Cynthia D. Crane, Vertebrate Paleontology and Taphonomy of the Late Cretaceous (Campanian) Bladen Formation, Bladen County, North Carolina (under the direction of Dr. Stephen J. Culver and Dr. Catherine A. Rigsby) Department of Geological Sciences, 2011.

Abstract

A site recently discovered near Elizabethtown, North Carolina, has produced a wealth of late Cretaceous (Campanian) age vertebrate fossil material revealing a variety of new taxonomic, paleoecologic, and biogeographic information. This site, the Bladen County Landfill Annex (BCLA), has yielded a greater abundance and diversity of vertebrate material than Phoebus Landing, a well-researched site located approximately 7 km (4.35 miles) southeast of Elizabethtown.

Bulk sampling of a bonebed located at the top of the Bladen Formation at the BCLA site yielded a diverse assemblage of fresh water, brackish water, and terrestrial organisms. The fossils from this site exhibit little or no abrasion, implying no transport or a short time and distance of transport. Fossils representing Chondrichthyes, Osteichthyes, Reptilia, Mammalia, and Amphibia were recorded. This fauna allows for regional correlation with Campanian age faunas from the Marshalltown Formation (Ellisdale Site), New Jersey and the Blufftown Formation, Georgia. Of particular note, the BCLA faunal assemblage also exhibits affinities with Campanian age microvertebrate fossil assemblages from the Aguja Formation of Texas, the Mesaverde Formation of Wyoming, the Judith River Formation of Montana, and the Oldman Formation of Alberta, Canada.

VERTEBRATE PALEONTOLOGY AND TAPHONOMY OF THE LATE CRETACEOUS (CAMPANIAN) BLADEN FORMATION, BLADEN COUNTY, NORTH CAROLINA

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by
Cynthia Danielle Crane
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Cynthia D. Crane

2011

I dedicate this work to my sons, Nathaniel and Christian:

my two greatest achievements.

And in memory of my father, Daniel Allen Crane (1944-1991),

I miss you. I know I've made you proud.

In recognition of those who seek answers

to their questions, regardless of the path or outcome.

Without you,

the discipline of science would not exist.

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Thank you to the North Carolina Fossil Club members, and to all amateur paleontologists and fossil hunters. Because of you, museums and research institutions are teeming with specimens and significant discoveries have been made. Always remember that passion for something does not require a degree, just fascination and determination. Thank you all for your kindness, encouragement, generosity, and willingness to assist me in any way you possibly could. I am a very fortunate person to be among friends like you.

Finally, in honor of the memory of my dear fossil-hunting friends,
Richard Tellekamp, Pamela Tellekamp, Luther (Mike) Milton, Douglas Meyer, Thomas McCabe, Fred Mount, Sharron Edwards, Robert Story, Becky Spencer, and Tony Furr. I will never forget you.

BSH…glad we found each other again after 20+ years…save me a seat up there.

Table of Contents Page

List of Symbols/Abbreviations

NCMNS – North Carolina Museum of Natural Sciences, Raleigh, North Carolina
USNM – National Museum of Natural History, Smithsonian Institution
ANSP – Academy of Natural Sciences, Philadelphia, Pennsylvania
BCLA – Bladen County Landfill Annex
USGS – United States Geological Survey
NCGS – North Carolina Geological Survey

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

The power of imagination makes us infinite.

John Muir

1.0 INTRODUCTION

1.1 STATEMENT OF PURPOSE

This thesis presents a new interpretation of the nature, preservation and taphonomy of the vertebrate fossil assemblage and associated depositional environments within the Upper Cretaceous (Campanian) Bladen Formation of southeastern North Carolina. It builds heavily upon the work of earlier investigators and provides a newly enlarged Campanian faunal record from this region.

Study of late Cretaceous vertebrate faunas in North Carolina has a lengthy but erratic history. Since the mid 1800's, only a handful of vertebrate paleontologists have probed this area. The most thoroughly researched late Cretaceous vertebrate-producing outcrop in North Carolina is located 7.6 kilometers (4.8 river miles) downstream of Lock and Dam #2, just south of the town of Elizabethtown, on the Cape Fear River in Bladen County. This locality is known as Phoebus Landing. The first study of the vertebrates from this site was carried out during the late 1960's by Halsey Miller who described a small assemblage of vertebrate fossils (Miller, 1967). These specimens are currently accessioned in the National Museum of Natural History (Washington, D.C.), the Sternberg Museum of Natural History (Hays, Kansas), and the Academy of Natural Sciences (Philadelphia, Pennsylvania) collections. In 1979, Donald Baird and John (Jack) Horner reassessed these fossils (Baird and Horner, 1979).

During the late 1990's, a new site discovered near Elizabethtown, North Carolina, produced a wealth of late Cretaceous vertebrate fossils. This locality, referred to as the Bladen County Landfill Annex (BCLA), has added substantially to the record of late Cretaceous vertebrate fossils from North Carolina. This study identifies and describes the vertebrate fauna from the BCLA, places it in a geological context, and relates the BCLA deposits to those at Phoebus Landing. Further comparison of the BCLA fauna is made to vertebrate faunas at localities extending from New Jersey, along the Atlantic and Gulf coasts, to the western United States. These comparisons with generally coeval sites add to the knowledge of Campanian age faunal and ecological studies within the Atlantic and Gulf Coastal Plains of North America.

1.2 OBJECTIVES

In fulfilling six primary research objectives, this thesis (1) describes and identifies the late Cretaceous (Campanian age) vertebrate fauna from the Bladen County Landfill Annex, (2) documents the diversity and relative abundance of that faunal assemblage, (3) characterizes the taphonomic features that typify the assemblage, (4) discusses taphonomic processes that result in the particular characteristics of the microvertebrate fossil assemblage, (5) reconstructs the paleoecology and paleoenvironments of the late Cretaceous in Bladen County, and (6) compares the Bladen County Landfill Annex's faunal assemblage with Campanian faunal assemblages locally, on the Atlantic Coastal Plain, and with localities in the western United States.

1.3 GEOLOGIC SETTING

1.3.1 Regional Geology

An unconformity separates Upper Cretaceous strata from Cenozoic strata along the Atlantic and Gulf Coastal regions (Fig. 1). Paleocene to Quaternary deposits rest directly on the Cretaceous beds. This regional unconformity has been the source of ongoing debate particularly concerning stratigraphic nomenclature and depositional environments (Heron and Wheeler, 1964; Sohl and Owens, 1991; Ward et al., 1991).

During the early 1900's Stephenson mapped this unconformity from Long Island, New York, to southwest Texas (Fig. 1) (Stephenson, 1914). Beneath it in North Carolina, Cretaceous strata crop out in bluffs along the Cape Fear River and its tributaries for over 100 miles from the fall line to Wilmington (Stephenson, 1912).

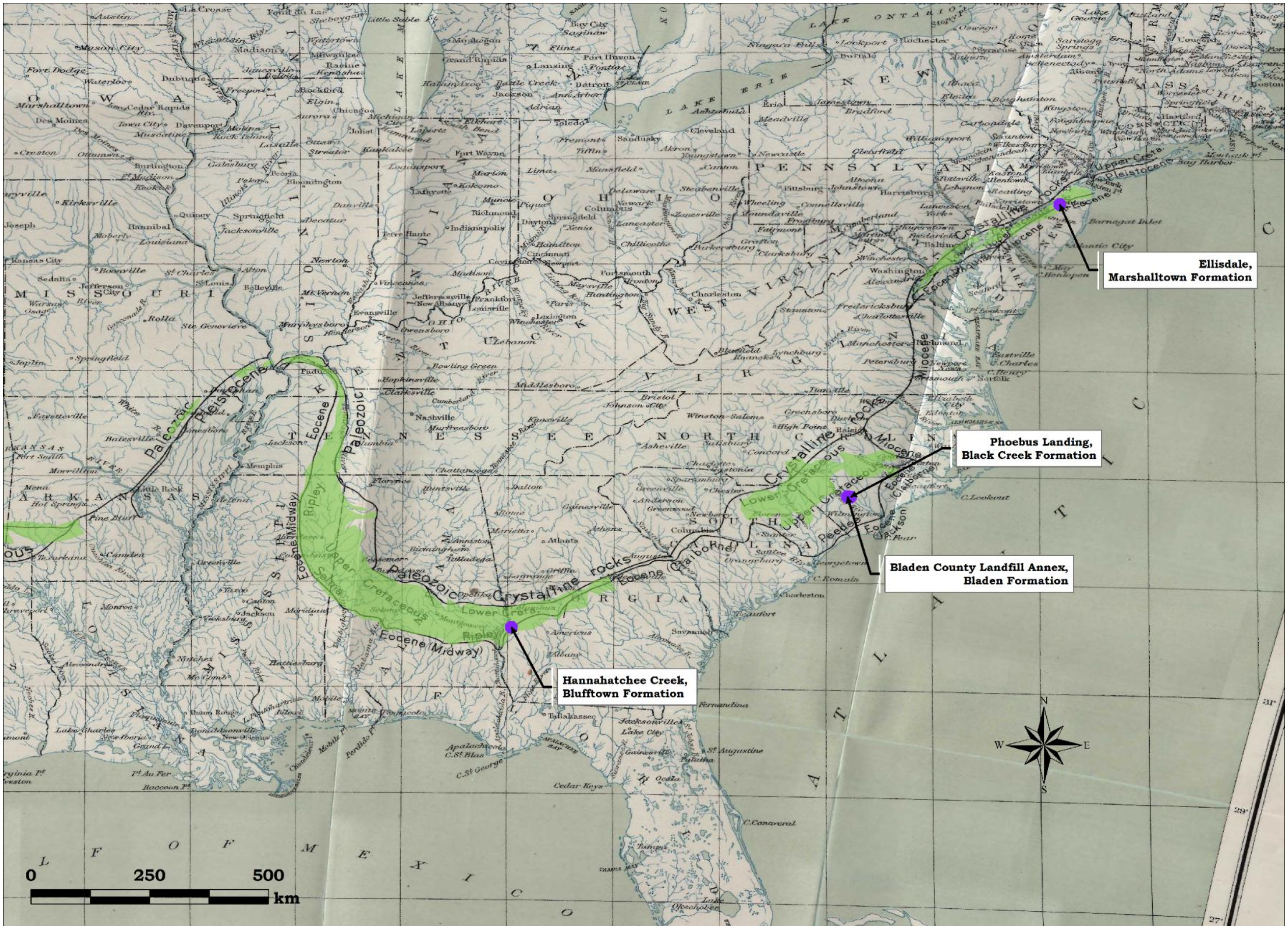


Figure 1. Map showing the Mesozoic (Cretaceous)-Cenozoic unconformity in the Atlantic and Gulf Coastal Plains. Map digitally scanned from Stephenson (1914).

1.3.2 Local (Bladen County) Lithostratigraphy and Chronostratigraphy

In North Carolina, the most extensive research on Cretaceous vertebrates has been conducted in southeastern North Carolina primarily in Sampson, Bladen and Robeson counties. Bladen County (Fig. 2), with its extensive outcrops of Upper Cretaceous strata along the banks of the Cape Fear River, has been the focus of numerous scientific investigations. Bladen County is located in the southeastern region of the North Carolina coastal plain (Fig. 2). It is bordered on the north by the South River and on the east by the Black River. The Cape Fear River meanders in a southeast direction through the central part of the county (Fig. 3).

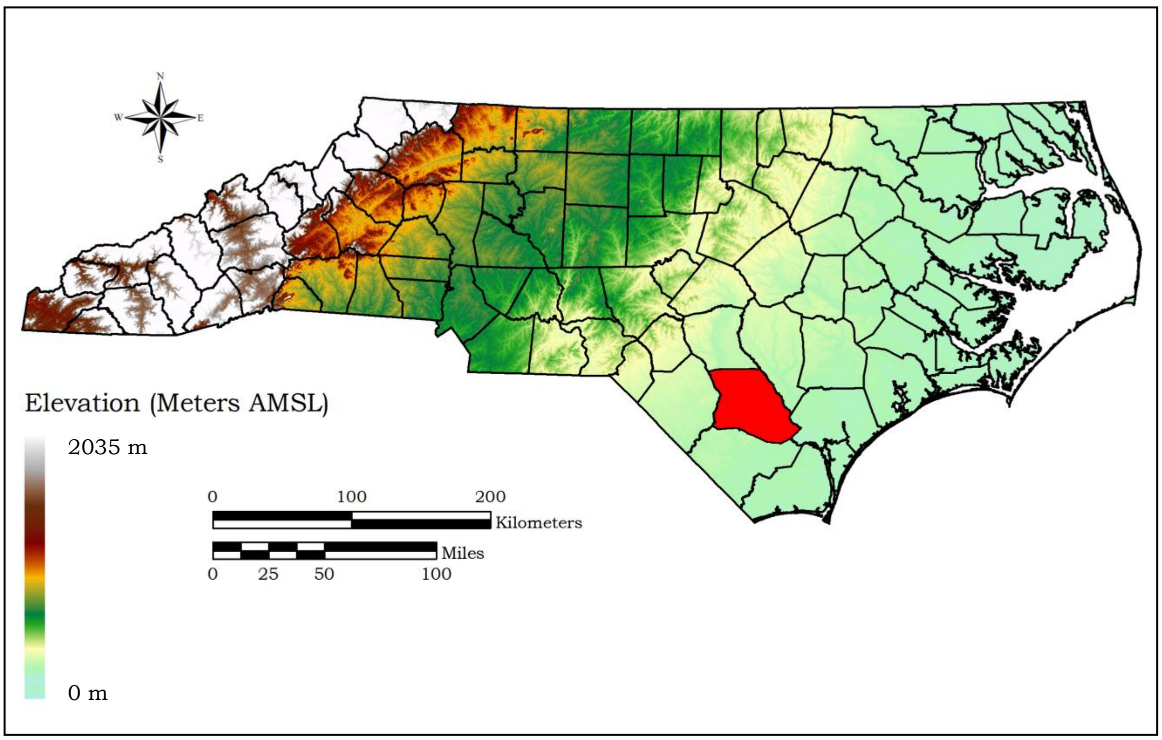


Figure 2. LiDAR map of North Carolina depicting the geographic position of Bladen County (red); elevation relative to sea level. Map Source: North Carolina Floodplain Project LiDAR.

During the early Cenozoic, this region was uplifted forming the Cape Fear Arch (Heron and Wheeler, 1964). The arch extends from the Piedmont to the coast with a northwest-southeast trend; its axis lies in Bladen County (Harris et al., 1986) (Fig. 3). Cretaceous rocks exhibit a 0.2° dip to the southeast in Bladen County (D. Lawrence, pers. comm., 2009). The Cape Fear River valley lies to the northeast, roughly parallel to this tectonic feature. Late Cenozoic and Pleistocene terrace deposits extend across the arch blanketing the Upper Cretaceous formations of the Bladen County area (Soller, 1988). According to Mallinson et al. (2010) the Cape Fear Arch is also referred to as the Mid-Carolina Platform High. It is defined by Paleozoic crystalline basement rock approximately 1 km below the surface, with a width extending from Cape Romain, South Carolina to Cape Lookout, North Carolina (Mallinson et al., 2010).

The stratigraphy of southeastern North Carolina and the nature of late Cretaceous depositional environments have been intensely debated over the years (Sohl and Owens, 1991) (Fig. 4). Heron (1958) recognized four late Cretaceous formations along the Cape Fear River between Fayetteville and Wilmington: the Cape Fear, Middendorf, Black Creek and Peedee formations.

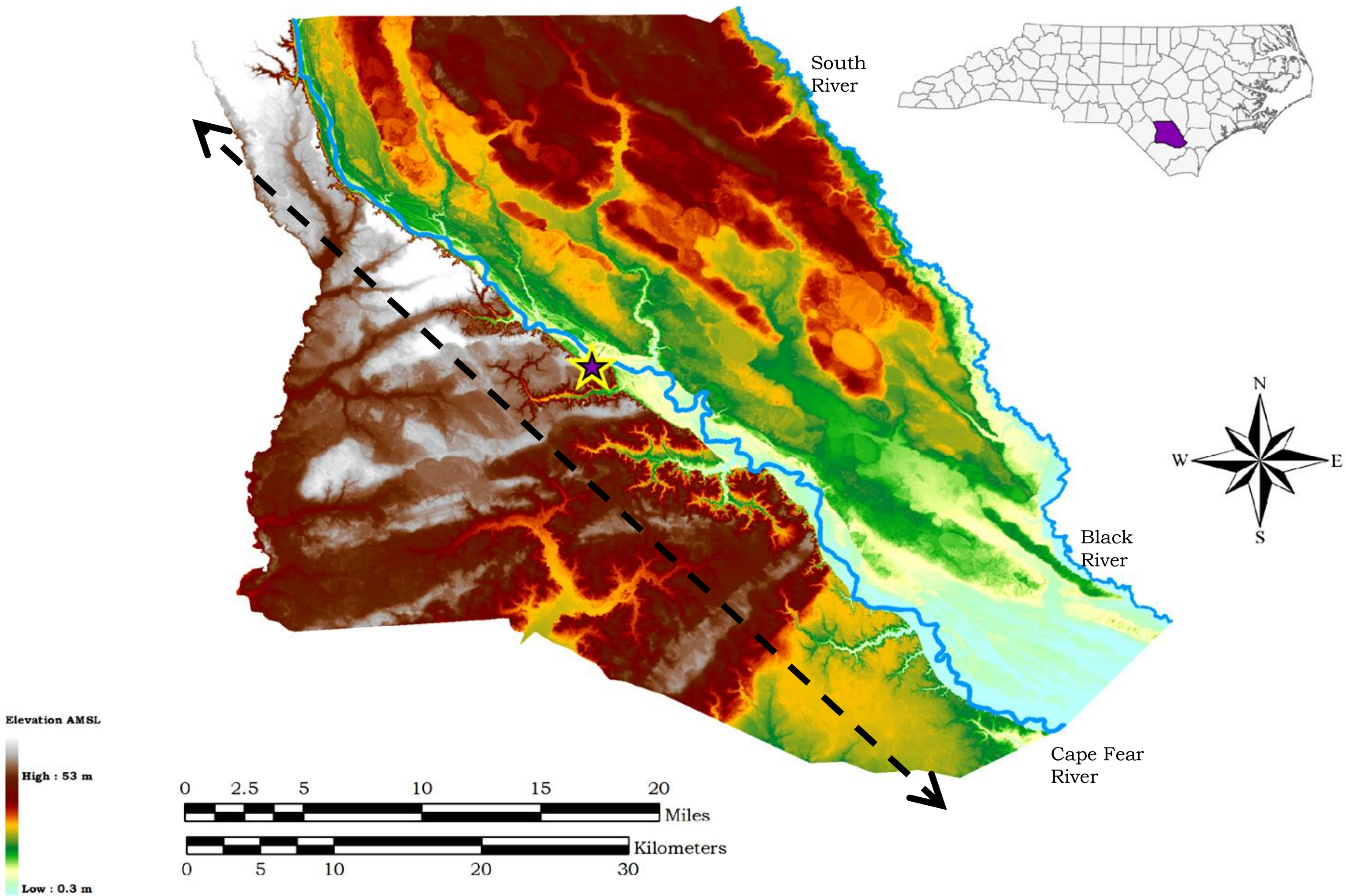


Figure 3. LiDAR map of Bladen County, North Carolina; elevation relative to meters above mean sea level (AMSL). Elizabethtown (and the Bladen County Landfill Annex) designated with the star. Inset shows the location of Bladen County (purple). Dashed arrow indicates the approximate location and trend of the Cape Fear Arch (Harris et al., 1986). Map Source: North Carolina Floodplain Project LiDAR.

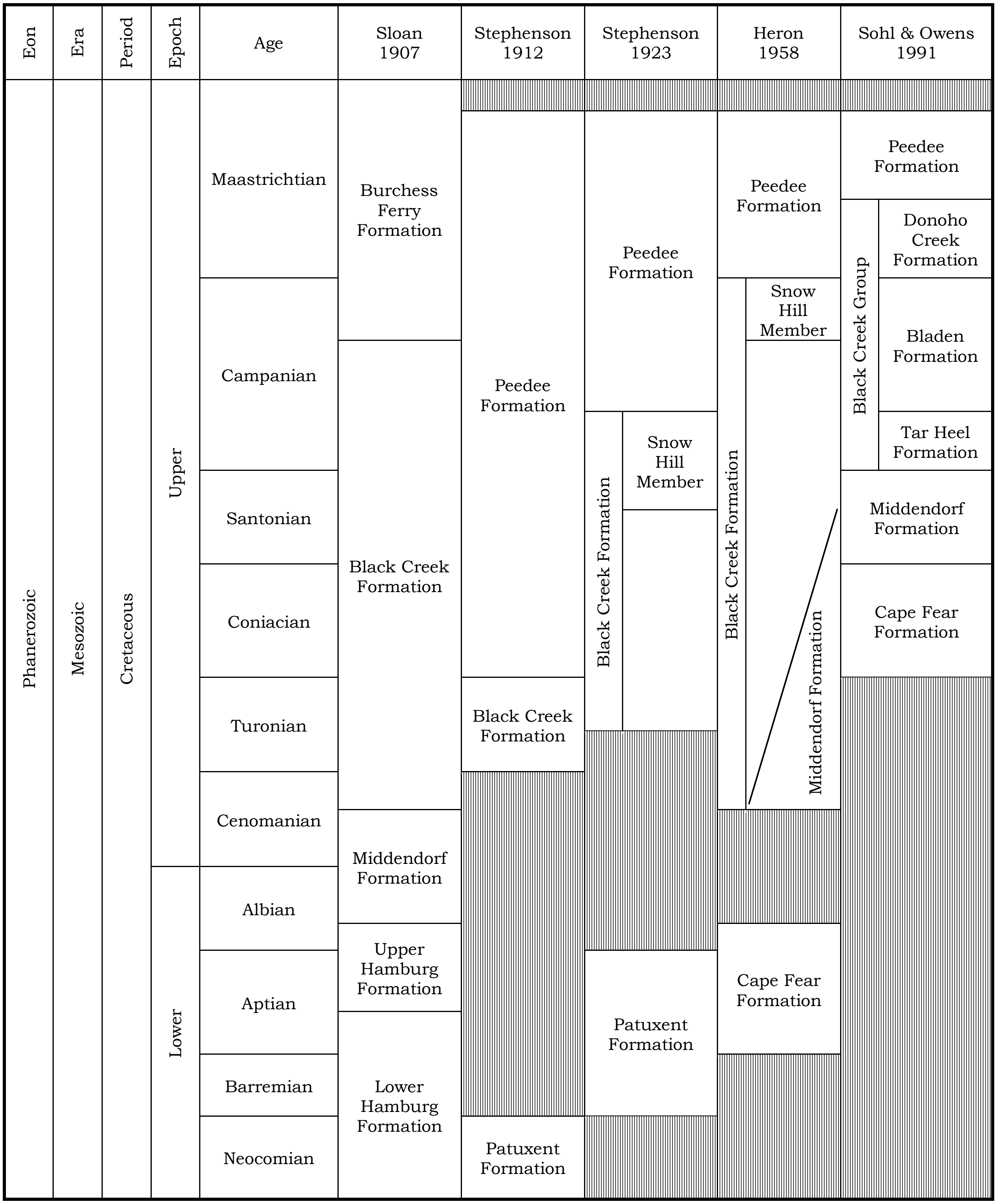


Figure 4. Stratigraphic interpretations of North Carolina and South Carolina depicting the designation of Cretaceous age strata since 1907. Modified from Sohl and Owens (1991).

1.3.2.1 The Cape Fear Formation

Described and named by Stephenson (1907), the Cape Fear Formation consists of approximately 100 meters (300 feet) of arkosic and micaceous sandstones and clays with various intergradations of arenaceous clays and argillaceous sands (Stephenson, 1907). Based on palynological data from New Jersey and nannofossil data from South Carolina, Sohl and Owens (1991) assigned a Coniacian age (Fig. 4) to the Cape Fear Formation.

Sedimentary units within the Cape Fear Formation consist of 1 to 4.5 meter thick massive sandstones containing intercalated layers of mudstone, quartz pebbles, and zones of intraformational conglomerate (Heron and Wheeler, 1964). The sandstones are devoid of fossils and are composed mainly of quartz with minor amounts of feldspars, mica, and rock fragments. Clay minerals are mostly montmorillonite and kaolinite with minor illite. The intraformational conglomerates consist of sub-rounded to angular fragments of mudstone and rounded quartz pebbles (Heron and Wheeler, 1964).

The Cape Fear Formation was interpreted by Heron and Wheeler (1964) as forming by turbidity flows within a marine environment. They identified sedimentary structures characteristic of deposition from turbidity currents, noted that the fluidity index (the ratio of detrital grains to detrital matrix) of the sandstone suggests deposition from high particle density fluids, and recorded the occurrence of montmorillonite believed (by Heron and Wheeler) to be a marine environment indicator. A more recent evaluation (Sohl and Owens, 1991) concluded that the Cape Fear Formation was deposited in an upper delta plain environment. This interpretation was based primarily on the absence of physical marine indicators (i.e., burrows), the absence of marine organisms, and the occurrence of abundant montmorillonite, which can also form in terrestrial soils.

