlation include a number of formations and members of formations in the surface and subsurface of the northern embayment (Table 2). In some cases, the formations or members of formations are the same lithofacies, but have different names or formation status in different states. For reference, the members and formations of the lithofacies used in correlation within this work are listed and described in Table 2.

Table 2. Lithologic descriptions of the upper Campanian and lower Maastrichtian lithofacies in the study area, in alphabetical order by formation. Lithologic descriptions from Counts et al. (1955), Sohl (1960), Plebuch and Hines (1969), Russell and Parks (1975), Raymond et al. (1988), Stinchcomb et al. (1994), Harrison et al. (1996), and Schrader and Scheiderer (2004). Abbreviations of states: AL = Alabama, AR = Arkansas, IL = Illinois, KY = Kentucky, MO = Missouri, MS = Mississippi.

Formation	Member	State	Lithology
Coffee Sand		MO, AR, IL, KY	Lignite-rich, micaceous, silty and sandy gray clay with some pebbles, gray silty sand and clay.
Coffee Sand	Upper	TN	White to light gray micaceous, fine to very fine sand, glauconitic. Weathers to yellow orange. Irregular bedding, thin bedding, cross-bedding, lenses, ripple marks. Lignitic plant material. Thick lenses of gray clay shales.
	Lower	TN	Calcareous gray clay shales and silty clay. Layers of silt, sand, clay, and lignitic plant material. Basal gravel.
Coon Creek	Upper	TN	Dark gray to greenish gray calcareous, glauconitic, micaceous, fine- to medium-grained clayey silts and sands. Locally siderite concretions. Locally fossiliferous, preservation poor, steinkerns, vertebrate material more common than shells.
	Lower	TN	Dark gray to greenish gray calcareous, glauconitic, micaceous, fossiliferous, very fine-grained clayey silts and sands. Well-preserved shells.
Demopolis Chalk		TN	Bluish gray to light gray, chalky, glauconitic, micaceous, marl. Locally fossiliferous, with some oyster reefs.
Demopolis Chalk	Bluffport Marl	MS, AL	Dark gray to light gray calcareous, sandy/silty clay, chalky marl, and clayey chalk. Locally fossiliferous.
Demopolis Chalk	Transitional clay	TN, MS	Silty, sandy, non-calcareous to calcareous, green-gray clay. Locally fossiliferous.
“Glenallen Clay” (proposed name)		MO	Dark blue-black plastic illite-smectite clay with very fine grained sand, lenses of red and yellow illite-smectite sandy clays. Blue clay contains terrestrial and aquatic vertebrate material. Basal clay has clasts of limestone and sandstone clasts.
McNairy Sand	Ardeola	MO	Composed of four layers (bottom to top): Sawdust Bed – yellow-brown clayey sand; Dodge Hill Bed – yellow to white micaceous sand; Zadoc Bed – light gray to brown-black clay with lignitic plant material; Leaf Bed – laminated orange sand and gray-brown clay.
	Commerce	MO	Composed of four beds (bottom to top): basal sandy gravel; gray to black organic rich sandy and silty clay interbedded with fine white sand; light gray clay with seams of fine orange sand; medium to coarse grained, light yellow-orange sand
McNairy Sand	Levings	IL	Lignitic, gray to black silt and clay with lignitic plant material.
McNairy Sand		IL, KY	Fine to coarse grained micaceous, yellow, light gray, or orange sand, poorly sorted. Locally may contain cross-bedding, <i>Ophiomorpha</i> , clay layers, Liesengang bands, or pebbles.
McNairy Sand	Upper	TN	Medium to coarse grained micaceous sand, poorly sorted, locally cross-bedded. <i>Ophiomorpha</i> common.
	Middle	TN	Fine to medium sand with thin beds of gray kaolinitic clay. Light gray when fresh, but weathers from yellow to reddish brown. Commonly included lenticular beds, and cut-and-fill structures, convoluted structures. Locally includes pebbles.

	Lower	TN	Light-gray, weathers to orange and red, fine grained silty and clayey, micaceous sand. Cross-bedded, lenticular, irregular bedding, sparsely glauconitic. Heavy minerals up to 3% by weight.
Nacatoch Sand	Upper	AR	Unconsolidated light gray, sandy marl and fine-grained sand. <i>Ophiomorpha</i> common.
	Middle	AR	Greenish gray coarse-grained sand sandstone. Locally fossiliferous.
	Lower	AR	Blue gray clay, sandy clay, marl, and clay rich sand. Locally fossiliferous.
Ripley	McNairy Sand	MS	Red to white cross-bedded sandy clay and sand. Locally fossiliferous.
	Coon Creek	MS	Grayish green glauconitic sand, clay, and sandy limestone. Locally fossiliferous.
Ripley		AL	Light gray to olive, micaceous, glauconitic, calcareous clay, fine sand, and thin bedded sandstone. Locally fossiliferous.
Post Creek		MO, AR, IL, KY	Ferruginous sand matrix supported conglomerate with subangular to subrounded chert clasts ranging from pebble up to cobble size.

5.1 Tennessee

The Mississippi Embayment in Tennessee includes most of the western side of the state from the West Highland Rim along the Tennessee River to the Mississippi River (3-5). Upper Campanian units include the upper Demopolis Chalk, the Coon Creek, and the Coffee Sand. The upper Demopolis Chalk in Tennessee is a fossiliferous, silty chalk and marl that grades into the overlying fossiliferous clayey sand of the lower lithofacies of the Coon Creek (Russell and Parks, 1975). The Demopolis is laterally traceable from central Henderson County southward into Mississippi and Alabama. The Coon Creek Formation in Tennessee is comprised of an upper and lower lithofacies, and extends from northern Henry County southward to the Mississippi-Tennessee boundary (Russell and Parks, 1975). The upper lithofacies is a silty sand with few fossils, whereas the lower lithofacies is a glauconitic fine-grained calcareous sand with a lagerstätte layer in the lower part of the lithofacies (Russell and Parks, 1975; Stearns, 1975; Dunagan and Gibson, 1993). The Coffee Sand, consisting of stratified micaceous sands and clay with lignitic plant material (Safford, 1864), lies along the eastern side of the Coon Creek, and the two units interfinger in the central to northern part of the Coon Creek's outcrop belt (Russell and Parks, 1975).

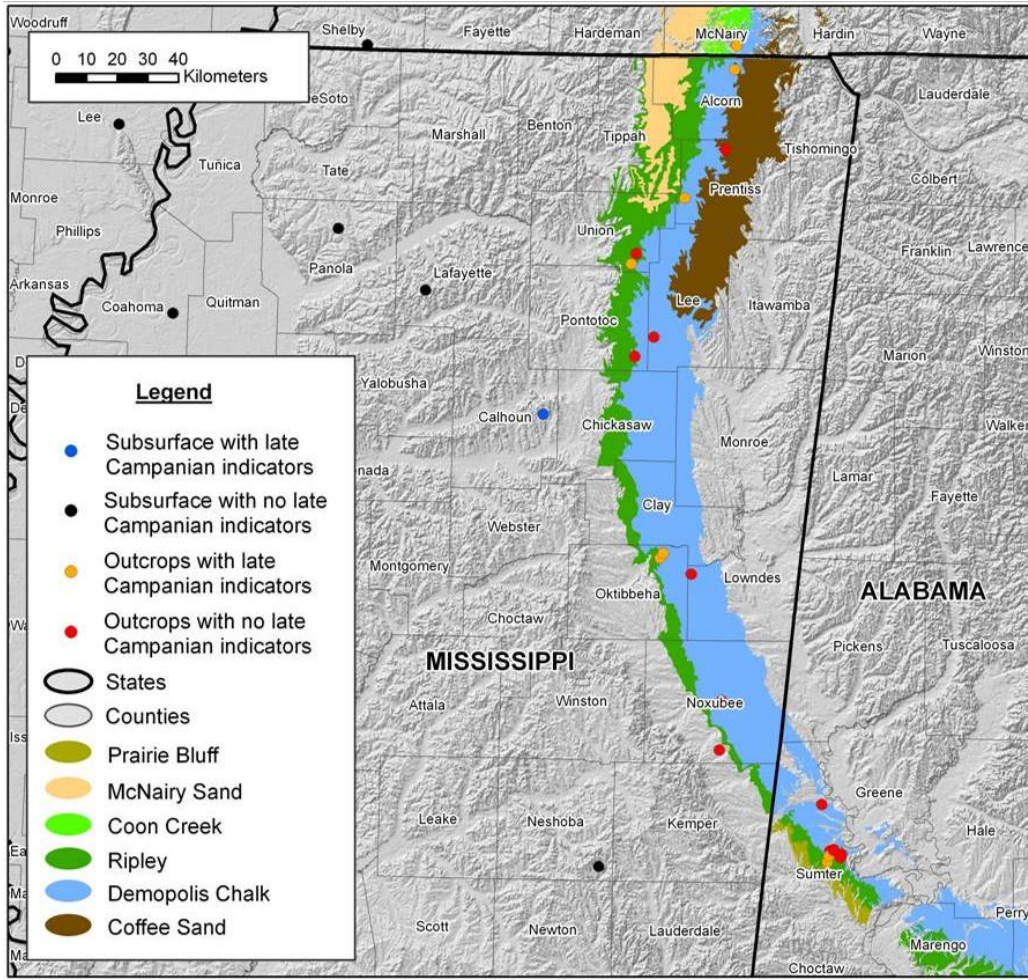


Fig. 4. Upper Campanian and lower Maastrichtian outcrop belts in Alabama, Mississippi, and Tennessee with points showing locations of surface and subsurface data used in this project.

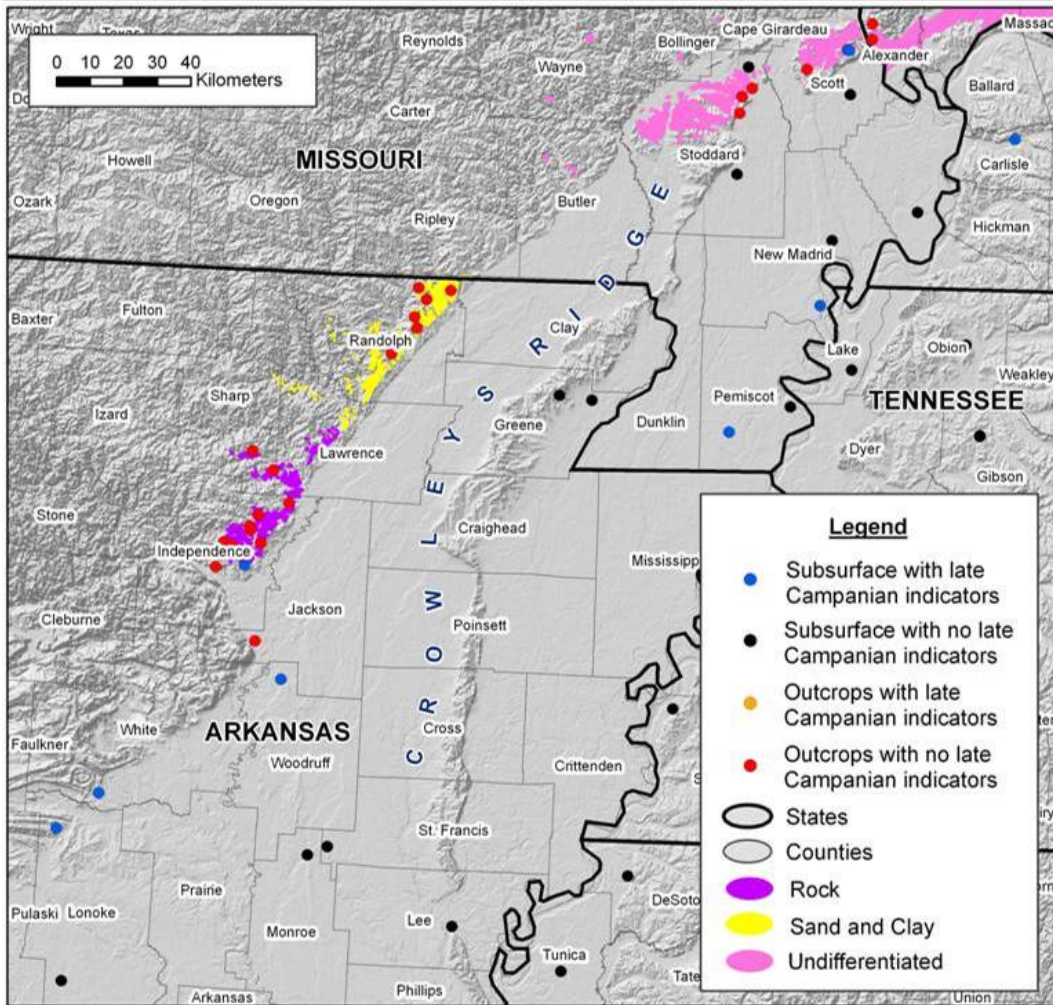


Fig. 5. Upper Campanian and lower Maastrichtian outcrop belts in Missouri and Arkansas with points showing locations of surface and subsurface data used in this project. Geologic units are listed as they appear on the state geologic maps.

5.1.1 The Coon Creek Type Section

The Coon Creek Type Section (CCTS) is in the lower lithofacies of the formation and grades into the underlying Demopolis Chalk downstream from the type section. Samples taken vertically through the type section show nannoplankton representative of Zone CC23a up to 3 m from the base of the creek, the lagerstätte section. Samples above the 3-m mark were barren of nannoplankton. Species identified in the lower 3-m section include the following: *Aspidolithus parvus constrictus*, *Quadrum sissinghii*, *Q. trifidum*, and *Reinhardtites levis*. This assemblage,

with the absence of *Eiffellithus eximius* and *Reinhardtites anthophorus*, is diagnostic of calcareous nannoplankton Zone CC23a in the Gulf Coastal Plain (Perch-Nielson, 1985).

A review of previously published literature (Berry, 1925; Cushman, 1931; Moore, 1974; Puckett, 1995; Frederick, 2003), and analysis of washed and sieved samples from the type section, reveal a lack of Campanian or Maastrichtian foraminiferan index species useful in age analysis. Samples collected for this project mainly contain the benthic foraminifera *Cibicides* and *Bolivina*. No *G. calcarata*, *G. gansserei*, *G. havanensis*, or *G. aegyptica* were identified.

Curled ammonites within the Coon Creek lagerstätte that are helpful in age determination include *Nostoceras hyatti* Stephenson II (upper Campanian to lowermost Maastrichtian), *N. approximans* (upper Campanian), *Solenoceras texanum* (upper Campanian to upper Maastrichtian), *Jeletzkytes nodosus* (upper Campanian), and *Didymoceras navarroense* (upper Campanian to lower Maastrichtian) (Wade, 1926; Stephenson, 1941; Cobban and Kennedy, 1994). A review of older literature shows *Baculites grandis* and *Baculites ovatus* as being present in the type section (Wade, 1926); however, Cobban and Kennedy (1994) and Larson et al. (1997) corrected these identifications as *B. undatus* and *B. claviformis* (Cobban and Kennedy, 1994; Larson et al, 1997; R. Brister pers. comm., 2007), both of which are uppermost Campanian by today's biostratigraphic definitions.

Other Coon Creek lagerstätte locations in Tennessee that correlate biostratigraphically with the one at the type section include an outcrop on Melton Creek along the eastern McNairy-Chester County line. This location exhibits shell preservation, fossil taxa, and sediment type very similar to that found at the type section (Dunagan and Gibson, 1993). Samples collected from this locality contain the nanno assemblage CC23a. Another location, now overgrown, but having a previously correlated biofacies to that of the type section based on macrofossils, is a roadcut on

State Highway 22 just north of the intersection with State Highway 100 in Henderson County (Russell and Parks, 1975). Although sediment samples from this overgrown roadcut are barren of calcareous nannoplankton, the roadcut exhibits shell preservation, fossil taxa, and sediment type similar to that found at the type section. It was correlated by Russell and Parks (1975) to be of the same stratigraphic section as that of the Coon Creek Type Section lagerstätte. In their Cretaceous palynostratigraphic investigations across in the Northern Mississippi Embayment, Tschudy (1975) and Wolfe (1976) reported samples from this same section to belong to the palynomorph assemblage zone CA-5B.

Samples from additional Coon Creek outcrops include 15 sites across McNairy, Chester, Decatur, Henderson, and Benton counties (Fig. 11; Table 3). All samples from upper Coon Creek lithofacies were found barren of calcareous nannoplankton and age-significant foraminiferans. Very little body fossil material was found at the upper Coon Creek sites, and most fossils were stienkerns.

Table 3. Cores, well cuttings, and outcrops biostratigraphically correlated to the lower Coon Creek lithofacies. Entries with no reference cited were dated based on samples collected by the author for this project.

Outcrop/Shallow auger hole Location	Formation	Lithology	County, State	Index fossils identified from sample/site	Reference
Coon Creek type section, on the Coon Creek, 1.6 km south of Enville	Coon Creek, lower lithofacies	Dark greenish gray, glauconitic sandy silt, lagerstätte, shells	McNairy, TN	Nanno-assemblage 23a, <i>Nostoceras hyatti</i> , <i>B. undatus</i> , <i>B. claviformis</i>	
Melton Creek just south of the McNairy-Chester county line	Coon Creek, lower lithofacies	Dark greenish gray, glauconitic sandy silt, lagerstätte, shells	McNairy, TN	Nanno-assemblage 23a	
Hwy 22 just north of the intersection with Hwy 100	Coon Creek, lower lithofacies	Dark greenish gray, glauconitic sandy silt, lagerstätte, shells	Henderson, TN	Palyno-assemblage zone CA-5B	Tschudy, 1975; Wolfe, 1976
Hwy 45, 5 km South of the 57-45 intersection (Kcc1)	Uppermost Demopolis Chalk	Transitional chalky clay	McNairy, TN	Nanno-assemblage 22b or 23a	Puckett, 1995
Hwy. 57, 3 km West of the 57-45 intersection (Kcc2)	Uppermost Demopolis Chalk	Transitional chalky clay	McNairy, TN	Nanno-assemblage 22b or 23a	Puckett, 1995
Hwy 45, just North of Guys Chewalla Road	Upper Demopolis Chalk	Light gray chalk, fossiliferous	McNairy, TN	Nanno-assemblage 23a	
Type section, Coffee Landing, ~6.5 km NE of Crump	Coffee Sand	Light gray micaceous, glauconitic sand with leaves of gray clay	Hardin, TN	Palyno-assemblage zone CA-4	Wolfe, 1976
Fort Pillow test well, 849.2-858.3 m deep	Clay lithofacies of the Saratoga and Demopolis Chalks undifferentiated	Glauconitic gray silty sand	Lauderdale, TN	<i>Guadryina rudita</i> and <i>Anomalina pseudopapillosa</i>	Moore and Brown, 1969
Well cutting #1280, 35.7-72.2 m deep, central eastern Hardeman Co.	Coon Creek	Dark greenish gray, glauconitic sandy silt, shells	Hardeman, TN	Nanno-assemblage 23a	
Hwy. 78, mi. marker 80	Demopolis Chalk	Light gray-white chalk	Lee, MS	Nanno-assemblage 23a	
Tallabinnela Creek at Shannon Road, ~1.3 km E of Troy	Coon Creek Member of the Ripley	Dark greenish gray silty sand, compacted shells, shark teeth	Pontotoc, MS	Nanno-assemblage 23a	
Intersection of Hwy. 78 and Hwy 9 South, 1 mi. [metric?] SW of Blue Springs	Ripley	Dark greenish gray silty sand, shells and bone fragments	Union, MS	Nanno-assemblage 24-25	
Troy Member type section	Troy Member of the Ripley	Light gray clayey sand	Pontotoc, MS	Nanno-assemblage 24	

NE¼, SW¼, sec. 4, T. 6 S., R. 6 E., Baldwyn Quadrangle (Kdb1)	Bluffport Marl Member of the Demopolis Chalk	Chalk	Prentiss, MS	<i>G. calcarata</i>	Puckett, 1995
S ½, NW ¼, sec. 4, T19N, R15E, Cedar Bluff Quadrangle (Kd1)	Demopolis Chalk	Chalk	Oktibbeha, MS	<i>G. calcarata</i>	Puckett, 1995
Alexander Schoolhouse Rd., Cedar Bluff Quadrangle (Kd3)	Demopolis Chalk	Chalk	Oktibbeha, MS	<i>G. calcarata</i>	Puckett, 1995
Well cutting #5142, 179.8-182.9 m		Sandy gray chalk	Calhoun, MS	Nanno-assemblage 23a	
Baker, Ridgeway, et al., McRae No. 1 well at 1191 m	Volcaniclastic sand unit of the Selma Chalk	Packed sand of vesicular and glassy volcanic clasts underlying chalk	Hinds, MS	Middle Late Campanian molluscan assemblage and foraminifera <i>Pseudorbitoides israelski</i>	Stephenson, 1946
North of centerline of secs. 27 and 34, T19N, R2E, Old Spring Hill Quadrangle (Kd5)	Demopolis Chalk	Chalk	Marengo, AL	<i>G. calcarata</i>	Puckett, 1995
Hwy 11, 0.3 km N of Parker	Ripley	Light gray sandy chalk	Sumter, AL	Nanno-assemblage 23a	
Hwy 11, Rush Medical, 1.6 km N of Livingston	Prairie Bluff	Light tan sandy chalk	Sumter, AL	Nanno-assemblage 23a – 23b	
Roadcut at intersection of Hwy 11 and Hwy 39, ~4.8 km SW of Epes	Ripley	Gray silty sand	Sumter, AL	Nanno-assemblage 23a	
Near the Grindstone Creek and Hwy 44 intersection, ~1.6 km S of Hamlin, auger hole	Coffee Sand	Very dark gray silty clay	Calloway, KY	Palyno-assemblage zone CA-5B to MA-1	Tschudy, 1965a; Blade, 1966
Hamlin and Paris Landing Quadrangles	Post Creek	Light gray gravel of pebbles and cobbles in silt and sand	Calloway, KY	Palyno-assemblage zone CA-4 to CA-5B	Harrison et al., 1996; Harrison and Litwin, 1997
ONC-3 in the New Concord Quadrangle, USGS paleobotanical locality D3341	Coffee Sand	White to black clay lenses and argillaceous sand	Calloway, KY	Palyno-assemblage zone CA-5	Tschudy, 1965a
ALC-1 in the Little Cypress Quadrangle, USGS paleobotanical locality D3286	Coffee Sand	Light gray, very fine micaceous sand, clay, and silt; chert gravel at base	Livingston, KY	Palyno-assemblage zone CA-5	Tschudy, 1965a
Auguer hole, 49.1 m deep, location USGS paleobotanical D3208, Paducah West Quadrangle, U.S. Hwy 60, 300' E. of Chestnut Hill Church.	Coffee Sand	Light gray, very fine sand, clay, and silt; chert gravel at base	McCracken, KY	Palyno-assemblage zone CA-5	Tschudy, 1965a

Oil test well in the Blandville Quadrangle, USGS paleobotanical locality D4079-A, 246.9 m in depth	Lower McNairy?	No description given	Carlisle, KY	Palyno-assemblage zone CA-5 – MA-1	Tschudy, 1973b
Post Creek Cutoff, at the Ohio River Scenic Byway overpass on Post Creek	Basal Coffee Sand	Sandy and silty, micaceous, marine clays	Pulaski, IL	Palyno-assemblage zone CA-5B	Tschudy, 1967; Harrison et al., 1996
Post Creek Cutoff, at the Ohio River Scenic Byway overpass on Post Creek	Post Creek	Gravel, clay, silt, and sand	Pulaski, IL	Palyno-assemblage zone CA-4	Tschudy, 1967; Harrison et al., 1996
Chronister dinosaur site	“Glenallen Clay,” proposed name	Nonmarine, blue clay	Bollinger, MO	Campanian vertebrate fauna, <i>Naomichelys</i> and <i>Hypsibema</i>	Stinchcomb et al., 1994; Baird and Horner, 1979
Benton Hills core hole BH-1, 53.3-59.1 m deep	Coffee Sand	lignite-rich silty and sandy clays	Scott, MO	Late Campanian palyno-assemblage	Harrison et al., 1996
New Madrid test well at depths 553.2-579.4 m	Clay lithofacies of the Saratoga and Demopolis Chalks undifferentiated	Gray micaceous silty sands and clays with lignite and carbonized wood fragments	New Madrid, MO	Palyno-assemblage zone CA-5	Fredericksen et al., 1982
Benton Hills core hole BH-2, 38.1-43.9 m deep	Coffee Sand	lignite-rich silty and sandy gray clay	Scott, MO	Late Campanian palyno-assemblage	Harrison et al., 1996
Benton Hills core hole BH-2, 43.9-53 m deep	Post Creek	subrounded gravel and clear and frosted fine grain quartz sand	Scott, MO	Middle to late Campanian palyno-assemblage	Harrison et al., 1996
Nestle-Purina Company site, 30-cm below the tektite layer	Owl Creek	Gray, micaceous, silty clay	Stoddard, MO	Middle Campanian – Paleocene nannoassemblage	
County Road 331, Crowley’s ridge	Porters Creek Clay	Greenish gray micaceous silt	Stoddard, MO	Paleocene nannoassemblage	
City of Steele Well #2, MO #9460 core at 661.1 m deep	Porters Creek Clay	Gray, micaceous silt with shell fragments	Pemiscott, MO	Nanno-assemblage zones 14 through 23a	
Lower lithofacies in shallow wells in the Newark and Magness area, 12.2-30.5 m deep	Middle Nacatoch	dark green glauconitic sand, weathered to red sand, with shells	Jackson, AR	Late Campanian to early Maastrichtian molluscan assemblage	Stephenson and Crider, 1916
Lower lithofacies in wells in the Saffel, Beebe, and Cabot area, 6.1-30.5 m deep	Lower Nacatoch	gray blue argillaceous material, some green sand, calcareous sandstone, and clay	Lawrence, White, and Lonoke, AR	Late Campanian to Maastrichtian molluscan assemblage	Stephenson and Crider, 1916
Craig Williams Co. core WM No. 6 at 25.6 m depth (T9N, R3W)	Saratoga Chalk	light gray, micaceous marl, with shell fragments	Woodruff, AR	Nanno-assemblage 23a	Core record, Craig Williams Co.

5.1.2 Other Units in Tennessee

The McNairy Sand is divided into an upper, middle, and lower member as described by Russell and Parks (1975) based on lithologic differences. The lower McNairy Sand is described as sparsely glauconitic, light gray and orange fine-grained quartz sand with lenticular bedding, cross-bedding locally, and variable thickness from 15 to 24 meters thick (Russell and Parks, 1975). This lowermost section of the McNairy Sand appears as lenses of cross-bedded basal McNairy Sand lithology within the Coon Creek Formation in places in Tennessee. One outcrop exhibiting this lithology is near Martin Camp in McNairy County (Russell and Parks, 1975). Here, the sand deposit is a 3-m thick, irregularly bedded lens with cross-bedding within the Coon Creek Formation. Other locations having McNairy Sand lenses buried within the Coon Creek include the northern side of Selmer in McNairy County, near Lexington in Chester County; near Camden in Benton County; near Purdy in McNairy County; and near Paris Landing in Henry County. Although no fossils have been described from these lenses that would help identify the age, no cross-cutting features are described, indicating the McNairy Sand and Coon Creek sediments were deposited concurrently, and are thus age-equivalent in these locations. North of Benton County, the Coon Creek grades into the McNairy until the lithology is no longer differentiated from the McNairy Sand (Olive, 1965; Russell and Parks, 1975); and within Benton County, the Coon Creek also grades laterally into the Coffee Sand.

Coffee Sand samples from outcrops are also barren of nannoplankton, foraminifera, and macrofossils, with the exception of lignitic and charcoalized wood fragments. At the Coffee Sand type section at Coffee Landing in Hardin County, Tennessee, palynostratigraphic research by Wolfe (1976) indicates a palynomorph assemblage of CA-4, one palynozone lower than the Coon Creek type section. Russell and Parks (1975) interpreted the Coffee Sand as progressively

younging northward, with northern units such as are found near Gisamond in Benton County (6.4 km south of Camden) to be lower Maastrichtian. In this area, the lower lithofacies of the Coffee Sand (fine-grained sands interbedded with gray clay) grades laterally into the glauconitic clayey sands of the Coon Creek Formation (Russell and Parks, 1975). According to Blade (1966), palynostratigraphic analysis showed the Coffee Sand in the Hamlin and Paris Landing Quadrangles (Kentucky-Tennessee bordering quadrangles) to be age-equivalent to the lower Coon Creek lithofacies.

Puckett (1995) analyzed samples from two outcrops in the mixing zone between the lowermost Coon Creek and the uppermost Demopolis Chalk from southern McNairy County (Fig. 3; Table 3). These samples were found to contain nannoplankton assemblages belonging to either the CC22b or CC23a nannoplankton zone (Puckett, 1995). Although Puckett (1995) interpreted this lithofacies to be either within the uppermost level of the *G. calcarata* zone or within 8 m above the zone, he noted that no *G. calcarata* specimens were found in the samples from these two sites. Based on biostratigraphy in current literature (see previous sections on the Campanian and Maastrichtian foraminiferans and calcareous nannoplankton), this lithofacies would be above the *G. calcarata* zone and one or less nannoplankton zone below the Coon Creek type section.

Samples from two outcrops of the uppermost Demopolis Chalk in southern McNairy County along U.S. Highway 45 had a nannoplankton assemblage zone of CC23a (Table 3). This matches results of previous research published by Puckett (1995) and Mancini et al. (1996) correlating Upper Cretaceous nanno and foram zones across southern Tennessee, Mississippi, and Alabama. Chalk samples from the outcrops were also wet sieved, and were found to include

numerous foraminifera including *Cibicides* and *Anomalina*, although none of the foraminifera identified are index species.