1.3.2.2 The Middendorf Formation

Named by Sloan in 1904, after exposures located along the railroad at Middendorf, South Carolina (Sohl and Owens, 1991), the Middendorf Formation is composed of massive sands containing thin discontinuous mudstone lenses and cross-bedded sands containing mudstones occurring as layers, pods, balls, and irregular masses (Heron and Wheeler, 1964). According to Sohl and Owens (1991), the Middendorf Formation is Santonian in age (Fig. 4). It is absent along the Bladen County segment of the Cape Fear River (Farrell et al., 2001). Although leaf impressions have been found in outcrops along the Cape Fear River upstream of Bladen County, the Middendorf Formation seems to be devoid of other fossils (Heron and Wheeler, 1964).

Heron and Wheeler (1964) suggested a fluvial depositional environment for the Middendorf Formation based on: the sands exhibit festoon (current-generated) bedding, relatively clean sands (free of clay), the presence of generally clay-rich lenses exhibiting small basin shapes, and the occurrence of clay ball conglomerates. Sohl and Owens (1991) concluded that the Middendorf Formation was of deltaic origin based mostly upon the deltaic interpretation for the underlying Cape Fear Formation.

1.3.2.3 The Black Creek Group

Earle Sloan proposed the name Black Creek in 1907 for exposures along the Black Creek, a tributary of the Great Pee Dee River, in Florence and Darlington counties, South Carolina (Stephenson, 1912). The Black Creek Formation is predominately thinly laminated ferruginous sands and clays that vary abruptly, both horizontally and vertically, between clay and sand. Large lenses of medium-grained, highly crossbedded sand occur locally (Stephenson, 1912).

Thin seams of lignite and comminuted (fragmented) vegetable matter are common components of the Black Creek Formation. Throughout the formation, iron sulfide, in the form of marcasite, is commonly associated with the lignite (Stephenson, 1912). Fossils of the Black Creek Formation include dinosaur, turtle and crocodile remains, multiple plant species, and oyster fragments (Heron and Wheeler, 1964; Swift, 1964; Stephenson, 1912).

Swift (1964) distinguished four depositional environments within the Black Creek Formation. Fluvial deposits were recognized based on alternating beds of clean sand and clay. A transitional river flood-dominated fluviomarine sequence was recognized by the presence of fine-grained sediments, increased clay content, a less defined occurrence of alternating beds of clean sands and clays, and the presence of foraminifera, oyster fragments, and almost 15% glauconite. A lagoonal sequence was identified based on the occurrence of lenticular, thinly-bedded, bioturbated sediments. Finally, a sequence of pale sand beds varying in thickness from 0.3 meters to 6.7 meters, with an average thickness of 0.8 meters, was identified as littoral in origin. Based on Swift's

(1964) descriptions of the lithology transitioning from sands to fine sands and clays to bioturbated sediments and back to sands, the four depositional environments were considered to represent a transgressive sequence (Swift, 1964).

Sohl and Owens (1991) re-evaluated the Upper Cretaceous formations along the Cape Fear River and presented a revised interpretation of the Black Creek Formation based on the recognition of disconformities coupled with lithologic changes above and below these breaks. They proposed promoting the Black Creek Formation to group rank and dividing it into three formations: the Tar Heel Formation (early Campanian), the Bladen Formation (late Campanian), and the Donoho Creek Formation (early Maastrichtian) (Sohl and Owens, 1991) (Fig. 4).

1.3.2.3.1 The Tar Heel Formation

The Tar Heel Formation, Owens (1989), is named after exposures along the Cape Fear River in Bladen County between Tar Heel Landing (milepost 88.5) and Courthouse Landing (milepost 77) (Owens, 1989). According to Sohl and Owens (1991), the Tar Heel Formation consists of thin, horizontally bedded, black carbonaceous clays interbedded with micaceous, white to buff colored sands. An early Campanian age for the Tar Heel Formation was determined from the characteristics of pollen, ostracode, and molluscan assemblages (Sohl and Owens, 1991) (Fig. 5). According to Sohl and Owens (1991), the Tar Heel

Formation is a prime example of a lithofacies progression from a shelf regime to a deltaic system.

1.3.2.3.2 The Bladen Formation

First named by Stephenson (1907) (then reinstated by Owens in 1989), after exposures along the Cape Fear River south of Elizabethtown, the Bladen Formation represents a continuation of a delta to shelf depositional system of late Campanian age (Fig. 5). The Bladen Formation is composed of mostly laminated dark clay with thin interbeds of glauconitic quartz sand. Lignite fragments are frequent whereas indurated fossil-bearing sands are rare (Sohl and Owens, 1991).

The Bladen Formation can reach up to 9 meters in thickness and has been divided by Sohl and Owens (1991) into upper and lower beds. The lower beds are composed of black clay with interbedded white sands showing burrowing. They are overlain by non-burrowed, irregularly bedded to cross-bedded lenses of fine to coarse sands interbedded with laminated, dark, carbonaceous clay. The upper beds are capped by a thin sequence of reworked phosphatic sand (Sohl and Owens, 1991).

1.3.2.3.3 The Donoho Creek Formation

The Donoho Creek Formation (Owens 1989), was named from exposures along the Bladen County reach of the Cape Fear River between Donoho Creek landing (milepost 50.2) and Black Rock Landing (milepost 37). It is the uppermost unit of the Black Creek Group and is early Maastrichtian in age (Sohl and Owens, 1991) (Fig. 4). According to Sohl and Owens (1991), the Donoho Creek Formation formed in a delta front-prodelta to shelf depositional environment.

The basal unit of the Donoho Creek Formation is comprised of thin sand with quartz and phosphate pebbles, bone and tooth fragments, and abraded shells. This unit is overlain by dark-gray, massive, slightly glauconitic, quartz sand characterized by appreciable clay content and scattered *Ostrea* fossils (Sohl and Owens, 1991). The upper beds of the Donoho Creek Formation are composed of massively bedded, dark-gray, micaceous, sparingly glauconitic, bioturbated clayey sand. The Donoho Creek Formation is capped by a disconformity with the overlying Peedee Formation (Sohl and Owens, 1991).

1.3.2.4 <u>The Peedee Formation</u>

Named by Ruffin (1843), after exposures along the Pee Dee River in South Carolina, the Peedee Formation is represented in North Carolina by dark greenish gray to dark gray micaceous glauconitic and argillaceous sands. It is characterized by indistinct mottling and vague bedding, suggesting a deep shelf environment that experienced little to no bottom currents (Heron and Wheeler, 1964). The Peedee Formation falls within the *Exogyra costata* Zone, a Maastrichtian biostratigraphic marker (Sohl and Owens, 1991) (Fig. 4).

Heron and Wheeler (1964) separated the Peedee Formation into two units. The lower Peedee consists of muddy sands, whereas the upper Peedee consists of thick bedded sandy muds. The fauna within the Peedee Formation along the Cape Fear River consists predominantly of mollusks and foraminifera (Heron and Wheeler, 1964). According to Sohl and Owens (1991), the Peedee Formation represents a period of marine shelfal sedimentation characterized by episodes of coarser clastic influx during regressive intervals.

1.3.2.5 Cenozoic Terraces

Johnson (1907) identified a series of terraces within the North Carolina Coastal Plain. He noted that the terraces were each separated by well-defined seaward facing escarpments with the same north-south trend as the terraces. Stephenson (1912b) produced descriptions and stratigraphic interpretations of the North Carolina terraces and named the terraces, using names from studies conducted in Maryland by Shattuck (1901, 1906). In Bladen County, Stephenson recognized and mapped two terraces, the Sunderland and the Wicomico (Stephenson, 1912b). Cooke (1930, 1931, 1936) utilized average contour elevations from Connecticut to Texas and studied the shore-facing features at 82 m (270 ft), 66 m (215 ft), 52 m (170 ft), 30 m (100 ft), 21 m (70 ft), 13 m (42 ft) and 8 m (25 ft) above sea level and proposed that glacial control of sea level was the basis of the formation of the terraces.

DuBar (1971, 1974) correlated the Bear Bluff, Waccamaw, and Socastee Formations of South Carolina with the strata previously described in North Carolina. Owens (1989) published a geologic map of the Cape Fear Region (Fig. 5) which identified and described the late Cenozoic formations of the southeastern region of North Carolina. They are the Duplin Formation (lower Pliocene), the Bear Bluff Formation (upper Pliocene), the Waccamaw Formation (lower Pleistocene), the Penholoway Formation (lower Pleistocene), the Canepatch Formation (middle Pleistocene), the Socastee Formation (upper Pleistocene), and the Wando Formation (upper Pleistocene) (Owens, 1989).

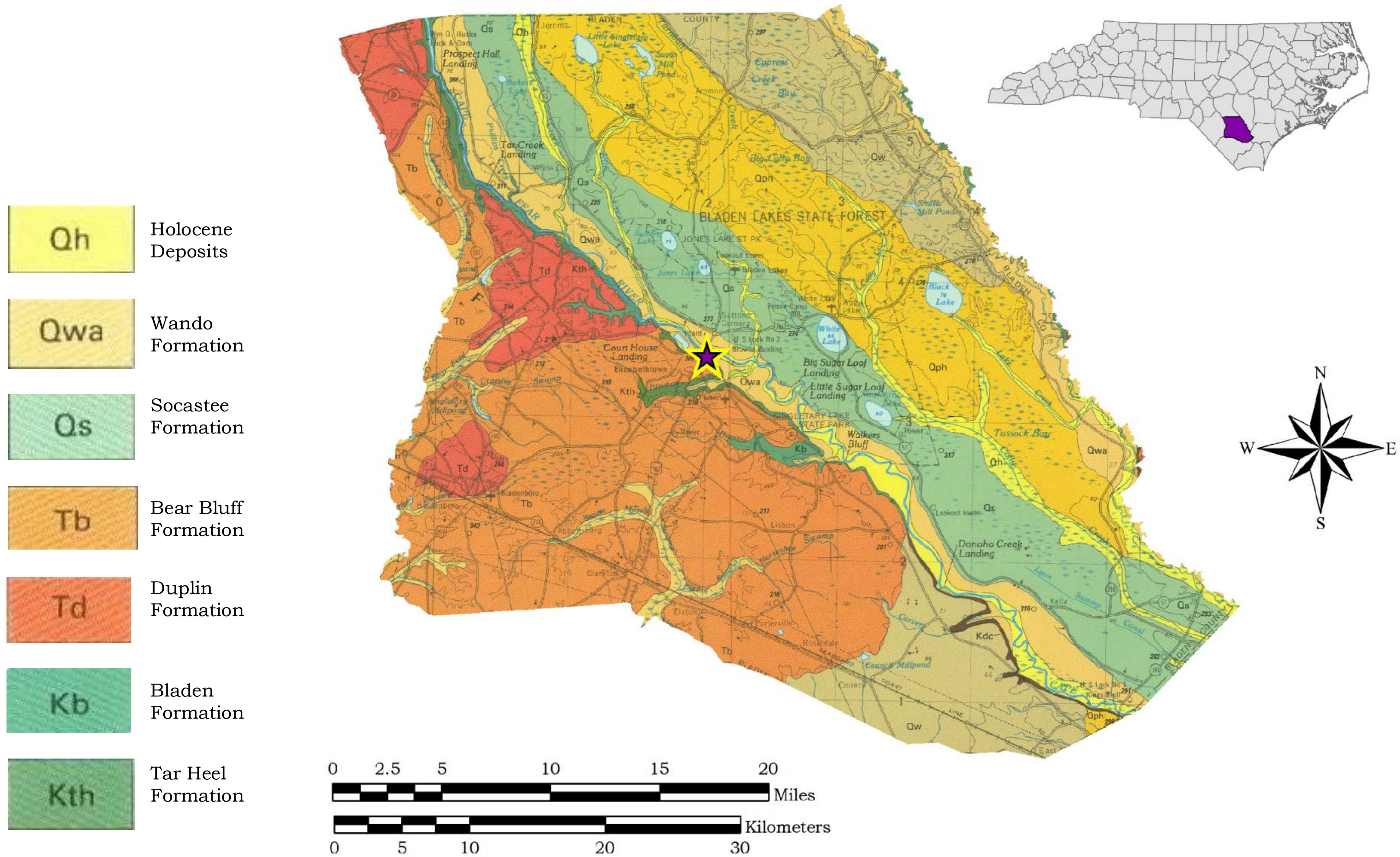


Figure 5. Geologic map of Bladen County, North Carolina. Elizabethtown designated with a star (from Owens, 1989).

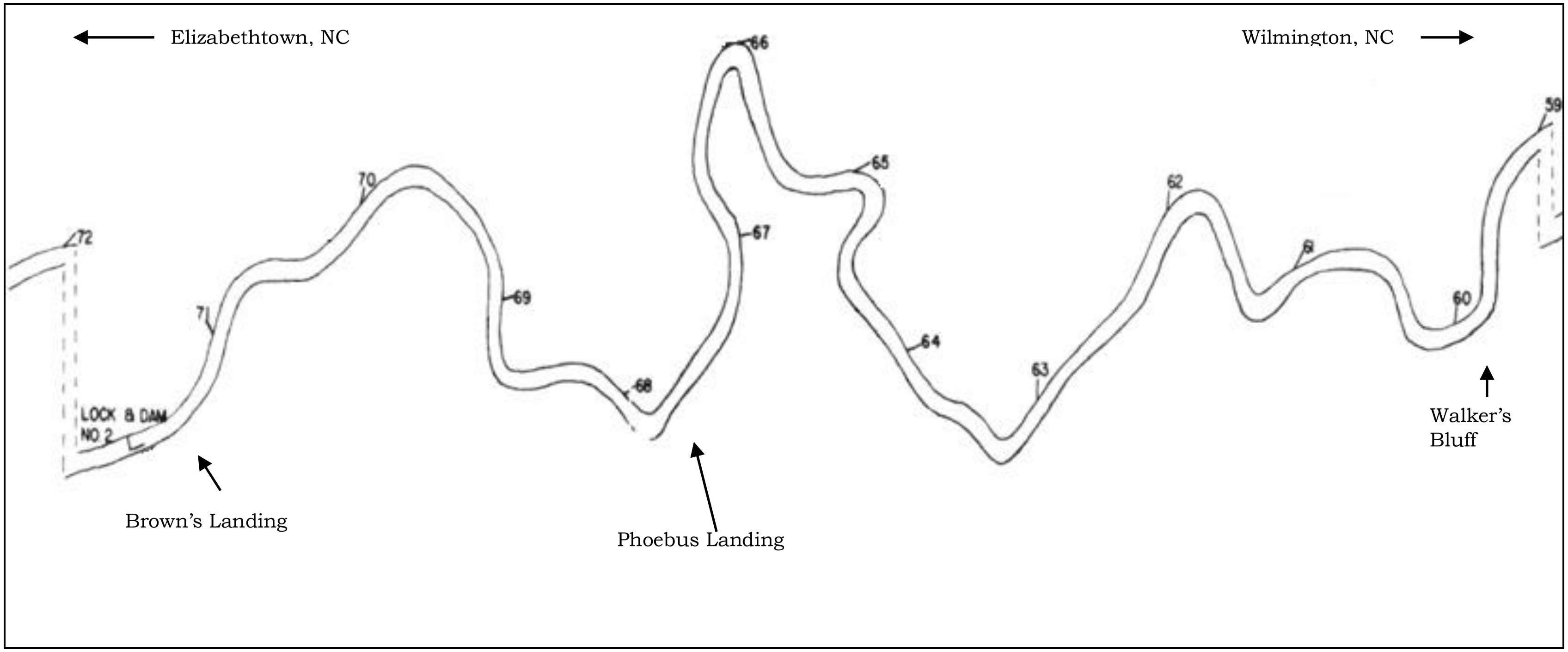


Figure 6. Cape Fear River transect from milepost (MP) 72 to milepost (MP) 59, downstream from Elizabethtown, North Carolina. Brown's Landing (MP 71.5), Phoebus Landing (MP 67.75), and Walker's Bluff (MP 60) designated. Modified from Powers (1951).

1.3.3 Geologic overview of Phoebus Landing, Bladen County, North Carolina

Heron and Wheeler (1964) noted that Phoebus Landing was the sole locality within the Black Creek Formation that repeatedly yielded the bones of large Cretaceous reptiles (Heron and Wheeler, 1964, p. 42). Past researchers, with the exception of Emmons (1858) (see below), identified the bonebed at Phoebus Landing as stratigraphically positioned at an unconformity between the underlying Cretaceous laminated sands and clays (or shales) and the overlying Cenozoic unconsolidated sands and clays. Emmons (1858) first described a small bluff on the right bank of the Cape Fear River downstream from Elizabethtown, between Brown's Landing (MP 71.5) and Walkers Bluff (MP 60) (Fig. 6). This small bluff is presumed (in this thesis) to be Phoebus Landing. The stratigraphic section of Phoebus Landing described by Emmons (Fig. 7), consisted of sand containing lignite with numerous fossils (unit 5), overlain by a 0.9 m (3 ft) thick shell marl (unit 4) capped by sand (unit 3), brown earth (unit 2) and pebbly sand at the surface (unit 1); units six and seven were not described. Emmons referred to the lignite-bearing unit (unit 5) as the "Miocene marl," (Fig. 8) but later re-evaluation indicated a Cretaceous age (Newberry, 1874).

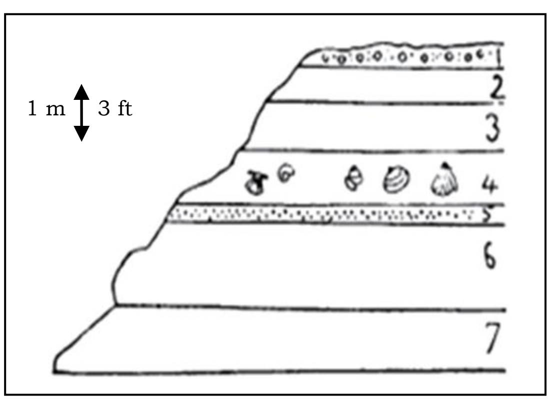


Figure 7. Geologic section between Brown's Landing and Walker's Bluff (presumably Phoebus Landing). From Emmons 1858, page 86, figure 4: digitized by Google Books

Stephenson (1912, p. 120) discussed the outcrop at Phoebus Landing and noted the occurrence of “badly broken and poorly preserved dinosaur bones, coprolites, crocodilian teeth, turtle and gavial plates, and sharks teeth imbedded in the clay and also lying loose upon the surface of the Black Creek Formation”. He recognized the overlying clay loam, sand, and gravel as being Pleistocene in age (Fig. 8). Later, Powers (1951) studied the Cretaceous Black Creek deposits along the Bladen County segment of the Cape Fear River (Fig. 6). Of particular importance to this thesis is an outcrop Powers (1951) described in the vicinity of Phoebus Landing approximately at river milepost 67.7. Powers’ (1951) description of this outcrop (referred to by Powers as Station 41) is as follows:

> Station 41, located 0.3 mile below milepost 68 is described as: “5.0 feet of alternating layers of white, sorted, subrounded to rounded, thin- to thick-bedded, medium-grained, loose sand; and dark gray when wet, light gray when dry, well-sorted, thin-bedded, poorly-indurated, micaceous, quartz, silty clayrock. Some of the clayrock layers contain a large amount of carbonized plant-matter fragments. This outcrop is overlain by soil slump.” (Powers, 1951, page 48)

In general, Powers (1951) recognized an unconformity between the alternating Cretaceous sands and clayrock and a modern soil slump at the stations close to the Phoebus Landing site. He did not note the presence of vertebrate fossils (Fig. 8).

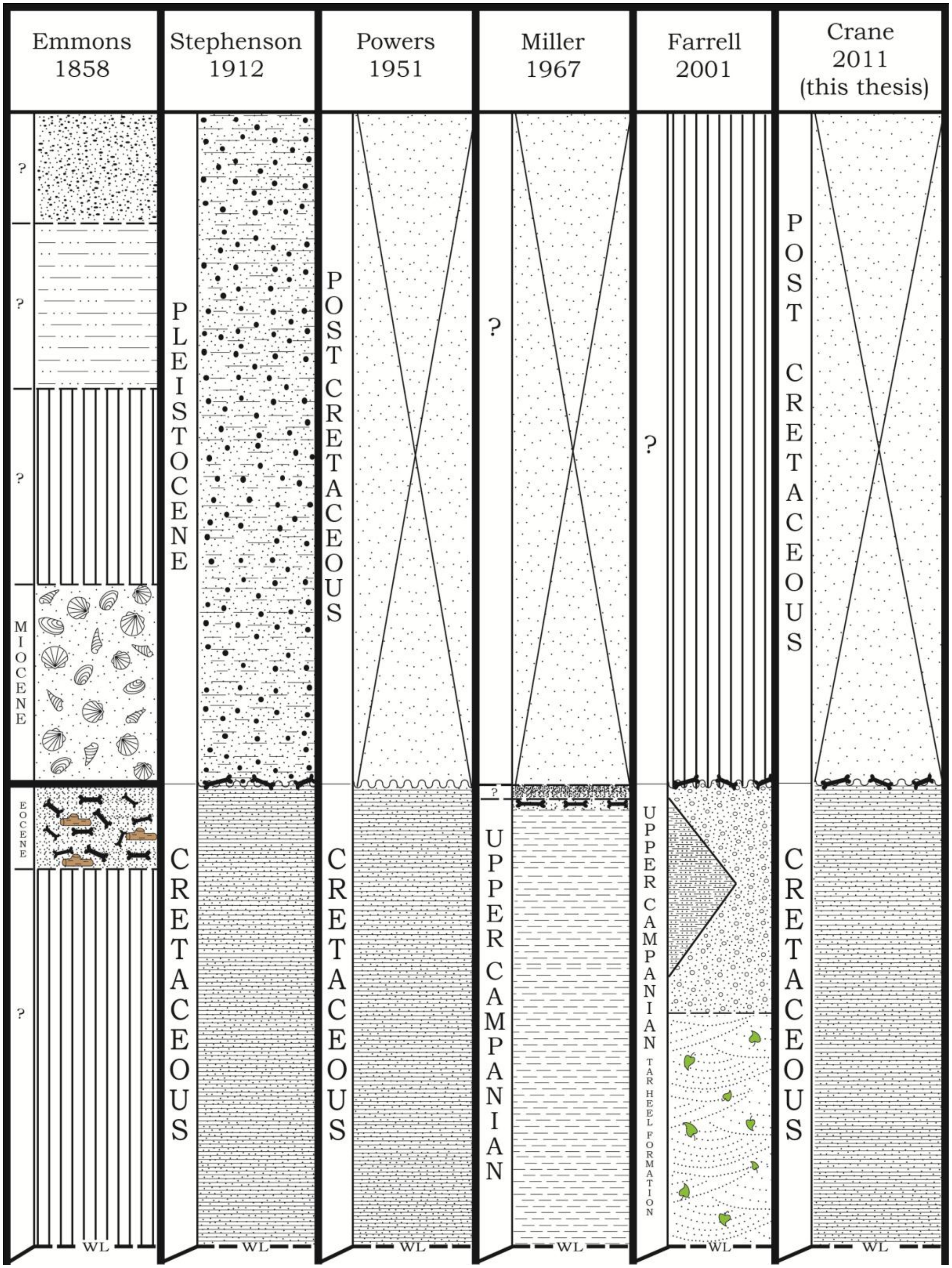


Figure 8. Composite stratigraphic correlation of Phoebus Landing lithostratigraphy using the fossil bearing unit as the stratigraphic datum. Figure 9 provides the key to the symbols.

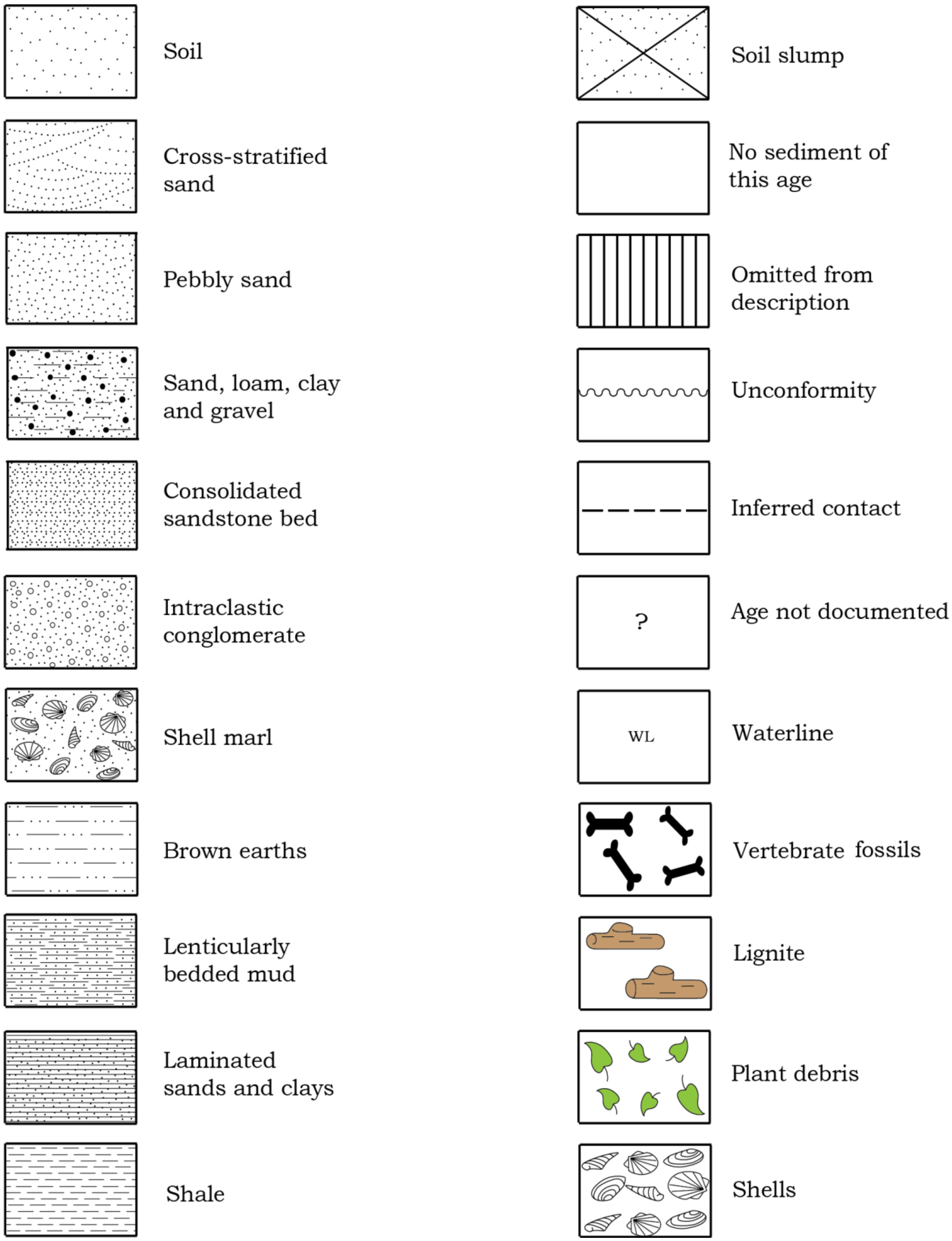


Figure 9. Key to lithologic symbols for Figures 8, 37, and 38.

Miller (1967) re-described the “bone-bearing bed” at Phoebus Landing as a (maximum of) 1.2 m (4 ft) thick and 24 m (80 ft) wide unconsolidated sand lens representing a channel fill that was downcut into the upper Campanian shales of the Black Creek Formation. The unconsolidated sand lens was overlain by a six inch thick consolidated sandstone bed which was overlain by slumped overburden. Miller (1967) noted that the bonebed (devoid of spores, pollen and invertebrates) contained Cretaceous fossils of marine and freshwater fish (mostly sharks) and reptiles (mosasaurs). Therefore, he reasoned that the unconsolidated sandstone lens containing the bonebed was likely to have formed as a component of the Black Creek Formation. When discussing the age and formation of the bonebed at Phoebus Landing, Miller (1967) stated that the majority of the bones were originally deposited in the unconsolidated sand lens, that some of the fragmentary and worn vertebrate fossils appeared to be reworked from an older bed (possibly from the underlying shale); yet “it was difficult to determine which bones had undergone the reworking process” (Miller, 1967, p. 221). He concluded that the vertebrate fossils recovered from Phoebus Landing were, for the most part, from either the unconsolidated sand lens or lying on the surface of the shale (following their erosion from the unconsolidated sand lens) (Fig. 8).

The most recent geologic description of the Phoebus Landing site was presented by Farrell (1998). She considered the exposed units to be the Tar Heel Formation of the Black Creek Group (Sohl and Owens, 1991). Farrell (1998) included a composite sketch of the bluff at Phoebus Landing (Fig. 10) and identified three main facies: cross-stratified sand; intraclastic conglomerate; and lenticularly bedded mud. The vertebrate fossils were noted within the upper surface of the intraclastic conglomerate ("lag") deposit. This upper surface (Fig. 8) contained "coprolites, vertebrate bones, shark's teeth, cemented intraclasts, mudball ripup clasts, pebbles, logs, and a variety of other clasts" (Farrell, 1998, p. 17). The stratum overlying the intraclastic conglomerate was not addressed by Farrell (Fig 8). A more recent assessment (this thesis) of the Phoebus Landing site is that the bonebed lies on an erosional surface at the top of the laminated sands and clays of the upper Campanian Tar Heel Formation and is overlain by unconsolidated slumped sand and soil of post-Cretaceous age (Fig. 8).

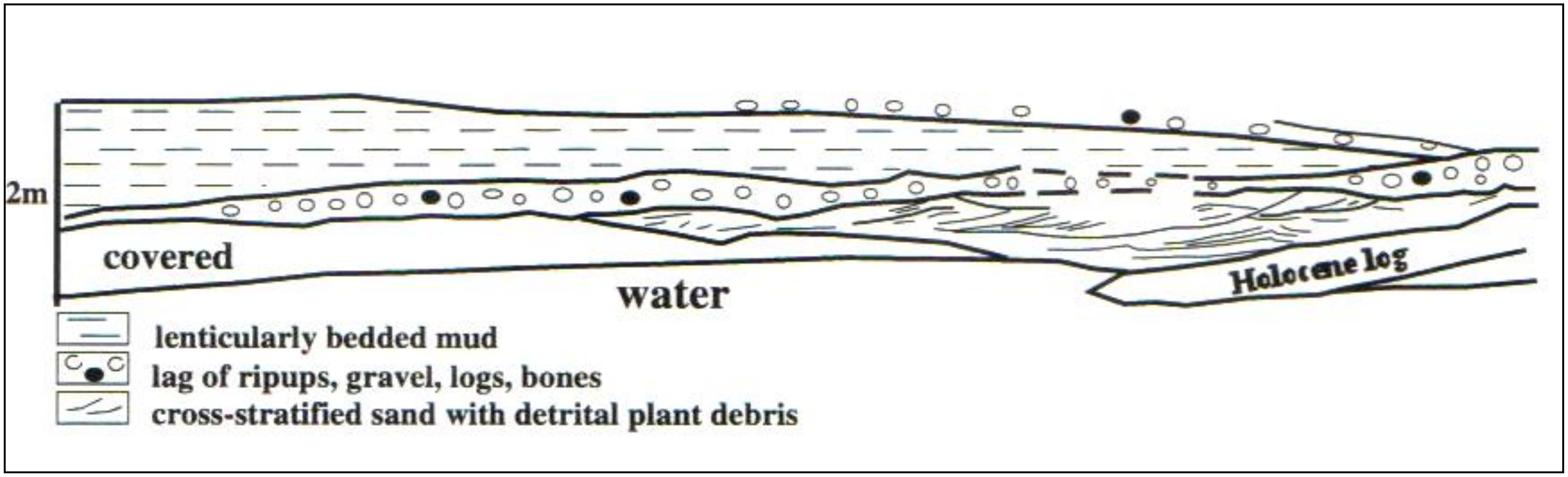


Figure 10. 3-D facies perspective of the Phoebus Landing, Bladen County, locality with a localized lens of lenticularly bedded mud within the conglomeratic lag deposit (from Farrell, 1998).

1.4 STUDY AREA: BLADEN COUNTY LANDFILL ANNEX

1.4.1 Introduction

The focus of this research is the Bladen County Landfill Annex (BCLA), 1522 Mercer Mill Road, Elizabethtown, North Carolina (latitude 34.6N, longitude 78.6W). The BCLA is located approximately 3.2 kilometers (2 miles) south of the center point of Elizabethtown, NC and approximately 7 kilometers (4.4 miles) WNW of Phoebus Landing. Although the site has been excavated over the years by both professional and amateur collectors, an extensive investigation of the vertebrate fossils and the depositional environment has not been conducted.

1.4.2 Previous research of the BCLA site

The first scientific field excavation of the BCLA site was carried out from autumn 1996 to spring 1998 by the North Carolina Museum of Natural Sciences, Raleigh (Schneider, 1998). Following the conclusion of the Museum's excavation, various amateur paleontologists collected at the site. The North Carolina Museum of Natural Sciences collection from this excavation has not been formally described in its entirety. This thesis focuses on the North Carolina Museum of Natural Science's collection supplemented with BCLA collections held by private individuals.

Bill Straight and James Lamb (unpublished) described the sediments at the BCLA site in 1997 (Fig. 11) during the North Carolina Museum of Natural Sciences excavations (Schneider, 1998). According to Lauck Ward (personal communication, August, 2010), the strata immediately overlying the fossil-bearing horizon are considered to be the Pliocene Bear Bluff Formation (Chowan River Formation equivalent), but this determination is questionable due to the lack of research on these sediments (Lauck Ward, personal communication, August 2010). Straight and Lamb divided the outcrop into units 1 through 4 (unit 1 being the oldest, unit 4 the youngest), and described the strata as follows:

Unit 1: Consisted of 24 inches (56.4 cm) of medium to coarse quartz arenite with minor mica. Unit is unfossiliferous and white in color.

Unit 2: A 121 inch (284.4 cm) thick section; the lower 92 inches (216.2 cm) consists of alternating beds of thin quartz arenite and finely laminated blue-black mud thinning upward to alternating thin beds of green-gray mud and very fine yellow sand or silt. The upper 29 inches (68.2 cm) of this unit consists of a 4 inch (9.4 cm) bed of iron stained fine sand overlain by 15 inches (35.3 cm) of grey clay with thin laminations of interbedded fine sand capped by a lag consisting of nodules, shark teeth, vertebrate fossils and wood. This 15 inch (35.3 cm) bed is overlain by 10 inches (23.5 cm) of brown grey clay capped by a lag of shark teeth.

Unit 3: Consisted of 20 inches (47 cm) of shell hash containing corals and mollusks confined within irregular lower and upper contacts.

Unit 4: Reddish brown medium sand to surface. Unit thickness was unmeasured.

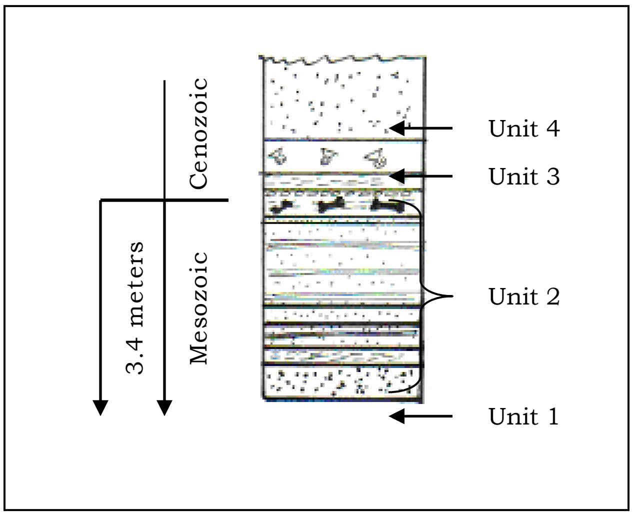


Figure 11. Stratigraphic section of the Bladen County Landfill Annex. Redrawn from field notes by Bill Straight and James Lamb in Schneider (1998).

1.4.3 Age and stratigraphic position of the BCLA site

The age of the fossiliferous horizon at the BCLA site has been debated since the site was discovered. The fossiliferous horizon has been postulated to be as old as the Tar Heel Formation (late Campanian) (Gaffney et al., 2009, p. 4) to as young as the Peedee Formation (Ross, 2003). These interpretations range from late early Campanian to early Maastrichtian.

Mitra (2002) conducted a palynological investigation of the Tar Heel Formation in North Carolina to determine if the biostratigraphic data produced from palynological analysis confirmed the early Campanian age for the Tar Heel Formation as previously determined using invertebrate faunal data. Mitra (2002) collected, processed, and evaluated 103 samples from six localities of the Tar Heel Formation. Four samples from the BCLA were included (these samples were obtained from the North Carolina Museum of Natural Sciences collection). Of the four BCLA samples, two (ET-1a and ET-2b) were from the laminated, dark clayey sand zone (with plant impressions) near the base of the section and the other two (ET-2a and ET-2b) were from the fossiliferous micaceous blue-gray clayey sand zone (with bone fragments and woody material).

Her analysis indicated a Campanian age for all six of the Tar Heel Formation localities, thus confirming the age obtained from invertebrate evidence. Of the four palynological samples from the BCLA, angiosperms (flowering plants) were the most common palynomorph component at 76%, followed by pteridophytes (ferns) (10%), fungal forms (7%), gymnosperms (conifers, cycads, *Ginkgo* and

Gnetales) (6%), and dinoflagellates (1%). The relative abundance of various palynomorph groups (represented in Table 1), show that the Elizabethtown site contained a higher abundance of angiosperms than the other five sites and had the lowest relative abundance of pteridophytes, fungal forms, and gymnosperms (see Mitra, 2002 p. 234-237 for species information). Mitra also used a minimum variance clustering technique to compositionally compare the localities. Her results showed that the Elizabethtown locality was significantly different from the other five localities sampled (see Mitra, 2002 p. 163, fig 6a.).

Table 1. Relative abundance (percent) of palynomorphs from six Campanian age (Tar Heel Formation) localities in North Carolina (from Mitra, 2002).

Location	**Angiosperms**	**Pteridophytes**	**Fungal forms**	**Gymnosperms**	**Dinoflagellates**
Elizabethtown	76	10	7	6	1
Goldsboro	44	22	10	20	4
Ivanhoe	59	13	13	12	3
Lock	63	15	10	11	1
Tar River	51	20	8	17	4
Willis Creek	56	16	10	14	4

2.0 PREVIOUS WORK ON CAMPANIAN AGE VERTEBRATES AND VERTEBRATE TAPHONOMY

2.1 PREVIOUS STUDIES OF CAMPANIAN AGE VERTEBRATES IN SOUTHEASTERN, NORTH CAROLINA

2.1.1 <u>1800s</u>

Geologic and paleontologic investigations on the Upper Cretaceous units of Bladen County began in the mid 1800s with studies by Ebenezer Emmons (1858) and Joseph Leidy (1865). Washington Caruthers Kerr (1875) (Fig. 12) and Edward Drinker Cope (Fig. 13) (1869a, 1869b, 1871, 1875) identified and described Cretaceous reptilian vertebrates discovered in Sampson County, including the first recorded dinosaur from North Carolina (*Hypsibema crassicauda*). The specimens identified and described by E. D. Cope were discovered and collected by Kerr in Sampson County.

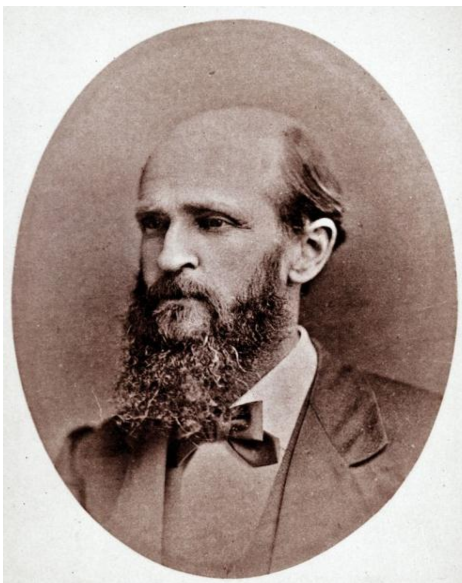


Figure 12. Photograph of Washington Caruthers Kerr, North Carolina State Geologist (1864-1882). Courtesy of North Carolina State Archives.

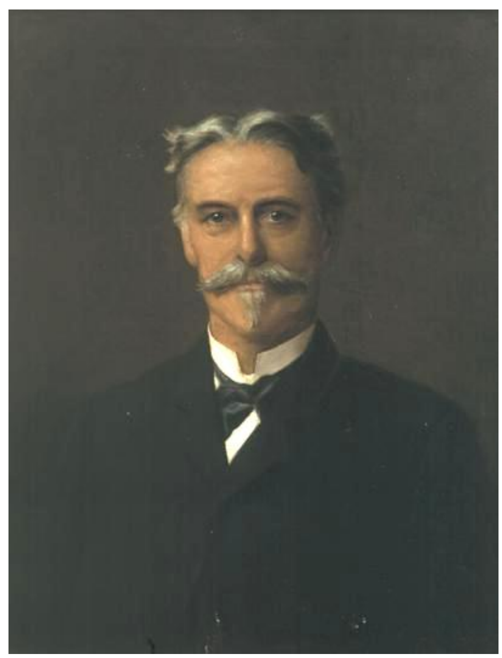


Figure 13. Image of Edward Drinker Cope, 1897. Courtesy of the Academy of Natural Sciences, Philadelphia, Pennsylvania

2.1.1.1 Emmons (1858)

While conducting an agricultural survey of North Carolina, Ebenezer Emmons (Fig. 14) recorded vertebrate fossils along the Cape Fear River within strata that he deemed as belonging to the "Miocene marl" (now known to be late Cretaceous). In his report, Emmons (1858) sketched two stratigraphic sections of the Cape Fear Bluffs of Bladen County; one from Brown's Landing, the other from an outcrop lying downstream of Brown's Landing (Fig. 6).

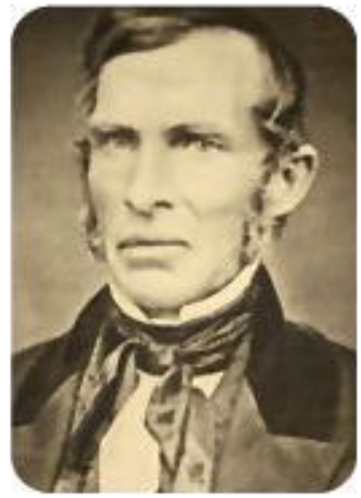
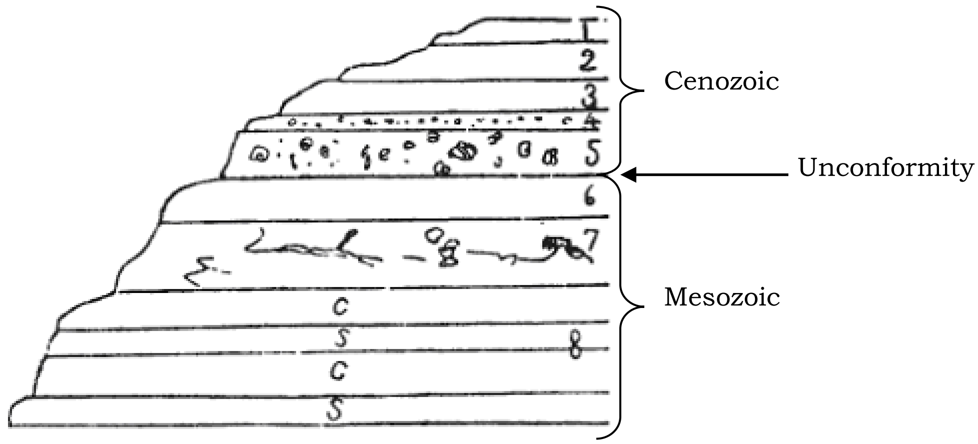


Figure 14. Photograph of Ebenezer Emmons. Courtesy of New York State Archives.

The Brown's Landing section (Fig. 15) is located near US Lock and Dam number 2 (Fig. 6) downstream of Elizabethtown, at approximately river milepost 71.5 (Emmons, 1858). The second section was from an unknown location along the Cape Fear River between Brown's Landing and Walker's Bluff (Fig. 7) (Emmons, 1858) and is likely the Phoebus Landing locality (Fig. 6). Unfortunately, due to the archaic method of documenting outcrops by means of land ownership (i.e., Mr. Flowers marl pit), it is difficult to ascertain the precise locations of sites identified by Emmons as containing vertebrate fossils.



Age	Unit	Description
Cenozoic	1	Sand
	2	Brown earth
	3	Clay; 4-5 feet thick
	4	Sand and pebbles
	5	Shell marl; base of unit consists of a pebbly bed containing rolled coprolites and fossil teeth
Mesozoic	6	Sand with consolidated beds which grades upward into gray sandstone with fossils and lignite
	7	Blue clay
	8	Alternating beds of sand (S) and clay (C)

Figure 15. Brown's Landing stratigraphic section located along the right bank of the Cape Fear River downstream of Elizabethtown, at approximately milepost 71.5. Lithologic units are described in the table below the figure. Emmons noted that unit 5 was of Miocene age while the underlying unit 6 was of Eocene age (due to the presence of lignite). He also stated that "the change in passing from Eocene (unit 6) to Miocene (unit 5) was attended with considerable violence." This "change" is interpreted here as the unconformity (labeled). From Emmons, 1858 page 85, figure 3.

Emmons (1858) described two crocodilian-like teeth discovered near Elizabethtown. He named the specimens *Polyptychodon rugosus* Emmons. Later, Leidy (1865) (Fig. 16) confirmed the identification of one *Polyptychodon rugosus* Emmons specimen (Emmons, 1858, p. 219, fig. 38) but assigned the other (Emmons, 1858, p. 220, fig. 39) to *Mosasaurus*. The specimen of *Polyptychodon rugosus* identified by Emmons and confirmed by Leidy is accessioned as the type specimen in the National Museum of Natural History collections (Smithsonian catalog #535447). This species has since been placed in the genus *Deinosuchus* (Baird and Horner, 1979).

Figure 16. Image of Joseph Leidy, 1882. Courtesy of the Academy of Natural Sciences, Philadelphia, Pennsylvania.

Emmons also described *Elliptonodon compressus* (Emmons, 1858, p. 222-223) and chelonian carapace fragments (referred to as "sculptured cranial plates," p. 221-222) from what he considered the "Miocene marl" near the Cape Fear River in Bladen County. *Elliptonodon compressus* Emmons is now considered *nomen dubium* and the taxon has been reassigned to *Tylosaurus* (Miller, 1967).

Leidy described two saurian teeth discovered by Emmons (Emmons, 1858, p. 223) within the "Miocene marl" deposit of the Cape Fear River and designated them as *Pliogonodon noblis* Leidy, which has since been reassigned to Crocodyliformes (Gauthier et al., 1988). Leidy also described *Drepanodon* *impar* Leidy from a tooth found by Emmons at Elizabethtown; it was later reassigned to the Mosasauridae by Miller (1967).

2.1.2 Early 1900s

2.1.2.1 Stephenson (1912 and 1923)

From the early 1900s to the 1920s vertebrate and invertebrate paleontological investigations were carried out by Lloyd William Stephenson (1912, 1923) (Fig. 17) and paleobotanical investigations by botanist Edward Wilbur Berry (1907, 1910, and 1911) within Bladen County. Stephenson discussed the outcrop at Phoebus Landing and gave a brief overview of the "badly broken and poorly preserved dinosaur bones, coprolites, crocodilian teeth, turtle and gavial plates, and sharks teeth" (1912, p. 120). A few of the specimens were identified by Charles Whitney Gilmore, (presumably through personal communication with Stephenson, since published work by Gilmore on the subject cannot be located; David Bohaska, personal communication, July 23, 2010) as dinosauria *Hypsibema crassicauda* Cope, *Trachodon tripos*? Cope, and an undetermined carnivorous species (*Zatomis*?). Gilmore also identified specimens of the

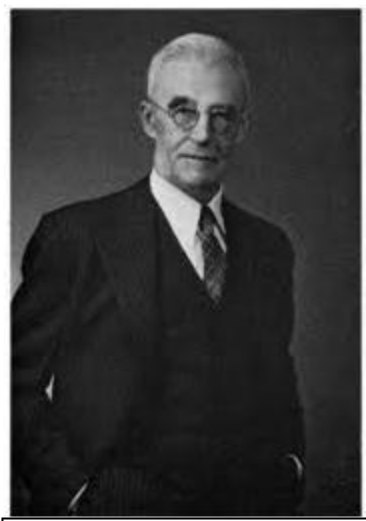


Figure 17. Photograph of Lloyd William Stephenson (about 1950). From Russell, R. D. (1970).

crocodylians *Thecachampsa rugosa* Emmons, and *Polydectes biturgidus* Cope as well as specimens of the turtles *Taphrosphys dares* Hay, and *Amyda* sp.

In 1923, Stephenson published research focused on the Cretaceous invertebrates (particularly the Coelenterata, Vermes, and Mollusca). Stephenson once again noted the occurrence of poorly preserved fossil bones (Dinosauria, Crocodilia, and Testudinata) at Phoebus Landing and stated that the fossils were representative of nearshore and land forms (Stephenson, 1923, p. 10).

2.1.3 Mid 1900s

Beginning in the late 1950s, geologic research along the Cape Fear River was renewed by scientists from the University of North Carolina at Chapel Hill (Powers, 1951; Brett, 1961; Heron, 1958, 1960; Heron and Wheeler, 1964; Swift, 1964; and Benson, 1968) who focused on lithologic, sedimentologic, stratigraphic, and depositional processes of the Black Creek Formation. Studies of Cretaceous age vertebrates along the Bladen County segment of the Cape Fear River during this time were conducted by Halsey W. Miller (1967, 1969) from High Point College.