Ten sets of well cuttings from western Tennessee counties were sampled and photographed (Fig 3; Table 3). One set of well cuttings (Hardeman County) yielded calcareous nannoplankton in samples from 35.7 to 72.2 m deep having a CC23a nanno assemblage. This particular sample contains sediment similar to that of the type section, and also contains fragmented shells (taxa unidentifiable from the small shell fragments). Other well cutting samples from western Tennessee include well cuttings from Henry, Gibson, Lauderdale, Lake, Carroll, Shelby, and Obion counties. Samples from these other well cuttings were either barren or had Paleocene nanno assemblages. Published results from a well in Ft. Pillow in Lauderdale County (Table 3) show the Demopolis Chalk at 895.5-904.9 m to contain the foraminifera *Planulina dumblei*, which the authors assign to the Taylor (Campanian to early Maastrichtian) Age (Moore and Brown, 1969). At 849.2-858.3 m in the Ft. Pillow test well, Moore and Brown (1969) indicated *Guadryina rudita* and *Anomalina pseudopapillosa* were recovered from what they interpreted as the Coon Creek Formation, described as a glauconitic gray silty sand. The foraminiferans recorded from this interval were interpreted by Moore and Brown (1969) as Navarroan-age (late Campanian and Maastrichtian) based on similar assemblages in Texas strata (Marks, 1950; Housh, 2007).

5.2 Mississippi and Western Alabama

All of Mississippi and most of western Alabama are covered by coastal plain deposits with the Cretaceous outcrop belt curving from the Mississippi-Tennessee-Alabama border southeasterly into central Alabama. Within Mississippi and western Alabama, the upper Campanian units include the Coon Creek Member of the Ripley Formation in Mississippi, the

Ripley in Alabama, the transitional clay of the Demopolis Chalk in Mississippi, and the Bluffport Marl Member of the Demopolis Chalk in Alabama (Fig. 4; Table 3; Puckett, 1995; Mancini et al., 1996). In Mississippi and Alabama, the Ripley is divided into the McNairy Sand Member, the Coon Creek Member, and a transitional clay between the Demopolis and the Coon Creek tongue (Parks, 1960; Sohl, 1960).

The Coon Creek lagerstätte found in Tennessee does not extend into Mississippi. Although shell material is preserved in some locations, the fossiliferous shelly lithology of the Coon Creek Member of the Ripley Formation in Mississippi is limited to only a few outcrops and shell preservation is often poor, based on field observations. Most of the Coon Creek Member outcrops visited in Mississippi exhibited a lithology and fossil preservation more similar to the upper lithofacies of the Coon Creek Formation of Tennessee (Sohl, 1960; Russell and Parks, 1975). The Coon Creek Member is glauconitic, micaceous, calcareous, sands and marls, containing laterally discontinuous layers of limestones and chalky sands (Sohl, 1960; Stephenson, 1914).

The Demopolis in Mississippi and western Alabama is a light to medium gray chalk overlain by the Ripley Formation. The unit is fossiliferous, with *Exogyra* being particularly abundant (Stephenson and Monroe, 1940; Russell and Parks, 1975). The uppermost section of the Demopolis varies from location to location, but is generally either chalky marl, chalky clay, or clayey chalk, and is known as the Bluffport Marl Member in Alabama (Raymond et al., 1988).

Outcrops sampled included sites in Mississippi in the Coon Creek Member of the Ripley, Demopolis Chalk, and Bluffport Marl Member of the Demopolis Chalk in Alcorn, Prentiss, Union, Pontotoc, Lee, Oktibbeha, Lowndes, and Noxubee counties (Fig. 4; Table 3). Sites in western Alabama were also sampled from Sumter County and include outcrops of the same

formations as in Mississippi. Mississippi and western Alabama sites that yielded a CC23a nannoflora assemblage include a Demopolis Chalk site in Lee County along U.S. Highway 78, a Coon Creek Member site in Union County, a second Coon Creek Member site in a creek near Troy, a Ripley exposure at a road intersection in Sumter County, a Bluffport Marl Member site just north of Parker (Fig. 4; Table 3). Additional outcrops sampled previously by Puckett (1995) include two Demopolis Chalk sites in Oktibbeha County and a Bluffport Marl site in Prentiss County (Fig. 4). Samples from these sites contain *G. calcarata* (Table 3; Puckett, 1995).

Of the cores and well cuttings sampled, only the cuttings from well #5142 in Calhoun County at 182.9 m deep yielded a CC23a nanno assemblage (Fig. 4; Table 3). Samples from the other well cuttings from Carroll, Desha, and Lafayette counties in Mississippi yielded no nannoflora (Fig. 4). Cores and well cuttings from additional counties were also collected, but due to time constraints, were not analyzed for calcareous nanoplankton.

In the west-central Mississippi subsurface, Upper Cretaceous igneous intrusions of lamprophyre, and extrusive alkalic basalts lie in the area of western Mississippi and southeastern Arkansas (Baksi, 1997; Cox and Van Arsdale, 2002). The area includes the subsurface Midnight Volcano and the Jackson Volcano in Mississippi, both of which are considered sources of the bentonite ash layers found in the Ripley in Mississippi, based on igneous petrographic studies (McGlothin, 1944; Cook, 1975; Sundeen and Cook, 1977; Merrill et al., 1988; Dockery et al., 1997). Multiple igneous samples from the area have been radiometrically dated, ranging from 80 ± 3 through 65 ± 3 Ma by Ar-Ar dating (Merrill et al., 1988; Cox and Van Arsdale, 2002).

A well in Hinds County (the Baker, Ridgeway, et al., McRae No. 1 well) penetrated a calcareous volcanoclastic deposit at the base of the Selma Chalk at 1,191.5 m in the SE $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, sec. 24, T7N, R1W, 16.1 km northwest of Jackson (Stephenson, 1946). This basal chalk

and sand can be found around the Jackson Volcano below the Maastrichtian to Paleocene Jackson Gas Rock (Dockery et al., 1997). The volcanoclastic sand was dated by Stephenson (1946) to be Campanian based on the molluscan assemblage that includes an abundance of shell material. Fossil fauna used in age determination includes the bivalves *Venericardia uvaldana* (*subterrea*) and *Inoceramus* (Stephenson, 1946). These two bivalves give a range somewhere between earliest Campanian to early late Campanian (Stephenson, 1946). Also present at 1,191.5 m deep is the foraminiferan *Pseudorbitoides israelski*, also shown to range into the late Campanian (Baumgartner-Mora and Denyer, 2002; Anthonissen and Gradstein, 2006). A second well, in Grenada County, also exhibits a similar fossiliferous volcanoclastic deposit at 832.1 and 838.2 m deep, but based on the form of *Inoceramus*, the *Cardium grenadense*, and *Pugnellus calcaris*, Stephenson (1946) estimated the age to be equivalent to the Coniacian upper Austin Chalk.

5.3 Kentucky

The Jackson Purchase area of Kentucky (the portion of the state west of Kentucky Lake) is the only area of the state in which Campanian and Maastrichtian units have been identified. The upper Campanian unit in this area is the Coffee Sand (Fig. 3; Table 3; Russell and Parks, 1975; Harrison et al., 1996) underlying, and sometimes undifferentiated from, the McNairy Sand. The lower McNairy Sand in western Kentucky is a reddish, crossbedded or scour-and-fill sand, locally with clay laminae that contains lenses of dark glauconitic clayey sand lenses of Coffee Sand lithology in its lower section (Roberts, 1929; Blade, 1966; Russell and Parks, 1975). The Coffee Sand lithology, however, is not laterally traceable at the surface and has often been grouped with the McNairy Sand as an undifferentiated unit on geologic maps and in publications (Roberts, 1931; Blade, 1966). Also interbedded in the McNairy Sand and Coffee Sand in

Kentucky are pockets of lignite such as are described from the Hico and Paducah areas in Calloway and McCracken counties, respectively (Hower, et al., 1990).

The McNairy Sand and Coffee Sand in Kentucky are mainly unfossiliferous with the exception of palynomorphs, lignitic plant material, and *Ophiomorpha* burrows (formerly called *Halymenites major* structures) in the Hamlin and Paris Landing (Blade, 1966), Briensburg (Lambert and MacCary, 1964), Hico (Olive, 1965), and Little Cypress (Amos and Wolfe, 1966) quadrangle map areas in Calloway, Marshall, and Livingston counties. No macrofossils were observed at the 10 outcrops visited in Kentucky, with the exception of small fragments of lignitic plant material. All outcrops visited had the same lithology of coarse- to medium-grained red to gray sand with subrounded pebbles and cobbles and thin layers of white clay. With the exception of small fragments of lignitic plant material, no macrofossils were observed. Outcrop samples analyzed were barren of calcareous nannofossils and foraminifera, but previous publications show Cretaceous outcrops in western Kentucky to be rich in palynomorphs (Blade, 1966; Tschudy, 1965b; 1965b; 1967, 1970a, 1973b).

Most Cretaceous samples analyzed by Tschudy in the U.S. Geological Survey series of open file reports on the palynostratigraphy of the Northern Mississippi Embayment (Tschudy, 1965b; 1965b; 1967; 1970a; 1973b) contain palynomorph assemblages equivalent to those found at the McNairy Sand type section in Tennessee. Samples from two Kentucky outcrops, however, contain palynomorph assemblages similar to those from the lower Coon Creek lithofacies in Tennessee: sample ONC-3 in the New Concord Quadrangle (USGS paleobotanical locality D3341) in Calloway County (Fig. 3; Table 3); and sample ALC-1 in the Little Cypress Quadrangle (USGS paleobotanical locality D3286) in Livingston County (Fig. 3; Table 3; Tschudy, 1965a). Additional palynostratigraphic analysis by Tschudy (Blade, 1966) was

conducted for geologic mapping of the Hamlin and Paris Landing geologic quadrangle map. Samples from auger holes at Grindstone Creek (Fig. 3; Table 3; USGS paleobotanical localities D3328-D3330), described as dark gray silty clay and sand (the Coffee Sand), were sent to the USGS for palynostratigraphic analysis. Tschudy's analyses indicated the uppermost samples to have palynomorph assemblages equivalent to that of the Coon Creek in McNairy County, Tennessee (Blade, 1966).

Another outcrop (now destroyed) near Kentucky Lake Dam in Marshall County was correlated on the basis of palynomorph assemblages with exposures in southern Illinois (Table 3). The outcrop was described by Olive (1980) as having two lithofacies comparable to the Tuscaloosa Group (rounded gravel clasts with percussion marks) overlain by a unit of angular clasts and sand. These lithofacies correlate to a similar outcrop in the Tamms Quadrangle in Alexander and Pulaski counties in Illinois (Devera et al., in press) and the Olmstead Illinois-Kentucky Quadrangle (Nelson, 2003; Bexfield et al., 2005), and were interpreted by Harrison and Litwin (1997) to be the middle to upper Campanian Post Creek Formation, based on palynomorph assemblages. The Post Creek unit in the Jackson Purchase area grades into the Coffee Sand, Ripley, and McNairy Sand lithologies in western Kentucky and southeastern Missouri, as described in geologic quadrangle descriptions (Wilshire, 1964; Blade, 1966; Harrison and Litwin, 1997).

Due to core sampling restrictions, cores were not sampled from western Kentucky. Biostratigraphic information from two subsurface samples was used for correlation, however. Tschudy (1965a) interpreted palynomorphs from samples (OLC-1) from a deep auger hole in the Paducah West Quadrangle in Livingston County (Fig. 3; Table 3; location D3208) at 49 m in depth to be equivalent to the palynomorph assemblages found in the lower Ripley of Tennessee.

Also analyzed by Tschudy (1973b) were samples from an oil test well in the Blandville Quadrangle in Carlisle County (Fig. 3; Table 3; USGS paleobotanical locality D4079). His analyses indicated the lowermost McNairy to be 246.9 m in depth, based on the Cretaceous palynomorph assemblage (Tschudy, 1973b).

5.4 Illinois

Upper Campanian and lower Maastrichtian units in southern Illinois include the McNairy Sand, Coffee Sand (referred to as the Levings Member of the McNairy Sand in subsurface well logs), and Post Creek (previously referred to as the Tuscaloosa) formations (Fig. 3). The Post Creek is primarily a poorly sorted gravel with sand, clay, and silt and subangular to subrounded clasts ranging from pebble up to cobble size (Harrison et al., 1996; Harrison and Litwin, 1997). The Coffee Sand is micaceous sand, silt, and clay with some pebbles, and rich with lignitic plant fragments in some layers (Harrison et al., 1996). The McNairy Sand in Illinois is described as a nonmarine micaceous gray sand locally with crossbedding and clay laminae (Harrison and Litwin, 1997).

The Post Creek Formation was originally correlated with the Tuscaloosa Group, based on its lithology (Pryor, 1960; Kolata et al., 1981; Harrison et al., 1996). Later, when a palynological analysis was performed (Tschudy, 1967; Harrison et al., 1996), results showed a middle Campanian palynomorph assemblage for the Illinois samples, and not the upper Cenomanian assemblage identified in samples from the Tuscaloosa type section in Alabama by Christopher (1980, 1982). This middle Campanian age is based on the occurrence of the several palynomorphs that do not occur until middle Campanian in the Gulf Coastal Plain units, according palynostratigraphic research of Wolfe (1976) and Harrison et al. (1996): Wolfe's (1976) C3B-I, C3B-2, and CP3D-3; *Extremipollis caminus* (Wolfe's NJ-2); and

Pseudoculopolollis admirabilis (Wolfe's FR-1). This age difference, and additional lithologic differences, allow the renaming of this lithofacies as the Post Creek Formation in southern Illinois (Harrison and Litwin, 1997).

The Post Creek Formation grades into the overlying unit, a lignite-rich, micaceous, silty and sandy gray clay with some pebbles, gray silty sand and clay. This gray lignitic clay is also present in southeastern Missouri just across the Mississippi River, and is referred to as the Coffee Sand in current literature. In Missouri, the Coffee Sand is the uppermost Campanian deposit, age-equivalent to the lower Coon Creek lithofacies based on palynostratigraphy performed in wells from the Benton Hills area in Scott County, Missouri and the Post Creek Cutoff in Illinois (Harrison et al., 1996). Although the Coffee Sand has a CA-4 palynomorph assemblage at its type section in Tennessee (Wolfe, 1976), the Coffee Sand in southeastern Missouri has a palynomorph assemblage more closely correlated with Wolfe's (1976) palynozone CA-5, the same zone as the Coon Creek lower lithofacies (Fig. 3; Table 3; Tschudy, 1975; Wolfe, 1976; Harrison and Litwin, 1997).

The Coffee Sand in southeastern Missouri is described by Harrison et al. (1996) as a lignite-rich, micaceous, silty and sandy gray clay with some pebbles, gray silty sand and clay. Although Harrison et al. (1996) suggested the Coffee Sand is absent in southern Illinois, well logs and core descriptions (e.g., the Frank Hepp Jr. wells #60203 and #60210; the D and G Drig. Co. well #12219; Illinois State Geological Survey (ISGS) wells #10939 and #10943; and ISGS core #10941) from Massac and Pulaski counties describe the Levings Member of the McNairy Sand as having similar lithology to that of the Coffee Sand in Missouri (as described by Harrison et al., 1996), and holding the same stratigraphic interval as the Coffee Sand in the Benton Hills area of southeastern Missouri. In addition to this, the lithology of the Levings Member in the

subsurface is the same as the description given by Russell and Parks (1975) of the Coffee Sand exposed in Tennessee along State Highway 69, 4 km south of Camden, which shows a dark gray silty sand and clay with lignitic material overlying a gravel atop the Paleozoic bedrock.

The Levings Member was originally mentioned by Pryor and Ross (1962) as a lignitic silt and clay layer in the McNairy Sand, but it has been found to occur only locally in outcrop and in different positions within the McNairy (in some places in the upper part, other places in the lower part) and is not considered laterally traceable in Illinois (Nelson et al., 2009). It is probable that the Levings Member of the lower McNairy Sand in the very southern parts of Pulaski and Massac counties as described in core and well descriptions is the same unit as the Coffee Sand in southeastern Missouri, but limited to a small geographic area. Based on well, core, and outcrop information, the Coffee Sand (labeled as the Levings Member) is present in Alexander, Maasac, and Pulaski counties, and is described in wells and cores (ISGS wells #10937, #10939 and #10943; ISGS core #10941; 10938; and Frank Hepp Jr. wells #60203, #60204, and #60210). Quadrangles such as Joppa (Nelson and Masters, 2008), Karnak (Nelson and Hintz, 2007), Olmsted (Nelson et al., 2009), Pulaski (Nelson and Williams, 2004) quadrangles, do not describe the McNairy Sand as including a lower section of Coffee Sand lithology, but instead note the basal McNairy Sand rests unconformably over the Post Creek or the Paleozoics. Based on subsurface data, the Coffee Sand ranges from zero to tens of meters thick in Missouri and in southernmost Illinois (Harrison et al., 1996; Frank Hepp Jr. wells #60203 and #60210), and is characteristically gray silty sand and clay, white micaceous silt laminations, some layers with up to 50% carbonized wood (Harrison et al., 1996; Frank Hepp Jr. wells #60203, #60204, and #60210; the ISGS wells #10939 and #10943; and ISGS core #10941).

Although field work was conducted in southern Illinois to identify and collect

sediment samples from outcrops, few outcrops were located (Fig. 3; Table 3). Outcrops include the type section for the Post Creek Formation and exposures along the Ohio and Mississippi Rivers. Samples of the sandstones and loosely cemented sands collected from the sites typically contain no macrofossils, foraminifera, or nannofossils, but have been shown to include palynomorphs (Harrison et al., 1996; Harrison and Litwin, 1997). One accessible outcrop on Fayville Road, 0.8 km SE of Fayville in Alexander County reveals a vertical exposure of clean white sands with a few subrounded pebbles. Although no foraminiferans nor calcareous nannoplankton were obtained from samples from this outcrop, the stratigraphic position and lithology suggest this is a Post Creek exposure, similar to other Post Creek sections in southern Illinois and southeastern Missouri as described in previous research (Harrison et al., 1996; Harrison and Litwin, 1997). Three cores were sampled from Pulaski County (the southernmost county in Illinois) at the Illinois Geological Survey's core facility. Cores contain silty, clayey, and calcareous sands down to 91.4 m. All samples collected from the cores were barren of nannofossils and macrofossils.

5.5 Missouri

Few upper Campanian and lower Maastrichtian deposits crop out in Missouri. Upper Cretaceous formations include the Owl Creek, McNairy Sand, Coffee Sand, and Post Creek. With the exception of Crowley's Ridge, most of the Cretaceous is overlain with Tertiary sediments (Gilmore and Stewart, 1945). Crowley's Ridge (Fig. 5), a topographic high striking southwest to northeast across the northwestern edge of the embayment, exposes the Maastrichtian Owl Creek Formation and McNairy Sand (Stephenson, 1955; Campbell et al., 2008). Four outcrops in southeastern Missouri were sampled along Crowley's Ridge in Stoddard and Butler Counties (Fig. 5; Table 3). One outcrop near the Missouri-Arkansas line is a red sandstone, similar to

McNairy-Nacatoch Sand lithology described for northeastern Arkansas (Dane, 1929; Harrison et al., 1996). Two outcrops in Bell City in Stoddard County have white and tan sand and blocky sandstone, and another outcrop along County Road 331 on Crowley's Ridge has dark greenish gray glauconitic silty clay. Although the County Road 331 site contains nannoplankton, the assemblage indicates a Paleocene age, and the formation was likely Porters Creek Clay. Samples from the other outcrops are barren of calcareous nannoplankton and foraminifera, but are most likely McNairy-Nacatoch outcrops given their location and lithology.

The Cretaceous exposure along Crowley's Ridge is the Nestlé-Purina Company Cretaceous-Paleocene site exposure of Cretaceous McNairy and Owl Creek and Tertiary Porters Creek in Stoddard County (Campbell et al., 2008) (Fig. 5; Table 3). Nannoplankton recovered from the gray silty, micaceous clay samples from the Nestlé-Purina site include a fauna ranging from middle Campanian through Paleocene, and is unfortunately not helpful in age constraint. This is likely due to the sediment disturbance and mixing from the Chixulub impact tsunami as the level at which the sample was collected was located only 30 cm below the tektite-containing coquina layer of the Cretaceous-Paleocene boundary (Campbell, 2008 personal communication; Campbell et al., 2008). Given the closeness to the K-P boundary, however, it is likely the lowest sample taken at the site (30 cm below the tektite layer) is the Maastrichtian Owl Creek Formation. Other samples collected in Stoddard County along Crowley's Ridge include micaceous greenish gray silt, containing a Paleocene nannoplankton assemblage matching the age of the Porters Creek Clay.

Although not found by the author, additional outcrops of lower Maastrichtian McNairy Sand crop out in Scott, Stoddard, and Bollinger Counties in gullies, creeks, and river bluffs (Stewart, 1927) and in downthrown fault blocks (Gilmore and Stewart, 1945; Stinchcomb et al.,

1994; Stinchcomb, 2006) along the northwestern edge of the embayment in Bollinger County (Fig. 13). Although Stewart (1927) referred to the Cretaceous gravels, sands, and clays overlying the Paleozoic bedrock as the lower Commerce Member of the McNairy Sand, the lithology (dark gray silty clay with lignitic material overlying a sandy gravel atop the Paleozoics) is the same as what Harrison et al. (1996) refers to as the Coffee Sand and Post Creek formations from the Benton Hills cores. Based on the lithology and stratigraphic position, it is interpreted here that Stewart's (1927) lower Commerce Member clay is equal to the upper Campanian Coffee Sand, and the basal sandy gravel described by Stewart (1927) is the same as the middle to upper Campanian Post Creek Formation as described by Harrison et al. (1996) in the Benton Hill cores. The Coffee Sand as described by Harrison et al. (1996) in the subsurface of southeastern Missouri is the uppermost Campanian deposit (based on palynomorph assemblage), and is a lignite-rich, micaceous, silty and sandy gray clay with some pebbles, gray silty sand and clay.

Another Campanian deposit exposed at the surface is a laterally discontinuous fossiliferous nonmarine clay in Bollinger, Wayne, and Butler Counties. The clays in Bollinger County have received the most attention, and have been published on with greater detail, especially on one particular site in the northwestern part of the county just north of Glenallen (Stinchcomb et al., 1994; Parris, 2006; Stinchcomb, 2006). Here, a pocket of clay was discovered during excavation for a well that was found to contain dinosaur material (Stinchcomb et al., 1994; Parris, 2006). Stinchcomb (2006) suggested the clays may be associated with graben structures similar to the ones east of Marble Hill (Amos, 1987) that contain McNairy Sand lithology. According to geologic worksheets, however, no faults or graben structures have been identified in or near the Glenallen area (Heller, 1943).

The deposits contain layers of weathered red and yellow illite-smectite clay and fossiliferous blue-black plastic illite-smectite clay overlying Ordovician bedrock (Stinchcomb et al., 1994; Stinchcomb, 2006). Previous X-ray diffraction analysis of the clays showed no glauconite present (Stinchcomb et al., 1994). The fossiliferous clays contain a number of aquatic and terrestrial reptiles, with most taxa having wide age ranges. Based on two taxa, the turtle *Naomichelys*, which has an Aptian to Campanian range (Stinchcomb et al., 1994), and the hadrosaur *Hypsibema*, which has been found previously in only Campanian units (Cope, 1869; Baird and Horner, 1979; Stinchcomb et al., 1994), it is interpreted here that these clays are most likely Campanian in age.

The blue clay in which the majority of the fossils are found was originally identified as Ripley (Heller, 1943), but further work on the site shows no similarity to the Ripley other than a Campanian age (Matthes, 1933; Stephenson, 1955; Grohskopf and Howe, 1961; Crone, 1981; Fredericksen et al., 1982; Mesko, 1988; Stinchcomb et al., 1994). Although these clays currently are labeled as McNairy Sand on Missouri Geological Survey geologic work maps (E. Starbuck, pers. comm., 2009), they do not match lithologic descriptions of clays in the McNairy Sand or any other formation in Missouri or the Mississippi Embayment as recorded from publications, geologic maps, or subsurface data. Because these clays contain freshwater and terrestrial faunas (Stinchcomb, 2006), are unlike any other formations in the area, and are not Maastrichtian as is the McNairy Sand with which the clays are currently placed, these fossiliferous clays should be considered a separate formation.

Subsurface Cretaceous units identified from cores and well cuttings include the McNairy Sand, Coffee Sand, and Post Creek (Grohskopf and Howe, 1961; Harrison et al., 1996; Harrison and Litwin, 1997). Of five cores sampled at the core facility at the Missouri Geological Survey,

three contain nannoplankton, but only one contains Cretaceous nannoplankton in its analyzed samples (Fig 5; Table 3). Results from MO#9460 at 661.1 meters in Pemiscott County indicate a Cretaceous age, but results are inconclusive with respect to which Cretaceous stage, as flora from Zones 14 through 23a (Santonian to uppermost Campanian) are present, including *Arkhangelskiella* sp., *Watznaueria barnesae*, *Micula decussata*, and *Aspidolithus parvus constrictus*.

Cores from the English Hill area of the Benton Hills in Scott County (Fig 5; Table 3) show intervals of Coffee Sand and Post Creek formations unconformably overlying a pre-Cenomanian (Willman and Frye, 1975) paleosol called the Little Bear Formation (Harrison et al., 1996). The Post Creek in the Missouri subsurface of the Benton Hills area is described as a gravel and sand with subrounded pebbles and cobbles and clear and frosted fine-grained quartz sand (Harrison et al., 1996), similar to the lithology of the Coffee Sand described in southern Illinois. The Coffee Sand in the English Hills area is described differently from the Coffee Sand of Illinois, however, and is described as being lignite-rich silty and sandy clays (Harrison et al., 1996). The Post Creek is interpreted as being middle to late Campanian in age in this location, based on the palynomorphs identified by Harrison et al. (1996). The Coffee Sand in the English Hill area was interpreted by Harrison et al. (1996) as having a upper Campanian palynomorph assemblage, based on Wolfe's (1976) and Tschudy's (1975) earlier northern Mississippi Embayment palynostratigraphic work.

A core from the New Madrid test well drilled in southeastern New Madrid County (Fig 5; Table 3) was collected and analyzed by Fredericksen et al. (1982). Samples studied were from 539.5 to 579.4 m deep (37.5 m above the Paleozoic basement). Although this interval was correlated to the McNairy Sand, palynozone CA-6/MA-1, palynomorphs recorded from nine

depths between 539.5 and 579.4 m indicate this range in depth can be separated into two pollen zones: CA-6/MA-1 and CA-5. This division is indicated by the presence of *Betulaceoipollenites* sp. A (Wolfe's NO-3), *Proteacidites* sp. E (Wolfe's PR-5), and *Plicatopollis cretacea* (Wolfe's NN-2) (Frederiksen and Christopher, 1978) in depths at and above 553.2 meters. The range of this flora occurs in CA-6/MA-1 only. Samples deeper than 553.2 meters contain *Holkopollenites* sp. C (Wolfe's CP3E-1), *Choanopollenites* sp. E (Wolfe's NA-7), *Plicapollis* sp. A (Wolfe's PR-7), *Triporate* type A (Wolfe's NU-1), *Momipites* sp. A (Wolfe's NP-1), *Casuarinidites* sp. A (Wolfe's NO-2), and *Choanopollenites* sp. A (Wolfe's NA-3). These taxa range from CA-5 to CA-3, whereas *Momipites* sp. A and *Casuarinidites* sp. A are found in only CA-5; thus, the depth 553.2 meters should be considered uppermost Campanian. Sediments at this depth include gray micaceous silty sands with lignite and carbonized wood fragments.

5.6 Arkansas

Northeastern Arkansas has a thin outcrop belt of Upper Cretaceous from the Missouri-Arkansas line in Randolph County trending southwestward through Lawrence, Sharp, and Independence counties. Small, disconnected pockets of Cretaceous continue southwestward into Pulaski County in the Little Rock area (Fig 5; Table 3). The counties of Hot Spring, Saline, Pulaski, Independence, Lawrence, Sharp, and Randolph were visited for field work to identify and sample potential Cretaceous units. The state geologic map (Haley et al., 1993) shows these units to be uncorrelated with other formations, and refers to the outcropping units as Kr (Cretaceous rock) and Ksc (Cretaceous sand and clay). On the unpublished 7.5' quadrangle worksheets (unpublished geologic maps with field notes, available at the Arkansas Geological Survey), the units are questionably assigned to the Nacatoch Sand.

In Arkansas, the Nacatoch Sand has variable lithology with lower, middle, and upper lithofacies (Dane, 1929; Cobban and Kennedy, 1991a, b). The upper lithofacies of the Nacatoch is unconsolidated light gray, sandy marl and fine-grained sand (Dane, 1929; Counts et al., 1955; Pleubuch and Hines, 1969; Schrader and Scheiderer, 2004); the middle lithofacies is a greenish gray fossiliferous coarse-grained sand sandstone (Dane, 1929; Petersen et al., 1985); and the lower lithofacies is blue gray clay, sandy clay, marl, and clay rich sand (Counts et al., 1955; Pleubuch and Hines, 1969; Schrader and Scheiderer, 2004). The Nacatoch disconformably overlies the Saratoga Chalk and, in southwestern Arkansas, disconformably underlies the Arkadelphia Marl (Pessagno, 1969; McFarland, 2004). In southwestern Arkansas, the lower and middle Nacatoch Sand in Hempstead County has been dated as late Campanian based on the *Nostoceras rugosum* ammonite zone (Cobban and Kennedy, 1991a), and the upper part of the Nacatoch Sand in the same area has been magnetostratigraphically dated to the early to middle Maastrichtian (Liddicoat et al., 1981). Underlying the Nacatoch Sand in southwestern Arkansas is the Saratoga Chalk, which also been dated by Cobban and Kennedy (1991b) as late Campanian based on the presence of *Nostoceras hyatti*. The lower Nacatoch Sand disconformably overlies the Saratoga Chalk and, in southwestern Arkansas, disconformably underlies the Arkadelphia Marl (Pessagno, 1969; McFarland, 2004).

Outcrops visited in northeastern Arkansas include sites in Hot Spring, Saline, Pulaski, Independence, Lawrence, Sharp, and Randolph counties (Fig 5; Table 3). All outcrops consists of red, yellow, and white micaceous unconsolidated clayey sands, likely weathered middle Nacatoch Sand based on the lithology. Another site (Sand Hill at Pocahontas in Randolph County) contains white and yellow loose sands with *Ophiomorpha* and *Asterosoma* burrows, a similar lithology to the upper Nacatoch Sand as described from southwestern Arkansas and

Texas (McGowen and Lopez, 1983). Age constraint based on biostratigraphy is not possible for these outcrops, because samples from the site were barren of calcareous nannoplankton and foraminiferans.

In a USGS geology and hydrology investigation of northeastern Arkansas, Stephenson and Crider (1916) reported 10 wells that contain Cretaceous fossils in the areas of Saffel (Lawrence County), Newark and Magness (Jackson County), Beebe (White County), and Cabot (Lonoke County). Lithologic descriptions include loose sands, dark-green glauconitic sand, bluish-gray calcareous clays and sands comparable to upper, middle, and lower Nacatoch Sand lithology (Fig 13; Table 3). Although no microfossils or nannofossils were reported from these units, macrofossils can be used in biostratigraphic and lithostratigraphic correlations to upper, middle, and lower Nacatoch Sand as previously described by Counts et al. (1955), Plebuch and Hines (1969), Schrader and Scheiderer (2004).

Outcrop descriptions and well descriptions from Newark and Magness are described by Stephenson and Crider (1916) as dark green glauconitic sand, weathered to red sand, with shell fragments: the same lithology as that of the middle Nacatoch as described by Schrader and Schneiderer (2004). One well 4.8 kilometers west of Newark describes a pebbly black clay with lignitic plant material at the bottom of the well, underlying the middle Nacatoch Sand lithology. Although similar to Coffee Sand lithology described from subsurface deposits in southeastern Missouri, additional information is needed before a clear correlation can be made, especially because this lithology is also found in the upper and middle McNairy Sand in southeastern Missouri and southern Illinois.

Fossils described from the Newark and Magness wells include *Cubitostrea tecticosta*, *Ostrea* sp., *Anomia* sp., shark teeth, *Exogyra* sp., and *Turritella trilira* (Stephenson and Crider,

1916; Sohl, 1964). Although the *Ostrea*, *Anomia*, *Exogyra*, and shark teeth are not helpful in narrowing down the age due to long biostratigraphic ranges, *C. tecticosa* and *T. trilira* can be used to help constrain the age. *Cubitostrea tecticosta* ranges from Campanian to upper Maastrichtian (Foulke, 1858; Sohl and Koch, 1983), whereas *T. trilira* ranges from uppermost Campanian to lower Maastrichtian (Sohl, 1964; Sohl and Koch, 1983; Sohl and Koch, 1987). The presence of *Turritella trilira* from the Newark and Magness wells indicates the middle Nacatoch Sand in northeastern Arkansas has an age somewhere between or equal to upper Campanian to lower Maastrichtian based on the stratigraphic range of *T. trilira* (Sohl, 1964; Sohl and Koch, 1983, 1987).

Lithologic descriptions from wells in the Saffel, Beebe, and Cabot areas (gray-blue argillaceous material, some green sand, calcareous sandstone, and clay) match the lithology described for the lower Nacatoch Sand by Counts et al. (1955) and Plebuch and Hines (1969). Fossil mollusks recovered from this argillaceous strata in these wells include taxa whose biostratigraphic ranges cross both Campanian and Maastrichtian stages. Wells in the Beebe, Cabot, and Saffel areas (Fig 5; Table 3) contain the following molluscan taxa according to Stephenson and Crider (1916): *Nucula percrassa*; *Gari elliptica*; *Cymbophora lintea*; *Discoscaphites conradi*; *Baculites anceps*; *Placenticeras* sp.; *Exogyra costata*; *Trachycardium efaulense*; *Leda pinnaforma*; *Anomia argentaria*; *Crassatellites* sp.; *Cardium* sp.; *Cyprimeria depressa*; *Scaphites* sp.; *Glycimeris* sp.; and *Anomia* sp..

Nucula percrassa ranges from lower Campanian through the Maastrichtian (Owens et al., 1970; Sohl and Koch, 1984; Bernstein, 1988); *C. lintea* ranges through both the Campanian and Maastrichtian (Sohl and Koch, 1983); *D. conradi* ranges from the uppermost Campanian and into the lower Maastrichtian (Elias, 1933; Sohl and Koch, 1983; Sohl and Koch, 1984; Landman

and Waage, 1993); *B. anceps* ranges from the Coniacian to upper Maastrichtian (McLearn, 1926; Anderson, 1958); and *Placenticerias* ranges from upper Cenomanian into the Maastrichtian (Elder, 1987; Stephenson, 1941). *Gari elliptica* appears to have been a misidentified mollusk, as *G. elliptica* is known from only Miocene to recent units (Stephenson and Crider, 1916). Because the rest of these taxa range through both the Campanian and the Maastrichtian (Veatch and Stephenson, 1911; Stephenson, 1956; Sohl, 1964; Owens et al., 1970; Sohl and Koch, 1983, 1984; Bryan and Jones, 1989; Landman and Waage, 1993), they are not helpful in further constraining the age. The presence of *D. conradi* from the gray-blue argillaceous strata of the Saffel, Beebe, and Cabot area wells indicates the lower part of the Nacatoch Sand in northeastern Arkansas is no younger than early Maastrichtian. Based on stratigraphic relationship to the middle Nacatoch Sand in northeastern Arkansas, however, it is most likely the lower Nacatoch Sand here is assignable to the uppermost Campanian.

The core facility at the Arkansas Geological Survey was visited for additional subsurface data and sampling for nannofossil analysis. Whereas most northeastern Arkansas cores available at the core facility include only Paleozoic basement, two cores from the northeastern part of the embayment do contain Cretaceous material (Fig 5; Table 3). One core from Woodruff County (Craig Williams core WM No. 6) contains the 23a nannoplankton assemblage zone at 257.3 meters in light-gray, micaceous marly sediment. Also in the core at depths from 239 to 255.7 m are numerous shell fragments.

Conclusions

Previous correlations of the northern embayment based mainly on lithology (due to absence of marine biostratigraphic indicators in clastic units) missed much of the latest Campanian lithologic diversity, and consequently, the paleoenvironmental diversity within the

area. The significance of the results of this project includes correlating the late Campanian palynostratigraphy with late Campanian marine biostratigraphy in the Gulf Coastal Plain and correlating the uppermost Campanian lithofacies in the northern Mississippi Embayment. Through comparison of biostratigraphic ranges of palynomorphs, foraminifera, calcareous nannoplankton, mollusks, ammonites, and vertebrates, this project succeeded in correlating upper Campanian and lower Maastrichtian terrestrial, marine, carbonate, and clastic facies in the northern Mississippi Embayment (Figs. 6, 7, and 8). Results of this project help fill in the biostratigraphic and lithostratigraphic correlation of the late Campanian and early Maastrichtian in the northern Mississippi Embayment, a significant portion of the Gulf Coastal Plain. Identifying age-equivalent lithofacies is an imperative step preceding any paleogeographic and paleoecologic interpretation of the northern embayment. Identifying age-equivalent lithofacies, will also help further tectonic research in the area by providing an age-equivalent surface from which to more accurately measure and compare uplift and subsidence.

In addition to the identification of latest Campanian age-equivalent lithofacies, other significant contributions of this project include: the clarification of stratigraphic relationships of named formations and members in southern Illinois (the Coffee Sand does exist, but was previously referred to as the Commerce Member in the lower McNairy Sand); clarification of the unnamed surface Cretaceous units in northeastern Arkansas, and the separation of the lithology into the upper, middle, and lower Nacatoch Sand; and clarification of independence of the bone-bearing clays in southeastern Missouri through contrast with the other upper Campanian and lower Maastrichtian units in the embayment, and support for formally proposing a new name for the lithofacies, the “Glenallen Clay.” With these correlations, identifications, and clarifications,

a clearer picture of the latest Campanian northern Mississippi Embayment overall has been obtained.

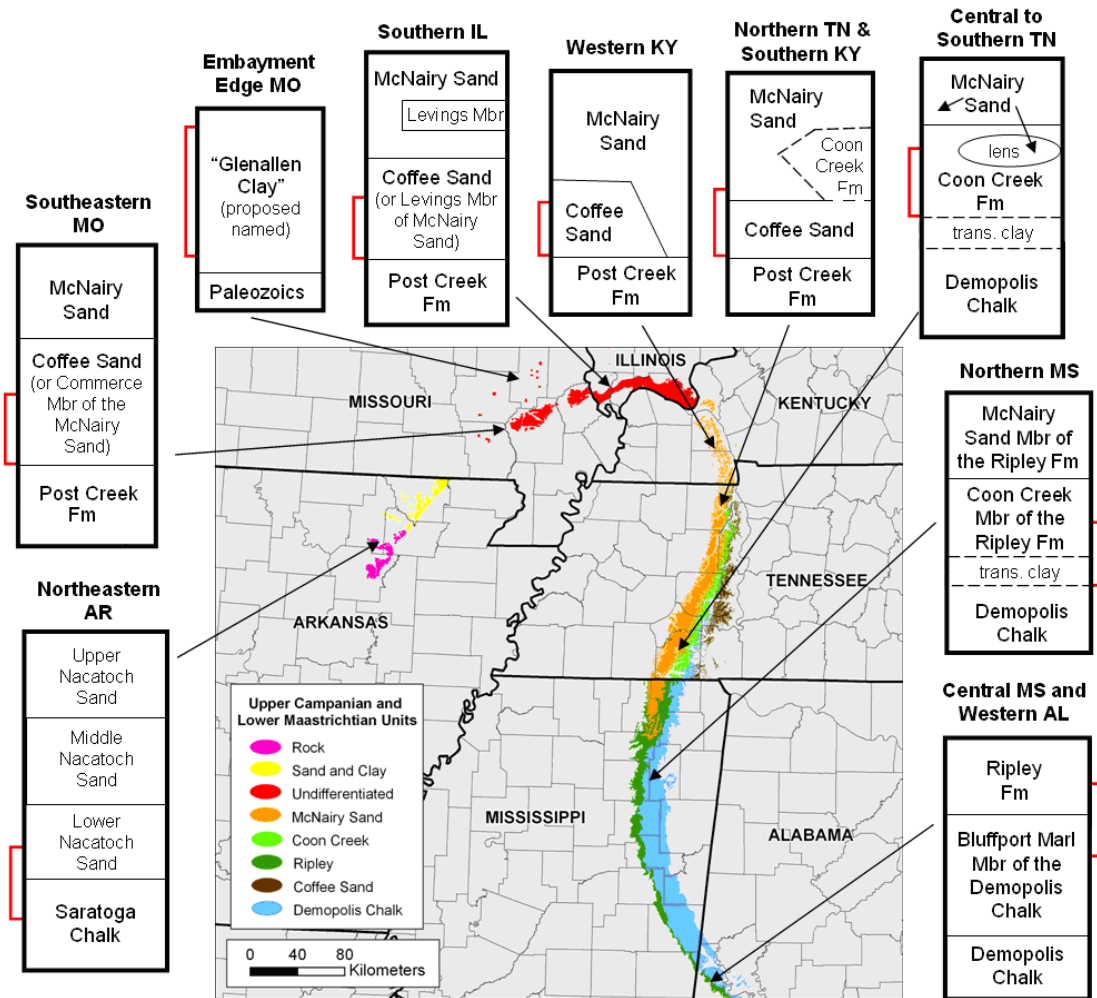


Fig. 6. The upper Campanian and lower Maastrichtian outcrop belt in the northern Mississippi Embayment study area. Formations on map appear as they are labeled on state geologic maps (Miller et al., 1966; Bicker, 1969; McDowell et al., 1981; Szabo et al., 1988; Haley et al., 1993; Middendorf et al., 2003; Kolata, 2005). Stratigraphic sections at this locality in the outcrop belt show the upper Campanian and lower Maastrichtian lithofacies in the area indicated with an arrow on the map. Red side bars on the stratigraphic sections indicate the lithofacies interpreted in this research to represent the uppermost Campanian lithofacies, age-equivalent to the lower Coon Creek lithofacies based on lithostratigraphy and biostratigraphic indicators. Thicknesses vary by location and stratigraphic sections shown here are not representative of thickness. See Table 3 for lithologic descriptions. Abbreviations: Fm = formation, Mbr = member, AL = Alabama, AR = Arkansas, IL = Illinois, KY = Kentucky, MO = Missouri, MS = Mississippi.

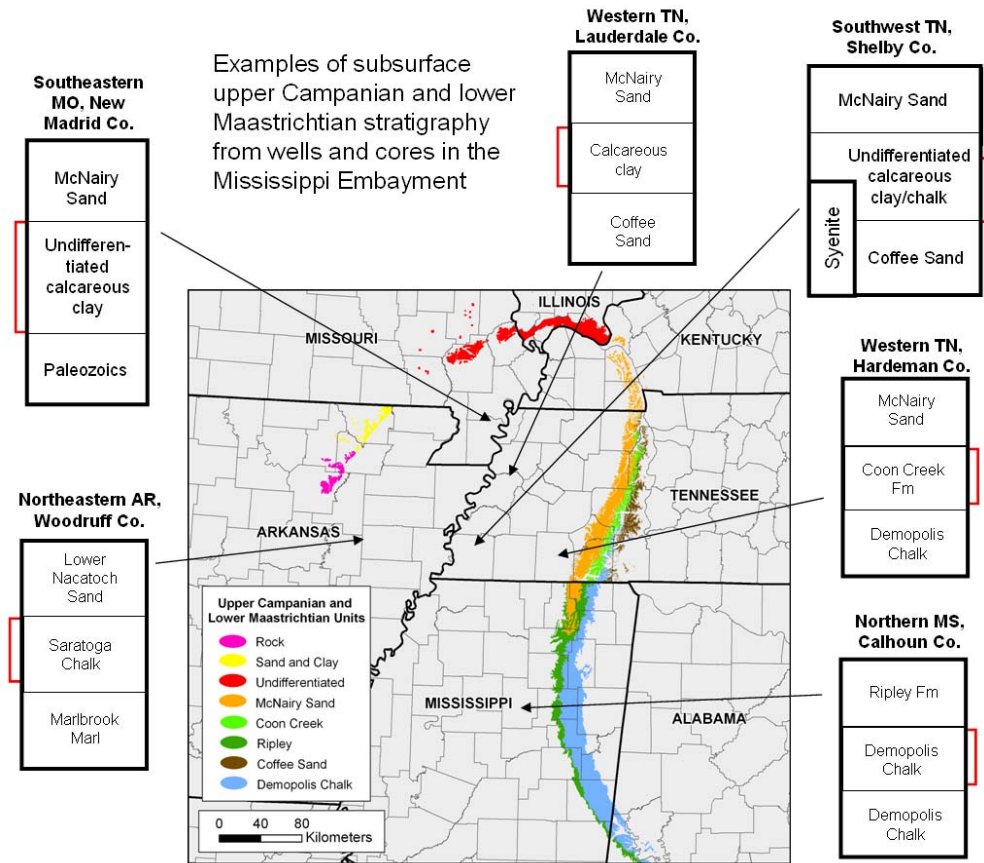


Fig. 7. Examples of subsurface Upper Campanian and lower Maastrichtian stratigraphy in the northern Mississippi Embayment study area. Upper Campanian and lower Maastrichtian formations in outcrop belt on map appear as they are labeled on state geologic maps (Miller et al., 1966; Bicker, 1969; McDowell et al., 1981; Szabo et al., 1988; Haley et al., 1993; Middendorf et al., 2003; Kolata, 2005). Stratigraphic sections were compiled from well logs and cores in the noted county. Red side bars on the stratigraphic sections indicate the lithofacies interpreted to represent the uppermost Campanian lithofacies, age-equivalent to the lower Coon Creek lithofacies based on biostratigraphic indicators. Thicknesses vary by location and stratigraphic sections shown are not representative of thickness. See Table 3 for lithologic descriptions.

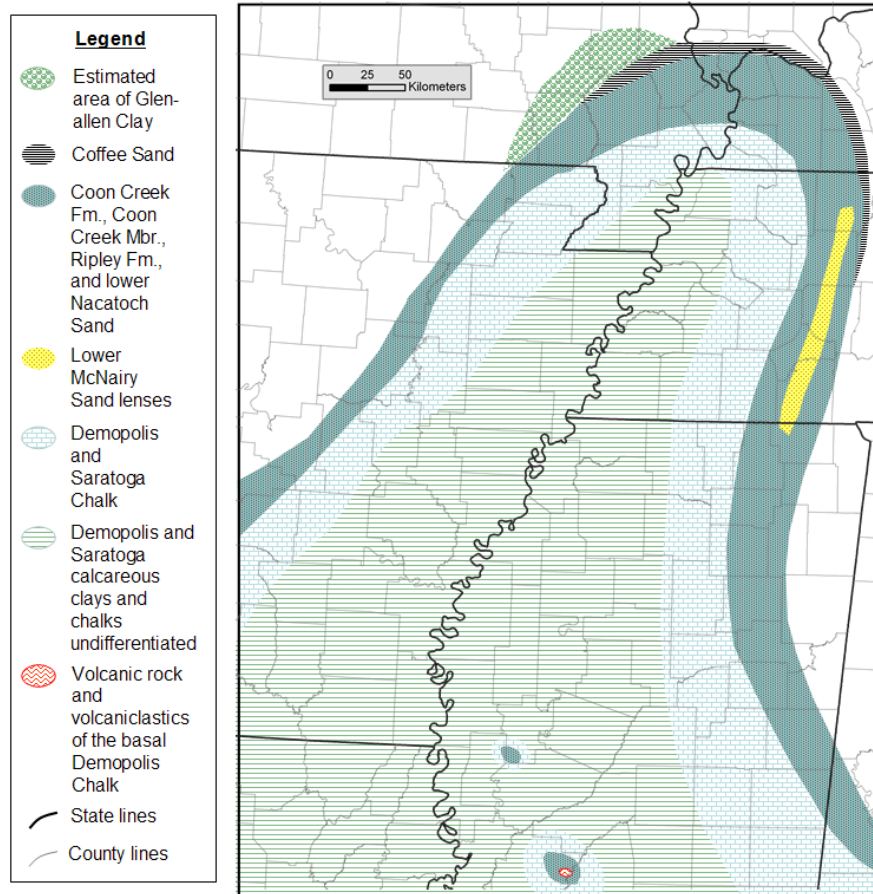


Fig. 8. The uppermost Campanian lithofacies in the subsurface of the northern Mississippi Embayment study area. Uppermost Campanian lithofacies are age-equivalent to the lower Coon Creek lithofacies based on lithostratigraphy and biostratigraphic indicators. Map compiled from river bluff exposures, road cuts, core, auger, and well log data.

Discussion

In Tennessee, the lower lithofacies of the Coon Creek Formation contains several index species that help identify its age and correlate it with other lithofacies across the embayment. According to analysis in this research and in previous publications, index species in the lower lithofacies of the Coon Creek in Tennessee include the palynomorph assemblage CA-5B, calcareous nannoplankton Assemblage Zone 23a, and *Nostroceras hyatti* (Wade, 1926; Tschudy, 1967a; Wolfe, 1976). The 23a nannoplankton assemblage can also be found westward into Hardeman County in subsurface units having similar lithology and shell preservation between

35.7-72.2 meters deep in well #1280. This is interpreted as a continuation of the Coon Creek lithology.

Further west, toward the central embayment in Tennessee, age equivalent (based on palynomorph assemblages) lithofacies include a similar glauconitic silty calcareous clay at 849.2-858.3 m deep in the Fort Pillow test well in Lauderdale County (Moore and Brown, 1969). In New Madrid County, Missouri, an uppermost Campanian (based on palynomorph assemblages) calcareous lithofacies is found much deeper at 553.2 to 579.4 m deep in the New Madrid test well (Fredericksen et al., 1982). Because the central part of the embayment is edged by the Saratoga Chalk to the west and the Demopolis Chalk to the east, this silty calcareous clay or clayey chalk is interpreted here as a calcareous clay lithofacies of the Saratoga and Demopolis Chalks undifferentiated (Fig. 8).

In Kentucky, the lowermost McNairy Sand interfingers the Post Creek and Coffee Sand. The Coffee Sand in Kentucky has been correlated with the Coffee Sand in southern Illinois and in southeastern Missouri (Fig. 8), based on lithology and palynostratigraphic assemblages (Tschudy, 1967a; Wolfe, 1976; Harrison et al., 1996; Harrison and Litwin, 1997). Previously described as a second Commerce Member in the lower McNairy Sand, the lower gray silty clay overlying gravel in southern Illinois is interpreted here to be equivalent to the latest Campanian Coffee Sand in Kentucky and in Missouri. This project also showed previous references to the lower Commerce Member of the McNairy Sand in Missouri are also the Coffee Sand based on litho- and biostratigraphy.

Nonmarine clay facies in the Bollinger County area (Fig. 6) are interpreted as Campanian in age (Baird and Horner, 1979; Stinchcomb et al., 1994). Although no index species of nannoplankton or foraminifera have been collected from these sites, vertebrate faunas with upper

Campanian biostratigraphic ranges were used for age estimation in these areas, based on biostratigraphic ranges of the turtle *Naomichelys* and the hadrosaur *Hypsibema* (Stinchcomb et al., 1994). Data for this project reveal that these bone-bearing blue clays do not correlate lithologically to any other Campanian or Maastrichtian formation or member of a formation in the northern Mississippi Embayment. Previous publications on these fossiliferous clays do not propose a name or a type section for these terrestrial clay deposits. Dinosaur material in the Gulf Coastal Plain and Mississippi Embayment is rare (Weishampel et al., 2004), and to have numerous taxa recovered from one site alone (Stinchcomb et al., 1994; Parris, 2006; Stinchcomb, 2006, shows these clay deposits can make a significant contribution to paleontology in the southeastern U. S., especially as most of the dinosaur material has not been identified to even genus level. Because the fossiliferous clays do not correlate to other Cretaceous units in the northern Mississippi Embayment, and one site in particular has already received multiple publications, is scientifically significant, and is accessible to researchers (G. Darrough, pers. comm., 2009), formally proposing a name for this lithofacies is recommended. As the Chronister site has received the most thorough research thus far, and is close to the town of Glenallen, a suggested proposed name would be the *Glenallen Clay* with the Chronister site being a good potential type section for the formation.

Arkansas geologic maps currently assign no name to the Cretaceous units cropping out in the northeastern part of the state (Fig. 6). Based on stratigraphic position, paleontology, and lithology, the outcrops in northeastern Arkansas can be correlated to Nacatoch Sand lithofacies in southwestern Arkansas as previously suggested by Stephenson and Crider (1916). This project further correlated these lithofacies to the different parts of the Nacatoch Sand, based on their paleontology and lithology: the loose sands in the Pocahontas area are assignable to the upper

Nacatoch Sand; glauconitic sands penetrated by wells in the Newark and Magness areas are middle Nacatoch Sand; and bluish-gray clayey sands penetrated in the Cabot, Beebe, and Saffel areas are assignable to the lower Nacatoch Sand (Fig. 6). Interpreted subsurface data from northeastern Arkansas show the Saratoga Chalk just east of the middle and lower Nacatoch lithofacies to be uppermost Campanian (Fig. 8).

Outcrops of the Coon Creek Member of the Ripley Formation in Mississippi, the lower Ripley in Alabama, and the uppermost Demopolis in Alabama and Mississippi were found to have latest Campanian age-equivalent nannoplankton assemblages (Fig. 6 and 7). The uppermost Campanian surface continues westward from the lowermost Ripley and uppermost Demopolis Chalk outcrop belt westward toward the central embayment dipping downward through the Demopolis Chalk and laterally merging with the Saratoga Chalk of Arkansas in an undifferentiated calcareous clay or clayey chalk in the central embayment (Fig. 8). Data from this project also show the Jackson Volcano was active during the latest Campanian and was rimmed by carbonate and clastic facies (Fig. 6).

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Of all the uppermost Campanian units in the northern Mississippi Embayment, the formation that has received the most attention and the most publications on its paleoecology is the Coon Creek Formation. The lower facies of the Coon Creek Formation is considered a lagerstätte because of its great biodiversity and preservation. Many papers have been published on the type section, suggesting different environments based on one particular faunal assemblage or taxon, but interpreted environments vary from lagoonal to open shelf. The Coon Creek Formation is an important part of the upper Campanian northern embayment, and its great biodiversity allows a detailed analysis of its depositional environment. This next paper uses this biodiversity to help compare this ancient environment to a modern analog to help identify the Coon Creek lower facies' depositional environment and relationship to its other age-equivalent facies.

CHAPTER 3

PALEOENVIRONMENTAL INTERPRETATION OF THE LOWER FACIES OF THE COON CREEK FORMATION

Abstract

Previous investigations of the paleoenvironmental setting of the Upper Cretaceous Coon Creek Formation type section (CCTS) have resulted in a wide range of interpreted paleoenvironments, including marine settings from shallow to deep and from hypo- to hypersaline conditions. Because the CCTS biofacies is a lagerstätte with high benthic biodiversity, and many of the fossil genera have extant species living in the Atlantic today, the section is a good candidate for a synecological approach to paleoenvironmental interpretation. This research identifies extant genera and analyzes their biogeographic and ecological niche ranges to help identify a modern analog environment to the CCTS. Biological and abiological environmental data from electronic databases were compiled, and geospatial analyses were performed in a Geographic Information System (GIS). Results indicate that 77 molluscan genera present at the CCTS are living in today's oceans. Of these extant genera inhabiting the tropical Atlantic, 98% inhabit the shallow waters along the western side of Florida Bay from the southern Florida coastline to the Florida Keys. The substrate of this area of Florida Bay is also similar to the CCTS lithology. Because of these similarities, the western edge of Florida Bay is interpreted in this paper as a modern environmental analog to the paleoenvironment of the CCTS lagerstätte.

1. Introduction

Late Cretaceous clastic and carbonate units crop out in a wide belt along the eastern edge of the northern Mississippi Embayment in Kentucky, Tennessee, and Mississippi. Among these units is the Coon Creek Formation, the depositional environment of which has previously been unresolved despite the high biodiversity and lagersatätte preservation at its type section.

Interpretations of the Coon Creek type section (CCTS) paleoenvironment range across a wide variety of marine settings, including near-coastal marine (Wade, 1926), delta-front platform (Pryor, 1960), mixing zone between deeper shelf and shallow marine (Russell and Parks, 1975), and freshwater marsh to hypersaline lagoon (Moore, 1974). Although many researchers have examined faunal communities within the formation (e.g., Wade, 1926; Moore, 1974; Gibson and Dunagan, 2003b), the paleoenvironment of the CCTS has remained unclear with respect to marine habitat descriptors such as water depth, salinity, temperature, relationship to coastal geography, and other abiotic characteristics. If a modern environment existed today with a similar faunal assemblage and substrate, the ancient environment could be better defined by examining the geological and biological characteristics of the modern analog environment.

Because many molluscan genera in Cretaceous deposits are still living in modern environments today (Kauffman, 1973; Sepkoski, 2002; Garrison et al., 2007), modern analog environments with similar faunal assemblages to that of a Cretaceous unit can be identified through biogeographic analyses. This synecological approach is strengthened when the fossil faunal assemblage examined is in a lagersatätte with high biodiversity, a unit in which a high percentage of the original faunal community was preserved. The high preservation and biodiversity of the molluscan fauna in the CCTS includes over 200 genera, a large sample size of the ancient molluscan community. Because such a high percentage of these genera is also

extant, the section is a good candidate for a synecological and modern analog approach to paleoenvironmental analysis.

Attempting a synecological biogeographical correlation of high numbers of genera in order to identify a modern analog environment, however, is no small task. Two hindrances to complex biogeographical and paleoecological projects such as this have, in the past, included provincial differences in taxonomy (Kauffman, 1973) and limited access to global biogeographical data (Alroy, 2003; Miller, 2003). As Kauffman (1973) noted in his research on Cretaceous bivalve paleobiogeography, accurate descriptions of paleobiology and paleobiogeography are dependent on global efforts on standardization of taxonomy. With the *Treatise on Invertebrate Paleontology*, as well as current efforts to build and maintain online global biological and paleontological databases, the effect of these obstacles has been reduced. In addition to this, computer capabilities with GIS software are also now able to handle geospatial overlays and analyses of large amounts of biogeographical data.

The objectives of this study are to: incorporate current, globally applied taxonomic, paleobiological, and modern biological data; identify extant genera; and use GIS spatial analyses to identify areas with similar modern faunal assemblages to that of the CCTS. In applying geospatial analyses to extant genera and their corresponding biogeographical data, modern analog environments to the CCTS are identified. Abiotic environmental characteristics of the analog environments, such as salinity, temperature, and currents, are also compared to help further infer paleoenvironmental traits.

2. Locality

2.1 Geologic setting

The Coon Creek Formation is an Upper Cretaceous regressive marine silty sand in western Tennessee (Fig. 1; Wade, 1926; Russell and Parks, 1975) that overlies the Demopolis Chalk and underlies the McNairy Sand. The formation consists of upper and lower lithofacies, with the lower lithofacies exposed at the type section. The upper lithofacies of the Coon Creek Formation has a low level of preservation and paleobiodiversity, with much of the fossil material existing as molds and casts rather than identifiable shell. The lower facies has an overall higher silt content and higher preservation and biodiversity than the upper facies. Cut by, and exposed along, the Coon Creek in northern McNairy County, Tennessee, the eroded creek bank exposes 12 m of dark greenish-gray glauconitic clayey sand of the type section (Fig. 1). Vertical variation includes changes in sand percentage with a general coarsening-upward trend, and multiple layers of concretions and biozones. The lowermost 3 m of the type section include the biofacies containing the highest preservation and biodiversity. This biofacies has been considered by many to be a lagerstätte for its high biodiversity (over 400 species), uncompressed nature, preservation of coloration and fine ornamentation, and unaltered shell chemistry (Fig. 1; Adams, 1994; Noble, 1996; Zepp, 1999; Gibson and Dunagan, 2003b).

Although the spatial extent of the lower lithofacies of the Coon Creek has not been mapped, the Coon Creek Formation outcrop belt stretches from southern McNairy County at the Tennessee-Mississippi border (the Coon Creek in Mississippi is considered a member of the Ripley Formation) to Henry County, Tennessee. The Coon Creek fossiliferous lithology is also found in the subsurface just west of the McNairy Sand outcrop belt. The McNairy Sand, a cross-bedded sparsely glauconitic fine- to coarse-grained sand (Russell and Parks, 1975), overlies the

Coon Creek Formation and can also be found as large lenses within the Coon Creek Formation as described by Russell and Parks (1975). Well cuttings (#1280) from Hardeman County at 72 m deep were analyzed and found to contain the same clayey and silty glauconitic sand with well preserved shell material as is found at the Coon Creek type section. Samples from these well-cuttings were found to be the same age (based on their calcareous nannoplankton assemblage, 23a) as samples from the Coon Creek type section.