2.1.3.1 Miller (1967 and 1969)

Miller (1967, 1969) described the vertebrate fossils from an outcrop of the Black Creek Formation at Phoebus Landing. These included: Carcharidae (shark), Pristidae (sawfish), Labridae (fish), Pelomedusidae (freshwater turtle), Trionychidae (softshell turtle), Mosasauridae (mosasaur), Crocodylidae (crocodile), Ornithomimidae (a coelurosaur), Tyrannosauridae, and Hadrosauridae. Miller (1969) amended his faunal list to include: Hybodontidae (shark), Dasyatidae (ray), Chimaeridae (cartilaginous fish), Pycnodontidae (ganoid fish), and Amiidae (bowfin fish).

2.1.4 Late 1900s

Since the late 1970s, geologic investigations and re-evaluations of the late Cretaceous depositional environments have been conducted by various researchers (Custer, 1981; Sohl and Christopher, 1983; Owens and Gohn, 1985; Harris et al., 1986; Owens and Sohl, 1989; Sohl and Owens, 1991; and Self-Trail et al., 2004a, 2004b). Vertebrate faunal assemblages of Bladen County were assessed by Baird and Horner (1979), and Robb (1989).

2.1.4.1 Baird and Horner (1979)

Baird and Horner (1979) re-evaluated the work of Miller (1967, 1969) in an attempt to further identify the limited number of vertebrate (particularly the dinosaurian) specimens from Phoebus Landing. They reassigned a maxilla described as *Gorgosaurus* to *Deinosuchus* (a crocodylian). They reassessed two theropod teeth identified by Miller as *Gorgosaurus libratus*, and remarked on their similarity to teeth of *Dryptosaurus aquilunguis* (Cope) as well as to those of *Albertosaurus* (i.e., *Gorgosaurus*). They also described a fragmentary femur (collected but not published on by Miller) and compared the specimen to *Dryptosaurus aquilunguis* (Cope) or *Albertosaurus sarcophagus* Osborn. Baird and Horner (1979) concluded that the material available precluded definitive classification of the theropod teeth and femur.

Baird and Horner (1979) also described two hadrosaurian teeth (a shed maxillary tooth and an unworn dentary tooth with partial root fang) and assigned the specimens to the subfamily Hadrosaurinae Lambe 1918 (hadrosaurine) but no generic level identification could be established. They also discussed caudal vertebral elements identified as *Hypsibema crassicauda* Cope, reassigned two other caudal vertebrae to this species, and discussed the lack of diagnostic material for familial assignment. Baird and Horner (1979) also re-evaluated a small phalangeal bone described by Miller (1967) as a coelurosaur and reassigned it to ?*Trionyx* (turtle). They also amended Miller's faunal list (1967, 1969) to include: Class Chondrichthyes (*Squalicorax pristodontus* (Agassiz), *Ischyrhiza mira* Leidy, and *Brachyrhizodus wichitaensis*

Romer); Class Osteichthyes (*Paralbula casei* Estes, and *Pycnodus phaseolus* Hay); Class Reptilia, Order Chelonia (*Trionyx* spp., and *Taphrosphys* sp.); Order Squamata, Family Mosasauridae (*Tylosaurus* sp. and *Platecarpus* sp.); Order Crocodilia (*Leidyosuchus* cf. *L. formidabilis* Erickson); Order Saurischia, Suborder Theropoda (cf. *Dryptosaurus* or *Albertosaurus* sp.); Order Saurischia, Suborder Sauropodomorpha (*Hypsibema crassicauda* Cope); and Order Ornithischia, Suborder Ornithopoda (Hadrosaurinae indet.)

2.1.4.2 Robb (1989)

In 1989, Albert J Robb III described the fish fauna (both Chondrichthyes and Osteichthyes) from Phoebus Landing and attempted to correlate his findings with fossils from similar aged Cretaceous localities in the United States. For completeness, he included a list of reptilian fossils: Order Chelonia (*Adocus* sp., *Bothremys barberi* (Schmidt), *Trionyx halophilus* Cope, and *Taphrosphys dares* Hay); Order Squamata, Family Mosasauridae (*Tylosaurus* sp., *Pronathodon* sp., *Halosaurus* sp., and *Platecarpus* sp.); Order Crocodilia (*Deinosuchus* (*Phobosuchus) rugosus* (Emmons), cf. *Thoracosaurus neocessariensis* DeKay, *Brachychampsa* sp., and *Leidyosuchus* cf. *L. formidabilis* Erickson); Order Saurischia, Suborder Theropoda (*Dryptosaurus* sp., and *Ornithomimus* sp.); Order Saurischia, Suborder Sauropodomorpha (*Hypsibema crassicauda* Cope); Order Ornithischia, Suborder Ornithopoda (Hadrosaurinae indet.) (Robb, 1989, table 3, p. 78).

Robb's conclusions were as follows. The Chondrichthyes represented 96% of the fish assemblage with *Scapanorhynchus texanus* (Roemer) comprising 79.2% followed by *Squalicorax kaupi* (Agassiz) (6.4%), *Ischyrhiza mira* Leidy (2.3%), and *Squalicorax pristodontus* (Agassiz) (1.6%). Robb concluded that the Campanian age Phoebus Landing fish fauna was not similar to that of the late Campanian Big Brook fish fauna of New Jersey, but was comparable in particular in the dominance of *Scapanorhynchus texanus* (Roemer) with the fish fauna of the Campanian age Blufftown Formation of western Georgia.

2.1.5 <u>2000s</u>

2.1.5.1 <u>Gaffney, Hooks, and Schneider (2009)</u>

Written as a correction and addendum to the Gaffney et al. (2006) bulletin on the evolution of the side-necked turtles (the families Bothremydidae, Euraxemydidae, and Araripemydidae), Gaffney et al. (2009) described new Campanian Bothremydid (turtle) cranial element material housed in the collections of the North Carolina Museum of Natural Sciences (NCMNS). The specimens were collected from two localities in Bladen County, North Carolina the Bladen County Landfill Annex (BCLA) and Phoebus Landing. Gaffney et al. (2009) reviewed eight NCMNS specimens; of the eight, six were identified as *Bothremydina* indet., one as *Bothremys* sp., and one as *Chedighaii* sp.

2.2 VERTEBRATE MICROFOSSIL ASSEMBLAGES

2.2.1 Overview

Vertebrate microfossil assemblages occur in stratigraphically limited units, include the remains of at least two species of vertebrates, and preserve vertebrate fossils in considerably greater abundance than in surrounding strata (Brinkman et al., 2005). These assemblages (also referred to as vertebrate microfossil localities, microvertebrate sites, or microsites) consist of concentrated accumulations of dense, robust, fossilized bone fragments, including small bones, teeth, and scales from a variety of vertebrates. According to Brinkman et al. (2005), these accumulations represent a sample of the paleocommunity within the immediate area of the site. Complemented by sedimentologic and taphonomic research, vertebrate microfossil assemblages contain a wealth of information that can be utilized in taxonomic comparisons and correlations (both chronologically and spatially) as well as for paleoecosystem reconstruction (Brinkman et al., 2005). Based on the above described characteristics, the fossiliferous horizon at the Bladen County Landfill Annex site is considered to be a microfossil bonebed.

2.2.2 Studies of Cretaceous vertebrate microfossil assemblages

2.2.2.1 Estes (1964): The Lance Formation, Wyoming

Estes (1964) reassessed the fauna recovered from the type area of the Lance Formation, Power River Basin, in eastern Wyoming in one of the first publications on Cretaceous vertebrate microfossil assemblages. The fauna consisted of more than thirty thousand fossil elements representing at least seventy-five vertebrate species. The faunal list included representatives of the Classes Elasmobranchii, Osteichthyes, Amphibia, Reptilia, Mammalia, and Aves. His data confirmed that quarry (bulk) sampling methods produced a more complete assemblage of vertebrate organisms from a site than surface collecting methods (Estes, 1964, table 4, p. 152). Estes (1964) performed relative abundance analysis of microvertebrate data from multiple sample sites. His results showed that for the majority of the six quarries sampled, assemblage composition and abundance of those elements were comparable. Referring to the species abundance results of the six quarries, Estes (1964) proposed a generalized ecological interpretation for the Lance Formation as being that of a "warm, humid, coastal plain with abundant riparian habitats and an abundant and diversified vertebrate fauna, which, with the exception of dinosaurs, has a distinctly modern aspect" (Estes, 1964, p. 1).

2.2.2.2 Rowe et al. (1992): The Aguja Formation, Texas

Rowe et al. (1992) reported on a microvertebrate locality in the Upper Cretaceous (late Campanian) Aguja Formation of the Big Bend region of Texas, known as the Terlingua Local Fauna. The fossiliferous horizon described included isolated occurrences of large bone elements (i.e., Hadrosaurine vertebrae) within the microvertebrate assemblage. Elements exhibited the fragmentation, varying degrees of abrasion, and rounding typical of microvertebrate assemblages. The Terlingua Local Fauna was predominately terrestrial intermixed with freshwater and saline-tolerant vertebrates. Rowe et al. (1992) correlated the Terlingua Local Fauna with Campanian (Judithian) age faunal assemblages of the Western Interior region of the United States and Canada.

2.2.2.3 Sankey (2001, 2008): The Aguja Formation, Texas; Sankey et al. (2002): The Judith River Formation, Alberta, Canada

Sankey (2001) identified and described dinosaur teeth from the late Cretaceous (late Campanian to Maastrichtian) Talley Mountain Microsites located in channel lag deposits within the Aguja Formation of western Texas. She compared the teeth with similar-aged specimens from Dinosaur Provincial Park, Alberta: the Milk River Formation (early Campanian; Dawson et al., 2008); Oldman and Dinosaur Park Formations (middle Campanian; Dawson et al., 2008); Horseshoe Canyon Formation (late Campanian-early Maastrichtian; Dawson et al., 2008); and the Scollard Formation (late Maastrichtian; Dawson et al., 2008).

These comparisons allowed Sankey (2001) to discuss the paleoecological and biogeographical implications of the Talley Mountain Microsites, particularly latitudinal differences in faunal abundances and diversity as a function of temperature and precipitation. She noted the occurrence of thirty-eight taxa (including fish, amphibians, turtles, squamates, crocodylians, dinosaurs, and mammals) identified from small teeth and bones from the sites. Sankey (2001) concluded that the diversity and abundance of dinosaurian taxa from the Talley Mountain Microsites were similar to those of the lower Maastrichtian Scollard Formation of Alberta, Canada (Dawson et al., 2008).

Sankey et al. (2002) studied theropod teeth recovered from microvertebrate sites within the Judith River Group, Alberta (late Campanian; ~74-79 ma). They concluded that the theropod population was more diverse during the late Campanian than during the Maastrichtian. In a more recent study, Sankey (2008) concluded that the dinosaurs of the Talley Mountain Microsite, Texas, were less diverse than their northern (Albertan) counterparts.

2.2.3 Taphonomic research on vertebrate microfossil assemblages

Taphonomy literally means *the study of the grave,* and thus is a key component to the interpretation of vertebrate microfossil assemblages. Dodson (1971, p. 53) defined taphonomy as “a broad field of integrated study of fossil beds from both biological and geological points of view in order to interpret the occurrence of fossils.” In a paleontological context, the term refers to studying the processes whereby a living community becomes a faunal assemblage (Raup and Stanley, 1971).

According to Dodson (1971) bonebeds represent a locally derived allochthonous fauna, and relative abundances of certain species within the bonebeds represent an Eltonian balance (a graphical representation of the trophic structure and function of an ecosystem; Elton, 1927) (Fig. 18). Dodson’s (1971) contention that the relative abundance of major groups of taxa occurring in bonebeds mirrored those occurring as articulated specimens remains unchallenged (Brinkman, 2008).

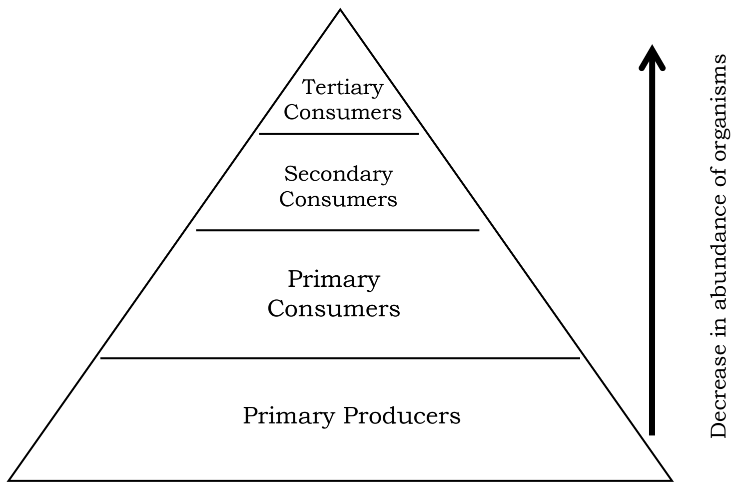


Figure 18. Graphical depiction of the "Eltonian Pyramid of Numbers" (also known as The Ecological Pyramid) representing the trophic structure and function of an ecosystem. From Elton (1927).

Microvertebrate assemblages (bonebeds) occur in a variety of taphonomic modes (Eberth and Brinkman, 1997), are closely related to the relationship between physical patterns of sedimentation (erosion, sediment budget, and deposition), and distribution (Rogers and Kidwell, 2000). Other scenarios constitute a combination of ecological and/or geological events occurring over a prolonged period of time (Dodson, 1971 and Behrensmeyer, 1982). This thesis addresses the taphonomy of part of the Black Creek Group. The following publications, therefore, were chosen for comparison based on the age of the subject material (Cretaceous), type of stratigraphic unit (fluvial-estuarine), and type of faunal assemblage (microvertebrate). The locations are Dinosaur

Provincial Park, Alberta, Canada (Dodson, 1971); Eberth (1990); Eberth and Brinkman (1997), north central Montana (Rogers and Kidwell, 2000, 2007); Rogers and Brady (2010), and Wyoming (Behrensmeyer, 1982, 1988).

2.2.3.1 Bone transport: origins and accumulations

The origins of bonebeds depend on a variety of associated processes and conditions (Rogers and Kidwell, 2007). Some bonebeds result from exhumation through erosion (Rogers and Kidwell, 2000) and others are formed through sediment starvation (Eberth and Brinkman, 1997). The behavior of vertebrate elements in water is a function of the size, shape and density of the individual element (Rogers and Kidwell, 2007). For hydraulic accumulations of vertebrate elements to occur, certain key factors must be incorporated into the equation: the nature of the hydraulic medium, the ratio of vertebrate elements to the sediment budget, and the number of vertebrate elements delivered or introduced into the system (Rogers and Kidwell, 2007). Mechanisms contributing to bonebed accumulations include trapping at in-channel obstructions, drops in flow velocities, as well as wave-induced strandline accumulations (often associated with plant debris).

Of all factors promoting the formation of bonebeds, the sediment budget is arguably one of the most critical factors. A low sediment budget occurring over a great length of time can ultimately result in a richer and more laterally continuous fossil concentration. Negative net sedimentation (erosion) can remove previously deposited sedimentary matrix, thus producing a vertebrate lag deposit. Low or zero net sedimentation can also increase the occurrence of destructive postmortem processes such as rounding or abrading (Rogers and Kidwell, 2007). Behrensmeyer (1982) noted that the removal of external (laminar) bone occurred after 1.5 km of transport while bone that underwent less than 1.5 km of transport remained essentially undamaged. Yet, the degree of abrasion on fossil elements in a bonebed is not only an indicator of transport distance but also an indicator of sediment load within the fluvial system (Behrensmeyer, 1982).

2.2.3.2 Depositional environments of bonebeds

2.2.3.2.1 Channel and splay deposits

Dodson (1971) interpreted fossiliferous channel-lag type deposits as residual accumulations of clastic material too heavy to be moved by the current. Behrensmeyer (1982) identified three possible sources for bone input to fluvial channel deposits (Fig. 19): 1- initial autochthonous burial in the floodplain, followed by partial destruction and/or reworking through bank erosion (denser and more compact elements, i.e., teeth and jaws); 2- overland transport directly into the channel (lighter, more transportable bones, i.e., ribs and vertebrae); and 3- carcasses or bones originally in the channel (skeletal elements with minimal postmortem damage).

Behrensmeyer (1988) introduced two taphonomic modes (channel-lag mode and channel-fill mode) defined primarily on their sedimentary context and secondarily on their taphonomic features. Channel-fill and channel-lag modes preserve unique biological and ecological information. Channel-fills primarily represent sporadic flood events, due to localized transport, sorting, and hydraulic concentrations of fossil elements. The rate of sedimentation is one of the most critical factors promoting preservation in channel-fills; the rate must be balanced with the rate of input of bone into the channel (Behrensmeyer, 1988, p. 193). Channel-fill fossil assemblages consist of autochthonous, abundant, well-preserved, unabraded, multitaxic skeletal elements within fine-grained facies (Behrensmeyer, 1988).

The channel-lag mode consists of “winnowed and sorted residues composed of relatively large or heavy particles that are above the threshold competence (transporting ability) of local currents” (Behrensmeyer, 1988, p. 184). Fluvial systems subjected to low subsidence rates and characterized by active migrating channels, would commonly generate channel-lag assemblages. Thus channel-lag mode refers to fossil elements that exhibit varying degrees of abrasion, are located in the lower part of an erosional channel, and are in direct association with coarse clastic material (Behrensmeyer, 1988).

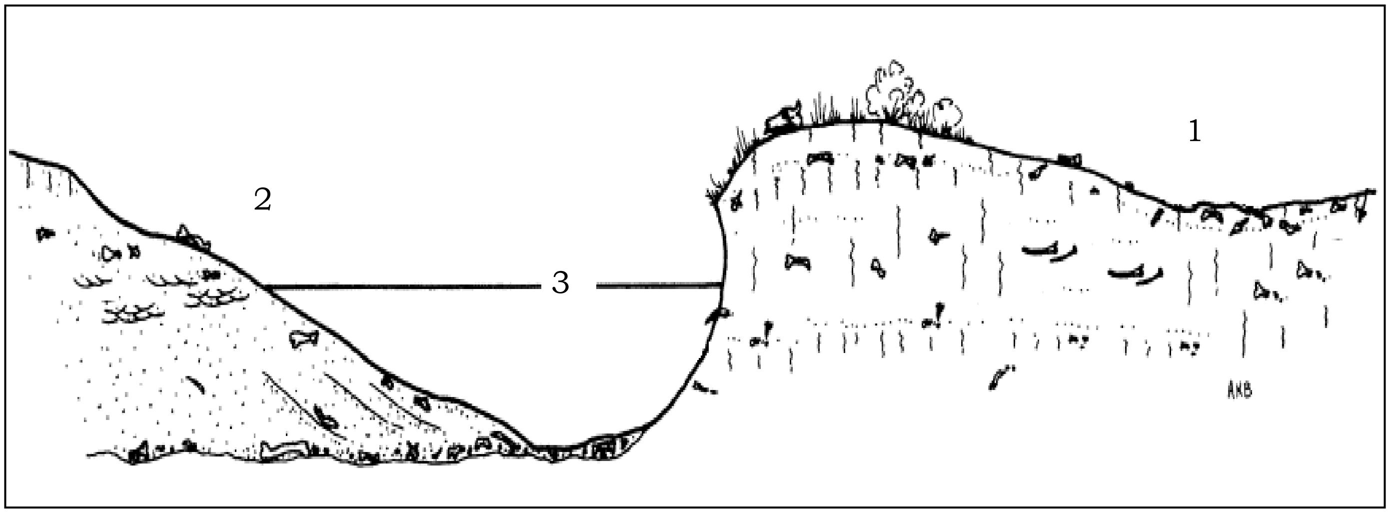


Figure 19. Sources of bone input to a fluvial channel.

1- Burial on the floodplain, followed by partial destruction then reworking through bank erosion.
2- Overland transport directly into the channel.
3- Bones originally in the channel.

Figure modified from Behrensmeyer (1982).

Channel-lag deposits include vertebrate elements derived from various sources (terrestrial, fluvial, estuarine, etc.) and are allochthonous. The fossils represent members of the community (or communities) inhabiting different environments along the drainage basin and provide a more representative sample of the overall paleocommunity (Behrensmeyer, 1988).

Intraclast (channel) deposits consist of microfossil assemblages that are associated with major scour/erosional surfaces and/or bank collapse. Sedimentologic characteristics of intraclast deposits include the presence of rounded mudstone pebbles (rip-ups of underlying mudstone deposits) and/or angular mudstone clasts (indicating bank collapse) (Eberth, 1990). The most productive microvertebrate sites of the Judith River Formation (Dinosaur Provincial Park, Alberta, Canada) are in two distinctive sedimentary facies, intraclast (channel) deposits and contorted siltstone/sandstone (splay) deposits (Eberth, 1990). Splay deposits consist of alternating organic material (carbonaceous plant fragments, wood, leaf impressions, and root traces) and stacked sequences of interlaminated sands and siltstones separated by erosional surfaces indicating repeated flood events and aggradation (Eberth, 1990).

2.2.3.2.2 Lacustrine deposits

Faunal assemblages from within lacustrine depositional environments are more likely to reflect locally derived (allochthonous) vertebrate fossil assemblages representing multiple generations spanning thousands of years (a parauthochthonous assemblage) (Rogers and Brady, 2010). Two models couple the ecologic and taphonomic components of lacustrine ecosystems with the dynamics of aggrading, avulsion-prone fluvial systems (Rogers and Brady, 2010). The Attritional Accumulation in Freshwater Aquatic Basin Model suggests that input of vertebrate material outpaces the masking effects of sedimentation in lacustrine settings and the vertebrate remains accumulate into concentrated levels characteristic of a bonebed. The second model (Preexisting Concentrations Reworked by Fluvial Channels Model) depicts the expected result of fluvial reworking of proximal fossil-rich facies. Thus, bonebeds develop shortly after a channel forms in new regions of the floodplain or in areas of a previously abandoned channel (Rogers and Brady, 2010).

2.2.3.2.3 Estuarine deposits

An estuary is defined as "the seaward portion of a drowned valley system which receives sediment from both fluvial and marine sources and contains facies influenced by tide, wave, and fluvial processes" (Dalrymple et al., 1992). According to Eberth and Brinkman (1997), estuarine channels typically display a three-fold division of energy and deposition modes representing transitions between marine, mixed-marine, and fluvial processes. At the point where fluvial processes meet marine processes, a central zone of mixed to low-energy occurs, resulting in an area of increased turbidity. A mixed-mode assemblage in the Judith River Formation is comprised of disarticulated fossils concentrated in association with single, thick, pebbly, basal lag deposits in fine grained sandstone bodies exhibiting a high abundance of autochthonous and parauthochthonous vertebrate fossil elements (Eberth and Brinkman, 1997). The heterogeneous nature of the vertebrate and invertebrate fossils within the estuarine deposit was the result of decreased sediment bedload in the central, low-energy zone of the estuary leading to the relative increase of fossils as bedload. Therefore, the low-energy interface between the fluvial system and the estuary acted as a trap for the fossil-dominated bedload (Fig. 20), resulting in the accumulation of fossil remains (Eberth and Brinkman, 1997). Estuarine-derived fossil assemblages are comprised of freshwater and marine vertebrates intermixed with coprolites, freshwater gastropods and pelecypods within coarse-grained sediments (Eberth and Brinkman, 1997).