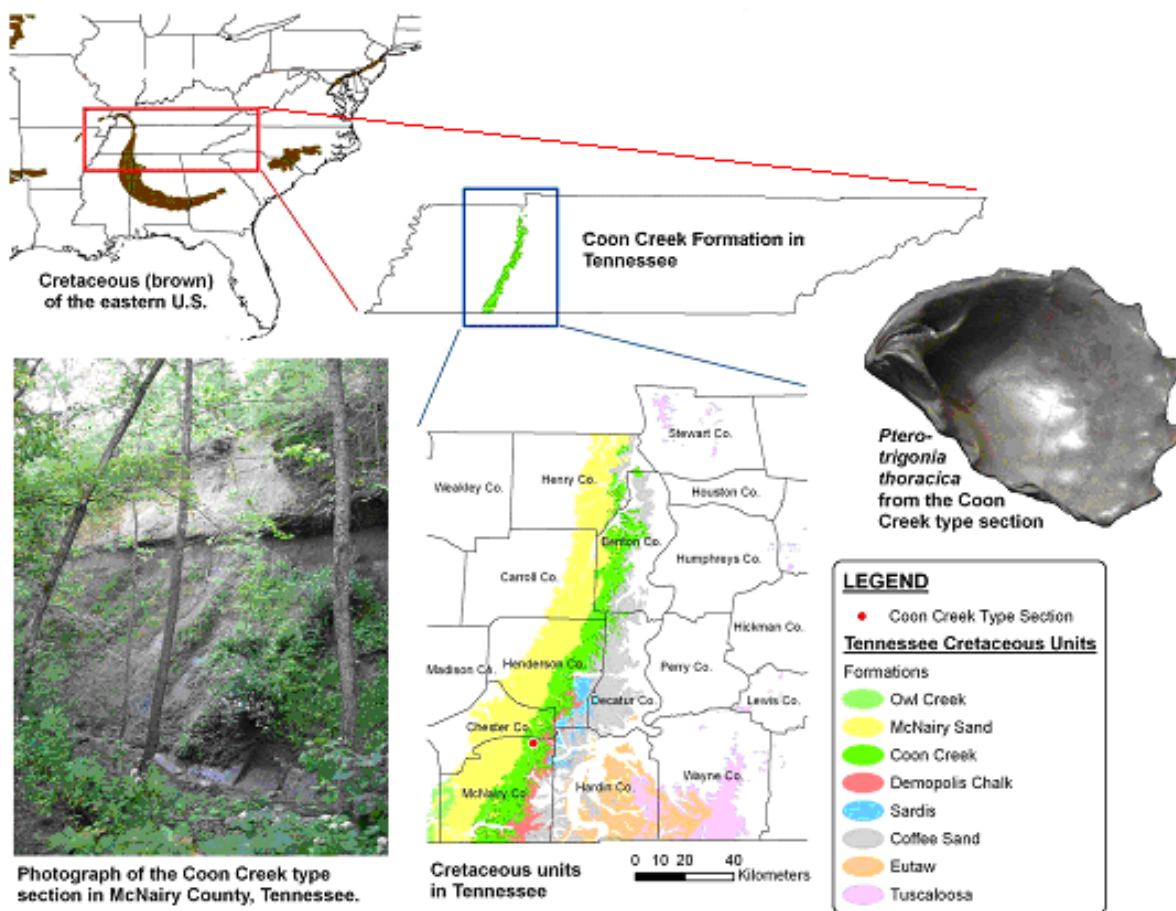


Fig. 1. The Coon Creek Formation type section in McNairy County, Tennessee and one of the well preserved fossils from the type section.

2.2 Paleofaunal and Paleofloral Overview

Macrofaunal phyla present at the type section and locality include Mollusca (the most abundant taxon), Cnidaria, Echinodermata, Arthropoda, Annelida, Porifera, Bryozoa, Brachiopoda, and Chordata (Wade, 1926; Gibson and Dunagan, 2003b). Of the macro-molluscan fauna, bivalves and gastropods are the most abundant (Moore, 1974) and diverse taxa, with almost 200 genera (Wade, 1926; Moore, 1974). Bivalves and gastropods comprise most of the molluscan fauna, with 55% gastropods (119 genera) and 38% bivalves (82 genera) (Tables 1, 2). The remaining 7% of the molluscan fauna includes two genera of Scaphopoda (*Dentalium* and *Cadulus*) and 14 genera of Cephalopoda including *Eutrephoceras*, *Baculities*, *Solenoceras*, *Jeletkytes*, *Nostoceras*, *Didymoceras*, *Helioceras*, *Pachydiscus*, *Lewysites*, *Parasolenoceras*, *Cirroceras*, *Hoploscaphites*, and *Discoscaphites* (Cobban and Kennedy, 1994; Larson, 2003; Brister and Young, 2007).

Table 1. Bivalves present in the Coon Creek type section. Status shows whether the genus is extinct (x) or still living today (Extant). Genera that have been renamed or revised are in parentheses and followed by the publication in which the revision is cited.

Family	Genus	Status
Anomiidae	<i>Anomia</i>	Extant
	<i>Paranomia</i>	x
	<i>Pulvinites</i>	x
Arcidae	<i>Arca</i>	Extant
	<i>Barbatia</i>	Extant
	<i>Glycymeris</i>	Extant
	<i>Postligata</i>	x
Arcticidae	<i>Arctica</i> (<i>Cyprina</i>)	Extant
	<i>Hartwellia</i> for <i>Cyprina</i> (Cox et al., 1969; Stenzel, 1971)	x
Astartidae	<i>Vetericardiella</i> for <i>Vetericardia</i> (Moore, 1974)	x
Caprinidae	<i>Antillocaprina</i> for <i>Caprinella</i> (Cox et al., 1969; Stenzel, 1971)	x
Cardiidae	<i>Criocardium</i> for <i>Cardium dumosum</i> (Cox et al., 1969; Stenzel, 1971)	x
	<i>Granocardium</i> for <i>Cardium</i> (Moore, 1974)	x
	<i>Laevicardium</i> for <i>Cardium</i> (Cox et al., 1969; Stenzel, 1971)	Extant
	<i>Trachycardium</i> for <i>Cardium</i>	Extant
Clavagellidae	<i>Clavagella</i>	Extant
Corbulidae	<i>Caestocorbula</i> for <i>Corbulamella</i>	x
	<i>Caryocorbula</i> for <i>Corbula</i>	Extant

	<i>Corbula</i>	Extant
	<i>Scambula</i>	x
Crassatellidae	<i>Crassatella</i> for <i>Crassatellites vadosus</i> (Cox et al., 1969; Stenzel, 1971)	Extant
	<i>Crassatellina</i>	x
	<i>Etea</i>	x
	<i>Cylichna</i>	Extant
Diplodontidae	<i>Tenea</i>	x
Dreissenidae	<i>Lycettia</i> for <i>Dreissensia</i> (Cox et al., 1969; Stenzel, 1971)	x
Gastrochaenidae	<i>Gastrochaena</i>	Extant
	<i>Kummelia</i> for <i>Gastrochnaea</i> (Moore, 1974)	x
Glossidae	<i>Glossus</i> (old name is <i>Isocardia</i>) (Cox et al., 1969; Stenzel, 1971; PaleoDB, 2008)	Extant
Hiatellidae	<i>Panopea</i> (<i>Panopea</i> for <i>Panope</i> ; Moore, 1974)	Extant
Laternulidae (Anatinidae)	<i>Anatimya</i>	x
Limidae	<i>Lima</i>	Extant
Limopsidae	<i>Limopsis</i>	Extant
Lucinidae	<i>Lucina</i>	Extant
Mactridae	<i>Cymbophora</i>	x
Mactromyidae	<i>Unicardium</i>	x
Mytilidae	<i>Crenella</i>	Extant
	<i>Inoperna</i>	x
	<i>Lithophaga</i>	Extant
Nuculanidae	<i>Nuculana</i> (<i>Nuculana</i> for <i>Leda</i> ; Moore, 1974)	Extant
Nuculidae	<i>Nucula</i>	Extant
Ostreidae	<i>Agerostrea</i> for <i>Ostrea falcata</i> (Cox et al., 1969; Stenzel, 1971)	x
	<i>Anadara</i>	Extant
	<i>Crassostrea</i>	Extant
	<i>Exogyra</i>	x
	<i>Ostrea</i>	Extant
	<i>Pycnodonte</i> for <i>Gryphaea</i> (Cox et al., 1969; Stenzel, 1971)	Extant
Parallelodontidae	<i>Cucullaea</i> and <i>Cucullaea</i> for <i>Inodearca</i> (PDB)	Extant
	<i>Nemodon</i>	x
Pectinidae	<i>Aequipecten</i> for <i>Pecten</i>	Extant
	<i>Chlamys</i> (<i>Radiopecten</i>) for <i>Pecten quinquenarius</i> (Cox et al., 1969; Stenzel, 1971; Moore, 1974)	Extant
	<i>Neithea</i> for <i>Pecten</i> (Moore, 1974)	x
	<i>Neitheops</i> for <i>Pecten quinquecostatus</i> (Cox et al., 1969; Stenzel, 1971)	x
	<i>Pecten</i>	Extant
Periplomatidae	<i>Periploma</i>	Extant
	<i>Periplomya</i> for <i>Periploma</i> (Moore, 1974)	x
Pernidae	<i>Cataceramus</i> for <i>Inoceramus</i> (Cox et al., 1969; Stenzel, 1971)	x
	<i>Gervillia</i> new for <i>Gervilliopsis</i> (Cox et al., 1969; Stenzel, 1971)	x
	<i>Inoceramus</i>	x
	<i>Isognomon</i>	Extant
Pholadidae	<i>Martesia</i>	Extant
Pholadomyidae	<i>Pholadomya</i>	Extant
Pleurophoridae	<i>Veniella</i>	x
Poromyidae	<i>Liopistha</i>	x

Protocardiinae	<i>Protocardia</i>	x
Pteriidae	<i>Pteria</i>	Extant
Solenidae	<i>Leptosolen</i>	x
Tellinidae	<i>Aenona</i>	x
	<i>Linearia</i> for <i>Liothyris</i> (Moore, 1974)	x
	<i>Tellina</i>	Extant
	<i>Tellinimera</i>	x
Teredinidae	<i>Teredo</i>	Extant
Trigoniidae	<i>Linotrigonia</i> for <i>Trigonia eufalensis</i> (Cox et al., 1969; Stenzel, 1971)	x
	<i>Pterotrigonia</i> for <i>Trigonia</i> (Cox et al., 1969; Stenzel, 1971)	x
Veneridae	<i>Aphrodina</i>	x
	<i>Cyprimeria</i> for <i>Cyclina</i> (Cox et al., 1969; Stenzel, 1971)	x
	<i>Icanotia</i>	x
	<i>Legumen</i>	x
	<i>Mercenaria</i> for <i>Arctica</i> (Cox et al., 1969; Stenzel, 1971)	Extant
	<i>Meretrix</i>	Extant
Veneroida	<i>Epilucina</i> for <i>Cyclina</i> (Cox et al., 1969; Stenzel, 1971)	x
Yoldiidae	<i>Yoldia</i>	Extant

Table 2. Gastropods present in the Coon Creek type section. Status shows whether the genus is extinct (x) or still living today (Extant). Genera that have been renamed or revised are in parentheses and followed by the publication in which the revision is cited. For genera added since Wade's 1926 volume, the reference follows with an asterisk.

Family	Genus	Status
Acmaeidae	<i>Acmaea</i>	Extant
Acteonidae	<i>Acteon</i>	Extant
	<i>Acteonina</i>	Extant
	<i>Eoacteon</i> (for <i>Acteon solidulus</i> and <i>ellipticus</i>) (Sohl, 1960, 1964)	x
	<i>Goniocylichna</i>	x
	<i>Nonacteonina</i> (for <i>Acteonina orientalis</i>) (Sohl, 1960, 1964)	x
	<i>Tornatellaea</i> (*Sohl, 1960, 1964)	x
Acteoninidae	<i>Parietiplicatum</i> (for <i>Acteon conicus</i>) (Sohl, 1960, 1964)	x
	<i>Troostella</i>	x
Aporrhaidae	<i>Anchura</i>	x
	<i>Aphorrhais</i> (subg. <i>Arrhoges</i>) (for <i>Anchura lobata</i>) (Sohl, 1960, 1964)	Extant
	<i>Drepanocheilus</i> (for <i>Anchura quadriliratus</i>) (Sohl, 1960, 1964)	x
	<i>Graciliata</i> (for <i>Anchura calcaris</i>) (Sohl, 1960, 1964)	x
	<i>Pterocerella</i>	x
Architectonicidae	<i>Pseudomalaxis</i>	Extant
Buccinidae	<i>Buccinopsis</i> (for <i>Seminola</i>) (Sohl, 1960, 1964)	x
	<i>Fulgerca</i> (for <i>Pseudoliva</i>) (Sohl, 1960, 1964)	x
	<i>Hydrotribulus</i>	x
	<i>Odontobasis</i>	x
	<i>Ptychosyca</i>	x
	<i>Stantonella</i>	x
Calyptraeidae	<i>Thylacus</i>	x
Cancellariidae	<i>Cancellaria</i>	Extant
	<i>Caveola</i>	x

	<i>Mataxa</i>	x
Capulidae	<i>Capulus</i>	Extant
	<i>Trichotropis</i>	Extant
Cerithiidae	<i>Cerithium</i>	Extant
	<i>Nudivagus</i>	x
Cerithiopsidae	<i>Seila</i> (for <i>Cerithiopsis</i>) (Sohl, 1960, 1964)	Extant
Columbellariidae	<i>Columbellina</i>	x
Conidae	<i>Cryptoconus</i> (for <i>Conorbis</i>) (Sohl, 1960, 1964)	x
Coralliophilidae	<i>Babelomurex</i> (new name for <i>Latiaxis</i>) (for <i>Hippocampoides sorratus</i>) (Sohl, 1960, 1964)	Extant
Costellariidae	<i>Mitridomus</i> (for <i>Fasciolaria</i>) (Sohl, 1960, 1964)	x
Epitoniidae	<i>Acirsa</i>	Extant
	<i>Belliscala</i> (for <i>Acirsa cerithiformis</i>) (Sohl, 1960, 1964)	x
	<i>Opalia</i> (for <i>Scala sillimani</i>) (Sohl, 1960, 1964)	Extant
	<i>Striaticostatum</i> (for <i>Scala sillimani</i>) (Sohl, 1960, 1964)	x
Eulimidae	<i>Eulima</i>	Extant
Euomphalidae	<i>Weeksia</i> (for <i>Pseudomalaxi</i>) (Sohl, 1960, 1964)	x
Fasciolariidae	<i>Anomalofusus</i>	x
	<i>Bellifusus</i> (for <i>Odontofusus</i>) (Sohl, 1960, 1964)	x
	<i>Boltenella</i>	x
	<i>Cryptorhytis</i>	x
	<i>Drilluta</i>	x
	<i>Euthriofusus</i> (for <i>Falsifusus</i>) (Sohl, 1960, 1964)	x
	<i>Fusinus</i> (for <i>Fusus</i>) (Sohl, 1960, 1964)	Extant
	<i>Graphidula</i> (for <i>Mesorhytis</i>) (Sohl, 1960, 1964)	x
	<i>Hercorhyncus</i> (for <i>Haplovoluta</i>) (Sohl, 1960, 1964)	x
	<i>Ornopsis</i>	x
	<i>Paleopsephaea</i>	x
	<i>Remera</i> (for <i>Anchura</i>) (Sohl, 1960, 1964)	x
	<i>Woodsella</i>	x
Mathildidae	<i>Lemniscolittorina</i> (for <i>Littorina</i>) (Sohl, 1960, 1964)	x
	<i>Mathilda</i> (old name <i>Gegania (Tuba)</i>) (Sohl, 1960, 1964)	Extant
	<i>Promathildia</i>	x
Maturifusidae	<i>Astandes</i>	x
Melongenidae	<i>Deussenia</i> (for <i>Rhombopsis</i>) (Sohl, 1960, 1964)	x
	<i>Lomirosa</i> (for <i>Lirosoma</i>) (Sohl)	x
	<i>Protobusycon</i> (for <i>Busycon</i>) (Sohl)	x
	<i>Pyrifusus</i>	x
	<i>Rhombopsis</i>	x
Muricidae	<i>Ecphora</i>	x
	<i>Lowenstamia</i> (for <i>Hippocampoides liratus</i>) (Sohl, 1960, 1964)	x
Naticidae	<i>Sargana</i>	x
	<i>Ampullina</i>	x
	<i>Euspira</i> (for <i>Polinices halli</i>) (Sohl, 1960, 1964)	Extant
	<i>Globularia</i> (for <i>Polinices umbilica</i> and <i>stephonsoni</i> and <i>Amauropsis</i>) (Sohl, 1960, 1964)	Extant
	<i>Gyrodes</i>	x
Neotaenioglossa	<i>Tintorium</i> (*Sohl, 1960, 1964)	x
Pachychilidae	<i>Melanatria</i>	Extant
Paladmetidae	<i>Paladmete</i>	x
Pholidotomidae	<i>Morea</i>	x
	<i>Paramorea</i>	x
	<i>Schizobasis</i>	x
	<i>Volutomorpha</i>	x

Pickworthiidae	<i>Urceolabrum</i> (for <i>Eucycloscala</i>) (Sohl, 1960, 1964)	x
Ptychactractidae	<i>Exilia</i>	x
Pyramidellidae	<i>Creonella</i>	x
	<i>Lacrimiforma</i> (for <i>Creonella</i>) (Sohl, 1960, 1964)	x
	<i>Odostomia</i>	Extant
Ranellidae	<i>Charonia</i> (for <i>Tritonium</i>) (Sohl, 1960, 1964)	Extant
Ringiculidae	<i>Cinulia</i>	x
	<i>Oligoptycha</i> (for <i>Eriptycha</i>) (Sohl, 1960, 1964)	x
	<i>Ringicula</i>	Extant
Rissoidae	<i>Anteglossia</i> (for <i>Rissoina</i>) (Sohl, 1960, 1964)	x
	<i>Rissoa</i>	Extant
	<i>Rissoina</i>	Extant
	<i>Rissoa</i> , Subgenus <i>Turboella</i> (for <i>Mesostoma costatum</i>) (Sohl, 1960, 1964)	Extant
Scaphandridae	<i>Cylichna</i>	Extant
	<i>Cylindrotruncatum</i> (for <i>Cylichna recta</i>) (Sohl, 1960, 1964)	x
	<i>Scaphander</i>	Extant
Siphonariidae	<i>Anisomyon</i>	x
Strombidae	<i>Pugnellus</i>	x
Subulinidae	<i>Obeliscus</i>	Extant
Trochidae	<i>Trochus</i>	Extant
Tudicidae	<i>Pyropsis</i>	x
Turbinellidae	<i>Lupira</i> (for <i>Xancus major</i>) (Sohl, 1960, 1964)	x
	<i>Napulus</i> (for <i>Perissolax</i>) (Sohl, 1960, 1964)	x
	<i>Xancus</i>	Extant
Turbinidae	<i>Calliomphalus</i>	x
Turridae	<i>Amuletum</i> (for <i>Turricula fasciolata</i>) (Sohl, 1960, 1964)	x
	<i>Beretra</i> (for <i>Turricula gracilis</i> , <i>amica</i> , and <i>ripleyana</i>) (Sohl, 1960, 1964)	x
	<i>Fusimilis</i> (for <i>Turris</i>) (Sohl, 1960, 1964)	x
Turritellidae	<i>Laxispira</i> (also a prev subg of <i>Nystiella</i>) (for <i>Vermicularia</i>)	Extant
	<i>Turritella</i>	Extant
Typhloplanidae	<i>Mesostoma</i>	x
Vermetidae	<i>Serpulorbis</i>	Extant
Vitrinellidae	<i>Teinostoma</i>	Extant
Volutidae	<i>Liopeplum</i>	x
	<i>Longochonca</i> (for <i>Volutoderma tennesseensis</i> , <i>protracta</i> , and <i>aprossa</i>) (Sohl, 1960, 1964)	x
	<i>Parafusus</i>	x
	<i>Parvivoluta</i>	x
	<i>Tectaplica</i>	x
	<i>Volutoderma</i>	x
Xenophoridae	<i>Xenophora</i>	Extant

Cnidarians identified at the type locality include *Micrabacia*, *Trochosmia*, and *Actinopora* (Wade, 1926; Brister and Young, 2007). Echinoderms present in the type section include the asteroid *Metopaster* (Wade, 1926), and a number of species of the echinoid orders Holasteroidea, Cassiduloidea, Spatangoidea (*Hemiaster*), and Diademetoidea (Ciampaglio, 2003;

Brister and Young, 2007). Arthropods described from the site include the crabs *Dakoticancer*, *Avitelmessus*, and *Raniella* (Wade, 1926; Bishop, 2003; Brister and Young, 2007), four lobster or crayfish (*Hoploparia*, *Eryma*, *Linuparus (Podocratus)*, and *Enoplocytia*), and shrimp *Penaeus* and *Callianassa* (Wade, 1926; Brister and Young, 2007). Annelida found at the type section include species of *Hamulus* and *Serpula* (Wade, 1926). Porifera have been identified through trace fossils (Griffin and Gibson, 1998), but have not been identified on a more detailed taxonomic level. Brachiopoda include the genus *Crania* (Wade, 1926). Bryozoa from the type section identified by Wade (1926) include 14 genera.

A wide range of chordates have been found at the CCTS (Corgan and Breitburg, 1996; Gibson and Dunagan, 2003b). Chondrichthyes include species of *Cretoxyrhinidae*, *Squalicorax*, *Squatina*, and *Ischyrhiza* (Table 3; Wade, 1926; Collins, 1951; Russell, 1967; Whetstone, 1977; Gibson and Dunagan, 2003a). Osteichthyes identified by bone material, teeth, and otoliths include species of *Enchodus*, *Saurodon*, *Anomaedus* (Nolf and Stringer, 1996; Stringer, 2001; Brister and Young, 2007), *Albula*, *Apogon*, *Pempheris*, and unidentified genera of the families Ariidae, Chlorophthalmidae, Trachichthyidae, and Colocongridae (Table 3; Stringer, 2003). Marine reptiles include the sea turtle *Toxochelys* (Collins, 1951), the mosasaurs *Plioplatecarpus*, *Mosasaurus*, and *Prognathodon*, and one plesiosaur, *Plesiosauria* (Whetstone, 1977; Gibson and Dunagan, 2003a).

Table 3. Vertebrate genera present in the Coon Creek type section. Status shows whether the family or genus is extinct (x) or still living today (Extant). Dash represents unidentified genus.

Superclass Osteichthyes (Boney fishes)				
Family	Family Status	Genus	Genus Status	Common name
Albulidae	Extant	<i>Albula</i>	Extant	Bonefish
Apogonidae	Extant	<i>Apogon</i>	Extant	Cardinalfish
Ariidae	Extant	unknown	--	Sea Catfish
Chlorophthalmidae	Extant	unknown	--	Greeneyes
Colocongridae	Extant	unknown	--	Conger eel
Pempheridae	Extant	<i>Pempheris</i>	Extant	Sweepers

Trachichthyidae	Extant	unknown	--	Roughies
Class Chondrichthyes (Cartilagenous fishes)				
Family	Family Status	Genus	Genus Status	Common name
Cretoxyrhinidae	x	--	--	Ginsu shark
Anacoracidae	x	<i>Squalicorax</i>	x	Crow shark
Squatinae	Extant	<i>Squatina</i>	x	Angel shark
Sclerorhynchidae	x	<i>Ischyrhiza</i>	x	Sawfish

Micro- and nanofossils preserved at the site include foraminiferans (Table 4; Berry and Kelly, 1929; Cushman, 1931; Moore, 1974; Frederick, 2003), ostracodes (Granata, 1960), calcareous plankton (pers. comm., C. Smith, 2007), and palynomorphs and spores (Tschudy, 1975; Wolfe, 1976). Preserved fossil flora includes lignitic plant fragments and leaves (Berry, 1925). Lignitic plant fragments and fruit that have been found at the type section include pieces of palm fronds of the genus *Geonomites* (Berry, 1925) and a specimen of fruit with seed identified as the Nipa palm genus *Carpolithus* (Berry, 1925).

Table 4. Foraminiferans present in the Coon Creek type section. Status shows whether the genus is extinct (x) or still living today (Extant).

Planktonic Foraminifera		
Family	Genus	Status
Candeinidae	<i>Pseudoguembelina</i>	x
Rugoglobigerinidae	<i>Archaeoglobigerina</i>	x
Benthic Foraminifera		
Family	Genus	Status
Anomalinidae	<i>Anomalina</i>	Extant
Bolivinitidae	<i>Bolivina</i>	Extant
Cibicididae	<i>Cibicides</i>	Extant
Miliolidae	<i>Quinqueloculina</i>	Extant
	<i>Triloculina</i>	Extant
Nodosariidae	<i>Nodosaria</i>	Extant
	<i>Fronicularia</i>	Extant
	<i>Lagena</i>	Extant
	<i>Lenticulina</i>	Extant
Nubeculariidae	<i>Spiroloculina</i>	Extant
Polymorphinidae	<i>Pyrulina</i>	Extant
Valvulinidae	<i>Gaudryina</i>	Extant
	<i>Tritaxia</i>	x

3. Materials and Methods

Although some of the CCTS fossil taxa are extinct, a large percentage is also extant, with many of the same fauna living in the western tropical Atlantic waters today. Tropical coastal waters of southern Florida, the Caribbean, Bahamas, northern South America, and eastern Central America are inhabited by faunal assemblages similar to those that would have inhabited the tropical Cretaceous Gulf of Mexico. Because so many of the fossil genera are extant, a unique opportunity exists to use biogeographic and habitat data of extant fauna to help identify a modern analog environment to the CCTS's lagerstätte paleoenvironment. To perform this modern analog analysis, habitat and biogeographic data of 426 extant species of CCTS genera were compiled in databases and analyzed in a GIS.

3.1 Paleontology and Biology Databases

To identify extant species of genera present at the CCTS, faunal databases with taxonomic breakdown were constructed that include both fossil and modern genera. Databases were compiled using multiple paleontological and biological resources, including the following: Wade's volume on the Coon Creek (Wade, 1926); museum specimen information from the Memphis Pink Palace Museum (owner of the type section property; Brister and Young, 2007); paleontology and biology publications; and online taxonomic databases. Electronic databases used include: the Paleobiology Database (PaleoDB) (2008); the Integrated Taxonomic Information System (ITIS) (2008); Global Biodiversity Information Facility (GBIF) (2008); the National Benthic Inventory (National Oceanic and Atmospheric Administration, 2008); and Malacolog Version 4.1.0 (Rosenberg, 2005). These electronic databases are compiled and maintained by universities and paleontological and biological researchers (Rosenberg, 2005; GBIF, 2008; ITIS, 2008; NOAA, 2008; PaleoDB, 2008), and are the main databases used by

many natural history museums and scientific collections to retrieve current taxonomic nomenclature in the scientific community (pers. comms., R. Brister, 2007; M. Bemis, 2008; M. Uhen, 2008).

The bulk of the paleofaunal list was obtained from Wade's USGS publication, which, although published in 1926, remains the most comprehensive overview of the fossil fauna at the type locality (Gibson and Dunagan, 2003b). Because many taxonomic revisions and reclassifications have been made since 1926, additional resources were reviewed to update this original 1926 faunal list. Gastropod taxonomy was based mainly on Sohl's (1960, 1964) revisions, and names were compared with modern taxonomic nomenclature from the aforementioned online biological databases and references. Bivalve revisions were based on comparisons of Wade's photographs and morphological descriptions to those given in the *Treatise on Invertebrate Paleontology* (Cox et al., 1969; Stenzel, 1971), Abbott's (1974) volume on American seashells, and PaleoDB (2008). Additions and revisions to nonmolluscan fauna included decapod identifications from Bishop (1991, 2003), fish families and genera identified from otoliths and teeth (Nolf and Stringer, 1996; Stringer, 2001; Brister and Young, 2007), shark genera (Collins, 1951; Russell, 1967; Whetstone, 1977; Gibson and Dunagan, 2003a), and confirmed foraminifera (Moore, 1974; Frederick, 2003).

After taxonomic revisions, each genus in the CCTS faunal list was queried in the previously mentioned biological databases, and searched for through comprehensive literature (Smith, 1937; Abbott, 1974; Meinkoth, 1981a) to identify extant genera. Once extant genera were identified, habitat information was compiled for multiple species of each extant genus. For each species, biogeographic information corresponding to water depth, latitude, and longitude ranges at which the species were found living, were recorded.

3.2 Biogeographic analysis

Biogeographic range information (bathymetric and geographic) was compiled for extant species and genera: 77 molluscan genera (426 species); 42 osteichthyan genera (42 species); 3 decapod genera (13 species); and 12 foraminiferan genera (Table 4; Fig. 2). Detailed biogeographical data for taxonomic groups higher than genus were not collected, as the taxa are too broad-ranging, and incorporate fundamental niches of multiple genera not necessarily related to the fossil genera. As Kauffman (1973) and others (Stehli et al., 1967; Ekman, 1967; Hallam, 1969) have noted, genus is the base-level taxon most commonly and successfully applied in paleobiogeographical and modern biogeographical analyses.

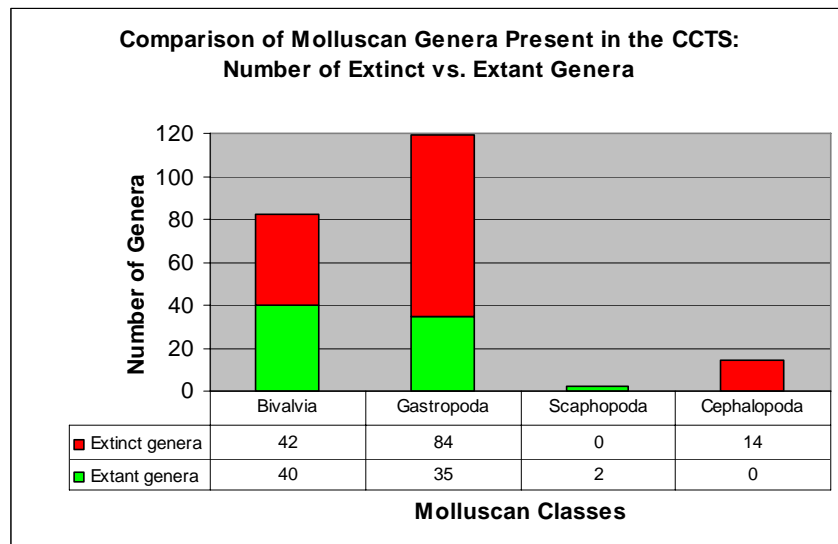


Fig. 2. Distribution of molluscan classes at the CCTS and their status as extinct or extant.