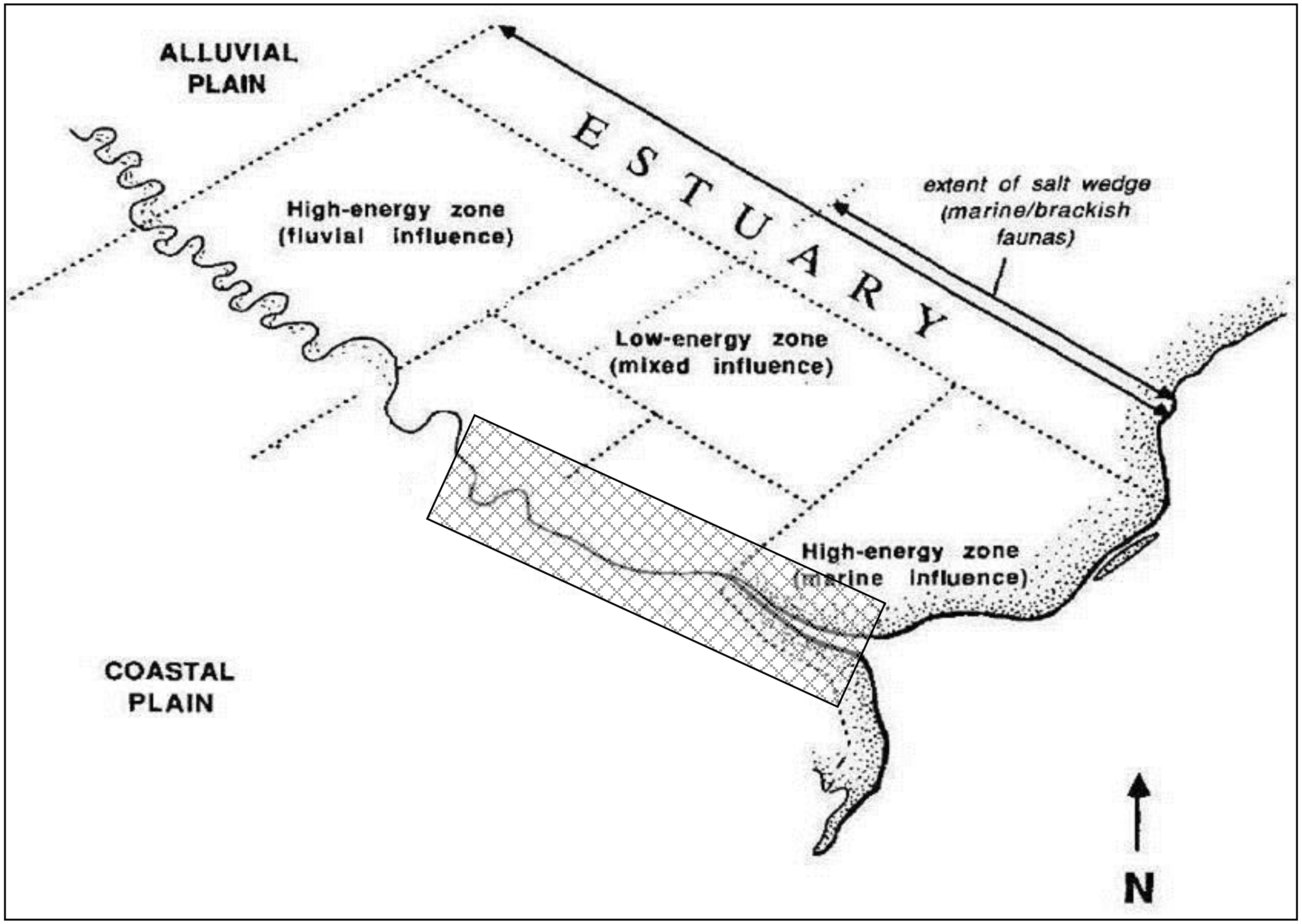


Figure 20. Diagram depicting the dynamic nature between the high-energy (fluvial) and low-energy (mixed) environments within a fluvial to estuarine transitional setting. Boxed area indicates area of fossil concentration. Modified from Eberth (1996).

2.2.3.3 Time resolution

Behrensmeyer (1982) formulated a time-averaged standard (based on modern-day observations and known sedimentary processes) for use in taphonomic interpretations. Her time-average standard for fossil assemblages located in channel deposits represented intervals of at least 100 years whereas basal conglomerates (representing a major depositional hiatus) represented deposition over much longer intervals of at least 100,000 to 1,000,000 years (Behrensmeyer, 1982). Tidally influenced depositional environments of microvertebrate accumulations also represent considerable time averaging (Rogers and Kidwell, 2000). This time-averaging is primarily the product of erosion (negative net sedimentation) which increases the likelihood that previously deposited fossils will be exhumed and deposited within a younger stratigraphic unit. Thus, the greater the erosive influence on the older strata, the increased likelihood of mixing of the stratigraphically older vertebrate elements with younger vertebrate material, resulting in a higher probability of time-averaged (fossils of different ages) and ecologically mixed fossil assemblages (Rogers and Kidwell 2000).

3.0 METHODOLOGY

3.1 COLLECTING FROM FOSSILIFEROUS HORIZON

Bulk samples from a 9 m x 9 m (30 ft x 30 ft) area of the fossiliferous unit at the BCLA were placed in ca. 60 five-gallon buckets (Fig. 21). Average weight of the buckets including matrix was 23 kg (50 lbs). Large or delicate specimens discovered while sampling were collected and retained. Following collection, four five-gallon buckets were randomly selected, labeled A, B, C, and D, and processed for specimens.

Figure 21. Field samples of the Campanian age fossiliferous horizon (stratigraphically located near the top of the Cretaceous strata), at the Bladen County Landfill Annex.
Photograph courtesy of John Paschal.

3.2 PROCESSING SEDIMENTS FOR VERTEBRATE FOSSIL SPECIMENS

Buckets of sediment were initially wet sieved through a 6.35 mm (¼ inch) screen. This initial sorting produced eight buckets, labeled A_1, B_1, C_1, and D_1 for material > 6.35 mm and A_2, B_2, C_2, and D_2 for material < 6.35 mm in size. Fossils greater than 6.35 mm were initially sorted by type (i.e., shark tooth, crocodylian tooth, bone fragment, etc.) (Fig. 22) and then sorted into specific faunal ordinal-level categories (Lamniformes, Salmoniformes, Crocodylia, etc.). The material less than 6.4 mm was further processed by wet sieving through a 1 mm (0 Φ) sieve. After drying the > 1 mm screened sediment, fossils were hand-picked under magnification, sorted by type (i.e., shark tooth, crocodylian tooth, bone fragment, etc.), and then sorted into ordinal-level categories. Fossils in these categories were then counted and abundances determined.

Figure 22. Photograph showing the cleaned sediment consisting of greater than 6.4 mm (1/4 inch) material. Photograph by author.

3.3 IDENTIFICATION OF VERTEBRATE FOSSIL ELEMENTS

Specimens from the Bladen County Landfill Annex accessioned in the collections of the North Carolina Museum of Natural Sciences and from private collections, were identified, recorded, measured (using a caliper and metric tape), and photographed. Specimens were identified to the Family level (species level where possible) and comparisons were conducted with late Cretaceous Campanian fauna from localities in New Jersey, Georgia, Missouri, Texas, Wyoming, Montana, and Alberta, Canada.

Specimen identification was based on literature comparisons. For Chondrichthyes and Osteichthyes, Estes (1964), Cappetta and Case (1975), Case (1978, 1979, 1987a, 1987b), Bell (1986), Schwimmer (1986), Cappetta (1987), Case and Schwimmer (1988), Robb (1989a, 1989b), Welton and Farish (1993), Maisey (1996), Case and Cappetta (1997), Schwimmer et al. (1997), Hooks et al. (1999), Case et al. (2001a, 2001b), and Brinkman (2010) were consulted. For Amphibia, Estes (1964, 1965, 1969), Denton and O'Neill (1995, 1998), and Brinkman (2010) were consulted.

For Reptilia, Miller (1967, 1969), Baird and Horner (1979), Rowe et al. (1992), Schwimmer (2002), Brinkman (2003, 2010), Gaffney et al. (2009) were employed. For Dinosauria, Miller (1967, 1969), Baird and Horner (1979), Horner (1990), Rowe et al. (1992), Schwimmer and Best (1989), Schwimmer et al. (1993), Schwimmer (1997), Sankey (2001, 2005, 2008), Sankey et al. (2002), Currie (2005), Weishample et al. (2004) and Brinkman (2010) were consulted.

Taxa identified from the Bladen County Landfill Annex were compared to North American studies conducted by Miller (1967, 1969), Baird and Horner (1979), Lauginiger and Hartstein (1983), Gallagher et al. (1986), Schwimmer (1986, 1997), Case and Schwimmer (1988), King et al. (1988), Fiorillo (1989), Robb (1989a, 1989b), Brinkman (1990, 2010), Grandstaff et al. (1992), Rowe et al. (1992), Schwimmer et al. (1993), Eberth and Brinkman (1997), Schwimmer et al. (1997), Sankey (2005, 2008), DeMar and Breithaupt (2006, 2008), Gates et al. (2010), and Gaffney et al. (2009).

3.4 ANALYSIS OF VERTEBRATE FOSSILS

3.4.1 Abundance analysis

The fossil elements were divided into ordinal groups and counted. Specimen counts were entered into an Excel spreadsheet and imported into the PAST program for analysis. PAST, created by Hammer et al. (2009), is an open source analytical program for paleontological research and is available for download at http://folk.uio.no/ohammer/past. It is a streamlined version of the extensive PALSTAT program created by Ryan et al. (1995).

3.4.2 X-Ray diffraction analysis

Three fossils were analyzed for mineralogical content utilizing X-ray diffraction. The fossils, a fragment of theropod bone (Dale A. Russell, personal communication, November, 2004), a *Deinosuchus* tooth fragment (based on comparison with Schwimmer, 2002), and a coprolite were reduced to powder using a tungsten carbide Spex ballmill. X-ray diffraction was performed on a PANalytical X'Pert Pro spectrometer using an X'Celerator detector. The peak matching program (X'Pert HighScore Plus) identified the mineral constituents.

4.0 RESULTS

4.1 STRATIGRAPHY AND SEDIMENTOLOGY

4.1.1 Stratigraphy and Sedimentology

During the early stages of this thesis, an accident that occurred in a neighboring quarry caused county officials to close the BCLA site, thus prohibiting continued sampling and on-site study. Therefore, the interpretation of the sedimentology and stratigraphy stems from a variety of sources including: scaled photographs (provided by John Pascal) during pre-closure collection trips to the BCLA; lithologic analysis of a pit dug at (N 34.61, W 78.58) using heavy machinery provided by Richard Allen of Bladen County (Fig. 23); and lithologic sections from Phoebus Landing produced by past studies.

The 13 m deep pit (dug approximately 1.75 km (1 mi) east of the BCLA) consisted of 8 meters of thinly laminated clays and sands capped by ca. 10 cm of pebbly sand and clay (Fig. 23). This section represents the Bladen Formation. It is unconformably overlain by 5 meters of crossbedded to massive bedded iron-stained sands of the Bear Bluff Formation.

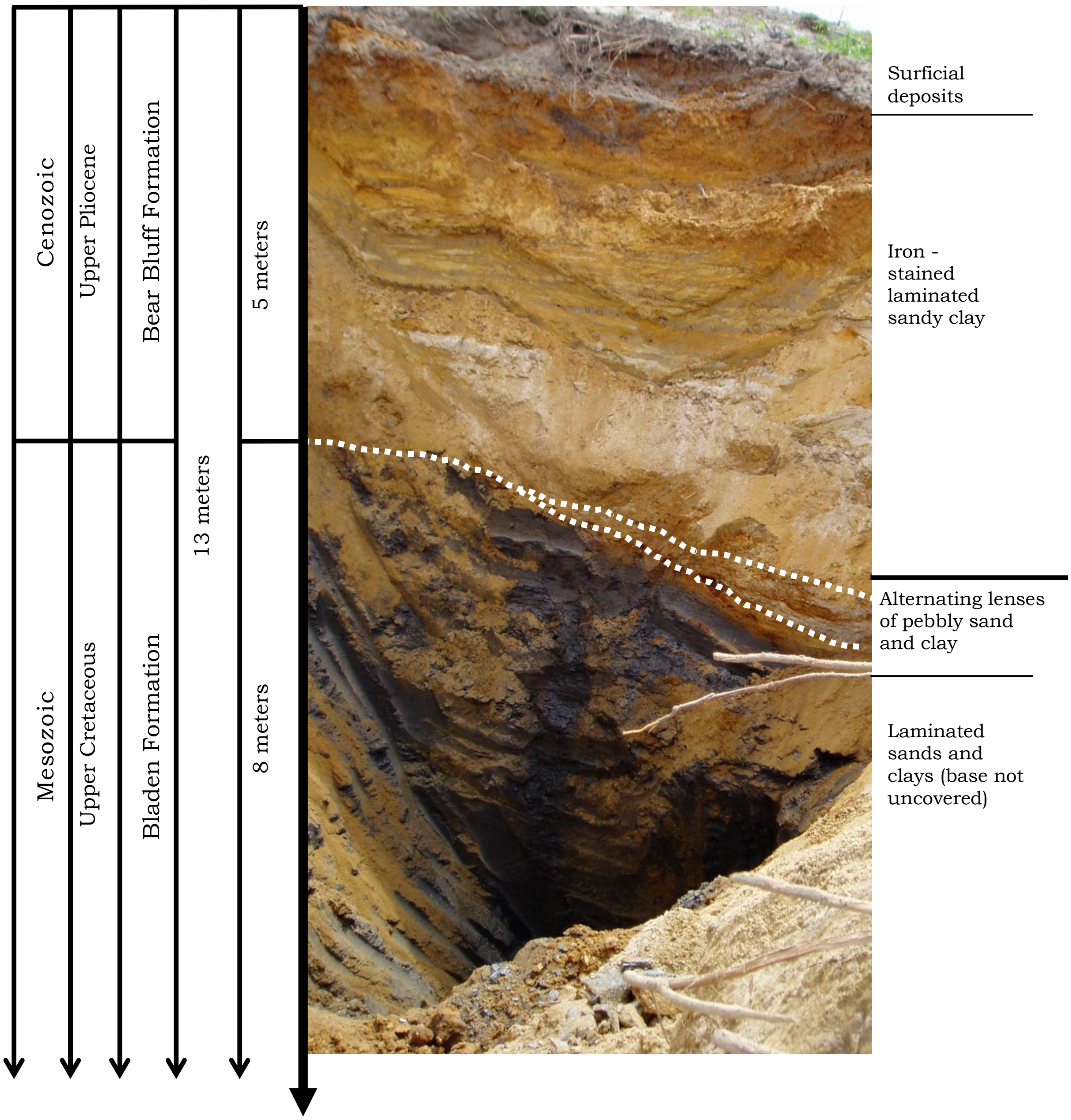


Figure 23. Photograph of exploration pit dug on land adjacent to the BCLA site depicting 8 m (26.3 ft) of laminated clay and sand of the Bladen Formation capped by ca. 10 cm of alternating sand and clay; overlain by 5 m (16.5 ft) of the upper Pliocene Bear Bluff Formation. Total depth of pit is 13 meters (42.8 feet); base of the Bladen Formation not uncovered. Photograph by author.

The BCLA site is approximately 1.75 km (1.1 mi) from the pit and at the same general (topographic) elevation. Thus, the exposed stratigraphic units at the BCLA site, including the fossiliferous lag, likely belong to the Bladen Formation. The BCLA outcrop of the Bladen Formation (Fig. 24) consists of laminated black clays and white sands (thickness to base not uncovered). Above the laminated clay and sand lies a 32.5 cm thick unit that contains a 5-15 cm thick fossiliferous horizon (bonebed) at its base overlain by a 17 cm thick clay cap (Fig. 25). From the top of the clay cap is 1.55 m (5 ft) of unconsolidated, iron-stained sandy clay that possibly represents a Cenozoic pedogenic horizon. Total thickness of the outcrop ranged from 2 to 4 meters (5 to 12 feet) (Fig. 24).

Within the fossiliferous horizon (Fig. 26), vertebrate fossil elements are mixed with sub-rounded to rounded fine sand to cobble size clasts, angular to slightly rounded bone fragments, lignite fragments ranging from mm to cm long twigs and branch segments (many with *Teredo* borings and occasional pyrite), and pebble to cobble size coprolites. The fossiliferous horizon was green-grey to brown (Fig. 27).

At the BCLA, vertebrate elements occurred consistently throughout the 9 x 9 m area examined, with shark teeth dominating the fossil-bearing unit. Larger elements were scattered laterally throughout the unit (Figs. 26-28). Pieces of fractured elements were ordinarily slightly displaced from each other. The majority of tooth elements exhibited sharp edges and unworn serrations. Some fossil tooth elements belonging to the Crocodylia family exhibited little to no wear, and many elements exhibited evidence of feeding such as worn occlusal surfaces (Plate III-E, Fig. 8a-b; Plate IV-C, Fig. 6a). The majority of theropod tooth elements exhibited intact, sharp serrations (Plate IV-C, Fig. 4a and 6a).

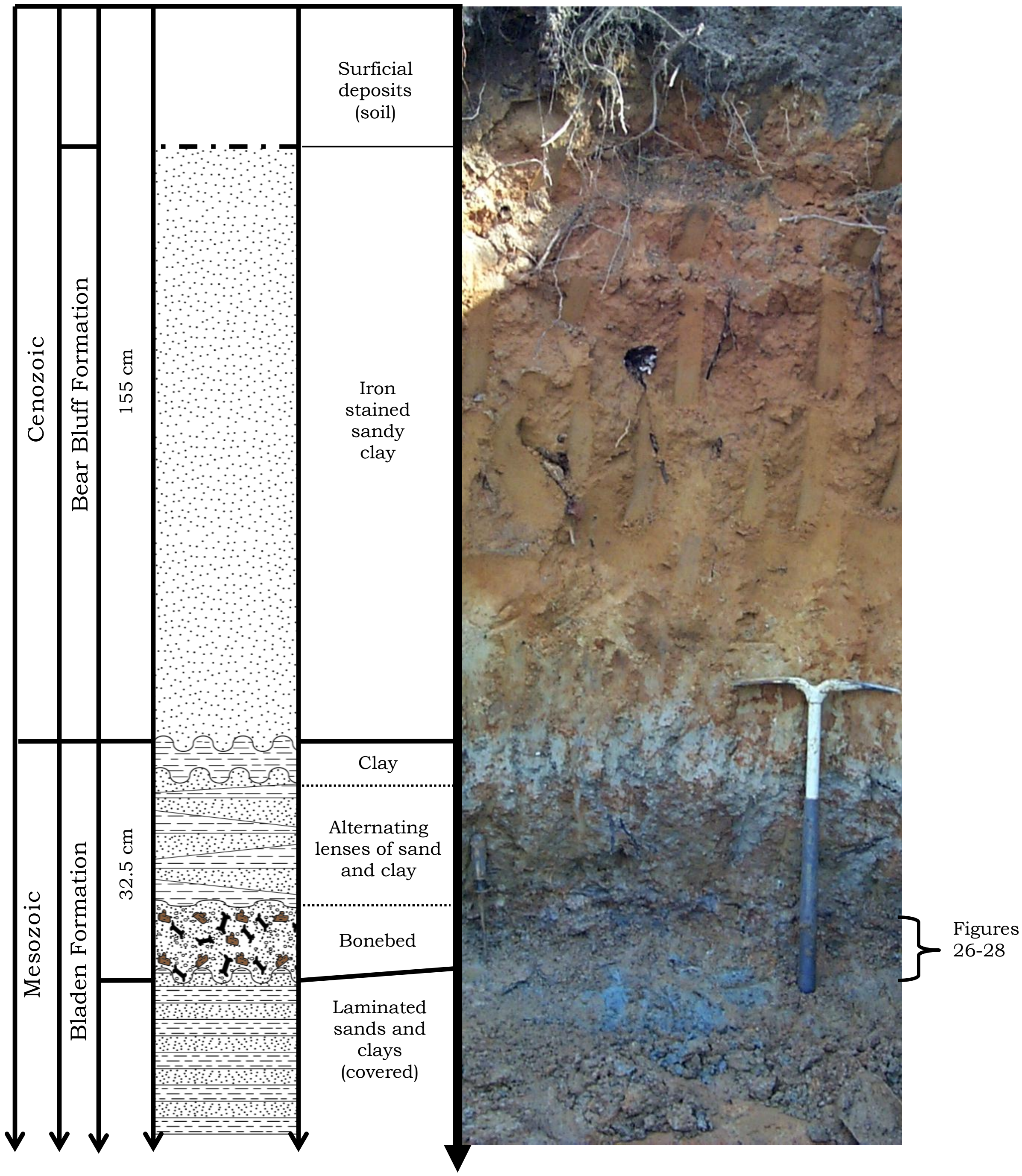


Figure 24. Photograph of the stratigraphic position of the fossiliferous horizon located at the BCLA site. Estwing Geo/Paleo Pick™ for scale (center-right) = 62.5 cm. Outcrop from base of pick to soil is 1.9 meters (6.2 ft). Thickness of the unit with the fossiliferous horizon (bonebed) at base is approximately 32.5 cm. The level of the vertebrate specimens (Figures 26, 27, and 28) is indicated on the right of the figure. Photograph courtesy of John Paschal.

Figure 25. Close up of the fossiliferous unit at the Bladen County Landfill Annex. Estwing Geo/Paleo Pick™ for scale (center-right) = 62.5 cm. Yellow bracket represents the thickness of the clay layer approximately 31.3 cm (fossil horizon at base). Fossil-rich horizon (white bracket) is 5 cm thick. Photograph courtesy of John Paschal.

Figure 26. Thoracic vertebra from an ornithischian (hadrosaurine) lying *in situ* within fine sand to pebble-cobble clay-rich fossiliferous horizon. Oyster knife for scale is 20 cm (8 in). Photograph courtesy of John Paschal.

Figure 27. *Deinosuchus* vertebral element lying *in situ* within fine sand to pebble-cobble clay-rich fossiliferous horizon. United States quarter for scale. Photograph courtesy of John Paschal.

Figure 28. Partial limb element *in situ* within fine sand to pebble-cobble clay-rich fossiliferous horizon. Photograph courtesy of John Paschal.

4.1.2 X-ray diffraction analysis

X-Ray diffraction analyses (XRD) were conducted on three fossil elements: two skeletal elements (a theropod bone fragment, and a *Deinosuchus* tooth fragment), and a coprolite. The XRD analyses (Appendix B) revealed that the theropod bone consisted of (in order of abundance): fluorapatite ($Ca_5(PO_4)_3F$) and minor pyrite (FeS_2) (Fig. 29). Analysis of the *Deinosuchus* tooth revealed fluorapatite, and a trace of quartz. The quartz is likely due to detrital quartz remaining on the specimen after cleaning (Fig. 30). The mineralogy of the coprolite was primarily fluorapatite with minor pyrite (Fig. 31).

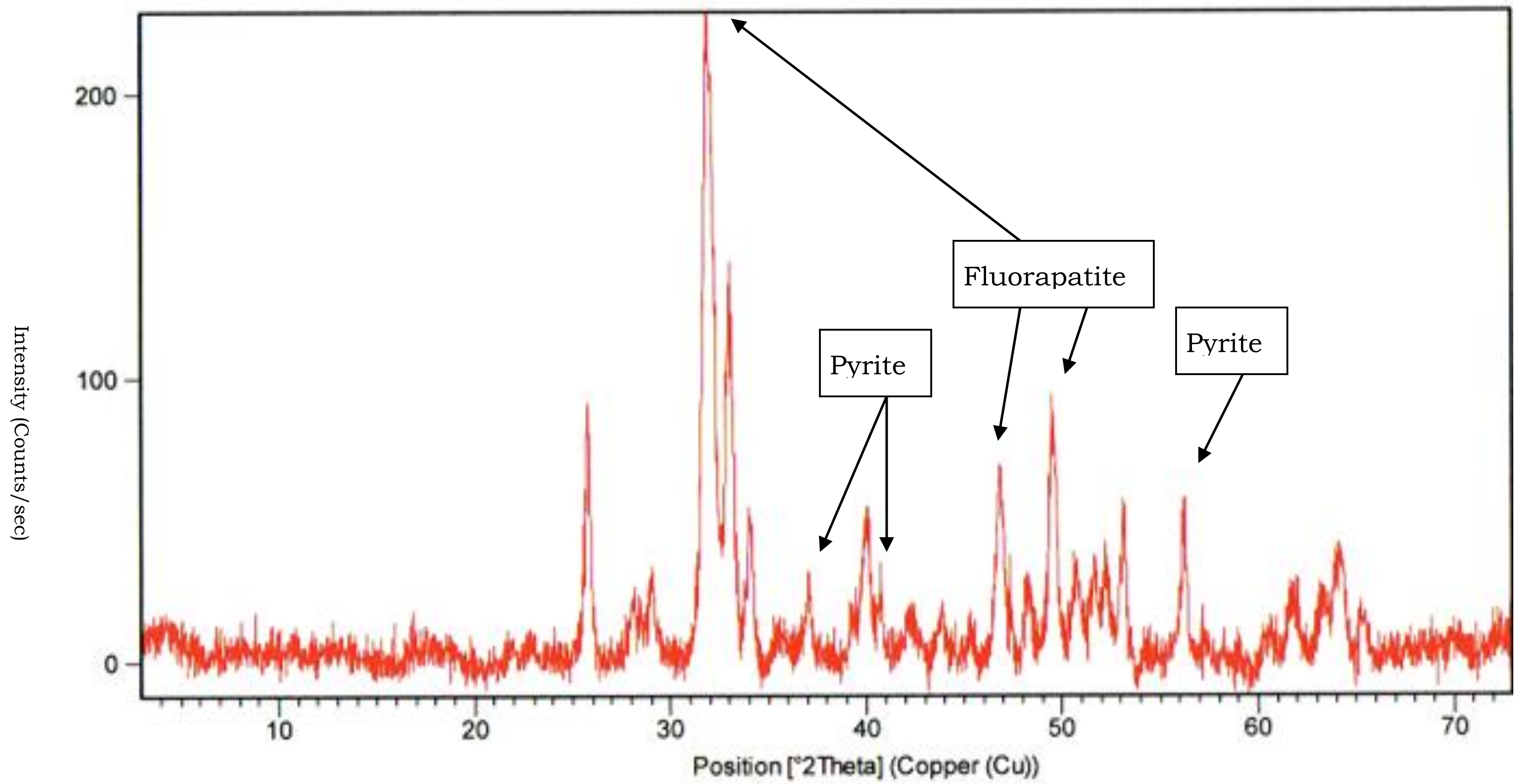


Figure 29. X-ray diffraction (XRD) pattern of a theropod bone from the Bladen County Landfill Annex near Elizabethtown, NC.