Biogeographical data collected were compiled in databases and analyzed in the GIS software ArcGIS 9.2. Bathymetric data used in the analysis were 1 arc-minute grid data downloaded from the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) grid translator (Amante and Eakins, 2008). Bathymetric data were subset to the species' geographic, creating a bathymetric range raster for each species. For

most species, geographical ranges were described as northern and southern latitude and western and eastern longitude in the biological databases. However, for some species, geographic coordinates were not available within the consulted databases and publications, but location information identified land masses around which the species were reported inhabiting. For these species, geographical ranges were based on the Marine Ecoregions Of the World (MEOW) polygons (Spalding et al., 2007) to which the geographical areas corresponded, and these areas were used as a mask to subset the corresponding bathymetric ranges. The resultant rasters were biogeographical ranges representing fundamental niche habitat for species. After range rasters were created for each species, species rasters of the same genus were mosaicked to create a biogeographical range raster for the corresponding genus (Fig. 3). For each genus range raster, pixel values were changed to 1 to denote presence of that genus within that pixel location. Genus range rasters were then summed using the raster calculator in Spatial Analyst tools of ArcMap to create a faunal assemblage raster with each pixel value equal to the number of genera whose biogeographical ranges fell within that pixel (Fig. 4). The faunal assemblage raster was displayed using a color scheme based on percentage of genera out of the total number of modern genera (Fig. 5). Geographic areas with the highest pixel values are areas identified as having a modern faunal assemblage similar to that of the fossil faunal assemblage as the CCTS.

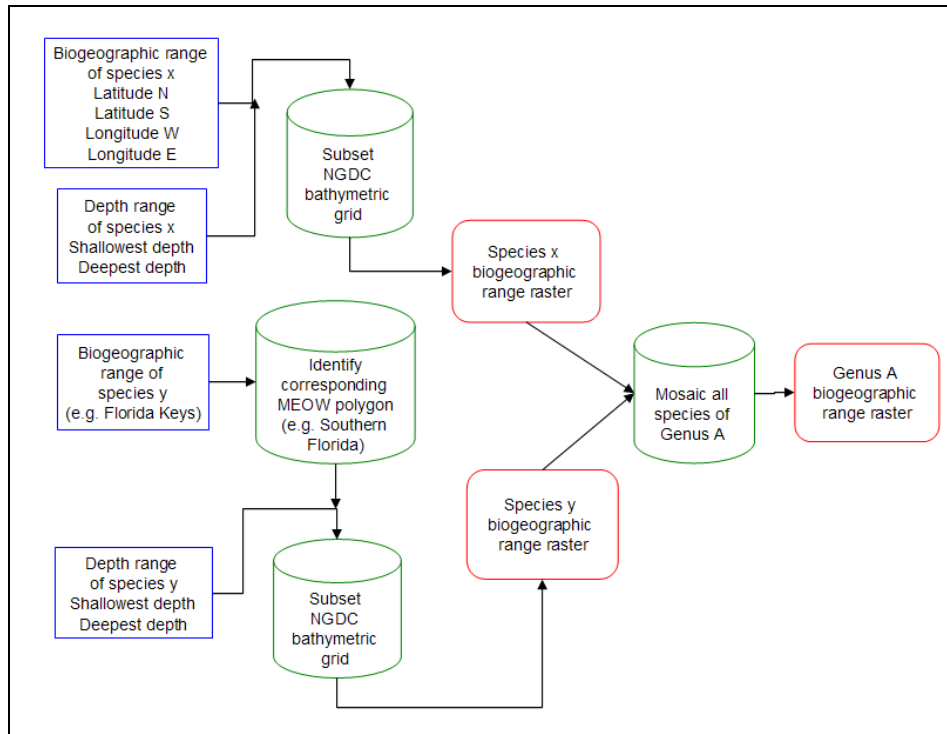


Fig. 3. Flow chart illustrating biogeographical modeling compiling species ranges to produce a biogeographic genus raster.

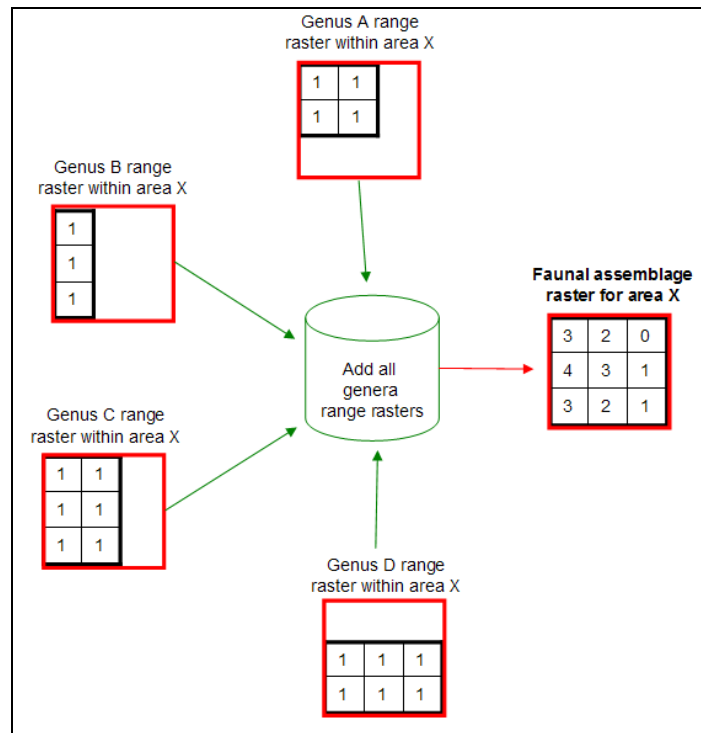


Fig. 4. Flow chart illustrating summation of biogeographical genus rasters to produce a faunal assemblage raster.

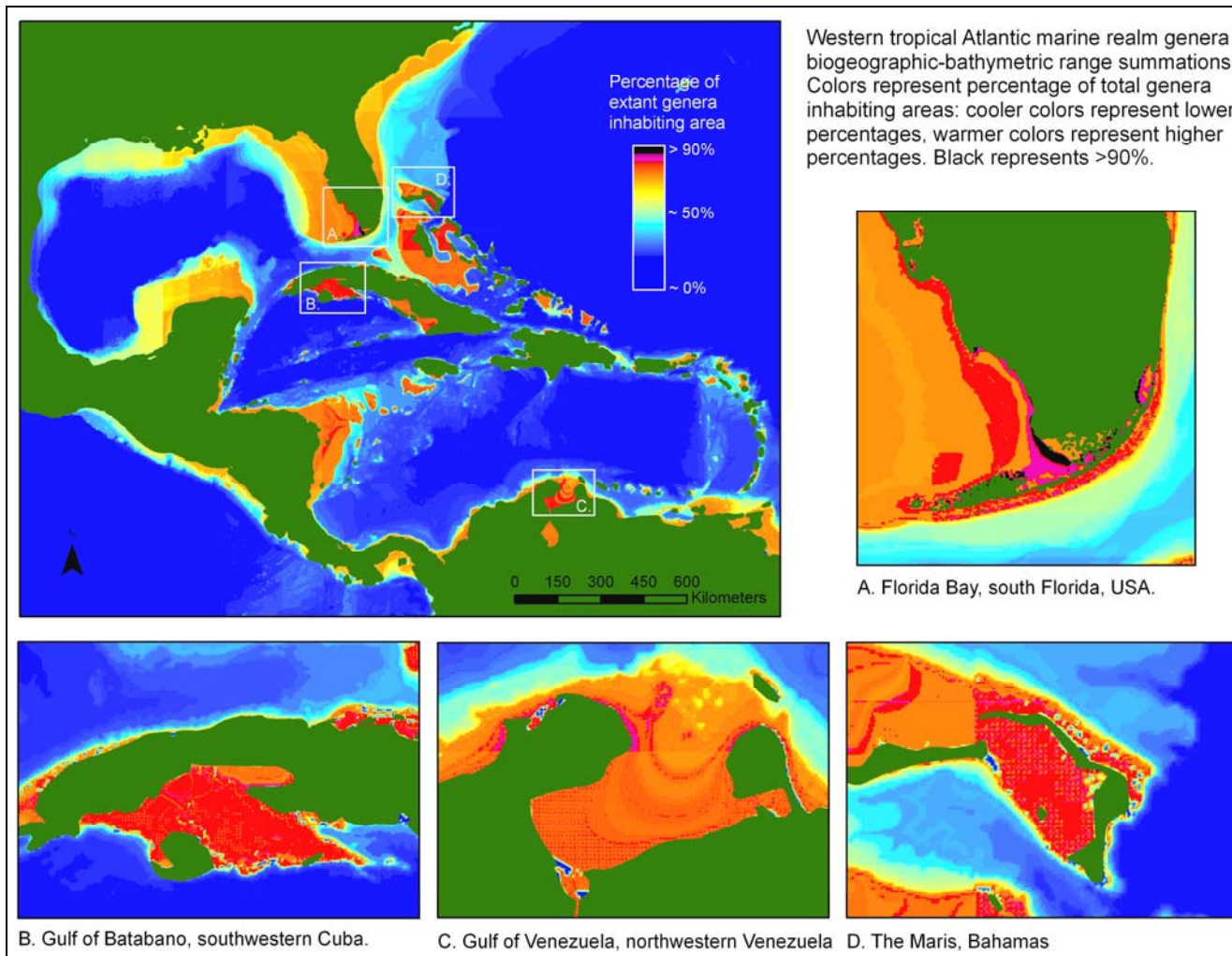


Fig. 5. The four areas identified in the biogeographic geospatial analysis identifying potential modern analog environments. Each of these areas have 80% of the extant genera inhabiting their waters. Florida Bay and Keys area (A) has the highest percentage (98%) of the extant genera, an average depth of 3 m, normal marine salinity, and substrate similar to that of the CCTS matrix.

3.3 Abiotic environmental characteristics

Although this research focuses mainly on the biological component of the environmental analysis, the abiotic component can also help extend environmental analysis. Sediment and sedimentary structures of the matrix can be paleoenvironmental indicators of physical and chemical characteristics of the ancient substrate (Boggs, 1993). To incorporate this abiotic component into the analog environment analysis, sediment samples were collected from the CCTS and analyzed for ancient benthic habitat assessment. The type section was measured and sediment samples collected from the lower 3 m of the type section. Sediment samples were dried in an oven, weighed, and wet-sieved using sieve sizes differentiating very fine (0.10-0.05 mm), fine (0.25-0.10 mm), medium (0.5-0.25 mm), coarse (1.0-0.5 mm), and larger (>1.0 mm). Dried sieved samples were weighed and grain-size distribution for each sample was calculated. Samples were also analyzed for clay percentage using a texture dispersing reagent and cylinder separation method.

For comparison to the ancient substrate, modern substrate data were also collected. Substrate data of western Atlantic coastal areas were obtained from the National Geophysical Data Center (NGDC) Marine Geology Data Seafloor Sediment Grain Size Database (NGDC, 2008a) and from NGDC Seafloor Surficial Sediment Descriptions Deck41 database (NGDC, 2008b). Grain size and surficial sediment data plotted in ArcMap for comparison to biogeographical results.

Additional abiotic data gathered for further environmental characterization include sea surface temperature (SST), sea surface velocity (SSV), and salinity. SST and SSV data were acquired from the Cooperative Institute for Marine and Atmospheric Studies (CIMAS). CIMAS include compiled data for SST from Advanced Very-High Resolution Radiometer data (Kearns

et al., 2000; Kilpatrick et al., 2001), and SSV data from the U.S. Coast Guard's Mariano Global Surface Velocity Analysis ship-drift data (Mariano et al., 1995) and buoy drifts (Hansen and Poulain, 1996). Salinity data were obtained through NOAA's National Oceanographic Data Center from the World Ocean Atlas 2005 (NODC, 2005). In addition to the NOAA bathymetric grid data, additional bathymetric and salinity maps were also consulted for comparison to geospatial analyses (Zeigler, 1964; McPherson et al., 1995; Brewster-Wingard and Ishman, 1999; Armenteros et al., 2008).

4. Results

4.1 Extant Genera

Of the rich biodiversity at the CCTS, a relatively high percentage of the fossil genera have extant counterparts in today's oceans. For class Bivalvia, approximately 50% of the fossil genera and 88% of the families are extant (Fig. 2). Approximately 30% of the fossil genera and 82% of the fossil families in class Gastropoda are extant (Fig. 2). Of the scaphopods, both fossil genera, *Cadulus* and *Dentalium*, are extant. Of the 77 extant mollusks, all but 4 bivalve genera (*Arctica*, *Clavagella*, *Crassatella*, and *Cucullaea*) and 2 gastropod genera (*Acirsa* and *Aporrhais*) inhabit the tropical Western Atlantic. The genera not inhabiting the tropical Atlantic include two genera living at high latitudes of the Atlantic and Pacific (*Arctica* and *Acirsa*) and four genera inhabiting the Pacific only (*Clavagella*, *Crassatella*, *Cucullaea*, and *Aporrhais*). For bivalves, all but *Cucullaea* have been found inhabiting waters as shallow as 6 m or less in depth (Fig. 6). Extant gastropod genera inhabit a much wider bathymetric range, but all but two genera inhabit waters as shallow as 6 m or less (Fig. 7). None of the molluscan genera for which data were collected have ecological niches restricted to depths greater than 10 m, supporting an

interpretation that the CCTS environment would have been a very shallow marine environment, with data suggesting a depth shallower than 10 m.

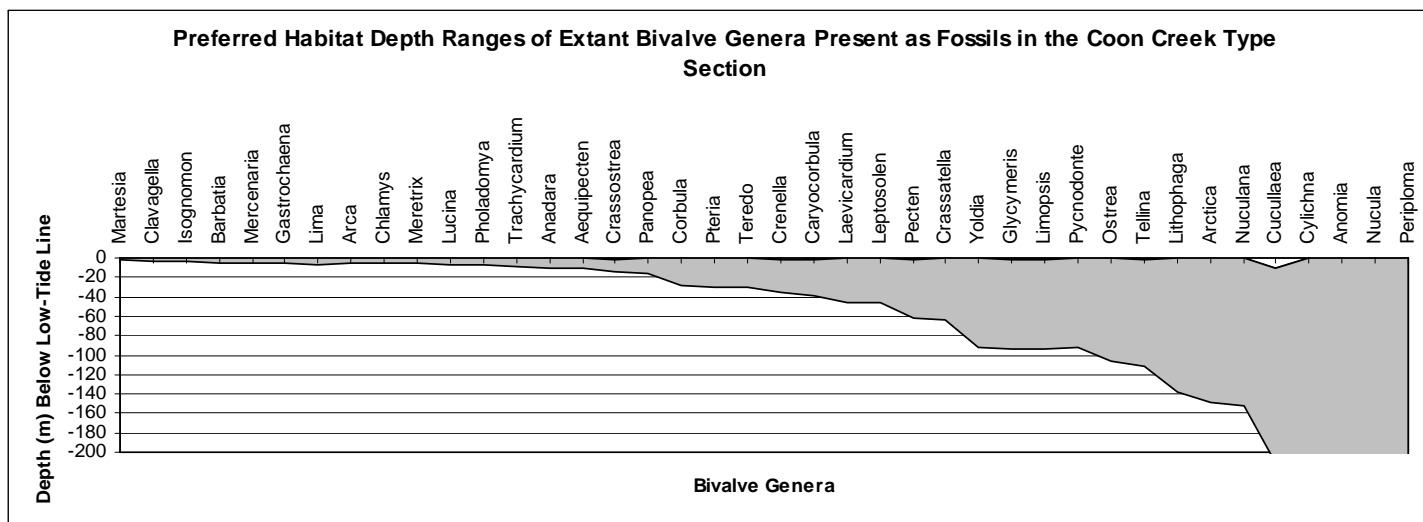


Fig. 6. Average realized niche depth ranges of extant bivalve genera for which depth ranges could be found in publications.

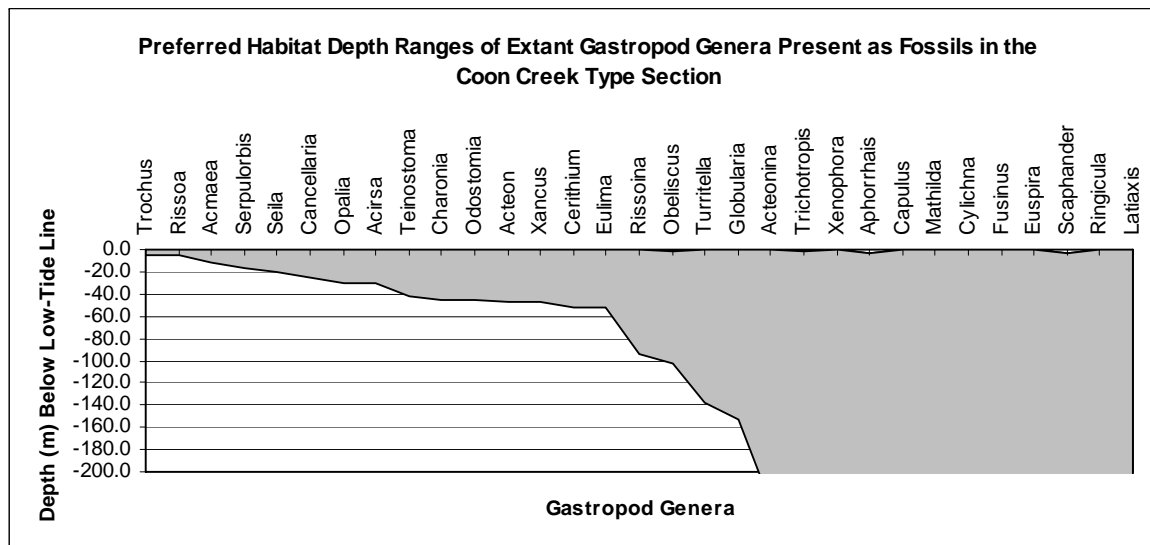


Fig. 7. Average realized niche depth ranges of extant gastropod genera for which depth ranges could be found in publications.

Of the remaining non-molluscan macrofauna, extant genera include the following: the sea urchin *Hemiaster*; the lobster *Linuparus*; the shrimp *Penaeus* and *Callinassa*; the annelid *Serpula*; and the fish *Albula*, *Apogon*, and *Pempheris* (Table 3). Modern species of *Hemiaster* inhabit a wide bathymetric range from very shallow coastal waters to deep waters in the Pacific; modern *Linuparus* inhabit deep marine waters of the Pacific and Atlantic (Holthuis, 1991); both modern shrimp genera *Penaeus* and *Callinassa* inhabit very shallow waters from high-tide to just below the low-tide line in the tropical Western Atlantic (Meinkoth, 1981b); and *Serpula* are found in waters up to 100 m deep globally (Meinkoth, 1981b). Extant species of the fish genera include a wide range of water depths in the Atlantic (Smith, 1997; Gilbert and Williams, 2002), although the *Albula* of the Atlantic are restricted to shallow waters less than 5 m deep (Smith, 1997). Of the 15 CCTS foraminiferan genera confirmed by Moore (1974) and Frederick (2003), 12 are extant (Table 4). Bathymetric ranges were not available in the surveyed literature for extant foraminiferan genera; however, many sources indicated overall shallow (10 m or less) and nearshore environments for all genera (Javaux and Scott, 2003; Murray, 2007).

4.2 Modern Analog Environments

The final summation raster (total overlapping biogeographic and bathymetric ranges of all extant genera) showed four areas in the tropical Atlantic marine realm with more than 80% genera density (areas in which the biogeographical-bathymetric ranges of more than 80% of all extant tropical Atlantic genera overlapped) (Fig. 5). These areas include: western Florida Bay to the Florida Keys, USA; the southern portion of the Gulf of Batabano, Cuba; the northern part of the Gulf of Venezuela, northwestern Venezuela; and The Maris area west of the Great Abaco Island, Bahamas (Fig. 5). The four areas identified in the biogeographic analyses also share many environmental characteristics including similar sea-surface temperatures (SST), salinities,

energy levels, and substrate (Table 5). All areas are very shallow (5 m or shallower), are nearshore, have normal marine salinities, and tropical sea-surface temperatures. Most of the higher percentage areas, including the four areas identified above, are also lower energy with recorded small ship and buoy drift (Hansen and Poulain, 1996), which supports Cretaceous paleocurrent and wind stress modeling (Cousin-Rittenmard et al., 2002).

Table 5. Abiotic characteristics of locations identified in the biogeographic analysis as potential modern analog environments to the CCTS.

Location	Percent Extant Genera Present	Average Depth (m)	Substrate	Average Salinity (ppt)	Average Annual SST (C) Range
Western edge of Floriday Bay, USA	98	3	Silty sand	36	25-30
Gulf of Batabano, southwestern Cuba	95	3	Silty sand	35	26-30
Gulf of Venezuela, northern Venezuela	92	6	Silty sand	35	25-30
The Maris (ocean west of Abaco, Bahamas)	81	2	Calcareous sand/mud	37	26-30

Of the four areas identified in the faunal assemblage raster, the area between the western edge of Florida Bay to the Keys has the highest percentage of extant CCTS genera. According to benthic ecological data, 98% of the modern tropical Atlantic molluscan genera live within the Florida region identified in the GIS analysis. Only the bivalve *Pholadomya* is not present in this region, although this genus was considered extinct until the discovery of a single living specimen off the Columbian coast in 2008 (pers. comm., J. Diaz, 2008). Also present in the Florida Keys and western Florida Bay are the nonmolluscan CCTS genera *Penaeus*, *Callianassa*, *Serpula*, *Albula*, *Apogon*, and *Pempheris*. Extant CCTS foraminiferan genera inhabiting southern Florida areas include *Gaudryina*, *Spiroloculina*, *Quinqueloculina*, *Triloculina*, *Lenticulina*, *Bolivina*, and *Cibicides*.

NGDC sediment data also show the substrate to be composed of a silty sand and mud, similar in grain-size distribution to that of the CCTS sediment. The CCTS grain-size distribution of the lowermost 3 m (the lagerstätte biofacies) averages the following: <1% coarse-grain sand, 11% medium-grain sand; 28% fine-grain sand; 33% very fine-grain sand; and 27% silt and clay (Pryor (1961) estimated ~10% clay). For the areas of Florida Bay and Keys, seafloor surface sediment (substrate) is typically defined as greater than 60% sand, 20% silt, and 15% clay, highly organic or muddy substrate (National Geophysical Data Center, 2008a and b).

5. Conclusions

5.1 Technology and Paleoecology

The methodology used in this research is an example of how advances in GIS and biological and paleontological databases can be applied to paleoecological analysis. Online access to biological, paleontological, and oceanic databases allow the global scientific community to share, agree on, maintain, and update data and classifications on a much larger scale than would be possible in publications alone. With continued data entries, more efficient and encompassing methods for geographically and taxonomically large investigations are possible. Integration of biogeographical, biological, and paleontological data will allow researchers to address and solve larger and more complex problems and spatio-temporal trends in the fields of paleontology, paleoecology, biogeography, and evolutionary biology that were in the past impossible or unattainable, given resource and data limitations. This research is just one example of how expanding, global databases can be applied in paleoecology and paleoenvironmental reconstruction.

5.2 Modern Analog Environment to and Interpreted Marine Habitat of the CCTS

Many of the fossil molluscan genera at the CCTS have extant counterparts in today's oceans, including the following: 50% of the bivalve genera; 30% of the gastropod genera; and both scaphodpod genera (Fig. 2). Of the 77 extant mollusks, all but 4 bivalve genera and 2 gastropod genera inhabit the tropical Western Atlantic region. For bivalves, all but one genus inhabit water 6 m or shallower (Fig. 6); for gastropods, all but two genera inhabit water 6 m or shallower (Fig. 7). None of the 77 extant molluscan genera have ecological niches restricted to depths greater than 10 m, and all but one of the non-molluscan extant fauna inhabit shallow settings as well.

Four areas in the tropical Atlantic marine realm were identified as having more than 80% of the CCTS extant genera inhabiting their waters today: western Florida Bay to the Florida Keys, USA; the southern portion of the Gulf of Batabano, Cuba; the northern part of the Gulf of Venezuela, northwestern Venezuela; and The Maris area west of the Great Abaco Island, Bahamas (Fig. 5). Of the four areas, the Florida environment contains 98% of the CCTS extant genera inhabiting the tropical Western Atlantic today and similar substrate to that of the Coon Creek sediment, suggesting the Florida Bay and Keys area to be a good modern analog environment to that of the type section.

Based on modern ecosystem descriptors from the national and Floridian marine and estuarine classification system (Allee et al., 2000; Madley et al., 2002), the corresponding Florida (and CCTS) habitat is a: marine; continental; subtidal; photic; shallow (likely 10 m or less); protected; tropical; soft bottom; sand substratum; normal marine salinity; normal marine alkalinity environment. Although some previous research suggested the CCTS to be an estuary environment, estuarine environments are defined as having lower salinities from influx of fresh

water (Cowardin et al., 1979). Ecological niche data of the extant genera assemblage do not support an interpretation of estuarine habitat, but instead indicate normal marine salinity. The type section paleoenvironment likely represents a back-bar environment, but not likely an enclosed lagoonal or estuarine environment.

Evidence of barrier bars can be seen as large lenses of McNairy Sand lithology within the Coon Creek Formation in McNairy County (as described by Russell and Parks, 1975) west of the Coon Creek type section. Other bar deposits can be found stretching from McNairy County northward to Henry County (Russell and Parks, 1975), suggesting a barrier bar complex or keys stretching along strike of the McNairy Sand outcrop belt in western Tennessee. This supports the conclusion that the Coon Creek type section represents a back-bar environment. To the west of the barrier bar complex in the subsurface, Coon Creek lithology with well-preserved shells is also present (as seen in the Hardeman County well cutting #1280 at 72 m depth) and likely represents a nearshore molluscan rich clastic shelf on the seaward of the barrier bar complex. The Florida Keys area also contains molluscan rich sands on the seaward side of the keys as well (Fig. 5). The fossiliferous lower Coon Creek lithofacies represents part of the shallow clastic molluscan rich environment of back bar (seen at the Coon Creek type section) and the nearshore sea-side of the barrier bar (seen in well cuttings of fossiliferous Coon Creek lithology west of the McNairy Sand outcrop belt) and depicted in Fig. 8.

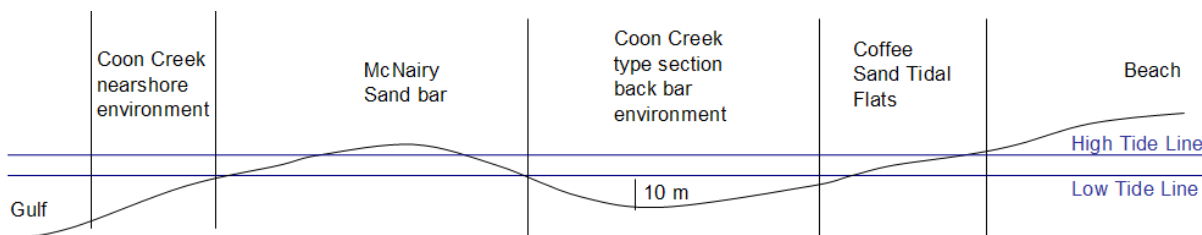


Fig. 8. A west-to-east cross section depicted the interpreted environment for the lower Coon Creek facies and Coon Creek type section environments.

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This last paper combines the data, correlations, and interpretations from the previous two papers, to allow a completed interpretation of the paleoenvironments within the northern Mississippi Embayment late Campanian gulf. Each uppermost Campanian lithofacies identified in the first paper is analyzed based on its lithology, sedimentary structures, and paleontology, and the paleoenvironmental interpretation from the second paper is combined with the paleoenvironmental interpretations of the other embayment lithofacies in this last paper. This final paper shows the spatial relationships between the different age-equivalent facies and their depositional environments, to help reconstruct the paleogeography of the late Campanian northern Mississippi Embayment area.

CHAPTER 4
PALEOGEOGRAPHY AND PALEOENVIRONMENTS OF THE LATEST CAMPANIAN
MISSISSIPPI EMBAYMENT GULF

Abstract

The Late Cretaceous northern Mississippi Embayment and its Upper Cretaceous facies have been interpreted as many different environments. Most previous reconstructions of the paleogeography illustrate a generalized gulf between Mississippi and Arkansas stretching from southeastern Arkansas into southern Illinois. The most detailed paleoenvironmental reconstruction was published by Pryor in 1960, showing a large river delta covering the entire northern embayment from southern Illinois to west-central Alabama. Pryor and others have cited metamorphic minerals present in the Cretaceous clastic deposits to be evidence of drainage from the Appalachian Mountains into a large river flowing into the northern embayment. Lack of age constraints, paucity of detailed geologic maps and subsurface data, and misunderstanding of the basin geometry led to inaccurate interpretations of the paleogeography in previous publications. With biostratigraphic and geologic data for surface and subsurface lithofacies, a more detailed interpretation can be made. This paper analyzes the uppermost Campanian lithofacies in the outcrop belt and subsurface, and interprets the different paleoenvironments around the northern Mississippi Embayment: molluscan-rich clastic shelf; carbonate shelf; estuaries and tidal flats; depression marshes and lakes; and volcanoes with clastic and carbonate rims. Basin geometry is controlled by the underlying Reelfoot Rift that was active during the Mesozoic. Instead of an

Appalachian source, sediment supply of heavy minerals is most likely the Paleozoic sedimentary rocks in the region that also contain the same metamorphic mineral grains.

1. Introduction

During the Late Cretaceous, most of the southern United States was covered by a shallow sea, with waters flooding a structural trough created from a failed rift that stretched from Louisiana northward into southern Illinois. This basin, called the Mississippi Embayment, is now filled with Late Cretaceous deposits. Previous publications have generalized the paleogeography of the embayment, but have fallen short in defining paleoenvironments within the embayment for a specific time period.

Previous paleomaps have shown multiple interpretations and estimations (Williams and Stelck, 1975; Cobban and Kennedy, 1994; Schwimmer, 2002; Scotese, 2003) of the coastline of the Late Cretaceous embayment, but these maps were produced on the continental scale, and focused on generalized lithostratigraphy without consideration of paleoenvironments within the embayment. The most detailed paleogeographic map of the embayment was illustrated by Pryor (1960) who proposed that a large delta covered the entire northern embayment from Illinois to the northern third of Alabama's Gulf Coastal Plain – twice the size of today's Mississippi River delta. Pryor's (1960) interpretation of a large river system draining the Appalachian Mountains was based the presence of heavy minerals in the Cretaceous clastic deposits, the east-to-west lens-shaped cross-sectional geometry of the basin, and cross-bedding in the McNairy Sand Formation.

Following Pryor's (1960) work, research was published that showed greater lithologic diversity within the northern embayment than what had previously been described. Significant publications included the mapping of the Cretaceous formations in western Tennessee (Russell and Parks, 1975), the naming of a new Cretaceous formation in southern Illinois (Harrison et al.,

1996), the palynostratigraphic analysis of multiple clastic units around the embayment (Tschudy, 1965a, 1965b, 1967, 1970a, 1970b, 1973a, 1973b, 1975; Wolfe, 1976), and the identification of the Reelfoot Rift underlying the embayment (Ervin and McGinnis, 1975). These publications provided vital information that allows stratigraphic correlation within the northern embayment and a more accurate interpretation of the depositional environments.

This paper builds on the integration of biostratigraphic, structural, and subsurface data of the northern embayment to complete a correlation of the uppermost Campanian lithofacies and interprets and maps paleoenvironments to create a paleomap of the northern Mississippi Embayment during the latest Campanian. The significance of this research includes: identification of an age-equivalent surface (or limited age-constrained zone) that could be applicable to tectonic investigations into vertical uplift and subsidence within the northern embayment; identification of sediment sources of Cretaceous embayment clastic deposits; and a paleomap of the embayment with age-equivalent depositional environments interpreted from paleontologic and surface and subsurface lithologic data. The latest Campanian was chosen specifically because one of the most significant paleontological sites in the United States (Bristler and Young, 2007) is an upper Campanian lagerstätte whose type section lies in the northern embayment, and whose paleoenvironment has remained a question. Because Coon Creek is a part of the embayment, this research also helps fit the Coon Creek Formation type section into its proper position with relation to the other embayment facies.

2. Materials and Methods

2.1 Geologic Setting

The Mississippi Embayment lies within the central U.S. in the lower Mississippi Valley, and can be seen on a national geologic map as a northward-pointing loop in the Cretaceous

outcrop belt (Fig. 1). The embayment is a series of downwarping Cretaceous and Tertiary strata with an axis striking from southern Illinois to Louisiana with a south-southwesterly dip. The Cretaceous deposits in the embayment overlie Ordovician, Devonian, and Mississippian sedimentary bedrock (Miller et al., 1966; Bicker, 1969; McDowell et al., 1981; Szabo et al., 1988; Haley et al., 1993; Middendorf, 2003; Kolata, 2005) and some Cretaceous igneous rock (Stearns, 1957; Dockery et al., 1997; Haley et al., 1993; Cox and Van Arsdale, 2002), and thicken to the south to over 1,000 m. The study area for this research encompasses the northern part of the embayment and includes northeastern Arkansas, southeastern Missouri, southern Illinois, western Kentucky, western Tennessee, northern Mississippi, and western Alabama (Fig. 1).

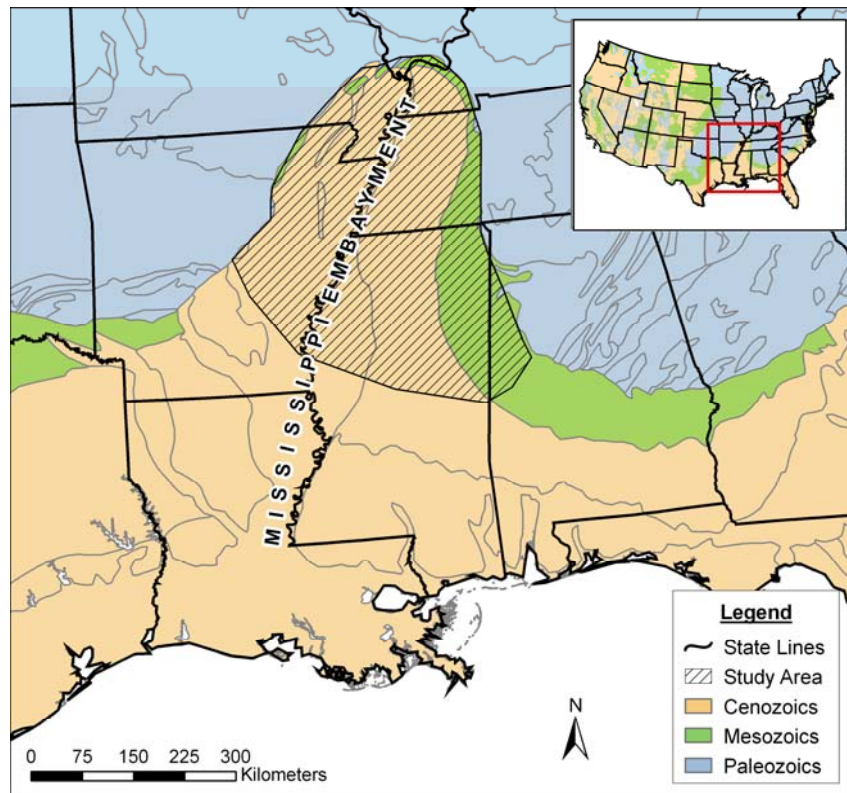


Fig.1. Geology of the study area and Gulf Coastal Plain. The study area includes the northern part of the Mississippi Embayment (diagonal lines) from western Alabama across to the Little Rock, Arkansas area and northward to southern Illinois. Mesozoics (green) shown in the Gulf Coastal Plain include Upper Cretaceous only.

The embayment first underwent extension in the late Precambrian as Laurentia pulled apart from Gondwana and was reactivated by rifting during the Mesozoic (Braile et al., 1986). During the Jurassic, the Mississippi Valley Graben underwent extension again (Hildenbrand, et al., 1982; Braile et al., 1986), and more faults, grabens, and igneous intrusions developed (Fig. 2; Hildenbrand et al., 1982; Cox and Van Arsdale, 2002). Igneous intrusions and faulting continued into the Cretaceous with further extension of the Reelfoot Rift. The crustal thinning, paired with a late Campanian eustatic sea-level high (Braile et al., 1986), allowed this area to flood with seawater from the Western Interior Seaway and northern Gulf of Mexico, forming the Mississippi Embayment. The Reelfoot Rift remains tectonically active today, with microseismic swarms delineating the Reelfoot Rift and New Madrid Seismic Zone (Fig. 2) (Cox and Van Arsdale, 2002).

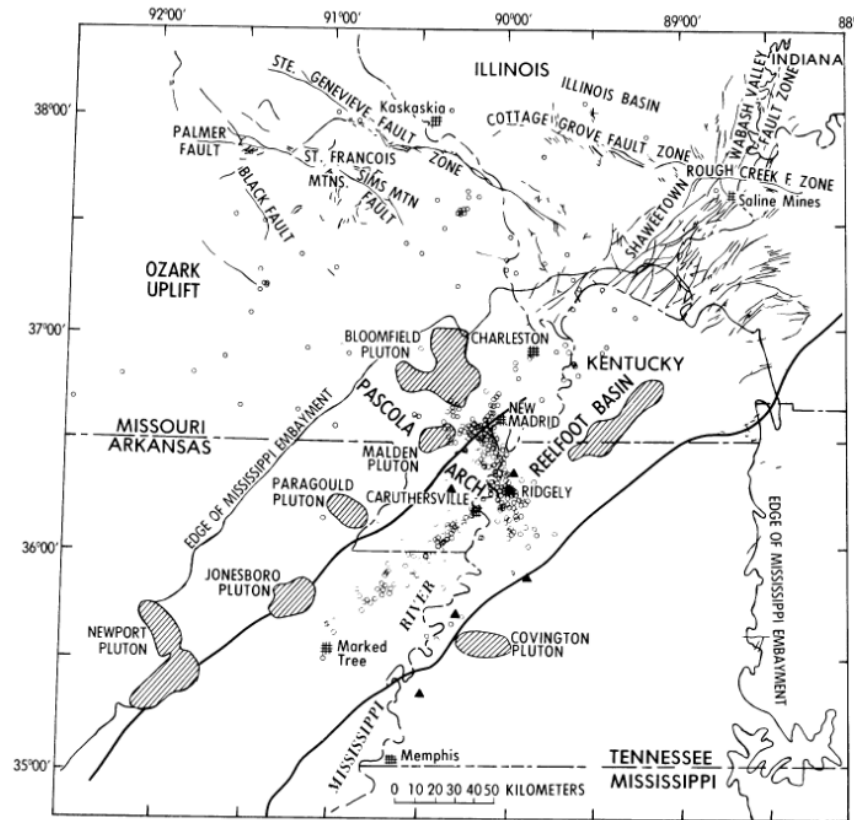


Fig. 2. The Reelfoot Rift within the Mississippi Embayment, from McKeown (1982). Small circles signs are epicenters of previous earthquake, with the highest point density areas delineating the New Madrid Seismic Zone. Gray areas are igneous intrusions.

Paleoclimate is considered to have been a global green house with a Cretaceous thermal maximum (Bice et al., 2002; Poulsen et al., 2003; Skelton, et al., 2003) that contributed to the high sea level. Some estimates of Late Cretaceous global temperatures suggest surface tropical sea temperatures may have been as much as 6 degrees Celcius higher than those of present day (Norris and Bice, 2002) and no polar ice (Skelton, et al., 2003), although many researchers now argue the formation of ice sheets during the Maastrichtian (Stoll and Schrag, 1996; Miller et al., 1999). Paleobotanical evidence found in Cretaceous strata also indicates that, although the majority of the polynomorphs suggest tropical paleoenvironments (Hower et al., 1990),

paleodendrochronologic evidence shows some seasonality (based on tree rings) existed in the northern embayment region (Creber and Chaloner, 1985).

3. Methodology

Northern Mississippi Embayment upper Campanian lithofacies that are age-equivalent to the lower Coon Creek were identified based on previous biostratigraphic correlations (see first paper of this dissertation). The previous biostratigraphic correlation is based on data from publications as well as analyzed samples from outcrops, cores, and well cuttings collected by the author. Location and depth of age-equivalent biostratigraphic points were plotted in the Geographic Information System (GIS) software ArcGIS 9.2. For areas with few biostratigraphic points, lithologic data for surface and subsurface were compiled from the author's field and core facility notes, publications, well logs, and geological survey data. Well logs used included those available through the United States Geological Survey (USGS) Geophysical Log Database for the Mississippi Embayment Regional Aquifer Study (MERAS; Hart and Clark, 2008), state geological surveys and core repositories, and publications (Moore and Brown, 1969; Fredericksen et al., 1982). Stratigraphy of wells and cores with biostratigraphic data were used with data from the other cores and well logs, to help correlate across the embayment, and estimate a depth to the uppermost Campanian surface.

Elevation of uppermost Campanian lithofacies for surface and subsurface points was recorded in the attribute table for all points, and data were interpolated to create a map showing estimated depth of the age-equivalent surface. Geomorphic corrections to the northwestern part of the embayment were made by filling elevation gaps in northeastern Arkansas and southeastern Missouri with respect to areas that had been uplifted and eroded during the Cenozoic. Geomorphic corrections include subtraction of 60 m from Crowley's Ridge (Fig 2; based on data

from Van Arsdale et al., 1995), and infilling of the previous Mississippi River valley on the western side of the Crowley's Ridge.

Paleontological information was gathered for the age-equivalent lithofacies from literature sources and museum and geological survey scientific collections. To account for taxonomic revisions, additional resources were used and included Bullock (1916), Sohl (1960; 1964), Cox et al. (1969), Stenzel (1971), Abbott (1974), and Kosnik (2002). Once fossil faunal lists were compiled for each lithofacies, the list was narrowed down to identify those faunas having extant genera, and habitat information of those genera was recorded. Sources of information for the extant genera include literature and electronic databases of compiled published data. Electronic databases used include: the Paleobiology Database (Kosnik, 2002); the Integrated Taxonomic Information System (2008); Global Biodiversity Information Facility (2008); the National Benthic Inventory (National Oceanic and Atmospheric Administration, 2008); and Malacolog Version 4.1.0 (Rosenberg, 2005). Literature sources used for modern faunal information include primarily Smith (1937), Abbott (1974), and Meinkoth (1981).

Lithology, sedimentary structures, and paleontology were combined to help interpret the paleoenvironments and bathymetry of each uppermost Campanian lithofacies. Corrected elevation for the northern embayment was compared with bathymetric habitat ranges of extant faunas and estimated paleobathymetric contours were produced. Shoreline was estimated based on interpreted paleoenvironments of facies in the outcrop belt and location of outcropping units. Correlated lithology (based on the surface and subsurface data) was combined with the paleobathymetry and shoreline to produce the final latest Campanian coastal geology map.

4. Results: Correlations and Lithologic Descriptions

4.1 Mississippi and Alabama

Based on biostratigraphy, the age-equivalent lithofacies to the lower Coon Creek include parts of the transitional clays between the lower Coon Creek Member of the Ripley Formation and upper Demopolis Chalk in northern Mississippi; the lower part of the Coon Creek Member in northern and west-central Mississippi; the lower part of the Ripley and the upper Bluffport Marl Member of the Demopolis Chalk in west Alabama (Fig. 3, Table 1). The Coon Creek lithofacies is mapped as a member of the Ripley Formation in Mississippi (Sohl, 1960), underlies the McNairy Sand Member of the Ripley, and has a gradational contact (transitional clays) with the underlying Demopolis Chalk (Stephenson and Monroe, 1940; Sohl, 1960; Puckett, 1995). The Coon Creek Member of the Ripley Formation in Mississippi is a dark gray to bluish gray, glauconitic, calcareous, silty sand or marl, and is locally fossiliferous (Sohl, 1960). The transitional clays of the upper Demopolis Chalk and lower Coon Creek are found in the southern part of the Cretaceous outcrop belt in Tennessee, and along the Cretaceous outcrop belt in northern Mississippi (Puckett, 1995; Mancini et al., 1996). The lithofacies includes fossiliferous silty and sandy calcareous clays (Puckett, 1995; Mancini et al., 1996). The Demopolis Chalk is a light gray or light brown chalk, clayey chalk, or marl (Raymond et al., 1988). In Mississippi and Alabama, the uppermost part of the Demopolis Chalk is the Bluffport Marl Member, a light gray sandy and calcareous silty, clayey chalk (Monroe, 1956; Raymond et al., 1988).

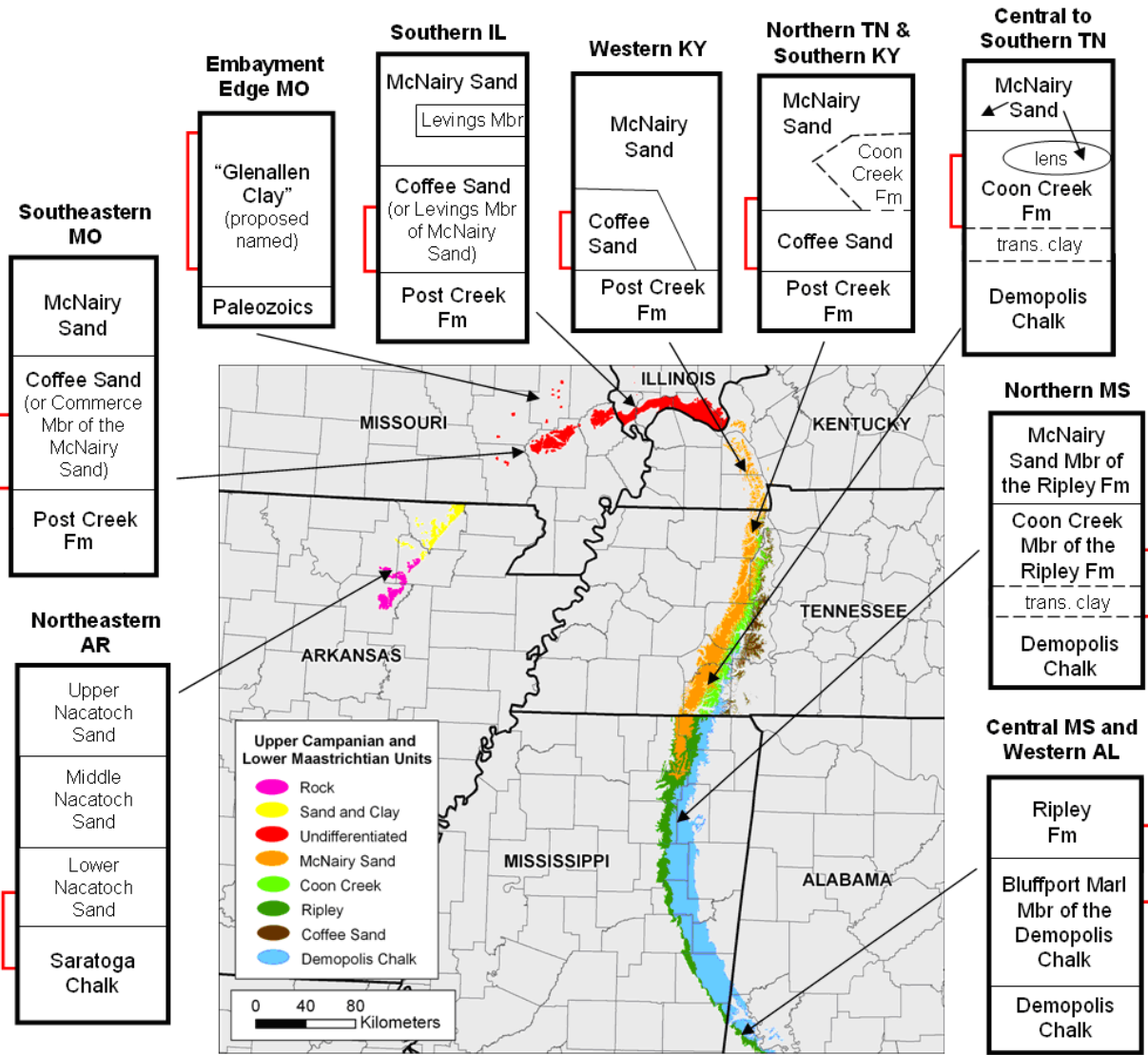


Fig. 3. The upper Campanian and lower Maastrichtian outcrop belt in the northern Mississippi Embayment study area. Formations on map appear as they are labeled on state geologic maps (Miller et al., 1966; Bicker, 1969; McDowell et al., 1981; Szabo et al., 1988; Haley et al., 1993; Middendorf et al., 2003; Kolata, 2005). Stratigraphic sections at this locality in the outcrop belt show the upper Campanian and lower Maastrichtian lithofacies in the area indicated with an arrow on the map. Red side bars on the stratigraphic sections indicate the lithofacies interpreted in this research to represent the uppermost Campanian lithofacies, age-equivalent to the lower Coon Creek lithofacies based on lithostratigraphy and biostratigraphic indicators. Thicknesses vary by location and stratigraphic sections shown here are not representative of thickness. See Table 3 for lithologic descriptions. Abbreviations: Fm = formation, Mbr = member, AL = Alabama, AR = Arkansas, IL = Illinois, KY = Kentucky, MO = Missouri, MS = Mississippi.

Table 1. Lithologic descriptions of the uppermost Campanian lithofacies (Coon Creek lower lithofacies age equivalent) in the northern Mississippi Embayment study area. Lithofacies are in alphabetical order by formation. Lithologic descriptions from Branner (1898), Counts et al. (1955), Sohl (1960), Plebuch and Hines (1969), Russell and Parks (1975), Raymond et al. (1988), Stinchcomb et al. (1994), Harrison et al. (1996), and Schrader and Scheiderer (2004).

Formation	Member	State	Lithology
Coffee Sand		MO, AR, IL, KY, northern TN	Lignite-rich, micaceous, silty and sandy gray clay with some pebbles, gray silty sand and clay. Referred to as the Levings Member of the lower McNairy Sand in Illinois and the lower Commerce Member of the McNairy Sand in Missouri.
Coon Creek	Lower lithofacies	TN	Dark gray to greenish gray calcareous, glauconitic, micaceous, fossiliferous, very fine-grained clayey silts and sands. Well-preserved shells.
Demopolis Chalk		Subsurface MS	Bluish gray to light gray, chalky, glauconitic, micaceous, marl. Locally fossiliferous, with some oyster reefs.
	Bluffport Marl	MS, AL	Dark gray to light gray calcareous, sandy/silty clay, chalky marl, and clayey chalk. Locally fossiliferous.
	Transitional clay	TN, MS	Silty, sandy, non-calcareous to calcareous, green-gray clay. Locally fossiliferous.
“Glenallen Clay” (proposed name)		MO	Dark blue-black plastic illite-smectite clay with very fine grained sand, lenses of red and yellow illite-smectite sandy clays. Blue clay contains terrestrial and aquatic vertebrate material. Basal clay has clasts of limestone and sandstone clasts.
McNairy Sand	Lower	TN	Light-gray, weathers to orange and red, fine grained silty and clayey, micaceous sand. Cross-bedded, lenticular, irregular bedding, sparsely glauconitic. Heavy minerals up to 3% by weight.
Nacatoch Sand	Lower	AR	Blue gray clay, sandy clay, marl, and clay rich sand. Locally fossiliferous.
Ripley	Coon Creek	MS	Grayish green glauconitic sand, clay, and sandy limestone. Locally fossiliferous.
		AL	Light gray to olive, micaceous, glauconitic, calcareous clay, fine sand, and thin bedded sandstone. Locally fossiliferous.
Saratoga Chalk		AR	Blue-gray fossiliferous sandy chalk with beds of marly chalk and chalky sand. Weathers to white to light brown.

Each of the uppermost Campanian lithofacies in Mississippi and western Alabama are fossiliferous, with fossil content varying by locality. Fossil lists for each of the lithofacies is well-documented with compiled faunal lists by lithofacies and locality in publications (Table 2; Stephenson, 1914, 1917; Stephenson and Monroe, 1940; Sohl, 1960, 1964; Sohl and Koch, 1983, 1987), and in museum and geological survey scientific collections. The majority of the fauna is molluscan, with a significantly higher number of genera in the Coon Creek Member than in the chalk units.

Table 2. Molluscan genera in the uppermost Campanian lithofacies in the Mississippian Embayment and range of water depth (shallowest to deepest) inhabited by the same modern

genera. Depth is in meters and table is arranged by increasing deepest habitat depth. An “x” denotes presence of this genus in corresponding lithofacies based on published data (Stephenson, 1914, 1917; Stephenson and Crider, 1916; Wade, 1926; Stephenson and Monroe, 1940; Sohl, 1960, 1964; Russell and Parks, 1975; Sohl and Koch, 1983, 1987; Brister and Young, 2007). Uppermost Demopolis Chalk includes the Bluffport Marl Member, as data show no faunal difference with respect to extant genera.

Class	Genus	Shallowest habitat depth (m)	Deepest habitat depth (m)	Lower Coon Creek Formation	Lower Nacatoch in NE Arkansas	Coon Creek Member of the Ripley	Upper Demopolis Chalk
Bivalvia	<i>Martesia</i>	0	-5	x			
Bivalvia	<i>Clavagella</i>	0	-10	x			
Bivalvia	<i>Isognomon</i>	0	-10	x			
Bivalvia	<i>Mercenaria</i>	0	-15	x			
Gastropod	<i>Trochus</i>	0	-15	x			
Bivalvia	<i>Barbatia</i>	-2	-15	x			
Gastropod	<i>Rissoa</i>	0	-17	x			
Bivalvia	<i>Arca</i>	0	-20	x			
Bivalvia	<i>Chlamys</i>	0	-20	x			
Bivalvia	<i>Gastrochaena</i>	0	-20	x			
Bivalvia	<i>Meretrix</i>	0	-20	x			
Bivalvia	<i>Lima</i>	-1	-20	x			
Bivalvia	<i>Lucina</i>	0	-21	x			
Bivalvia	<i>Pholadomya</i>	-9	-25	x			
Bivalvia	<i>Trachycardium</i>	-1	-30	x	x		
Bivalvia	<i>Aequipecten</i>	0	-36	x			
Bivalvia	<i>Anadara</i>	-1	-36	x			
Gastropod	<i>Acmaea</i>	0	-40	x			
Bivalvia	<i>Crassostrea</i>	-5	-40	x			
Bivalvia	<i>Panopea</i>	0	-50	x			
Gastropod	<i>Serpulorbis</i>	0	-56	x			
Bivalve	<i>Venericardia</i>	-54	-60		x		
Gastropod	<i>Epitonium</i>	0	-65				
Gastropod	<i>Seila</i>	0	-66	x		x	
Gastropod	<i>Cancellaria</i>	0	-82	x			
Bivalvia	<i>Plicatula</i>	0	-90				
Bivalvia	<i>Corbula</i>	-1	-90	x		x	
Gastropod	<i>Opalia</i>	0	-99	x			
Gastropod	<i>Acirsa</i>	0	-100	x			
Bivalvia	<i>Teredo</i>	0	-100	x		x	
Bivalvia	<i>Pteria</i>	-1	-100	x		x	
Bivalvia	<i>Crenella</i>	-6	-110	x		x	
Bivalvia	<i>Caryocorbula</i>	-3	-125	x			
Gastropod	<i>Teinostoma</i>	0	-138	x			
Gastropod	<i>Charonia</i>	0	-148	x			
Bivalvia	<i>Leptosolen</i>	0	-150	x	x	x	
Gastropod	<i>Odostomia</i>	0	-150	x			
Bivalvia	<i>Laevicardium</i>	-2	-150	x			
Gastropod	<i>Acteon</i>	-2	-152	x			

Gastropod	<i>Xancus</i>	0	-155	x			
Gastropod	<i>Cerithium</i>	0	-171	x			
Gastropod	<i>Eulima</i>	0	-171	x			
Bivalvia	<i>Pecten</i>	-3	-200	x		x	x
Bivalvia	<i>Crassatella</i>	-10	-210	x			
Bivalvia	<i>Pycnodonte</i>	0	-300	x		x	x
Bivalvia	<i>Yoldia</i>	-2	-300	x			
Bivalvia	<i>Glycymeris</i>	-5	-300	x	x		x
Bivalvia	<i>Limopsis</i>	-5	-300	x		x	
Bivalvia	<i>Cuspidaria</i>	-20	-300				
Gastropod	<i>Rissoina</i>	0	-310	x			
Gastropod	<i>Obeliscus</i>	-5	-330	x		x	
Bivalvia	<i>Ostrea</i>	0	-350	x		x	x
Bivalvia	<i>Tellina</i>	-6	-360	x			
Bivalvia	<i>Lithophaga</i>	0	-450	x			
Gastropod	<i>Turritella</i>	-2	-450	x	x	x	
Bivalvia	<i>Arctica</i>	0	-488	x			
Gastropod	<i>Globularia</i>	0	-500	x			
Bivalvia	<i>Nuculana</i>	-2	-500	x		x	
Gastropod	<i>Capulus</i>	0	-585				
Bivalvia	<i>Cucullaea</i>	-33	-660	x			
Gastropod	<i>Acteonina</i>	0	-745	x			
Gastropod	<i>Trichotropis</i>	-6	-990	x			
Gastropod	<i>Xenophora</i>	0	-1480	x			x
Gastropod	<i>Aphorrhais</i>	-10	-1800	x			
Bivalvia	<i>Anomia</i>	0	-1930	x	x	x	x
Gastropod	<i>Capulus</i>	0	-2171	x			
Bivalvia	<i>Nucula</i>	-2	-2500		x		x
Gastropod	<i>Mathilda</i>	0	-3861	x			
Bivalvia	<i>Periploma</i>	0	-4971	x			
Gastropod	<i>Cylichna</i>	-2	-6000	x			
Gastropod	<i>Fusinus</i>	-1	-6045	x			
Gastropod	<i>Euspira</i>	0	-8180	x			
Gastropod	<i>Scaphander</i>	-10	-8652	x			
Gastropod	<i>Ringicula</i>	0	-16000	x			
Gastropod	<i>Latiaxis</i>	-1	-16000	x			

4.2 Tennessee

The uppermost Campanian lithofacies in Tennessee are the lower Coon Creek, the Coffee Sand (in the very northern part of the outcrop belt), the lower McNairy Sand (where the lithofacies cuts into the Coon Creek), and the transitional clay of the upper part of the Demopolis Chalk (Fig. 3, Table 1). The lower Coon Creek is a calcareous silty and clayey fine sand, with the lowermost portion grading into a transitional clay of the underlying Demopolis Chalk

(Moore, 1974; Russell and Parks, 1975). The type section (Fig. 4) of the formation, in northern McNairy County, Tennessee, is the lower lithofacies only, and is considered a lagerstätte for its high biodiversity and excellent preservation (Wade, 1926; Gibson and Dunagan, 2003). Wade (1926) and Moore (1974) provided the most complete fossil fauna lists for the lower Coon Creek lithofacies, and many of the genera present in the Coon Creek are extant (Table 2). A full description of the taxa present at the type section is listed in the first paper of this dissertation.



Fig. 4. Fossils in clayey sand matrix at the Coon Creek type section, Coon Creek lower lithofacies.

The McNairy Sand is divided into an upper, middle, and lower member as described by Russell and Parks (1975), based on lithological differences reflecting different paleoenvironments. The lower McNairy Sand is described as sparsely glauconitic, light gray and orange fine-grained quartz sand with lenticular bedding, cross-bedding locally, and variable thickness from 15 to 24 m thick (Russell and Parks, 1975). This lowermost section of the McNairy appears as lenses of cross-bedded basal McNairy Sand lithology within the Coon Creek Formation in places in Tennessee. One outcrop exhibiting this lithology is near Martin Camp in McNairy County (Russell and Parks, 1975). Here, the sand deposit is a 3-meter thick, irregularly

bedded lens with cross-bedding, and is interpreted by Russell and Parks (1975) to be characteristic of barrier bar geometry. Other locations showing this basal lensatic cross-bedded McNairy sands include a roadcut 11.3 km northeast of Selmer in McNairy County, near Lexington in Chester County; near Camden in Benton County; near Purdy in McNairy County; and near Paris Landing in Henry County. The Coon Creek grades into the McNairy Sand in northern Henry County and Benton County until the lithology is no longer differentiated from the McNairy Sand (Blade, 1966; Russell and Parks, 1975). In northern Henry County and in western Kentucky, the basal McNairy Sand is replaced by the middle McNairy Sand (a conglomeratic and pebbly medium- to coarse-grained sand) that conformably overlies the Coffee Sand (Russell and Parks, 1975). With the exception of lignitic plant material and some leaves within the clay beds (Berry, 1925), the lower McNairy Sand does not contain fossil material in Tennessee (Blade, 1966; Russell and Parks, 1975).