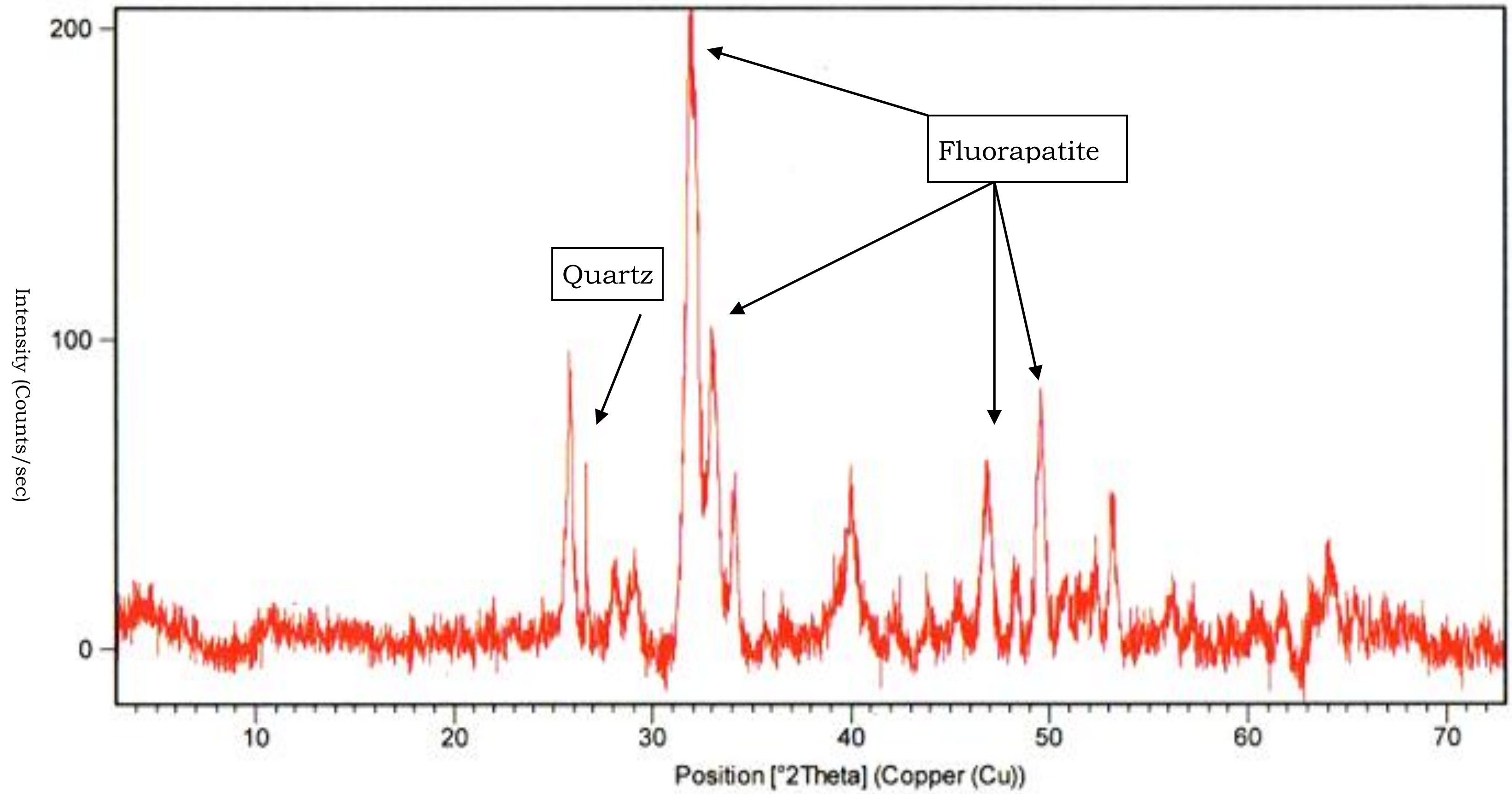


Figure 30. X-ray diffraction (XRD) analysis of a *Deinosuchus* tooth from the Bladen County Landfill Annex near Elizabethtown, NC.

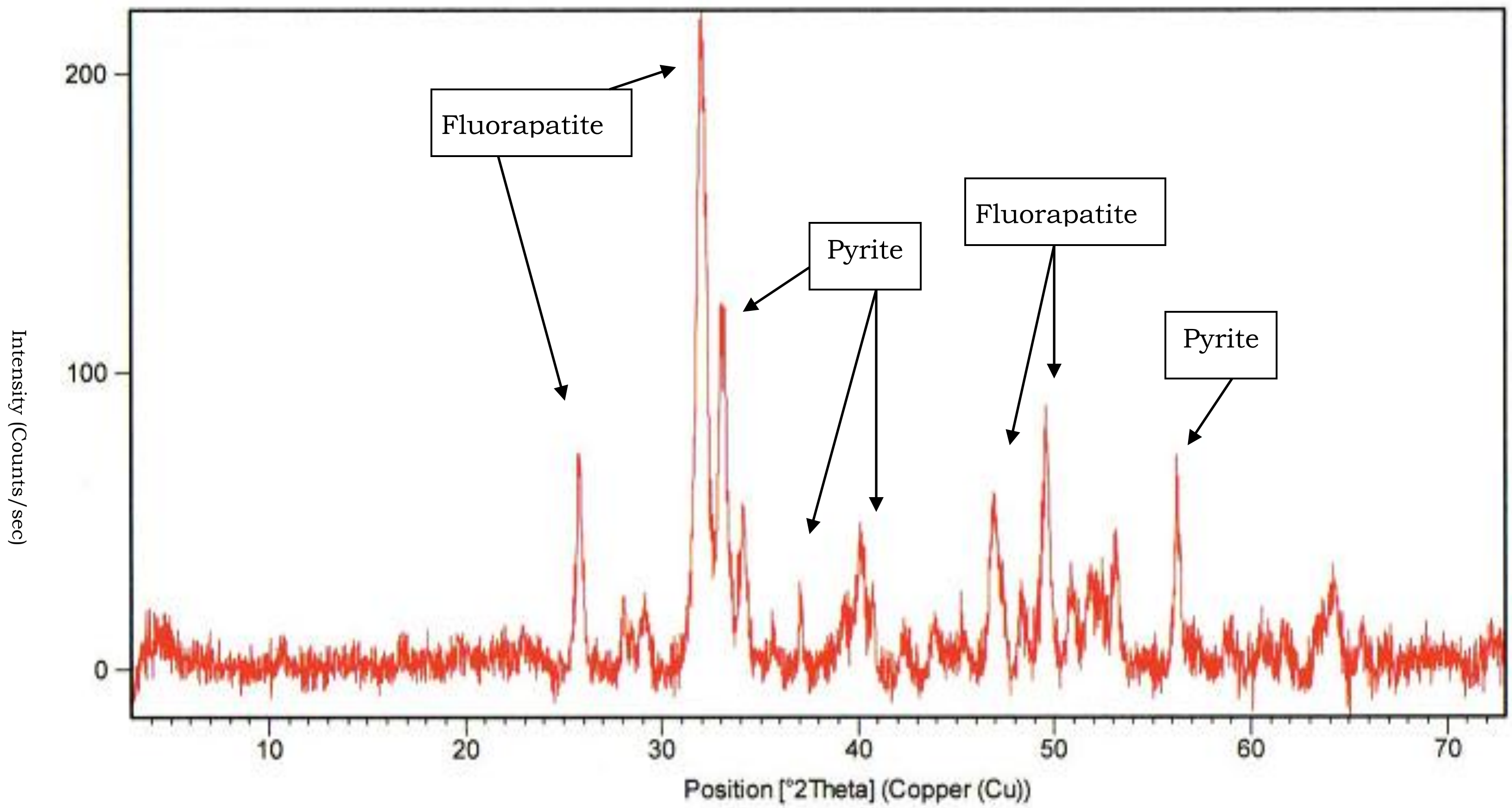


Figure 31. X-ray diffraction (XRD) analysis of a coprolite from the Bladen County Landfill Annex near Elizabethtown, NC.

4.2 PALEONTOLOGY

In this work thirty-five taxa are recorded (Appendices C and D). Of these, twenty-nine are illustrated in Plates I-A to IV-I. For each taxon, the synonymy lists the original reference followed by publications used to identify the specimens. The material section indicates the ownership of the fossil(s) and refers to the illustrated specimens. Abundance data of species are provided in Appendix A. Material indicated as “author’s collection” is currently in the possession of the author and will eventually be designated a catalogue number in the collections of the North Carolina Museum of Natural Sciences. “Private collection” refers to those specimens that are in private ownership; ownership information will be furnished by the author to qualified researchers upon request. The description section refers to the illustrated specimens. The occurrence section includes the stratigraphic, geographic, and environmental distribution of a taxon.

4.2.1 Systematic descriptions

Class CHONDRICHTHYES Huxley, 1880
Subclass ELASMOBRANCHII Bonaparte, 1838
Family HYBODONTIDAE Owen, 1846
Genus HYBODUS Agassiz, 1837
Hybodus sp.

(Plate I-A: Figure 1a-2c)

Hybodus sp. 1 Cappetta and Case, 1975, p. 5, text fig. 2.
Hybodus sp. Welton and Farish, 1993, p. 49, figs. 1-4.
Hybodus sp. Robb, 1989b, p. 87, figs. 2 and 3.

Material: Author's collection; lower lateral tooth lacking root; basal platform of cephalic hook lacking enameled hook; fragmentary dorsal fin spine.

Description: Tooth possesses a singular, tall median cusp with widely spaced mesial cusplets. Labial and lingual crown faces have distinct longitudinal ridges originating from the apron of the blade extending apically for a distance of approximately half to two-thirds the cusp height. Tooth lacks root, yet base exhibits the typical anaulacorhizous root. Tooth measures 6 mm from base to apical tip of median cusp; greatest base width is 6 mm. Fragmentary dorsal fin spine (29 mm in length) from the mesial section exhibits tuberculated ornamentation on lateral face and is laterally compressed in cross-section. Cephalic hook basal platform exhibits tri-lobed projections.

Occurrence: Hybodontidae are primitive sharks (Cappetta, 1987) whose freshwater forms are confined to the Mesozoic Era. They first appeared in the Triassic of South Africa (Rees and Underwood, 2002), becoming widespread until their extinction at the close of the Cretaceous (Maisey, 1996). *Hybodus* teeth occur in shallow coastal marine, brackish, and freshwater deposits (Welton and Farish, 1993). *Hybodus* sp. tooth elements (cephalic hooks and fin spines are also commonly found) have been documented in Campanian sediments from Alberta, Canada (Peng et al., 2001), Chihuahua (Mexico) (Cope et al., 2003), Alabama (Whetstone and Collins, 1982), Delaware (Lauginiger, 1984), Georgia (Schwimmer, 1986), Montana (Fiorillo, 1989), New Jersey (Grandstaff et al., 1992), New Mexico (Hutchinson and Kues, 1985), North Carolina (Miller, 1967), South Carolina (Cicimurri, 2007), Texas (Rowe et al., 1992), and in the Maastrichtian of New Jersey (Gallagher et al., 1986).

Superfamily HYBODONTOIDEA Owen, 1846
Family LONCHIDIIDAE Herman, 1977
Genus LONCHIDION Estes, 1964
Lonchidion selachos Estes, 1964

(Plate I-B; Figure 3a-c)

Lonchidion selachos Estes, 1964, p. 7, figs. a-d.
Lonchidion selachos Estes; Rees and Underwood, 2002, p. 473, figs. 2, 3G-L.

Material: Author's collection; tooth.

Description: Tooth with a moderately developed labial crown protuberance; crown is low, about 1.8 mm in maximum height and 3.8 mm in width, without serrations or ornamentation. Occlusal profile is elongate, tapered at the ends, inflated in the middle, and has a well developed continuous transverse cutting ridge. Tooth is broadly triangular; labial and lingual crown faces are smooth.

Occurrence: Isolated remains of hybodont sharks often occur within Mesozoic sediments. *Lissodus,* considered by Duffin (1985) to be synonymous with *Lonchidion*, is an extinct genus of freshwater shark of the Hybodont family whose fossil record ranges from the Carboniferous to the late Maastrichtian (Rees and Underwood, 2002). *L. selachos* has been documented in Campanian to late Maastrichtian sediments from New Mexico (Armstrong-Ziegler, 1978), Texas (Rowe et al., 1992), Wyoming (DeMar and Breithaupt, 2006), Montana (Estes, 1965), North Dakota (Pearson et al., 2002), and Colorado (Carpenter, 1979).

Order LAMNIFORMES Berg, 1958
Family MITSUKURINIDAE Jordon, 1898
Genus SCAPANORHYNCHUS Woodward, 1889
Scapanorhynchus texanus (Roemer, 1852)

(Plate I-C and I-D: Figures 4a-7c)

Lamna texanus Roemer, 1852, p. 29, pl. 2, fig. 7
Scapanorhynchus texanus (Roemer); Cappetta and Case, 1975, p. 14, pl.1, figs. 13-16, pl. 2, fig. 1-36.

Material: Author's collection; teeth.

Description: Anterior teeth of *S. texanus* are large, elongate (averaging 2-5 cm in height), and signoidal in lateral aspect with similarly shaped lateral cusplets. Striae on the lingual face are parallel near the base, become more flexuous near the top, and often extend almost the whole length of the crown. The root is large with a deeply furrowed median boss on the lingual face, with long, thin moderately divergent root branches. Lateral and anterio-lateral teeth are broader and more flattened than the anterior ones. Also, they may possess poorly developed striae that are limited to the crown-margin region. One or two triangular cusplets occur on each side of the crown. The root is flatter, broader, shorter, and more divergent than the root of an anterior tooth.

Occurrence: *Scapanorhynchus* (goblin shark) is an extinct genus of lamniform shark that is restricted to the Cretaceous (Welton and Farish, 1993). It is known worldwide from the Albian (Lower Cretaceous) to the Maastrichtian (Upper Cretaceous) (Cappetta and Case, 1975). Fossils of this genus are the most common shark fossils in Upper Cretaceous Atlantic and Gulf Coastal Plain deposits (Case and Schwimmer, 1988). Modern species within the family Mitsukurinidae are benthic, live in deep waters of the continental slope mainly at depths between 270 to 700 meters. At night they may enter shallower waters (Compagno et al., 2005). *S. texanus* has been documented in the Campanian of Georgia (Schwimmer, 1986), North Carolina (Miller, 1967), New Jersey (Grandstaff et al., 1992), Mississippi (Dockery and Jennings, 1988), Texas (Welton and Farish, 1993, and Lehman and Tomlinson, 2004), Delaware (Lauginiger, 1984), and Wyoming (Case, 1987b), and the Maastrichtian of New Jersey (Krause and Baird, 1979, and Gallagher et al., 1986), North Carolina (Case, 1979), and Texas (Welton and Farish, 1993).

Family CRETOXYRHYINIDAE Glickman, 1958
Genus CRETOLAMNA Glickman, 1958
Cretolamna appendiculata lata (Agassiz, 1843)

(Plate I-E: Figures 8a-b)

Otodus latus Agassiz, 1843, p. 271, pl. 32, fig. 26.
Cretolamna appendiculata lata (Agassiz); Cappetta and Case, 1975, p. 21, pl. 3, figs. 10-28.

Material: Author's collection; tooth.

Description: Tooth element measures 12 mm (root width) and 9 mm (crown length) and has an elevated, smooth, broad, triangular shaped central cusp, and one pair of similarly shaped diverging cusplets on either side. The lingual face of the crown and root are convex with the labial face and the root surface is nearly flat. The root has no medial groove on the lingual face and has an obtuse lobe angle.

Occurrence: *Cretolamna appendiculata lata* (a mackerel shark), is an extinct species of lamniform shark that lived from the Albian (Lower Cretaceous) to the Lower Eocene (Cappetta, 1987). Lamniformes are pelagic, (although some genera have been known to frequent shallow coastal waters) and are known to be predators (Cappetta, 1987). *C. appendiculata lata* has been documented in the Campanian of Georgia (Schwimmer, 1986), New Jersey (Grandstaff et al., 1992), and Mississippi (Dockery and Jennings, 1988), and Texas (Welton and Farish, 1993), and the Maastrichtian of New Jersey (Krause and Baird, 1979, and Case et al., 2001) and Texas (Welton and Farish, 1993).

Family ANACORACIDAE Casier, 1947
Genus SQUALICORAX Whitley, 1939
Squalicorax kaupi (Agassiz, 1843)

(Plate I-F: Figures 9a-10b)

Corax kaupi Agassiz, 1843, p. 225, pl. 26A, figs. 25-34; pl. 26, figs. 4-8.
Squalicorax kaupi (Agassiz); Cappetta and Case, 1975, p. 8, pl. 7, figs. 17-29.

Material: Author's collection; teeth.

Description: Teeth exhibit a roughly triangular shape and average 12 mm in height and 15 mm in width. Teeth have a broad, slightly curved, coarsely serrated blade and a small lateral shoulder. Roots are robust and make up approximately ½ the entire tooth height. Teeth possess a notch on the posterior edge of the crown, and the root-boss exhibits no furrow or groove.

Occurrence: *Squalicorax kaupi* (crow shark), an extinct species of lamniform shark, occurs in Santonian to Maastrichtian sediments (Cappetta, 1987). *S. kaupi* has been documented in the Campanian of Delaware (Lauginiger, 1984), Georgia (Schwimmer, 1986), Mississippi (Dockery and Jennings, 1988), Montana (Case, 1978), New Jersey (Grandstaff et al., 1992), North Carolina (Miller, 1967), South Carolina (Cicimurri, 2007), Texas (Welton and Farish, 1993), and Wyoming (Case, 1987b), and the Maastrichtian of New Jersey (Krause and Baird, 1979, and Case et al., 2001) and Texas (Case and Cappetta, 1997).

Family ANACORACIDAE Casier, 1947
Genus SQUALICORAX Whitley, 1939
Squalicorax pristodontis Agassiz, 1843

(Plate I-F: Figures 11a-b)

Squalicorax pristodontis Agassiz, 1843, p. 224, pl. 26, figs. 9-13.
Squalicorax pristodontis Agassiz; Cappetta and Case, 1975, p. 8, pl. 7, figs. 30 - 41.

Material: Author's collection; tooth.

Description: Tooth is large, measuring 2 cm wide, similar in shape to *Squalicorax kaupi,* yet larger in overall size. The crown is crescent shaped and lacks the distinct posterior notch characteristic of *S. kaupi* (the distal edge is curved rather than angular). Crown serrations are fine, distinct, and complete. The root is large and broad making up two-thirds of the overall tooth height in lingual view.

Occurrence: *Squalicorax pristodontis* (crow shark) is an extinct species of lamniform shark that occurs in Campanian and, more abundantly, in Maastrichtian marine sediments (Cappetta, 1987; Welton and Farish, 1993). *S. pristodontis* has been documented in the late Cretaceous of Alabama (Applegate, 1970), the Campanian of Colorado (Kass, 1999), Delaware (Lauginiger, 1984), Kansas (Cicimurri and Everhart, 2001), Montana (Douglass, 1902), North Carolina (Miller, 1967), South Carolina (Cicimurri, 2007), Texas (Welton and Farish, 1993), and Wyoming (Case, 1987b), and the Maastrichtian of New Jersey (Baird and Case, 1966 and Krause and Baird, 1979), North Carolina (Carter et al., 1988), and Texas (Case and Cappetta, 1997; Welton and Farish, 1993).

Order SQUATINIFORMES Buen, 1926
Family SQUATINIDAE Bonaparte, 1838
Genus SQUATINA Duméril, 1806
Squatina hassei Leriche, 1929

(Plate I-G: Figures 12a-13c)

Squatina hassei Leriche, 1929, p. 206, figs. 1-3.
Squatina hassei Leriche; Cappetta and Case, 1975, p. 9, pl.1, figs. 17-24.

Material: Author's collection; tooth and vertebra.

Description: Tooth is small, 4.5 mm in height (from base to apical tip) and 5.5 mm in basal width. A single elevated central cusp is located centrally on the labial root edge, overhanging and forming a distinct uvula on the root below. Labial and lingual crown faces are smooth; mesial and distal shoulders low, and elongate. Root distinctly triangular in basal view and projects lingually at right angle to crown; basal attachment surface is broad, weakly concave and possesses a distinct nutrient foramen centrally located on the root base. *Squatina* vertebrae possess unequal ovoid faces with calcified cartilage surrounding the smaller anterior face.

Occurrence: *Squatina* (angel shark) is an extant genus having an extensive fossil record beginning in the Upper Jurassic. Externally, they have ray-like characteristics, but, based on anatomical features, they are sharks (Welton and Farish, 1993). Today, Squatiniformes are mainly found on muddy to sandy substrates in cool temperate waters ranging from intertidal to continental shelves and continental slopes (Compagno et al., 2005). In tropical waters, Squatiniformes tend to prefer deeper environments. Life habits of extant Squatiniformes indicate that they do not swim far and are subjected to population isolation (Compagno et al., 2005). Fossil elements of this taxon are found in fluvio-marine sediments (Case and Schwimmer, 1988). *S. hassei* has been documented in the Campanian of Canada (Alberta) (Peng et al., 2001), Delaware (Lauginiger, 1984), Georgia (Schwimmer, 1986), New Jersey (Grandstaff et al., 1992), North Carolina (Miller, 1967), South Carolina (Cicimurri, 2007) and Texas (Welton and Farish, 1993), and the Maastrichtian of New Jersey (Gallagher at al., 1986, and Case et al., 2001a), and Texas (Welton and Farish, 1993).

Order ORECTOLOBIFORMES Applegate, 1972
Family GINGLYMOSTOMATIDAE Gill, 1862
Genus GINGLYMOSTOMA Müller and Henle, 1837
Ginglymostoma globidens Cappetta and Case, 1975

(Plate I-H: Figures 14a-c)

Ginglymostoma globidens Cappetta and Case, 1975, p. 12, text fig. 6A-G, pl. 9, figs. 24, 25.

Material: Author's collection; tooth.

Description: Small tooth 4 mm high by 5 mm wide; possesses a flat base and a broad crown inclined about 45 degrees lingually. A triangular elevated central cusp is separated from two smaller lateral cusplets on each side by a broad enameloid depression except near the basal margin. The presence of strong, irregular enameloid ridges on the labial crown face is an important diagnostic feature. The basal margin of the crown is complete and forms a fairly smooth overhanging arch. A large foramen is centrally located on the root-boss on the lingual surface.

Occurrence: *Ginglymostoma* (nurse shark) is an extant genus with a fossil record beginning in the Albian (Lower Cretaceous) (Cappetta and Case, 1975). They are common within near-shore littoral zones (Case and Schwimmer, 1988). Today, *Ginglymostoma* resides in subtropical to tropical continental and insular waters including coral and rocky reefs, areas with sandy substrate, reef lagoons, and mangrove keys (Compagno et al., 2005). They are nocturnal, social, bottom feeders that rest on the seabed in small groups (Compagno et al., 2005). *G. globidens* has been documented in the Campanian of Georgia (Schwimmer, 1986; Case, 1987b), Mississippi (Dockery and Jennings, 1988), and Wyoming (Case, 1987b), and in the Maastrichtian of New Jersey (Cappetta and Case, 1975).

Superorder BATOMORPHII Cappetta, 1980
Order SCLERORHYNCHIFORMES Kriwet, 2004
Suborder SCLERORHYNCHOIDEI Cappetta, 1980
Family SCLERORHYNCHIDAE Cappetta, 1974
Genus BORODINOPRISTIS Case, 1987
Borodinopristis schwimmeri Case, 1987

(Plate I-I: Figure 15a)

Borodinopristis schwimmeri Case, 1987a, p. 25-33, figs. 1a, 2a-f, and 4g.
Borodinopristis schwimmeri Case; Wueringer et al., 2009, p. 454, fig. 5.

Material: Author's collection; fragmented rostral tooth.

Description: Rostral tooth is small, 3 mm in length. Spine consists of two collared areas contributing to the appearance of barbs along the posterior margin.

Occurrence: See *Ischyrhiza mira* for environmental distribution. *B. schwimmeri* has been documented in the Campanian of Georgia (Case, 1987a) and South Carolina (Cicimurri, 2007).

Family SCLERORHYNCHIDAE Cappetta, 1974
(= Ganopristinae Arambourg, 1940)
Genus ISCHYRHIZA Leidy, 1856
Ischyrhiza avonicola Estes, 1964

(Plate I-J: Figures 16a-b)

Ischyrhiza avonicola Estes, 1964, p. 13-14, fig. 6.
Ischyrhiza avonicola Estes; Welton and Farish, 1993, p. 140, figs. 1a-4b.

Material: Author's collection; rostral tooth.

Description: Rostral tooth is small and short (total length measures 8 mm) with the crown being less than half the total tooth height. The enameled crown is inclined posteriorly, and possesses coarse, short longitudinal ridges that are restricted to the crown foot and directed toward the apex. Root is widely splayed and expands continuously from the crown foot to the base.

Occurrence: See *Ischyrhiza mira* for environmental distribution. *I. avonicola* has been documented in the Campanian of Montana (Case, 1978), New Mexico (Armstrong-Ziegler, 1978), Texas (Welton and Farish, 1993), Delaware (Lauginiger, 1984), South Carolina (Cicimurri, 2007), and Wyoming (Case, 1987), and in the Maastrichtian of North Dakota (Pearson et al., 2002), Colorado (Carpenter, 1979), Texas (Welton and Farish, 1993), and Wyoming (Estes, 1964).