From northern Henry County northward into western Kentucky, the McNairy Sand is underlain by the Coffee Sand, which is age-equivalent in this location to the lower Coon Creek lithofacies, based on palynostratigraphic (Tschudy, 1965a) samples from the Hamlin quadrangle. In Benton and Henry Counties, the Coffee Sand consists of dark gray silty clay, locally interbedded with thin layers of white to orange sand, and in many places containing lignitic plant material and carbonized wood. With the exception of plant fragments, the Coffee Sand in the northern outcrop belt does not contain fossil material (Blade, 1966; Russell and Parks, 1975). Of the outcrops visited in the northern outcrop belt in Tennessee, the Coffee Sand contains gray silt and clay, mud drapes, thin wavy layers of black clay and white silt, and cross-beds (Fig. 5). Most outcrops visited contain carbonized and lignitic wood ranging from coarse particle size to larger branches.



A



B

Fig. 5. Outcrop of the Coffee Sand near Camden, Tennessee. A north-facing roadcut exhibiting cross-bedded sand, silt, and clay containing carbonized wood (**A**). Close-up of a freshly cut surface (**B**) at the outcrop. Wavy and flaser bedding of fine sand, silt, and clay such as seen at this outcrop is common in the Coffee Sand in northern Benton County. Tool in photo is approximately 15.2 cm long.

4.3 Kentucky

The uppermost Campanian in western Kentucky is the Coffee Sand (Fig. 3, Table 1). Samples from the Coffee Sand in Kentucky from the Hamlin (Blade, 1966), New Concord (Wilshire, 1964), Little Cypress (Amos and Wolfe, 1966), Paducah West (Finch, 1966), and Paducah East (Olive, 1966) quadrangles contain a palynoassemblage equal to that of the lower Coon Creek (Pree et al., 1957; Tschudy, 1965a). The Coffee Sand lithofacies in western Kentucky and northern Henry County, Tennessee, includes silty, plastic dark gray clays and shales with lignitic plant material (Wolfe, 1963; Wilshire, 1964; Olive, 1965; Blade, 1966; Amos and Wolfe, 1966), locally glauconitic, flaser beds of fine sands, and laminae of micaceous white and yellow silts (Fig. 5B; Blade, 1966; Russell and Parks, 1975). Trough cross-bedding, scour-and-fill structures, and the trace fossil *Ophiomorpha* are also described in the Hico and Hamlin quadrangles (Olive, 1965; Blade, 1966). The Coffee Sand lithology is described as being contained within the McNairy Sand as lenses and light gray silt laminations in some areas of the Little Cypress (Amos and Wolfe, 1966) and Calvert City (Amos and Finch, 1968) quadrangles. The Hamlin Quadrangle map (Blade, 1966) describes the Coffee Sand lithofacies as glauconitic. In the New Concord (Wilshire, 1964), Dexter (Wolfe, 1963), and Hico (Olive, 1965) quadrangles the Coffee Sand contain lignitic clays.

With the exception of *Ophiomorpha*, no Cretaceous fossil fauna from western Kentucky is described in current publications. The fossil flora described includes only pollen and spore taxa. In the Hico Quadrangle (Olive, 1965) in particular, lignite sections in the Coffee Sand lithofacies contain abundant pollen and spore taxa (Hower et al., 1990), including *Cupuliferoidaepollenites*, related to today's chestnut trees (Nichols, 1970; Frederiksen, 1981); *Taxodiaceapollenites*, a fern (Raymond et al., 1997); *Hamulatisporites*, related to ferns and

mosses (Hower et al., 1990); *Gleicheniidites*, a fern (Vajda et al., 2001); Fern spore B (Tschudy, 1970); *Triporopollenites*, related to today's hackberry trees (Frederiksen, 1988; Graham et al., 2000); *Laevigatosporites*, a fern (Graham et al., 2000; Vajda et al., 2001); *Lygodiumsporites*, a fern (Graham et al., 2000); *Sterisporites*, peat moss (Hower et al., 1990); and *Taxodium*, a cypress (Little, 1980).

4.4 Illinois

The uppermost Campanian deposit in Illinois is the Coffee Sand Formation (Fig. 1, Table 1), referred to as the Levings Member in the lower McNairy Sand in core and well logs. The lithofacies is correlated with the uppermost Campanian Coffee Sand in Scott County, Missouri (age assignment from the palynoassemblage analyzed by Harrison et al. (1996)), based on lithology and stratigraphic position (see paper 1 of this dissertation). The Coffee Sand is located in the subsurface only, and is characteristically gray silty sand and clay, white micaceous silt laminations, and some layers containing up to 50% carbonized and lignitic wood (Harrison et al., 1996). Sedimentary structures are difficult to interpret from the cores, but thin layers of alternating clay and silt are common, and appear to exhibit wavy and flaser bedding (Fig. 6). Well logs and core descriptions from southern Alexander, Pulaski, and Maasac Counties show the presence of this lithology (e.g., ISGS wells #10937, #10939 and #10943; ISGS core #10941; 10938; ISGS Johnson test boring (Nelson et al., 2009); and Frank Hepp Jr. wells #60203, #60204, and #60210). The Joppa (Nelson and Masters, 2008), Karnak (Nelson and Hintz, 2007), and Pulaski (Nelson and Williams, 2004) quadrangles, do not show the McNairy Sand including a lower section of Coffee Sand lithology, but instead show the basal McNairy Sand resting unconformably over the Post Creek Formation or the Paleozoics. Faults associated with the Rough Creek and Wabash Valley Fault Systems cross southern Illinois forming horst and graben

structures in the area (Bexfield et al., 2005), and are connected to erosion of parts of the Cretaceous units in the area (Bexfield et al., 2005; Nelson et al., 2009).

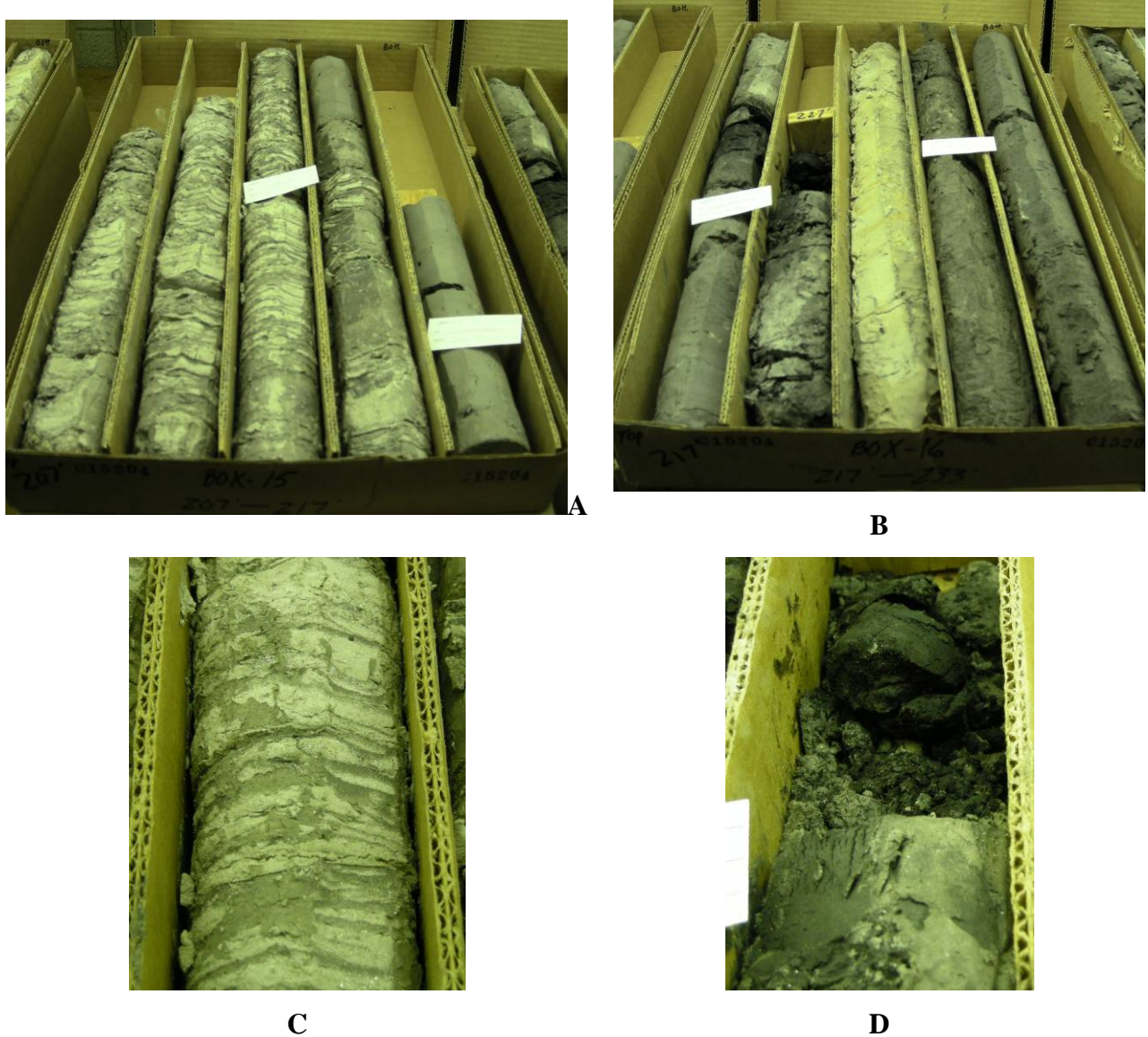


Fig. 6. Photos of ISGS core #15204 from Pulaski County for depths 63-66 m (A), 66-71 m (B), 64.5 m (C), and 69 m (D). The depth and lithology is referred to as the Levings Member of the lower McNairy Sand with alternating layers of silt, sand, and dark gray clay with lignitic material. Lithology and sedimentary structures vary and can exhibit wavy and flaser bedding (C) and lignitic layers (D).

Whereas no fossil fauna has been described in publications from the Coffee Sand in Illinois, the thick layers of lignitic and carbonized plant material have provided multiple genera of fossil flora. Plant material includes leaves from willow, myrtle, walnut, and pondweed (Nelson et al., 2009). Additional plant material of the same genera from southern Illinois Cretaceous clays is housed in the collections at the Illinois State Museum (pers. comm., C. Widga and R. Leary, 2009), but because these were collected at the surface from white clays, it is likely this plant material was collected from the upper McNairy Sand or younger deposits.

4.5 Missouri

The upper Campanian deposits in southeastern Missouri (Fig. 3, Table 1) include the Coffee Sand (also called the lower Commerce Member of the McNairy Sand in older literature) and the unnamed nonmarine clay (referred to in this paper as the Glenallen Clay). The Coffee Sand crops out in Scott, Stoddard, and Bollinger Counties in gullies, creeks, and river bluffs (Stewart, 1927). The Coffee Sand as described by Harrison et al. (1996) in southeastern Missouri is an upper Campanian (based on its palynomorph assemblage) lignite-rich, micaceous, silty and sandy gray to black clay with some pebbles. Other than lignitic plant material in the Coffee Sand in southeastern Missouri, no fossils are described from surface or subsurface deposits.

The Glenallen Clay in Bollinger, Wayne, and Butler Counties is represented by deposits of laterally discontinuous fossiliferous nonmarine clays. The Campanian age assignment is based on two vertebrate taxa from the Chronister site in west-central Bollinger County: the turtle *Naomichelys* which has an Aptian to Campanian range (Stinchcomb et al., 1994), and the hadrosaur *Hypsibema*, which has been found in only Campanian units (Baird and Horner, 1979; Stinchcomb et al., 1994). The clay exposed north of Glenallen is described by Stinchcomb et al. (1994) as layers of blue-gray to blue-black plastic illite-smectite clay, overlain by additional red

and yellow lenses of illite-smectite clays. The clays overlie Ordovician bedrock, with large boulders at the base of the clay from Plattin and Kimswick limestones (Stinchcomb et al., 1994; Stinchcomb, 2006). X-ray diffraction analysis of the clays shows no glauconite present (Stinchcomb et al., 1994).

Information on the Chronister site, in the northwestern part of the county just north of Glenallen, has been published repeatedly, due to the significant dinosaur material recovered from the site. Vertebrate material from the site includes several terrestrial and aquatic taxa. The terrestrial fauna includes saurischian material from the dinosaur families Ornithomimidae, Tyrannosauridae, Dromaeosauridae, and ornithischian material from the hadrosaur genus *Hypsibema* (Parris, 2006). The remaining fauna recovered from the site includes the turtles *Adocus*, *Naomichelys*, and *Trionyx*; the crocodile *Leidyosuchus*; the boney fish *Lepisosteus* and *Platacodon*; and the cartilaginous fish *Lissodus* (a hybodontid shark) and an unidentified ray of the order Batoidea. Lignitic plant material is also found at the site in small pockets. According to Guy Darrough (personal communication, 2009), recently identified plant material includes *Metasequoia*.

4.6 Arkansas

Most of Arkansas' Cretaceous outcrop belt is in the southwestern part of the state that is part of the lower Gulf Coastal Plain (Haley et al., 1993). The uppermost Campanian deposits in the southwestern part of the state include the Saratoga Chalk and the lower Nacatoch Sand (Fig. 3, Table 1). The lower lithofacies of the Nacatoch Sand is a blue-gray clay, sandy clay, marl, and clay-rich sand (Counts et al., 1955; Pleubuch and Hines, 1969; Schrader and Scheiderer, 2004), and is estimated to be late Campanian to early Maastrichtian in age, based on the presence of the *Nostoceras rugosum* ammonite zone (Cobban and Kennedy, 1991) in Hempsted County in

southwestern Arkansas. Underlying the Nacatoch Sand is the Saratoga Chalk which has also been dated by Cobban and Kennedy (1991) as late Campanian, based on the presence of *Nostoceras hyatti*. The Saratoga Chalk is described by Branner (1898) as a blue-gray fossiliferous sandy chalk with beds of marly chalk and chalky sand that weathers to white to light brown.

A thin outcrop belt of Cretaceous deposits is found in northeastern Arkansas, west of Crowley's Ridge. The state geologic map identifies these surface exposures as unnamed Cretaceous sand and clay and Cretaceous rock (Haley et al., 1993). Based on Stephenson and Crider's (1916) lithologic descriptions of wells in these areas and their fossil content, additional correlations to the upper, middle, and lower units of the Nacatoch Sand as described by Counts et al. (1955), Plebuch and Hines (1969), Schrader and Scheiderer (2004) were made in paper 2 of this dissertation. Lithologic descriptions (gray-blue argillaceous material, some green sand, calcareous sandstone, and clay) from wells in the Saffel, Beebe, and Cabot areas match the lithology described for the lower Nacatoch Sand by Counts et al. (1955) and Plebuch and Hines (1969). The age assignment of the lower Nacatoch Sand in northeastern Arkansas is based on the ammonite *Discoscaphites (Scaphites) conradi*, which has an age between or equal to late Campanian to early Maastrichtian, based on the stratigraphic range of *D. conradi* (Elias, 1933; Sohl and Koch, 1983, 1984; Landman and Waage, 1993). Additional fossil fauna recovered from this argillaceous strata in these wells includes: *Nucula percrassa*, *Cymbophora (Veleda) lintea*, *Baculites anceps*, *Placenticeras* sp., *Exogyra costata*, *Anomia* sp., *Trachycardium (Cardium) eufaulense*, *Cardium* sp., *Cyprimeria depressa*, *Nucula* sp., *Glycimeris* sp., *Leptosolen biplicata*, and sharks teeth (Stephenson and Crider, 1916).

No outcrops of the Saratoga Chalk are shown on the geologic map (Haley et al., 1993); however, core descriptions and well logs show the Saratoga Chalk to be present in the subsurface of much of northeastern Arkansas (Stearns, 1957; Moore and Brown, 1969). A sample from the Saratoga Chalk in a core from Woodruff County (Craig Williams core WM No. 6) was found to be age-equivalent to the latest Campanian. The sample was taken from this core at 257 m deep, and was found to have a calcareous nannoplankton assemblage of Zone 23A, correlating to the same age as was biostratigraphically estimated by Cobban and Kennedy (1991). The lithology at this depth is light-gray, clayey Saratoga Chalk, containing shell fragments, and is overlain by blue-gray micaceous silty and clayey sand of the lower Nacatoch Sand (Fig. 7).



Fig. 7. Photos from Woodruff County Craig Williams core MW No. 6 from 254.8-257.6 m. Core shows lithologic change from the blue gray micaceous silty and clayey sand of the lower McNairy Sand (left side) to the light gray Saratoga Chalk (right side) in **A**. Bivalve (**B**) shell material is from 255.5 m deep (lower Nacatoch Sand).

4.7 Central Embayment

The deepest part of the embayment runs along the axis of the trough, and deepens southwestward, with formations from both the eastern and the western sides of the embayment dipping toward the center of the trough (Stearns, 1957; Moore and Brown, 1969; Russell and Parks, 1975), a failed rift active during the Late Cretaceous (Luzietti et al., 1995; Harrison et al., 1996; Cox and Van Arsdale, 2002). Although Stearns (1957) and others (Pryor, 1960; Moore and Brown, 1969; Russell and Parks, 1975) correlated subsurface units, biostratigraphic age constraints were not used. Published biostratigraphic data for Late Cretaceous subsurface embayment units is very limited (Table 3), and the majority of core and well cutting samples collected and analyzed in this project unfortunately were barren of nannoplankton, or contained Paleocene nanno-assemblages (see paper #1 of this dissertation). To help fill spatial gaps in the subsurface for correlation purposes, well logs from MERAS (Hart and Clark, 2008) and well logs and core data from state geological surveys, were combined with biostratigraphic data from subsurface samples and biostratigraphic data from publications. By combining the biostratigraphic data (Table 3) with the subsurface lithologic data, an estimated uppermost Campanian surface can be correlated across the embayment. Subsurface lithofacies with biostratigraphic information include: the Coffee Sand in the northern embayment; upper Demopolis Chalk and Coon Creek lower lithofacies in the eastern embayment; Saratoga Chalk in the western embayment; a Demopolis and Saratoga Chalk undifferentiated calcareous clay in the central part of the embayment; and a volcanoclastic sand beneath the lower Demopolis Chalk on the Jackson Dome in the southernmost part of the embayment study area in Hinds County, Mississippi.

Table 3. Subsurface samples from uppermost Campanian lithofacies in the northern Mississippi Embayment used in this study. Age determined from biostratigraphic correlations of calcareous nannoplankton, palynomorph, foraminiferal, and molluscan assemblages. Subsurface data with no reference are well cuttings and cores sampled by the author for this project.

Core/Well; depth in meters	Formation	Lithology	County, state	Index fossils identified from sample/site	Reference
Auger hole, U.S. Hwy 60, 300' E. of Chestnut Hill Church; 49 m,	Coffee Sand	Light gray, very fine sand, clay, and silt; chert gravel at base	McCracken, KY	Palyno- assemblage zone CA-5	Tschudy, 1965a
Benton Hills core hole BH-1; 59 m	Coffee Sand	Lignite-rich silty and sandy clays	Scott, MO	Palyno- assemblage zone CA-5	Harrison et al., 1996
Benton Hills core hole BH-2; 38 m	Coffee Sand	Lignite-rich silty and sandy clays	Scott, MO	Palyno- assemblage zone CA-5	Harrison et al., 1996
New Madrid test well; 580 m	Clay lithofacies of the Saratoga and Demopolis Chalks undifferentiated	Light gray calcareous micaceous silty clay, traces of lignitic material	New Madrid, MO	Palyno- assemblage zone CA-5	Fredericksen et al., 1982
Fort Pillow test well, 859 m	Clay lithofacies of the Saratoga and Demopolis Chalks undifferentiated	Medium gray calcareous clay with fine micaceous silty laminae	Lauderdale, TN	Foraminifera <i>Guadryina rudita</i> and <i>Anomalina pseudopapillosa</i>	Moore and Brown, 1969
Well cutting #1280; 72 m	Coon Creek	Dark greenish gray, glauconitic fine sand and silt, shells	Hardeman, TN	Nanno- assemblage 23a	
Craig Williams Co. core WM No., T9N, R3W; 26 m	Saratoga Chalk	Light gray, micaceous marly chalk, with shell fragments	Woodruff, AR	Nanno- assemblage 23a	
Wells in the Cabot area; 14 m	Lower Nacatoch Sand	Gray blue argillaceous material, glauconitic sand, calcareous sandstone, and clay	Lonoke, AR	Late Campanian molluscan assemblage	Stephenson and Crider, 1916
Well cutting #5142; -183 m	Upper Demopolis (compared to MS Bureau of Geology electric log #60)	Sandy gray chalk	Calhoun, MS	Nanno- assemblage 23a	
McRae No. 1 well; -1189 m	No formation assigned	Chalk underlain by calcareous, packed sand of vesicular and glassy volcanic clasts	Hinds, MS	Middle Late Campanian molluscan assemblage and foraminifera <i>Pseudorbitoides israelski</i>	Stephenson, 1946

Within the central part of the embayment just south of the confluence of the Ohio and Mississippi Rivers, a layer of gray calcareous clay interbedded with thin layers of glauconitic fine-grained sand and silt is described by Moore and Brown (1969) and Fredericksen et al.

(1982). This lithofacies stretches in the subsurface embayment southward along the Mississippi River, and can be seen in several well logs, including the following: the New Madrid test well (Fredericksen et al., 1982); the Ft. Pillow test well (Moore and Brown, 1969); the Shelby County well Sh: T-018, 52128090010601_47157_ShT-0 (Hart and Clark, 2008); and the St. Francis County, Arkansas well 345724091070701_EPELESET01 (Hart and Clark, 2008). Previous research assigns this lithofacies to either the Saratoga or the Demopolis Formations (Stearns, 1957; Moore and Brown, 1969; Fredericksen et al., 1982).

4.8 Volcanoes

Although igneous intrusions are present in the central and northern part of the embayment, they are unconformably overlain with Campanian age sediments, with erosional surfaces of these igneous intrusions being apparent in some of the cores (Moody, 1949; Kidwell, 1951; Caplan, 1954; Hildenbrand et al., 1982; Baksi, 1997; Cox and Van Arsdale, 2002). Two volcanoes are in the study area in western central Mississippi: the Jackson and Midnight Volcanoes. Both volcanoes were active during the late Campanian, based on radiometric dating from core samples (Baksi, 1997; Cox and Van Arsdale, 2002), and the top of the Jackson Volcano would have been above sea level as an island (Dockery et al., 1997). The Jackson Volcano is considered a source of the bentonite ash layers found in the upper Ripley (Vestal, 1936), based on petrographic studies (McGlothlin, 1944; Cook, 1975; Sundeen and Cook, 1977; Merrill et al., 1988; Dockery et al., 1997). Multiple igneous samples from the area have been radiometrically dated ranging from 80 ± 3 through 65 ± 3 Ma by Ar-Ar dating (Merrill et al., 1988; Cox and Van Arsdale, 2002). Core and well data indicate two eroded surfaces, one along the bottom of the Selma Group closest to the dome, and the other across the upper part of the Cretaceous separating Cretaceous chinks from the Jackson Gas Rock overlying the dome. At 685

m below the surface, a Maastrichtian to Paleocene (McKibben (1988) gas rock (an algal limestone reef) caps the volcanic dome, covering a 72.4 km diameter area (Dockery et al., 1997) with an erosional surface separating the base of the gas rock from the rest of the dome. Portions of the Jackson Gas Rock on the northern side of the dome are found in a lower elevation than the top of the Selma Group, suggesting deposition of some of the Jackson Gas Rock and the Selma Group were contemporaneous (Dockery et al., 1997).

A well in Hinds County penetrated a calcareous clastic deposit at the base of the Demopolis Chalk at 1,189 m (Stephenson, 1946). This basal chalk and sand can be found in a concentric area around the Jackson Volcano igneous rock, and below the Jackson Gas Rock of Paleocene age (Dockery et al., 1997), with the northwestern side of the deposit thicker and elongated. The sand is dated latest Campanian, based on the molluscan assemblage that includes an abundance of shell material in a sand composed of glassy vesicular volcanic clasts. The fossil fauna includes the bivalves *Barbatia* (the only extant genus of the assemblage from this well), *Vetoarca hindsana*, *Postligata monroei*, *Venericardia subterrea*, *Tenea*, *Inoceramus*, *Anomia microlirae*, and the gastropods *Turritella*, *Cerithium*, *Odostomia* (Stephenson, 1946). The deposit also contains pieces of what Stephenson (1946) identified as a red algae (seaweed).

5. Conclusions

5.1 Tennessee Barrier Islands

The lower McNairy Sand within the Coon Creek in McNairy County, Tennessee, exhibits a suite of sedimentary structures and lithology that are similar to those found in barrier islands and bars today. Russell and Parks (1975) suggested the basal McNairy Sand, where it lies below the top of the Coon Creek, and is included as lenses within the Coon Creek, may be evidence of a barrier bar environment. Foreshore to upper shoreface of barrier islands exhibit planar and

trough cross-bedding, and fine-grained clean sands (Moslow, 1984). Regressive barriers often display a coarsening-upward trend (Moslow, 1984), which is also present in the McNairy Sand from the lower to middle to upper members of the formation as described by Russell and Parks (1975). Regressive barrier islands in general are elongate islands, wedge-shape in cross section, parallel to the shoreline of the mainland, and often are separated from the mainland by lagoons and estuaries (Moslow, 1984). This is similar geometry to what Russell and Parks (1975) described, and that can be seen on the geologic maps (Miller et al., 1966). Although the middle and upper McNairy Sand is Maastrichtian, the lower McNairy Sand below the top of the Coon Creek lithofacies is likely age-equivalent to the Coon Creek, and represents a barrier island or bar complex during the latest Campanian that developed into a larger barrier island in the Maastrichtian.

In addition to the McNairy barrier bar complex, the faunal assemblage and sedimentology of the lower lithofacies of the Coon Creek at the type section is very similar to the faunal assemblage and substrate of today's Florida Keys area (as seen in the previous paper of this dissertation). Habitat ranges of similar faunal assemblages (compared to the fossil faunal assemblage at the Coon Creek type section) in the Gulf of Mexico suggest a shallow (6 m or less) marine environment, normal salinity, protected marine environment. Although the lower lithofacies of the Coon Creek is similar in lithology, the biodiversity is not exhibited in all localities. It is likely that this configuration of stratigraphically lower lenses of the McNairy Sand within the Coon Creek represents a series of barrier bars or keys similar to those seen in the Florida Keys region today, with the diverse, molluscan-rich lower facies lying behind the bars or keys. The combination of the basal McNairy Sand, the molluscan assemblage, and the lithology of the lower Coon Creek indicates an offshore to transition zone deposit. Modern barrier bar and

surrounding habitats share similar characteristics including sandy silts and clays, some burrowing, rare laminae of silty sands, and diverse molluscan fauna (Moslow, 1984; Reinson, 1992).

In the northern part of the Cretaceous outcrop belt in Tennessee, the Coon Creek lithofacies pinches out and the underlying Coffee Sand is the lower Coon Creek age-equivalent unit. In Benton and Henry Counties, the Coffee Sand's wavy bedding, silty clays, and lignitic plant material indicate a much shallower environment, similar to a backshore lagoonal or tidal flat environment (Galloway and Hobday, 1983; Moslow, 1984; Dalrymple, 1992). The wavy and flaser bedding seen in the outcrops near Camden in Benton County are good examples of tidal flats with cross-bedding, wavy bedding, and alternating layers of dark gray clay and white silt, mud drapes, and abundant lignitic and carbonized plant material (Fig. 5). Outcrops exhibiting this type of lithology and sedimentary structures were deposited in intertidal to subtidal areas in an estuarine setting. No evidence of barrier bar deposits within the upper part of the Coffee Sand Formation north of Benton County, suggests the northernmost extent of the barrier bar or island complex ends somewhere in Benton County.

5.2 Kentucky, Illinois, and Missouri Estuaries and Wetlands

Thin and wavy beds of alternating layers of dark gray clay and white silts indicate rhythmic tidal currents often seen in tidal flats (Galloway and Hobday, 1983; Moslow, 1984; Dalrymple, 1992), and can be seen in the sediments in the Coffee Sand in Benton County, Tennessee, and in cores from Massac and Pulaski Counties in Illinois. The presence of high amounts of lignitic plant material in the Coffee Sand lithofacies in some locations (e.g., the Levings Member in cores in Illinois; the outcrop near Camden, Tennessee; and the Coffee Sand or lower Commerce Member in Missouri) is expected in estuarine facies. The build-up of plant

material can be seen in modern estuarine environments (areas in which a river or streams discharge into a shallow marine basin) that trap and decompose plant material washed down by rivers and streams (Cohen, 2000; Kerr et al., 2003). Thicker deposits such as those in the Olmsted Quadrangle in Illinois, the lignite deposits in the Hico Quadrangle in Kentucky, and other thick carbonatized and lignitic wood deposits in southern Illinois cores, are indicative of more highly vegetated marshes or wooded wetlands (Dalrymple, 1992).

Of the pollen and spores identified from the lignite in the Hico Quadrangle in Kentucky, the fern spores have been found in paleoenvironments ranging from forests to wooded freshwater to brackish lakes, rivers, and estuaries (Raymond et al., 1997; Hargrove and Englehardt, 1997; Graham et al., 2000), with *Laevigatosporites* specifically indicating a marsh or swamp habitat (Kroeger, 1985; Graham et al., 2000). Hackberries (*Triporopollenites*) today live in forests near freshwater, chestnuts and their relatives within family Fagaceae can inhabit forests with freshwater supply as well as brackish environments (Raymond et al., 1997), and cypress inhabit freshwater to brackish water settings. Hower et al. (1990) pointed out that a combination of intertode trinite, mineral grains, and humode trinite suggests some of the material may be allocthonous, likely carried downstream by rivers or streams in the area.

Plant material identified from the Levings Member (Nelson et al., 2009) suggests a wooded wetland environment, based on habitat preferences of the plant material. Willow and myrtle both thrive in ground with a high moisture content or shallow groundwater, but not standing water. Pondweed thrives in shallow cool waters with high nutrient input, but does not grow in brackish water. This would be an area upstream from an estuary, but not an area that would be continually under water. Plant material that washes down from rivers and into estuaries is often washed back and forth by tides and is further broken down by wave action and bacteria

(Cohen, 2000; Kerr et al., 2003). Foliage in this area, however, is described as a thick layer with well-preserved leaves, with no alternating layers of clays and silts or sands that would indicate tidal activity, and no biological and physical decomposition of the plant material. Because of the silt and clay composition of the sediment, and thin laminate bedding, absence of glauconite, floral habitat preferences, and good preservation of leaves, this environment is interpreted as a wooded marshy floodplain for the Levings Member in the lower McNairy Sand of southern Illinois.

5.3 Missouri Depression Lakes

The lithology of the upper Campanian bone-bearing clays in southeastern Missouri does not correlate with any other formally described and named formation in surface or subsurface Cretaceous deposits in southeastern Missouri or elsewhere in the embayment. Although these clays currently are labeled as McNairy Sand on geologic work maps (pers. comm., E. Starbuck, 2009), they do not match lithologic descriptions of the clays in the McNairy Sand in any other locations in the embayment as recorded from publications, geologic maps, or subsurface data. The McNairy Sand clays have not been found to contain freshwater aquatic faunal material, and are Maastrichtian age based on palynostratigraphy (Harrison et al., 1996).

Previous publications on these bone-bearing clays in the Glenallen area do not propose a name or a type section for the clay deposit, but because the Chronister site near Glenallen has the most thorough description, with lithostratigraphic description, x-ray diffraction analysis of the mineralogy, paleontological records, and is accessible to researchers (pers. comm., G. Darrough, 2009) who currently owns the site property and is involved in paleontological research of the site), this site would be most appropriate for a proposed type section. An appropriate name would be based on the nearby town of Glenallen.

Although Stinchcomb et al. (1994) interpreted the clays at the Chronister site in Bollinger County, Missouri to be weathered volcanic ash layers, no Cretaceous bentonite layers are recorded in upper Campanian sediments in the western part of the embayment, including Missouri. The closest volcanoes to this area are to the southwest and are early to middle Campanian (Baksi, 1997; Cox and Van Arsdale, 2002). Campanian-age volcanoes in the embayment region include the Jackson and Midnight volcanoes in central Mississippi. Sea surface and climate modeling, however, indicates the winds would have blown ash from these volcanoes to the east-northeast (Cousin-Ritemard et al., 2002; Hay, 2008), not in the direction of Missouri. Because illite-smectite clays are often derived from chemical weathering of rocks containing mica, magnesium, calcium, and iron (such as granites and shales), especially in areas of leaching or stagnant waters (Prothero, 1989), it is more likely the Glenallen clays in this area formed by chemical weathering of bedrock, such as the Butler Hill Granite, that also crops out in northwestern Bollinger County.

Of the fauna described from the Chronister site in Bollinger County, Missouri, one taxon is considered to have a freshwater-only habitat: *Platacodon* a freshwater drum. The possible *Metasequoia* fragments also suggest a moist to freshwater environment, considering the habitats of the only surviving species of *Metasequoia* today in China which grow in moist valleys and along stream banks (Raven et al. 1986; Silba 1986; Hendricks 1995). Of the remaining aquatic fauna, all have been shown to inhabit freshwater and brackish water habitats, either by observations of modern genera (Lee et al., 1983; Ernst and Barbour, 1989; Stevens and Last, 1998; Wiley, 1998; Monks, 2006) or by the fossil record (Miller, 1967; Estes et al., 1969; Carroll, 1988; Bryant, 1989; Maisey, 1989; Cappetta et al., 1990; Eberth and Brinkman, 1997; Eaton, 1999; Hirayama et al., 2000; Cuny et al., 2005; Sankey, 2006). Because the fauna shows a

range of environments from terrestrial to brackish water, and the bone material was recovered together mainly from one particular layer within the blue clay (Stinchcomb et al., 1994), it is likely the environment was a depression lake. Depression lakes are formed by dissolution collapse of limestones, forming sinkholes that fill with water. Multiples of these depression ponds and lakes can be found in one area, and can be surrounded by saltwater or freshwater marshes similar to the area found in the lower Florida panhandle today (Fig. 8; Florida Department of Natural Resources, 1990). According to the Florida Department of Natural Resources (1990), these depression lakes often contain stagnant water from surface runoff (which accounts for the smectite-illite composition), clay with little sand (from the decomposition of surrounding limestones), lensatic geometry, and steep cliff walls with boulders of surrounding bedrock (as are found at the bottom of the blue-black clay).

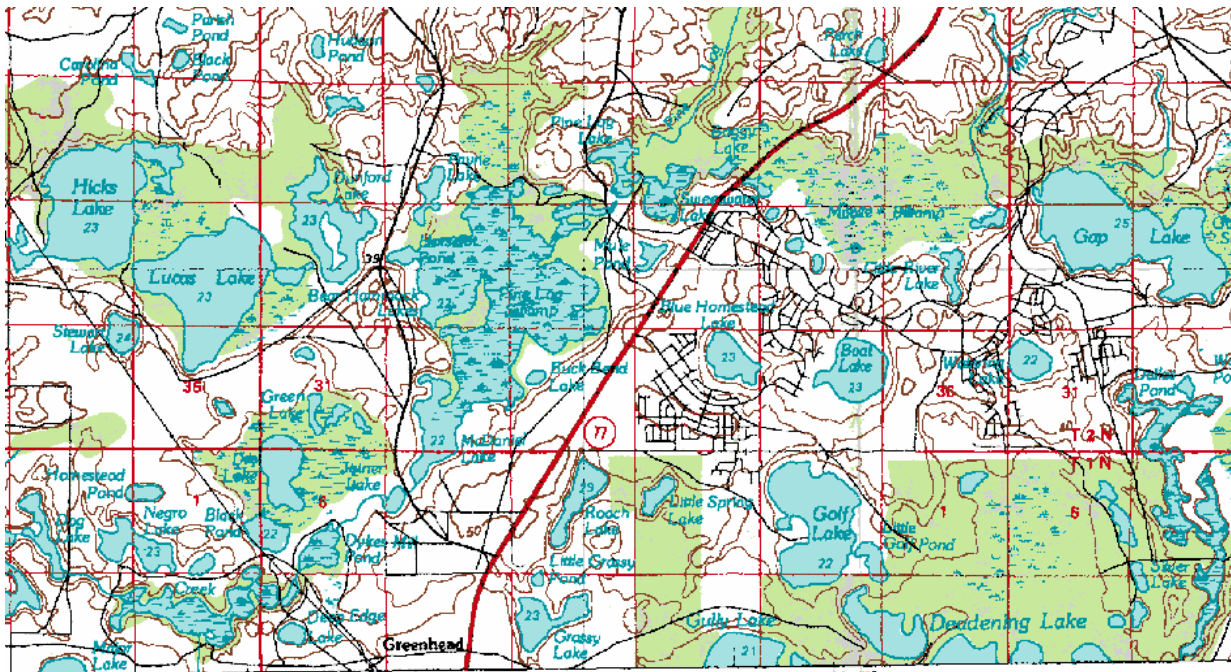


Fig. 8. Depression lakes and marshes in a section of the Marianna 1:100,000-scale topographic map in Washington County, Florida, north of Greenhead. 1979, USGS, 1:100,000-scale metric topographic map of Marianna.

5.4 Northern Mississippi Embayment Carbonate and Clastic Shelf

In the southern part of McNairy County, the Demopolis Chalk underlies the Coon Creek Formation. Based on biostratigraphy, parts of the upper transitional clay between the Demopolis Chalk and the Coon Creek are age-equivalent to the lower Coon Creek. This separation from the barrier island lithology, and merging of carbonate and off-shore clastic lithologies, is comparable to the West Florida Shelf and Key Largo areas, where silty sands rich with mollusks and molluscan diversity meet the algae and foraminiferan carbonate muds and clays (Jones and Desrochers, 1992). The Coon Creek in the subsurface of Tennessee west of the McNairy Sand outcrop belt, the Coon Creek Member of the Ripley in Mississippi, the Ripley in western Alabama, and the lower Nacatoch Sand in northeastern Arkansas represent a continuation of the shallow nearshore quartz-rich and molluscan-rich sands of the clastic shelf. Molluscan assemblages of these facies indicate a deepening trend from the Coon Creek lower facies in Tennessee to the lower Nacatoch Sand in Arkansas to the Coon Creek and Ripley in Mississippi and Alabama. However, based on similar modern molluscan assemblages and environments in the Gulf of Mexico and Caribbean today, these latest Campanian-age clastic facies were likely all shallower than 50 m (Fig. 9).

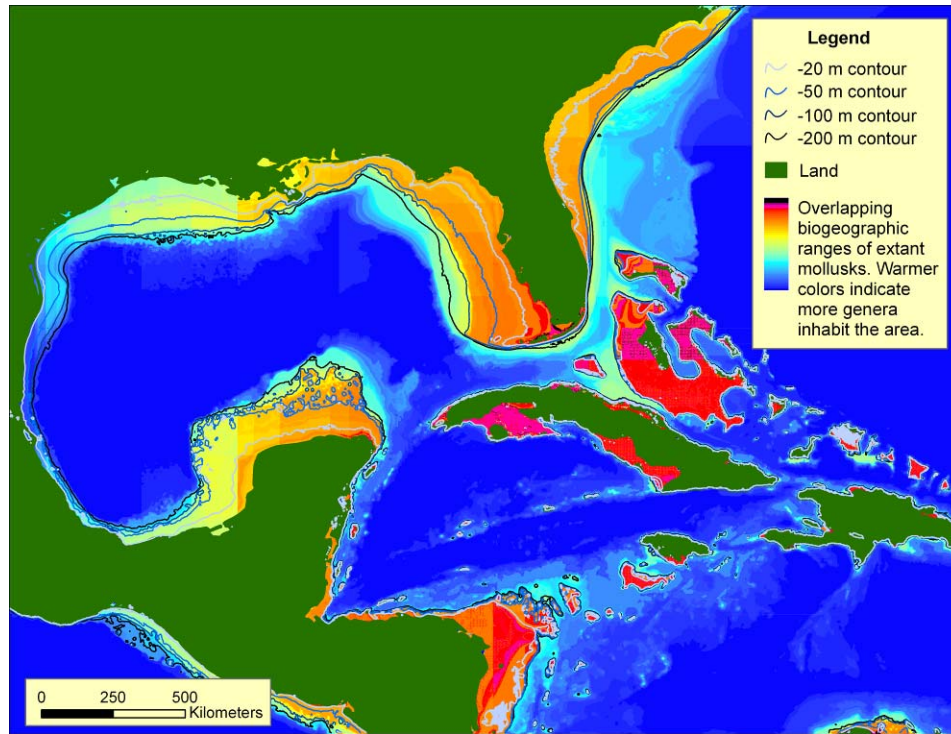


Fig. 9. Molluscan biogeographic and bathymetric ranges and bathymetry. Ranges of extant genera (Table 2) were overlain for the Gulf of Mexico and Caribbean area. Magenta and black areas represent the highest concentration of overlapping ranges (areas that contain the highest number of genera, 90% or more of the genera listed in Table 2). All magenta and black areas are in water shallower than 20 meters.

This same pattern can be seen on the western side of the embayment as well, where the lower Nacatoch Sand (similar in lithology to the Coon Creek Member of the Ripley Sand in Mississippi and representing a similar environment) and the Saratoga Chalk meet. The carbonate lithology can be traced across the embayment, and as far north as New Madrid County in southeastern Missouri. Based on the well log and core data, this carbonate lithofacies thins and grades into the clastic lithofacies which is the Coffee Sand (Commerce Member of the McNairy Sand) of southeastern Missouri in Scott and Stoddard Counties, the Coffee Sand (Levings Member of the McNairy Sand) in southern Illinois, and the Coffee Sand of western Kentucky and northwestern Tennessee. On the western edge of the embayment, the carbonate lithofacies grades into the lower Nacatoch; on the eastern side of the embayment, it grades into the Coon

Creek in Tennessee, the Coon Creek Member of the Ripley in Mississippi, and the Ripley in western Alabama. The clastic lithofacies on the eastern and western sides of the embayment tend to be molluscan-rich compared to the carbonates (e.g. Table 2; the lower Nacatoch Sands in Arkansas and the lower Coon Creek facies in Tennessee). A similar pattern of nearshore molluscan-rich clastics with seaward carbonates can be seen in off the coast of Florida today.

At the southernmost edge of the study area, the Jackson and Midnight Volcanoes would have been prominent bathymetric features. The sediment and faunal assemblage at 1189 m deep represents a shallow (<100 m conservatively) clastic shelf environment, based on the genera recovered from this depth. This difference in depths suggests approximately 1 km of subsidence of this area since the latest Campanian. Surrounded by carbonate platform, these volcanoes would have had volcanoclastic shallows and beaches elongated toward the northwest from southeasterly currents pushing sediment northwestward. These volcanoclastic sediments can be seen in previous maps compiled by Dockery et al. (1997). The clastic shallows ringing the Jackson Volcano provided the shallower nutrient waters needed from the diverse molluscan assemblage as found by Stephenson (1946).

5.5 Sediment Sources

Stewart (1927), Pryor (1960), and Russell and Parks (1975) noted the presence of heavy minerals (e.g. kyanite, staurolite, ilmenite, zircon, tourmaline), and radioactive grains in the northern Mississippi Embayment clastic deposits such as the McNairy Sand, Coffee Sand, and Coon Creek Formations. Although Pryor (1960) suggested these grains were transported by a large river system eroding Appalachian rocks 482.8 km to the east, it is more likely that these minerals, especially those in the northern and western embayment sediments, are from a parent rock within the immediate or nearby area. The same heavy minerals, as well as frosted quartz

grains that are found in the Coffee Sand and Post Creek (Harrison et al., 1996), are also found in the Ordovician St. Peter Sandstone (Giles and Bonewits, 1930; Tyler, 1936), which underlies the embayment region and crops out in northern Arkansas, eastern Missouri, and western and northern Illinois (Fig. 10; Dake, 1921; Giles and Bonewits, 1930). Based on the composition of the St. Peter Sandstone, it is more probable that the St. Peter Sandstone is the main sediment source for the Upper Cretaceous clastics in the northern and western embayment. This suggests a northern and western drainage basin for Cretaceous sediments in southern Illinois, southeastern Missouri, and northeastern Arkansas, and not sediment supply from the Appalachians 560 km away as Pryor (1960) suggested.

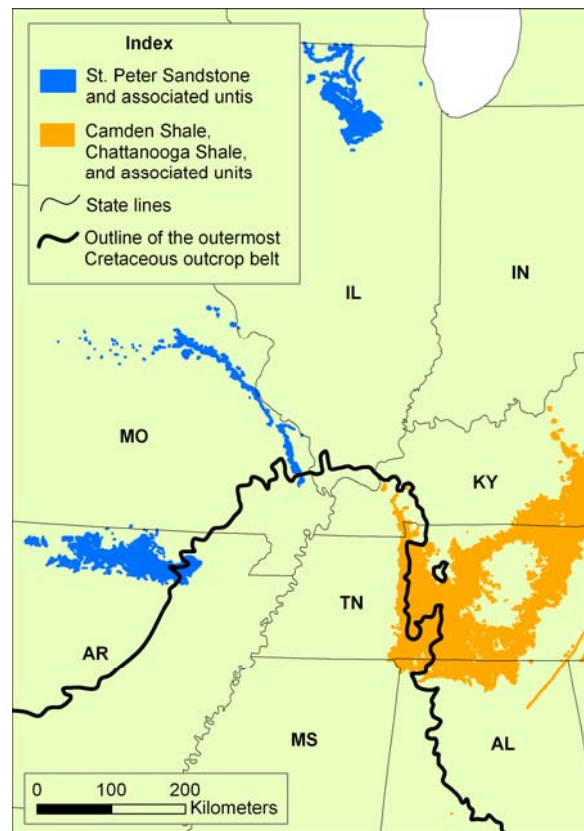


Fig. 10. Spatial extent of the outcrop belt of regional bedrock units containing heavy minerals. Outcrop belts would have been wider during the latest Campanian given the erosion that has taken place over the past 71 million years. Geologic data from state geologic maps (Miller et al., 1966; McDowell et al., 1981; Szabo et al., 1988; Haley et al., 1993; Middendorf, 2003).

With respect to the heavy mineral grains in the McNairy Sand, Coffee Sand, and Coon Creek Formations in Tennessee, Kentucky, Mississippi, and Alabama, these likely also have a closer parent rock than the Appalachians. The Devonian-to-Mississippian-age Chattanooga Shale and the Devonian Camden Shale crop out in western Kentucky, western Tennessee, and northern Alabama (Fig. 10), and contain the same heavy minerals, including uranium (Pirkle et al., 2007), as are found in the Cretaceous clastic deposits as noted by Pryor (1960) and Russell and Parks (1975). The presence of these heavy minerals in the regional bedrock suggests another alternate source of sediment supply for the embayment clastics than just the Appalachians.

5.6 Basin and Shoreline Geometry

Shoreline for the study area during the latest Campanian would have been close to the uppermost Campanian outcrop belt, as these deposits are nearshore deposits (Figs. 3 and 11). The size of such a large body of water with normal marine conditions enclosed on three sides, defines the paleoenvironment of the northern Mississippi Embayment during the latest Campanian to be a gulf by current definitions of the term (Trujillo and Thurman, 2007). The term gulf is favored here over bay for the large size, depth, and normal marine conditions (bays tend to be shallower with a lower salinity, due to large influx of freshwater from rivers).

The trough-like geometry of the northern Mississippi Embayment is not due to aggradation of deltaic sediments as proposed by Pryor (1960), but is due primarily to the tectonic failed rift that underlies the embayment. This rift has been well-documented in previous studies examining regional gravity anomalies and igneous intrusions (Moody, 1949; Kidwell, 1951; Caplan, 1954; Hildenbrand et al., 1982; Baksi, 1997; Cox and Van Arsdale, 2002), faults and structures (Braile et al., 1986, 1997; Harrison et al., 1996; Harrison et al., 1999; Cox and Van Arsdale, 2002), and recent seismic activity (Zoback et al., 1980; Stauder et al., 1981; Braile et

al., 1997; Harrison et al., 1999). The deepest Paleozoics are over 1,000 meters below sea level in the Reelfoot Rift, the ancient rift that was undergoing tension, uplift, and igneous intrusion during the Late Cretaceous (Cox and Van Arsdale, 2002). Mapping subsurface elevations of the latest Campanian samples (Table 3), and correlating with well logs, gives elevation points for an uppermost Campanian interpolated surface. The paleobathymetry shows a geometry with the deepest portions following the Reelfoot Rift, deepening toward the axis of the rift and southwestward toward the Gulf of Mexico (Fig. 2 and 11).

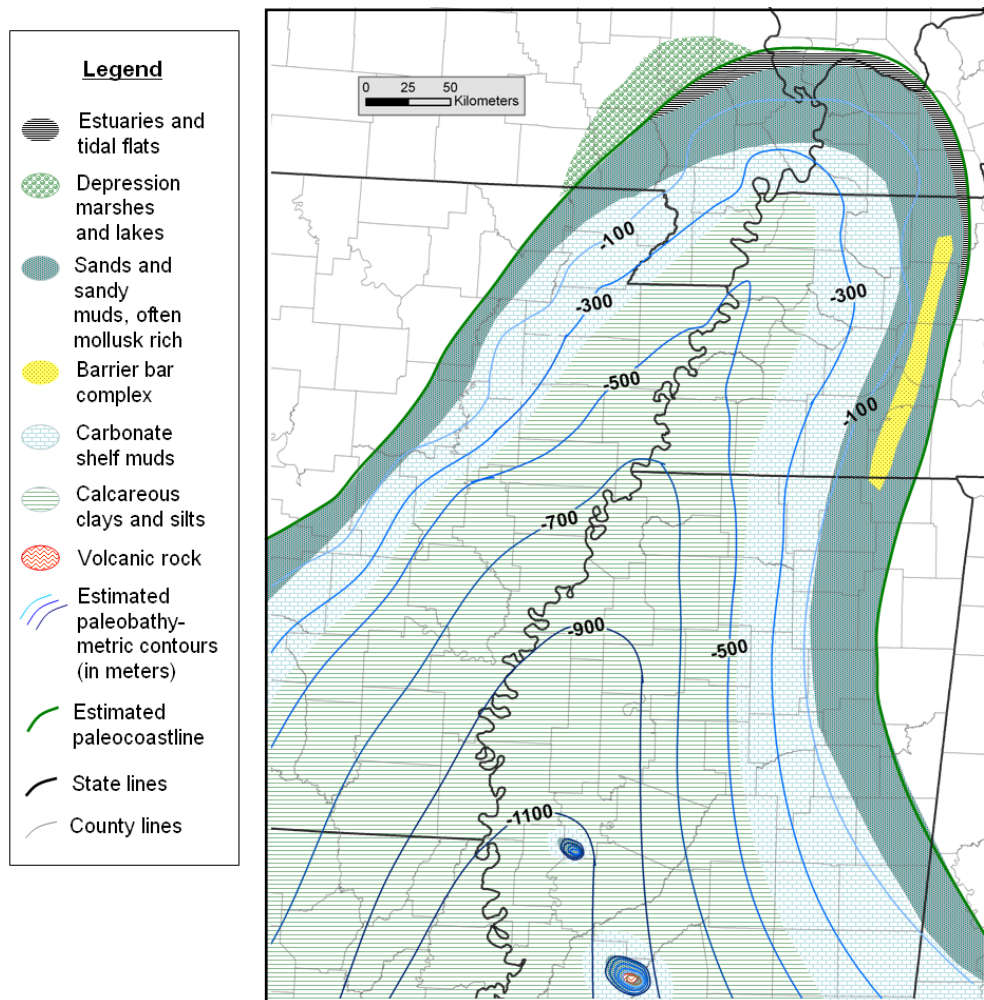


Fig. 11. Estimated paleobathymetry and surface sediments of the gulf in the latest Campanian Mississippi Embayment. The estimated paleocoastline averages 110 meters above current sealevel in the northernmost reaches (Missouri, Illinois, and Kentucky).

Although latest Campanian beach deposits are not present around the northern embayment in the outcrop belt, it is likely the shoreline was just landward of the Coon Creek lithology in western Alabama, Mississippi, and Tennessee. A long and narrow barrier bar complex (the basal McNairy Sand) would have stretched from northwestern Alcorn County, Mississippi, up to the southeastern corner of Henry County, Tennessee. The shoreline in Kentucky, Illinois, and Missouri would have been very near, the landward-most extent of the Coffee Sand that represents estuarine and wooded wetland habitat in southern Alexander, Pulaski, and Massac Counties in Illinois. The northern curve of the embayment from Benton County, Tennessee, into western Kentucky, southern Illinois, and Scott and Stoddard Counties, Arkansas, was farther inland, and would have seen lower wave energy. Although currently a prominent feature in today's topography, Crowley's Ridge during the latest Campanian would not have been an island, as Van Arsdale et al. (1995) showed the ridge was uplifted approximately 60 m during the Tertiary. Distributaries, marshes, and tidal flats dominated the coastal areas in this northern part of the study area. Shoreline of the western side of the gulf would have been just to the west of the edge of the embayment deposits.

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CHAPTER 5

CONCLUSIONS

The importance of this study is its contribution to Upper Cretaceous stratigraphy in the Mississippi Embayment. By combining the marine and nonmarine biostratigraphic record for the upper Campanian and lower Maastrichtian, correlation of uppermost Campanian stratigraphy was achieved, allowing a paleogeographic and paleoenvironmental interpretation of the northern Mississippi Embayment for the late Campanian. These correlations and interpretations of the facies allows a clearer picture of the relationships among these facies as parts of the whole, the embayment gulf during the late Campanian.

Conclusions and findings by paper are summarized as follows:

Significance and Findings of Paper 1

This paper shows the lower Coon Creek lithofacies to be key in matching up the palynostratigraphic and marine biostratigraphic record for the northern Mississippi Embayment. The incredible biodiversity and preservation of the Coon Creek lagerstätte plays an important role in allowing additional biostratigraphic correlations in the northern embayment to be made. Palynomorphs, calcareous nannoplankton, and ammonites are all key biostratigraphic indicators used in Gulf Coastal Plain and Western Interior Seaway biostratigraphy. The lower Coon Creek lithofacies at its type section in Tennessee contains all three of these important taxa, which allow biostratigraphic correlation southward into Mississippi and Alabama, northward into Kentucky and Illinois, and westward into Arkansas and Missouri.

Although the upper Campanian and lower Maastrichtian subsurface units in Kentucky, Illinois, and southeastern Missouri have been called different names and different ages, this project was able to compile ample lithologic and biostratigraphic data to correlate these lithofacies and clarify their stratigraphic relationships. Biostratigraphic and lithostratigraphic correlations in the first paper include the following results:

1. The uppermost Campanian Coffee Sand in Kentucky (once referred to as Ripley) overlies the Post Creek Formation (previously referred to as the Tuscaloosa Gravel).
2. The Levings Member of the McNairy Sand is described as two different units – one in the middle of the McNairy Sand (Maastrichtian) and one in the lower McNairy Sand (uppermost Campanian). The Levings Member in the lower McNairy Sand is actually the uppermost Campanian Coffee Sand and overlies the Post Creek (previously referred to as the Tuscaloosa Gravel).
3. The uppermost Campanian Coffee Sand in southeastern Missouri was previously referred to as the Commerce Member of the McNairy Sand, but it can be lithologically and biostratigraphically separated from the McNairy Sand, and the basal gravel is the Post Creek Formation (previously referred to as the Tuscaloosa Gravel).
4. The Cretaceous rocks, sand and clay in northeastern Arkansas can be divided into the upper, middle, and lower Nacatoch Sand, based on age and lithology. The lower Nacatoch Sand and the upper Saratoga Chalk are the uppermost Campanian strata in northeastern Arkansas.

5. The dinosaur bone-bearing clays in southeastern Missouri that were previously related to the Ripley and then to the McNairy Sand are non-marine, Campanian clays, not related to either of these formations or to any other Upper Cretaceous formation in the northern embayment. This paper supports formally proposing a new name for the lithofacies, the “Glenallen Clay.”
6. Uppermost Campanian lithofacies in Mississippi and Alabama include the Coon Creek Member of the Ripley Formation in Mississippi, the lower Ripley Formation in western Alabama, and the uppermost Demopolis Chalk in western Alabama. Subsurface uppermost Campanian lithofacies includes a molluscan-rich clastic deposit at the base of the Selma Chalk rimming the Jackson Dome.
7. The uppermost Campanian lithofacies in the subsurface of the central embayment is a calcareous clay joining the Saratoga Chalk in the west with the Demopolis Chalk in the east. The lithologies are undifferentiated on well logs.

Significance and Findings of Paper 2

This paper shows that with the advancement of marine biology, marine geology, and geographic data analysis, more thorough GIS analyses can be made to help interpret ancient environments by comparison with modern analog environments. Compiling biogeographic data of extant genera assemblages, equivalent to fossil genera assemblages found in a biofacies, allows comparison with and identification of modern analog environments. Combining these data with sediment, current, and salinity data in a GIS, allows spatial multi-variable analysis on a much higher level than once was possible. This project shows how GIS can be a valuable tool for paleoenvironmental interpretation. The data compiled in this paper also provide additional

biogeographical and ecological information for interpreting shallow paleoenvironments of other lower Coon Creek age-equivalent lithofacies in the embayment as well.

The results of this paper show the Coon Creek lower facies lagerstätte is a preserved shallow clastic facies that was present in both the seaward and the back barrier side of the barrier bar complex. This barrier bar complex is exhibited as layers of McNairy Sand lithology (representing a cross-sectional view of a barrier bar) within the Coon Creek lithology, and the bar complex stretches from the Tennessee-Mississippi line northward into Benton County, Tennessee. North of Benton and Henry Counties, no further inclusions are seen and lagerstätte is no longer found. A modern analog to the Coon Creek type section is the Florida Keys area, which exhibits molluscan-rich, shallow clastic depositional facies surrounding low lying islands.

Significance and Findings of Paper 3

Once late Campanian age-equivalent lithofacies in the northern embayment were identified, the paleoenvironments of each were interpreted and mapped to create a paleogeographic map of the northern Mississippi Embayment. Comparison between lithologic and paleontologic characteristics with those of modern depositional systems and faunal assemblages, allows a clearer interpretation of paleoenvironments for the Coon Creek lower facies and for its age-equivalent lithofacies in the embayment. The interpreted paleoenvironments and paleogeographic map allow a clearer and more accurate picture of the depositional systems within the embayment and the system as a whole.

Structural, lithological, and paleontological data do not support the previous interpretation of the northern embayment as a large deltaic environment. Instead, the identified environments show more variation, and include estuarine, tidal flats, depression marshes and lakes, shallow clastic shelf, carbonate shelf, volcano with clastic rim, barrier bar, and back

barrier bar. Sedimentological data do not indicate a large river system depositing sediment eroded from the Cretaceous Appalachians. Instead, mineral composition of the sediment indicates erosion of the parent rock in the immediate area of the northern embayment as a source for the sediments.

Overall Significance of This Project

This project identifies a gap in the Gulf Coastal Plain stratigraphy, and use nonmarine and marine index taxa to fill this gap through biostratigraphic correlation. Upper Campanian and lower Maastrichtian lithofacies are lithologically and biostratigraphically correlated; age-equivalent facies are identified with corrections to previous stratigraphy in Illinois; the Cretaceous deposits in northeastern Arkansas are divided stratigraphically; and a significant nonmarine lithofacies is identified in Missouri and is shown to be distinctly different from the other Campanian and Maastrichtian units in the embayment. Upper Campanian paleoenvironmental analysis clarifies the spatial and environmental relationship between the lower Coon Creek facies and the basal McNairy Sand as a barrier bar complex with adjoining shallow marine environment. Paleoenvironmental results indicate the Saratoga Chalk on the western side and the Demopolis Chalk on the eastern side of the embayment merge in the central embayment in an undifferentiated calcareous clay unit. Paleoenvironmental analyses also contrast the paleoenvironment of the Missouri bone-bearing clays with those of other age-equivalent paleoenvironments in the embayment, supporting the separation of the clay deposits from correlation to other units as a distinct geologic formation.

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