Family SCLERORHYNCHIDAE Cappetta, 1974
(= Ganopristinae Arambourg, 1940)
Genus ISCHYRHIZA Leidy, 1856
Ischyrhiza mira Leidy, 1856

(Plate I-K: Figures 17a-18c)

Ischyrhiza mira Leidy, 1856, p. 221.
Ischyrhiza mira Leidy; Cappetta, 1987, p. 149-150, fig. 126 I – J.
Ischyrhiza mira Leidy; Welton and Farish, 1993, p. 141, figs. 1 – 8b.

Material: Author's collection; rostral and oral teeth.

Description: Rostral tooth measures 29 mm in length and possesses a thick, elongate, trenchant, and laterally compressed smooth enameloid crown. The crown is slightly sinuous and is about the same length as the root; anterior and posterior cutting edges are sharp and extend from the crown apex toward the base but do not intersect the crown foot. Root is massive, almost square in cross-section at the base, and basally expanded with a median longitudinal furrow and deeply scalloped root lobes. Oral teeth of *I. mira* are extremely small, 4 mm in width and 3 mm tall. Crown is smooth, except for a few enameloid folds near crown foot. Root high, strongly bilobate with a flat attachment surface, subdivided by a deep nutrient groove.

Occurrence: Sclerorhynchidae (rays resembling modern sawfish) occupied ecological and functional niches comparable to those occupied by modern sawfishes (Welton and Farish, 1993). They have a fossil record extending from the Turonian (Upper Cretaceous) to the Thanetian (late Paleocene). Modern sawfish are bottom dwellers and have a worldwide distribution in warm to tropical seas (Welton and Farish, 1993). They live nearshore, particularly near river mouths and prefer brackish to estuarine conditions. They frequently enter and breed in freshwater river systems (Estes, 1964). *I. mira* has been documented in the Campanian of Alberta (Canada) (Peng et al., 2001), Alabama (Kiernan and Schwimmer, 2004), Georgia (Schwimmer, 1986), Montana (Case, 1978), North Carolina (Miller, 1967), New Jersey (Grandstaff et al., 1992), Mississippi (Dockery and Jennings, 1988), Delaware (Lauginiger, 1984), South Carolina (Cicimurri, 2007), Tennessee (Sohl, 1960), Texas (Welton and Farish, 1993), and Wyoming (Case, 1987b), and in the Maastrichtian of New Jersey (Gallagher et al., 1986) and Texas (Welton and Farish, 1993).

Family incertae sedis
Genus PTYCHOTRYGON Jaekel, 1894
Ptychotrygon triangularis (Reuss, 1845)

(Plate I-L: Figures 19a-d)

Ptychodus triangularis Reuss, 1845
Ptychotrygon triangularis (Reuss); Cappetta and Case, 1975, p. 32, text fig. 9, pl. 4, figs. 23-28.
Ptychotrygon triangularis (Reuss); Welton and Farish, 1993, p. 151, figs. 1-5.
Ptychotrygon vermiculata Cappetta, 1987, p. 156-157, fig. 136 A-D.

Material: Author's collection; oral teeth.

Description: Teeth are small, about 4 mm at widest point. Crown is high, elongate, and triangular with the labial face overhanging the root and the lingual face ending abruptly at the root's edge. Crowns also have a broadly wrinkled occlusal enamel surface, and possess three prominent, well separated, transverse ridges; one along the middle of lingual face, one along the junction of the lingual and labial faces, and one across the middle of the labial face. The occlusal outline is bilaterally symmetrical, elongate, and rhomboidal with tapering ends. The root platform is rhomboid in outline and bilobed.

Occurrence: *Ptychotrygon triangularis* is classified within the Batoidea, which are rays that resemble modern sawfish (see *Ischyrhiza mira* for environmental distribution). *P. triangularis* has been recorded in the Campanian of New Mexico (Hutchinson and Kues, 1985), and Texas (Welton and Farish, 1993), and the Maastrichtian of Texas (Welton and Farish, 1993).

Order MYLIOBATIFORMES Compagno, 1973
Superfamily DASYATOIDEA Whitley, 1940
Family DASYATIDAE Jordan, 1888
Genus DASYATIS Rafinesque, 1810
Dasyatis sp.

(Plate I-M: Figures 20a-c)

Dasyatis spp. Welton and Farish, 1993, p. 156, figs. 1a-3c.
Dasyatis Cappetta, 1987, p. 162-163.

Material: Author's collection; tooth.

Description: Tooth is small, measuring 5 mm in length. Crown is strongly convex without a distinct cusp (female). A transverse ridge separates a flat labial face from a broadly sloping and smooth lingual face. Labially, the crown overhangs a strongly bilobate root, which is projected beyond limits of the crown. Bilobate hook like root is separated by a deep nutrient groove containing a centrally located basal foramina.

Occurrence: Modern species of *Dasyatis* (whiptail stingray) occur worldwide in warm, shallow waters but they often stray into brackish and freshwater. They are bottom dwellers, often found completely buried in sandy substrates (Welton and Farish, 1993). *Dasyatis* sp. tooth elements exhibit strong sexual dimorphism. The oldest representative of this genus is from the Cenomanian of Texas (Cappetta, 1987). *Dasyatis* sp. has been documented in the Cenomanian of Texas (Welton and Farish, 1993), and the Maastrichtian of New Jersey (Case et al., 2001a) and Texas (Welton and Farish, 1993).

Superfamily MYLIOBATOIDEA Compagno, 1973
Family MYLIOBATIDAE Bonaparte, 1838
Genus BRACHYRHIZODUS Romer, 1942
Brachyrhizodus wichitaensis Romer, 1942

(Plate I-N: Figures 21a-c)

Brachyrhizodus wichitaensis Romer, 1942, p. 221, pl. 1, figs. 7, 8.
Brachyrhizodus wichitaensis Romer; Cappetta, 1987, p. 171-172, fig. 145 A-F.
Brachyrhizodus wichitaensis Romer; Welton and Farish, 1993, p.153, fig. 1a-e.

Material: Author's collection; isolated mouth plate.

Description: Lateral tooth element measures 13 mm in length, 6 mm in width, and 5 mm in height. Laterally elongate, bilaterally symmetrical, thick with a massive smooth crown, and has a hexagonal occlusal outline. The crown enamel on the occlusal surface is textured with irregular shallow cracks and is pleated near the crown margin. The bi-lobed root has two visible nutrient grooves.

Occurrence: *Brachyrhizodus* (eagle ray) generally inhabits shallow, warm, tropical to temperate seas (Cappetta, 1987), and some are seasonal migrants to temperate waters (Welton and Farish, 1993). *Brachyrhizodus* species are pelagic, benthic feeders that probe the seabed for shellfish and crustaceans, consuming them with their powerful pavement-type teeth (Welton and Farish, 1993). *B. wichitaensis* has been recorded in the Campanian of Georgia (Schwimmer, 1986), New Jersey (Grandstaff et al., 1992), Delaware (Lauginiger, 1984), South Carolina (Cicimurri, 2007), and Texas (Welton and Farish, 1993), and in the Maastrichtian of New Jersey (Krause and Baird, 1979).

Family RHOMBODONTIDAE NOV.
Genus RHOMBODUS Dames, 1881
Rhombodus binkhorsti Dames, 1881

(Plate I-O: Figures 22a-c)

Rhombodus binkhorsti Dames, 1881, p. 115–117, p. 116, figs. a–d.
Rhombodus binkhorsti Dames; Cappetta, 1987, p. 174 - 175, fig. 146 F-I.
Rhombodus binkhorsti Dames; Welton and Farish, 1993, p. 155, fig. 1a-6d.
Rhombodus levis Cappetta and Case, 1975, p. 36, pl. 9, figs. 12-20.

Material: Author's collection; isolated pavement tooth.

Description: Tooth measures 6 mm in height, 6 mm in width, and 6 mm in depth. The crown is rhomboidal in occlusal view, and is enameled on the occlusal surface, the sides, and the underside adjacent to the crown margin. The bilobate root is smaller in diameter than the crown and the base exhibits a generally porous surface. A canal with a centrally located foramen separates the two root lobes.

Occurrence: *Rhombodus binkhorsti*, an extinct species of the extinct family Rhombodontidae (stingrays), has been recorded in the late Cretaceous of North Carolina (Case, 1979), and the Maastrichtian of New Jersey (Case et al., 2001a), South Carolina (Knight et al., 2007), and Texas (Welton and Farish, 1993).

Class OSTEICHTHYES Huxley, 1880
Subclass NEOPTERYGII Regan, 1923
Order LEPISOSTEIFORMES Hay, 1929
Family LEPISOSTEIDAE Cuvier, 1825
Genus LEPISOSTEUS Lacépède, 1803
Lepisosteus sp.

(Plate II-A: Figure 1a)

Lepisosteus sp. Case and Schwimmer, 1988, p. 298, figs. 6.10 and 6.11.
Lepisosteidae indet. Robb, 1989b, p. 90, fig. 18 A.

Material: Author's collection; scale.

Description: Scale measures 16 mm in length, is rhomboidal in shape with an enameled outer surface. The enameled surface is speckled with minute pores. The underside of the scale has a bony composition.

Occurrence: Lepisosteids (garpike) are freshwater carnivorous fish that have a fossil record extending back to the early Cenomanian (Upper Cretaceous). Living lepisosteids inhabit large river systems and some have been known to frequent brackish and coastal marine waters (Wiley, 1976). Cretaceous *Lepisosteus* are found in estuarine deposits (Case and Schwimmer, 1988). *Lepisosteus* sp. has been recorded from the early Cenomanian of Utah (Garrison et al., 2007), the early Coniacian of Utah (Eaton et al., 1999), the late Santonian to early Campanian of Utah (Eaton, 1999), the late Campanian to early Maastrichtian of Alberta (Canada) (Langston, 1975), the Campanian of Alberta (Langston, 1975) and Saskatchewan (Canada) (Russell, 1935), Georgia (Schwimmer, 1986), Wyoming (Pappas et al., 2003), Coahuila (Mexico) (Aguillón-Martínez et al., 2004), Arizona (Miller, 1964), Delaware (Lauginiger, 1984), Montana (Dodson, 1984), and New Mexico (Hutchinson and Kues, 1985), and the Maastrichtian of Alberta (Canada) (Langston, 1975), Saskatchewan (Canada) (Johnston, 1980), Montana (Wilson, 2008), Wyoming (Estes, 1964), South Dakota (Gilmore, 1910), New Mexico (Gilmore, 1916).

Subclass ACTINOPTERYGII Cope, 1887
Order PYCNODONTIFORMES Berg, 1940
Family PYCNODONTIDAE Agassiz, 1833
Genus ANOMOEODUS Forir, 1887
Anomoeodus phaseolus (Hay, 1899)

(Plate II-B: Figures 2a-4b)

Pycnodus phaseolus Hay, 1899, p. 788.
Anomoeodus phaseolus (Hay); Robb, 1989b, p. 91, fig. 19.

Material: Author's collection; fragmentary splenial jaw section with two splenial crusher teeth, isolated mandibular tooth and anterior vomerine tooth cap.

Description: Splenial jaw section consists of two splenial crusher teeth. Splenial teeth, which are elongate, convex, and smooth, have an average measurement of 21 mm in length and 7 mm in width. The isolated splenial tooth element is 18 mm in length and 7 mm in width, the basal area lacks a root, and exhibits a deeply scooped (canoe-shaped) pulp cavity. The anterior vomerine tooth cap (crusher tooth) is round in occlusal view, measures 3 mm, and exhibits a smooth convex occlusal surface.

Occurrence: Pycnodontids ("crowded tooth") are an extinct group of ray-finned (bony) fish that lived in reef environments from the Triassic to the Eocene. Fossil pycnodontids have also been found in river and lake deposits as well as in brackish (estuarine) deposits (Maisey, 1996). *Anomoeodus phaseolus* has been recorded throughout the Cretaceous (particularly the Campanian) of the Atlantic and Gulf Coastal Plain (Robb, 1989b). *A. phaseolus* has been documented in the Campanian of Delaware (Lauginiger, 1984), Georgia (Case, 1987), New Jersey (Lauginiger, 1986), North Carolina (Miller, 1967), and South Carolina (Cicimurri, 2007), and the Maastrichtian of New Jersey (Gallagher et al., 1986).

Family PHYLLODONTIDAE Sauvage, 1875
Subfamily PARALBULINAE Estes, 1969
Genus PARALBULA Blake, 1940
Paralbula casei Estes, 1969

(Plate II-C: Figures 5a-7b)

Paralbula casei Estes, 1969, p. 322, fig. 3.
Paralbula casei Estes; Robb, 1989b, p. 92, figs. 22 C-D.

Material: Author's collection; crushing teeth.

Description: Teeth are small, averaging 25 mm in diameter. Individual tooth caps are round or slightly oval in occlusal view, with a shallow concave pulp cavity. The convex occlusal surface has a thin enamel covering, and also has faintly developed but coarse and radial sculpturing.

Occurrence: Elopomorphs (sea-fish forms) include the tarpons and tenpounders, bonefish, and eels (Maisey, 1996). *Paralbula casei* occurs in late Cretaceous to early Cenozoic freshwater, estuarine and marine deposits (Estes, 1969). *P. casei* has been documented in the Campanian of Alberta (Canada) (Eberth and Brinkman, 1997), Alabama (Schwimmer, 1986), New Mexico (Armstrong-Ziegler, 1978), North Carolina (Miller, 1967), New Jersey (Grandstaff et al., 1992), Delaware (Lauginiger, 1984), and South Carolina (Cicimurri, 2007), and the Maastrichtian of New Jersey (Olson and Parris, 1987; Gallagher et al., 1986), Montana (Estes, 1965), and Alberta (Canada) (Langston, 1975).

Order ELOPIFORMES Sauvage, 1875
Family ALBULIDAE Bleeker, 1859
Genus ALBULA Gronow, 1763
Albula sp.

(Plate II-D: Figures 8a-c)

Albula sp. Case and Schwimmer, 1988, p. 298, figs. 19, 20.
Albula sp. Robb, 1989b, p. 92, figs. 22 A-B.

Material: Author's collection; crushing teeth.

Description: The crushing teeth are small and on average 3 mm in diameter. Teeth are generally round in occlusal view with an enameled smooth surface and distinctive, triple-tiered concentric terracing on the occlusal surface. The teeth lack distinctive roots, and the basal aspect is irregular but flat.

Occurrence: Elopomorphs (sea-fish forms) include the tarpons and tenpounders, bonefish, and eels (Maisey, 1996). Based on their large orbits, *Albula* sp. were probably active at night, preying on benthic organisms. Modern species of the family Albulidae live in tropical waters, mainly marine, and rarely in brackish and freshwater (Maisey, 1996). *Albula* sp. has been documented in the Campanian of Alabama (Case and Schwimmer, 1988), and North Carolina (Robb, 1989b) and the Maastrichtian of Wyoming (Clemens, 1964).

Order SALMONIFORMES Bleeker, 1859
Family ENCHODONTIDAE Woodward, 1901
Genus ENCHODUS Agassiz, 1835
Enchodus cf. *E. petrosus* Cope, 1874

(Plate II-E: Figures 9a-c)

Enchodus petrosus Cope, 1874, p. 44.
Enchodus petrosus Cope; Case and Schwimmer, 1988, p. 298, figs. 6.23-6.26.

Material: Author's collection; isolated palatine fang.

Description: The long, relatively slender palatine tooth measures 34 mm from base to apex. It possesses a convex smooth enamel anterior surface and a strongly convex longitudinally striated posterior enamel surface that is minutely concave at the base. In cross-section, the tooth element is asymmetrically compressed.

Occurrence: Enchodontids ("spear tooth") are fast swimming predators with needle-like teeth and are common in marine environments worldwide (Maisey, 1996). During the late Cretaceous, *Enchodus* was globally distributed (Case and Schwimmer, 1988). *E. petrosus* has been recorded from the Campanian of Georgia (Schwimmer, 1986; Case and Schwimmer, 1988), North Carolina (Miller, 1967), New Jersey (Grandstaff et al., 1992), and South Carolina (Cicimurri, 2007).

Subclass NEOPTERYGII Regan, 1923
Division TELEOSTEI Müller, 1846
Order ICHTHYODECTIFORMES Bardack and Sprinkle, 1969
Family ICHTHYODECTIDAE Crook, 1892
Genus XIPHACTINUS Leidy, 1870
Xiphactinus vetus Schwimmer, Stewart, and Williams, 1997

(Plate II-F: Figures 10a-b)

Xiphactinus audax Leidy, 1870, p. 12.
Xiphactinus audax Leidy; Robb, 1989b, p. 91, fig. 20 (not Leidy, 1870).
Xiphactinus vetus Schwimmer, Stewart, and Williams, 1997, p. 612, figs. F - Z.

Material: Author's collection; isolated tooth.

Description: Tooth is elongate, slender, and laterally compressed with well developed anterior and posterior carinae. Crown length measures 30 mm, basal cross-section is 9 mm wide and elliptical in form. Crown exhibits a slight curvature both lingually and posteriorly.

Occurrence: *Xiphactinus vetus* is an extinct form of primitive tarpon (ray-finned fish) that is restricted to the Campanian. *X. vetus* has been documented in Georgia (Schwimmer et al., 1997), North Carolina (Miller, 1967) and Wyoming (Lillegraven and McKenna, 1986; DeMar and Breithaupt, 2006).

Remarks: Prior to the publication by Schwimmer et al. (1997) on the occurrence of *Xiphactinus vetus* and *Xiphactinus audax,* all *Xiphactinus* species found in Cretaceous age sediments on the Atlantic Coast of North America were assigned to *X. audax*. It is now considered to be restricted to the Santonian, whereas *X. vetus* is restricted to the Campanian (Schwimmer et al., 1997). Therefore, most if not all of the previously identified *X. audax* from New Jersey and North Carolina likely should be assigned to *X. vetus.*

Order SEMIONOTIFORMES Arambourg and Bertini, 1958
Family HADRODONTIDAE Thurmond and Jones, 1981
Genus HADRODUS Leidy, 1857
Hadrodus priscus Leidy, 1857

(Plate II-G: Figures 11a-13b)

Hadrodus priscus Leidy, 1857, p. 167
Hadrodus priscus Leidy; Bell, 1986, p. 1122, fig. 1.
?Stephanodus sp. Case and Schwimmer, 1988, p. 298, figs. 6.27.

Material: Author's collection; isolated vomer crushing teeth and pharyngeal teeth.

Description: Vomer (crushing) teeth are ovate and rounded, irregularly-sized with a single depressed conical crest. The diameter of these oral teeth averages 5 mm. The small, translucent, pharyngeal teeth are claw shaped and measure, on average, 8 mm in length.

Occurrence: Semionotids ("flag back") are an extinct group of neopterygians that lived in seas and freshwaters from the Permian until the late Cretaceous (Maisey, 1996). They were especially successful in lakes, rivers, and shallow seas from the Triassic until their demise at the end of the Cretaceous (Maisey, 1996). *Hadrodus priscus* was a primitive gar that had thick, enameled scales and jaws with peglike teeth. Today, most gar species inhabit freshwater, enter brackish waters and, on occasion, can enter marine waters (Maisey, 1996). *H. priscus* has been documented in the Campanian of Alabama (Bell, 1986). It has also been recorded (as ?*Stephanodus* sp.) in the Campanian of Chihuahua (Mexico) (Cope et al., 2003), Georgia (Case and Schwimmer, 1988), North Carolina (Miller, 1967), Delaware (Lauginiger, 1984), New Jersey (Lauginiger, 1986), and South Carolina (Cicimurri, 2007) and from the Maastrichtian of New Jersey (Gallagher et al., 1986; Krause and Baird, 1979).

Class REPTILIA Laurenti, 1768
Order SQUAMATA Oppel 1811
Family MOSASAURIDAE Gervais 1853
Genus TYLOSAURUS Marsh 1872
Tylosaurus sp.

(Plate III-A: Figures 1a-2b)

Tylosaurus sp. Miller, 1967, p. 227.
Tylosaurus sp. DeMar and Breithaupt, 2006, p. 43.
Elliptodon compressus Emmons, 1858, p. 222, fig. 41 and 42.

Material: Author's collection; isolated tooth and cervical vertebra.

Description: Tooth possesses a longitudinal carina (bicarinate) that separates the tooth into lingual and buccal surfaces. The sparsely enameled crown exhibits vertical ridges and the apex curves posteriorly. The base of the tooth is elliptical becoming sub-ellipitcal at the apex. Anterior to posterior base measurement is 18 mm. Lingual to buccal base measurement is 15 mm. Length from base to worn apex is 25 mm.

Occurrence: *Tylosaurus* species were nearshore marine carnivores (Kiernan, 2002). *Tylosaurus* sp. has been reported in Campanian age strata of Delaware (Baird and Galton, 1981), North Carolina (Miller, 1967), South Dakota (Martin and Bjork, 1987), Texas (Thurmond, 1969), and Manitoba, Canada (Bardack, 1968).

Order PLESIOSAURIA de Blainville, 1835
Superfamily PLESIOSAUROIDEA Welles, 1943
Family ELASMOSAURIDAE Cope, 1869a
gen. et sp. indet.

(Plate III-B: Figures 3a-d)

Plesiosaurus De la Beche and Conybeare, 1821, pl. 41, figs. 1-11.
Plesiosaurus sp. De la Beche and Conybeare, 1821; Owens, 1860, p. 224-225.
Plesiosaurus sp. De la Beche and Conybeare, 1821; Storrs, 1997, p. 170-171.
Elasmosauridae Cope, 1869a; Gasparini et al., 2001, p. 54, figs. 3-6.

Material: Isolated vertebra.

Description: The vertebral element exhibits flat to slightly concave articular surfaces and the ventrally positioned nutrient foramens are closely spaced. Anterior and posterior views are kidney-shaped and the edges are rounded to slightly rugose. The ventral to dorsal width is 63.4 mm; the lateral width is 105 mm.

Occurrence: Plesiosauroidea are extinct reptiles that first appeared in the Triassic and became extinct during the early Maastrichtian. Plesiosauria is considered to be one of the most successful, widely distributed, and fully marine groups of tetrapods of the Mesozoic (Storrs, 1997). Elasmosauridae have been reported in the Campanian of Kansas (Everhart, 2000), South Dakota (Cope, 1894), Wyoming (Loomis, 1915), and Anderson River, Northwest Territory, Canada (Russell, D. A., 1967).

Order CROCODYLIA Gmelin, 1789
Family CROCODYLIDAE Cuvier, 1807
Genus BOREALOSUCHUS Brochu, 1997
Borealosuchus sp.

(Plate III-C: Figures 4a-5a)

Leidyosuchus sp. Lambe, 1907, pl. 2, figs. 4-7.
Leidyosuchus sp. Estes, 1964, p. 141.
Borealosuchus sp. Brochu, 1997

Material: Isolated tooth, mandible fragment.

Description: Tooth is a slender cone that is smooth with anterior and posterior ridges. Tooth measures 20 mm from base to apex. Mandible fragment possesses deeply pitted structures and consists of 6 tooth aveoli. Length of the mandible fragment is 6 cm.

Occurrence: *Borealosuchus* sp. (formally *Leidyosuchus* sp.), an extinct genus of crocodyliform whose fossil record extends from the Campanian to the middle Eocene, lived in estuarine to freshwater environments (Brochu, 1997). *Borealosuchus* sp. has been recorded in the Campanian of North Carolina (Miller, 1967; Baird and Horner, 1979), and in the Maastrichtian of Montana (Estes, 1964), South Dakota (Pearson et al., 2002), Wyoming (Estes, 1964), and Colorado (Carpenter, 1979).

Suborder EUSUCHIA Huxley, 1875
Family CROCODYLIDAE Cuvier, 1807
Genus DEINOSUCHUS Holland, 1909
Deinosuchus rugosus (Emmons, 1858)

(Plates III-D, III-E, and III-F: Figures 6a-10d)

Polyptychodon rugosus Emmons, 1858, p. 219, fig. 38.
Deinosuchus hatcheri Holland, 1909, p. 282-284, figs. 1-4; p. 289, figs. 9-10.
Deinosuchus rugosus (Emmons); Schwimmer, 2002, figs. 2.10, 2.11, 2.13, and 6.6.

Material: Isolated teeth, vertebra and osteoderm.

Description: Teeth are large and range from 60 mm to 76 mm in height; base diameter ranges from 85 mm to 100 mm. Tooth elements are thick, conical, relatively long, and slightly curved. Enameling of the crown is traversed longitudinally by numerous ridges (rugose cracks). Base of specimens are circular in cross-section. The distal surface of the osteoderm is distinctively thick, inflated, and convex with deep and widely spaced pitting. The medial surface is slightly convex and possesses a woven texture. Width measurement of the osteoderm is 75 mm and overall thickness is approximately 25 mm.

Occurrence: *Deinosuchus* sp., an extinct genus of crocodyliform, was a giant predator of the late Cretaceous that lived in estuarine to freshwater environments in warm, temperate latitudes (Schwimmer, 2002). *Deinosuchus* sp. has been documented in the Campanian of Georgia (Schwimmer, 1986), New Jersey (Grandstaff et al., 1992), North Carolina (Miller, 1967; Baird and Horner, 1979), Texas (Rowe et al., 1992), Montana (Urban and Lamanna, 2006), and New Mexico (Lucas et al., 2006).

Class DINOSAURIA Owen, 1842
Suborder THEROPODA Marsh, 1881
Infraorder ORNITHOMIMOSAURIA Barsbold, 1976
Family ORNITHOMIMIDAE Marsh, 1890
Genus ORNITHOMIMUS Marsh, 1890
Ornithomimus sp.

(Plate IV-A: Figures 1a-2b)

Ornithomimus sp. Miller, 1967, pl. 3, fig. 7
Ornithomimus sp. Baird and Horner, 1979, p. 9-10
Ornithomimosauria Makovicky et al., 2004, p. 144, fig. 6.4G-K.
Ornithomimus sp. Longrich, 2007, p. 991. Fig. 9B

Material: Private collections; pedal phalanx and fragmentary manual ungual.

Description: The pedal phalanx is well preserved and possesses a deep pit on each side of the distal end. Proximal to distal length is 41 mm. Sulcus measures 5 mm (ventral to dorsal) and 6 mm (proximal to distal). Thickness of proximal region (from ventral to dorsal) is 16 mm. Fragmentary manual ungual: this specimen is referred to Ornithomimidae based on the elongated and moderately curved nature of the ungula, its ventrally flattened appearance, and the distal location of a reduced flexure tubercle. Proximal to distal measurement length is 4 cm.

Occurrence: Ornithomimosauria are medium to large, lightly built theropods that lived in central Asia and North America during the Cretaceous (Makovicky et al., 2004). They are considered to be terrestrial, gregarious, actively mobile omnivores, and are viewed as a basal coelurosaur (Makovicky et al., 2004). *Ornithomimus* sp. has been documented in the Campanian of North Carolina (Miller, 1967; Baird and Horner, 1979) and Utah (DeCourten and Russell, 1985), and the Maastrichtian of Alberta, Canada (Russell, 1967), Saskatchewan, Canada (Sternberg, 1924), Colorado (Carpenter and Young, 2002), and Wyoming (Clemens, 1964).

Suborder THEROPODA Marsh, 1881
Infraorder COELUROSAURIA Heune, 1914
Order MANIRAPTORIFORMES Holtz, 1996
Family DROMAEOSAURIDAE Matthew and Brown, 1922
gen. et sp. indet.

(Plate IV-B: Figures 3a-c)

Saurornitholestes sp. Currie et al., 1990, p. 111, fig. 8.2 S.
cf. *Dromaeosaurus* Rowe et al., 1992, p. 483, fig. 5 G.
cf. *Saurornitholestes* Kiernan and Schwimmer, 2004, p. 91, fig.1.

Material: Author's collection; isolated tooth.

Description: Tooth element is strongly recurved, laterally compressed, and possesses prominent posterior denticulations compared to the minute denticles on the anterior carina.

Remarks: This tooth element is preliminarily identified as belonging to the family Dromaeosauridae. This is due to the lack of diagnostic characteristics of Tyrannosauroids (see above).

Occurrence: Dromaeosauridae were small to medium-sized terrestrial, solitary, actively mobile carnivores whose fossil record extends from the Middle Jurassic to the late Maastrichtian (Norrell and Makovicky, 2004). Dromaeosauridae have been documented in the Campanian of Alabama (Kiernan and Schwimmer, 2004), Alaska (Fiorillo and Gangloff, 2001), Alberta, Canada (Matthew and Brown, 1922; Peng et al., 2001), Montana (Fiorillo and Currie, 1994), and the Maastrichtian of Montana (Wilson, 2008), and Alaska (Fiorillo and Gangloff, 2001).

Suborder THEROPODA Marsh, 1881
Infraorder COELUROSAURIA Heune, 1914
Superfamily TYRANNOSAUROIDEA Walker, 1964
Family TYRANNOSAURIDAE Osborn, 1906
gen. et sp. indet.

(Plate IV-C: Figures 4a-6d)

Tyrannosauridae Baird and Horner, 1979, p. 7, fig. 2A.
Theropoda Carpenter, 1982, p.15, pl. 1, figs. 1a, b.

Material: Author's collection; isolated teeth.

Description: Tooth elements presented here are tentatively assigned to the Tyrannosauridae. Figures 4 and 6 both illustrate denticulate carinae, most notable on the posterior carina. The anterior (mesial) carina possesses a slight denticulation near the crown tip and trends lingually toward the crown base. Both teeth are laterally compressed and exhibit a rounded (D-shaped) outline. Denticles (best observed in Figure 4a) exhibit slightly rounded to flattened tips and deep interdenticle spaces typical of Tyrannosauroids. The specimen illustrated in Plate IV-C, Figure 5 also possesses a typical Tyrannosauroid (D-shaped) outline and is flattened laterally. Posterior serrations have been broken off, and the overall appearance suggests that the tooth was possibly a shed tooth that was digested. This interpretation is primarily due to the lack of denticulations (the tooth area most vulnerable to digestive processes) and the overall degeneration of the enameling (see Currie et al., 1990, p. 117 gives further information on characteristics of digested shed teeth).

Occurrence: Tyrannosauridae were terrestrial, solitary carnivores that lived from the Campanian to Maastrichtian (Holtz, 2004). Because the number of fossil elements from the BCLA is limited, identifications cannot be made beyond Family Tyrannosauridae. Acknowledging previous research on theropod elements from Phoebus Landing (North Carolina), these teeth could be *Albertosaurus* (Baird and Horner, 1979). Theropoda have been documented from coastal plain Campanian sediments of Alabama (Carr et al., 2005), Delaware (Gallagher, 1993), Georgia (Schwimmer et al., 1993), New Jersey (Gallagher, 1993), and North Carolina (Miller, 1967; Baird and Horner, 1979) and Maastrichtian deposits of Delaware (Baird and Galton, 1981; Gallagher, 1993), Maryland (Baird, 1986), New Jersey (Baird and Horner, 1977; Olson and Parris, 1987; Gallagher, 1993), and South Carolina (Weishampel and Young, 1996).

Order ORNITHOPODA Marsh, 1881
Superfamily HADROSAUROIDEA Sereno, 1986
Family HADROSAURIDAE Cope, 1869a
gen. et sp. indet.

(Plates IV-D, IV-E, IV-F, IV-G, and IV-H: Figures 7a-12b)

Hadrosauridae, Miller, 1967, pl. 4, figs. 2, 7, 8.
Hadrosauridae, Baird and Horner, 1979, p. 7, fig. 2b-c, and 7.
Hadrosauridae, Carpenter, 1982, p. 15, pl. 1, figs. 3a-b.

Material: Author's collection; isolated teeth. Private collection: dentary battery, thoracic and caudal vertebra, and ungual.

Description: Dentary tooth element possesses a complete diamond-shaped enameled crown with marginal denticulations, and a straight, singular median carina with no secondary ridges, and marginal denticulations. Maxillary tooth element exhibits a narrow, asymmetrically diamond-shaped enameled surface with a blunt tip and no accessory ridges. Left lower dentary battery fragment lingual surface shows impressions of 11 alveoli. Measurement from the posterior (hinge) to anterior (bill) is 92 mm. Eruption surface measures 78 mm. Thickness of alveoli from eruption surface to base is 45 mm. Alveoli (tooth slots on ridge) thickness measurements range from 11 mm to 6 mm. Vertebral elements consist of medium to large-sized posterior caudal vertebrae with neural arches, and a large thoracic vertebra with a neural arch. Ungual phalanx dorsal view measurements: length (proximal to distal) is 78 mm and width (right lateral to left lateral) is 43 mm.

Remarks: The dentary tooth element is possibly from a *Kritosaurus* sp., based on the tooth morphology and crown to root angle characteristics. The maxillary tooth element is similar to the maxillary teeth of *Lophorhothon atopus*, a crested hadrosaurine, as described by Langston (1960). *Lophorhothon atopus* maxillary teeth have a very distinct mid-ridge reaching its maximum sharpness slightly above the center of the crown, and no accessory ridges. The enamel surface along the lower half of the crown is thick and the upper half of the crown is regularly serrated (Langston, 1960).

Occurrence: Hadrosauridae were terrestrial, gregarious, herbivores that lived from the Barremian to the end of the Maastrichtian (Lull and Wright, 1942). Hadrosauridae have been documented in the Campanian of New Jersey (Gallagher, 1993; Baird and Horner, 1979; Olson and Parris, 1987), Delaware (Gallagher, 1993), North Carolina (Miller, 1967; Baird and Horner, 1979), Georgia (Reinhardt et al., 1981; Schwimmer and Best, 1989; Schwimmer et al., 1993), Mississippi (Lull and Wright, 1942; Carpenter, 1982), and Tennessee (Bryan et al., 1989, 1991), and in the Maastrichtian of Missouri (Gilmore and Stewart, 1945; Horner, 1979), New Jersey (Olson and Parris, 1987), Delaware

(Baird and Galton, 1981; Gallagher, 1993), Maryland (Baird, 1986), and South Carolina (Weishampel and Young, 1996). *Kritosaurus* sp. has been recorded in Campanian age deposits of New Mexico (Kirkland et al., 2006), Alberta, Canada (Russell, 1935), and Coahuila, Mexico (Rivera-Sylva et al., 2009). *Lophorhothon atopus* has been documented in Campanian sediments of Alabama (Langston, 1960).

4.2.2. Relative Abundances of the BCLA fauna

Ordinal level faunal abundances showed similar trends in the four buckets selected at random (Figs. 32, 33). This verified the consistency of the field collection methods, lab processing techniques, and indicated that the composition of the fossiliferous unit was laterally consistent. Analysis was also conducted on the faunal counts for each bucket. For consistency, only tooth elements were counted (Appendix A) and were grouped by Order. Following Sankey (2008), chelonian (turtle) elements were excluded from the analysis because “numbers are dependent on degrees of fragmentation.”

Sharks and rays (74%), dominated Bucket A (Fig. 34 A) followed by crocodylians (14%) and bony fish (11%). Dinosaur elements constituted 1% of the Bucket A assemblage. Buckets B, C and D (Figs. 34 B, C, and D) produced abundance results similar to Bucket A; sharks and rays (78%, 78%, and 73% respectively), crocodylians (13%, 11% and 14% respectively), and bony fish (9%, 10%, and 12% respectively). Dinosaurs represented 1% of the assemblage in buckets C and D, but less than 1% in bucket B (Fig. 34).

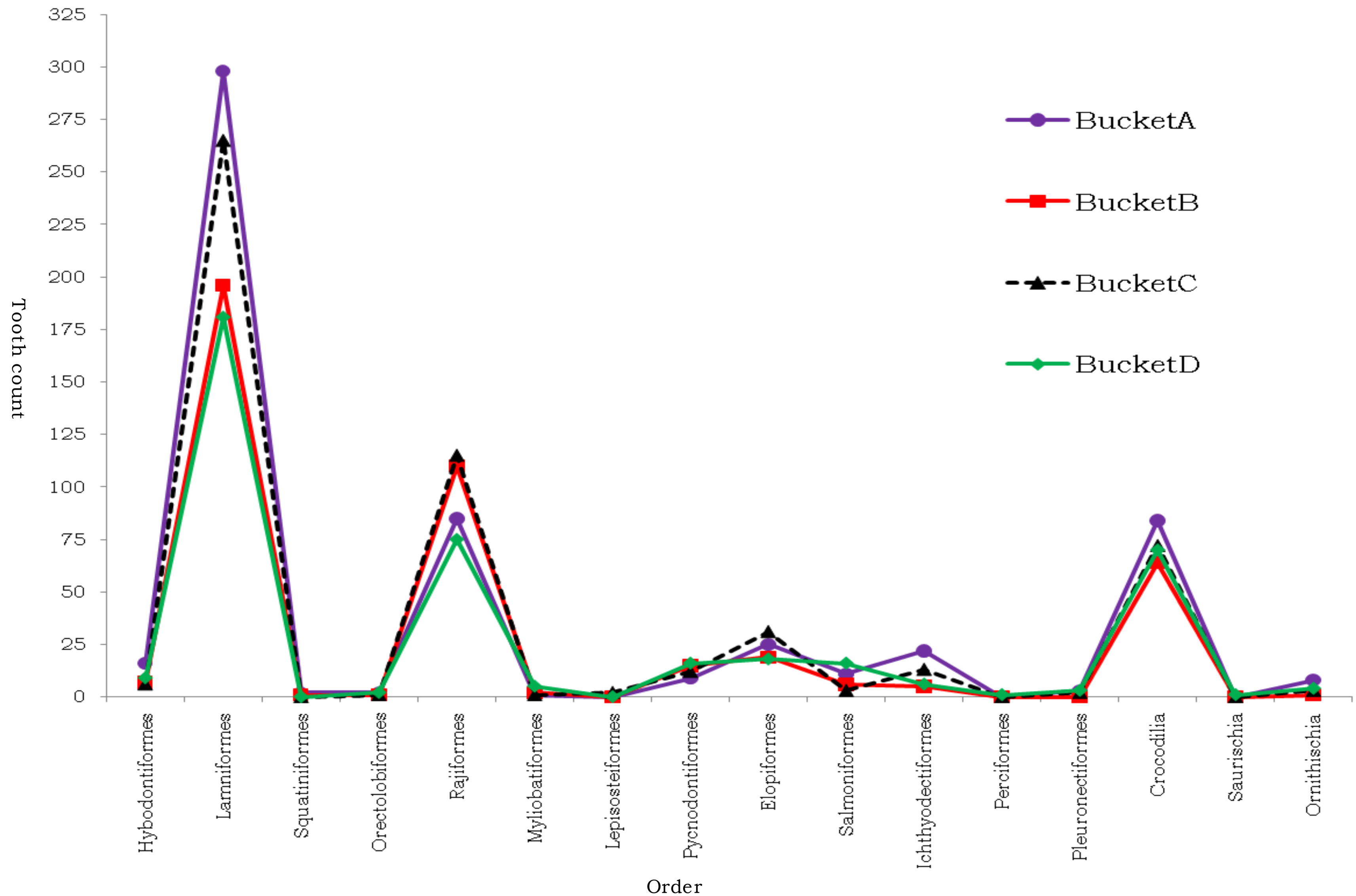


Figure 32. Plot of abundance of vertebrate (tooth) elements in each of four bulk samples, sorted by order.

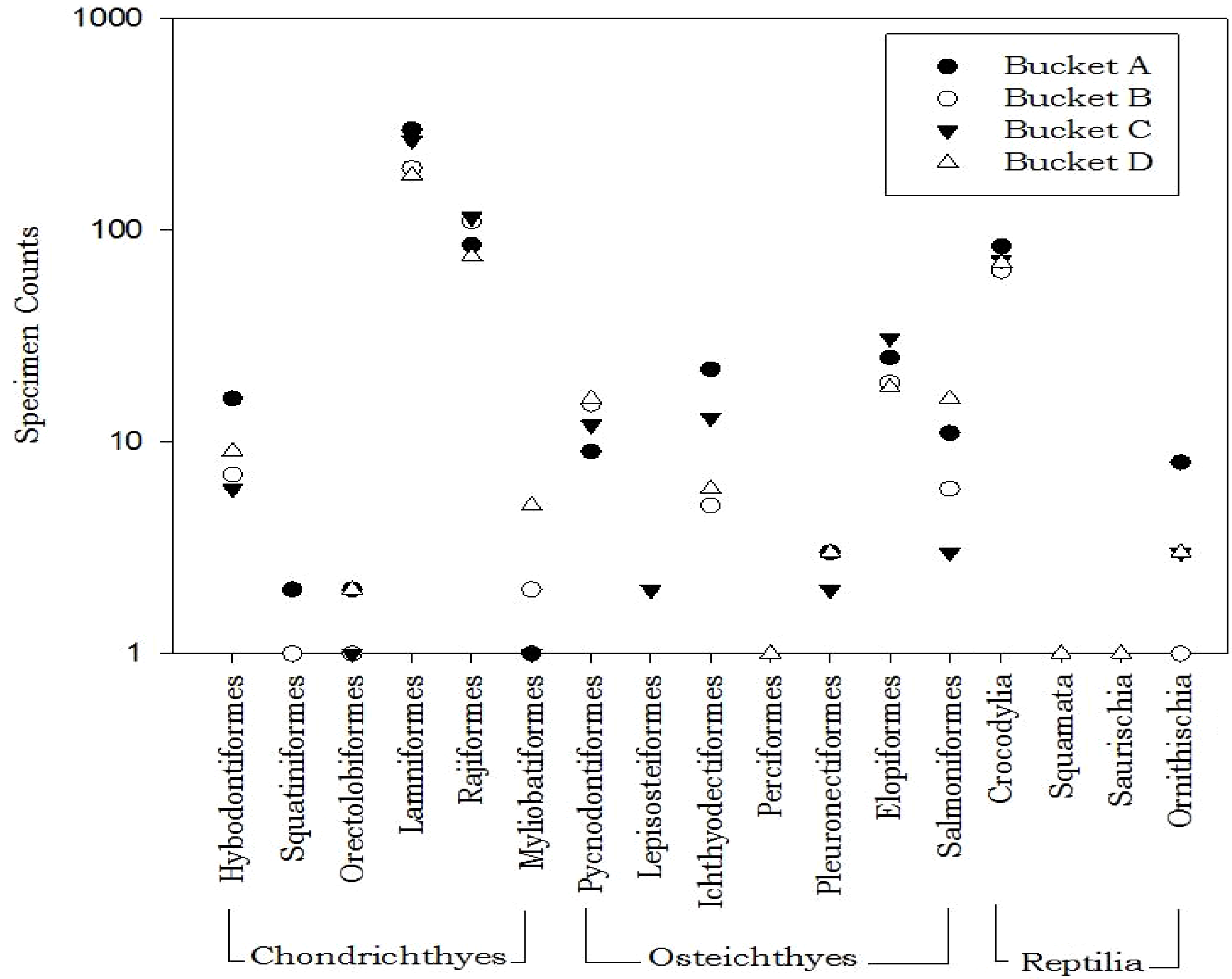
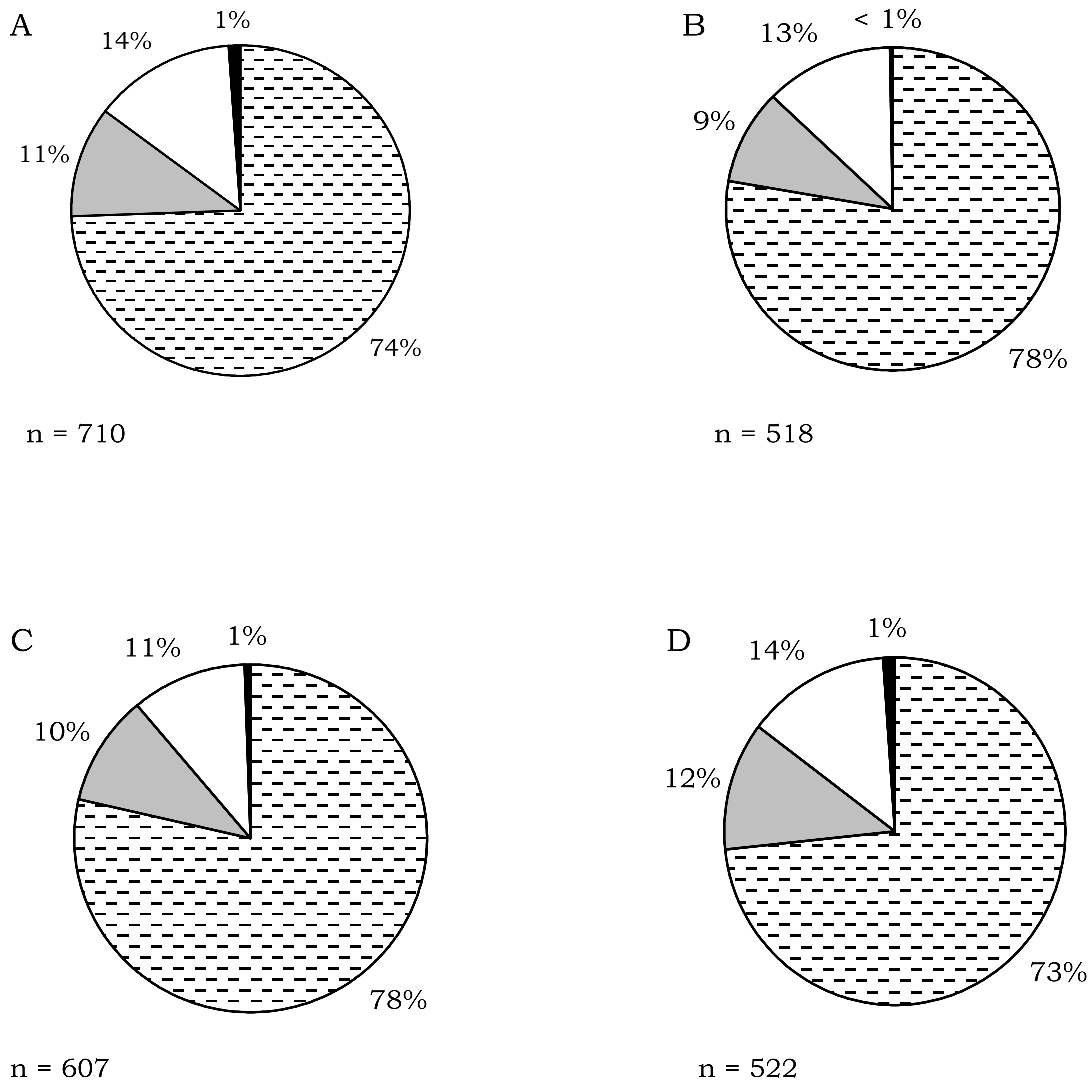


Figure 33. Abundances of vertebrate (tooth) elements in four bulk samples, sorted by order.



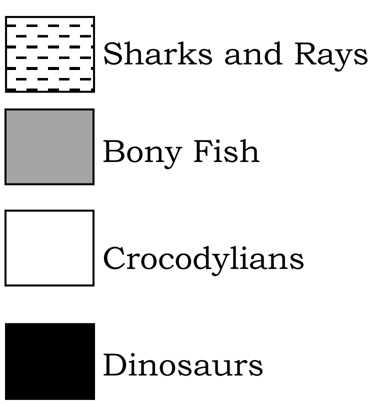


Figure 34. Plot of class-level tooth abundance for each bucket (A-D). The letter n represents number of specimens counted per bucket.

Using combined data from four buckets, trends in environmental preference were plotted to acess the depositional environment of the assemblage. Each taxon was allocated a binary ranking (0 or 1) based on the published record of its habitat (Appendix A). Zero represents no tolerance to a particular habitat whereas a 1 represents an environment in which the species could function. For instance, a deep ocean shark species was ranked with a 1 for marine environment, and zeros for brackish, freshwater, and terrestrial environments. A solely terrestrial organism (such as a theropod dinosaur) was ranked with a 1 for terrestrial, and zeros for freshwater, brackish, and marine environments (see Table 2 for general examples). Following the determination of the ranking, the ranking of 1 (preferred environment) was counted per environment and a percentage of organism preference per environment was generated (Fig. 35).

Table 2. Modern-day examples of the binary ranking of environmental preference for species. Ranking of 1 indicates an environment in which a particular organism survives and functions. A ranking of 0 indicates an environment of which a species does not function or survive.

Taxa	Terrestrial	Freshwater	Brackish	Marine
Great White Shark	0	0	0	1
Sawfish	0	1	1	1
Catfish	0	1	0	0
Squirrel	1	0	0	0

The vertebrate fossil assemblage represents a mix of terrestrial, freshwater, brackish water, and marine organisms (Fig. 35). Marine organisms dominate the assemblage (36%). Freshwater organisms, such as gars, comprise 22% of the assemblage. Brackish water organisms (such as sawfish) comprise 31% of the collection. The large crocodylian *Deinosuchus,* which thrived in estuarine to swampy coastal regions is also noted. Turtle and small crocodylian species are also well represented including the freshwater turtle *Bothremys* and the crocodylian *Borealosuchus.*

Terrestrial organisms are also present with the fossil assemblage (representing 11% of the assemblage) with hadrosaurian (duckbill dinosaurs) being the dominant type (Fig. 35). The discovery of many hadrosaurine tooth elements representing a range of sizes indicates the occurrence of various age groups (from baby to adult) (Russell, 1997). Rare theropoda (Dromaeosaur and Albertosaur) fossils are also represented. Significant terrestrial fossils have been preliminarily identified as amphibian (family Albanerpetontidae; Robert Denton, personal communication, March, 2010), mammal (family Cimolomyidae, *Cimolomys* sp.; Kevin Shannon, personal communication, December, 2010), lizard (incertae sedis), and a snake (family Aniliidae). These results can indicate either the interplay of marine and freshwater environments, where the local environment supported a diversity of species through time, or the processes of bonebed formation mixing fossils from distinct facies into one condensed bonebed.

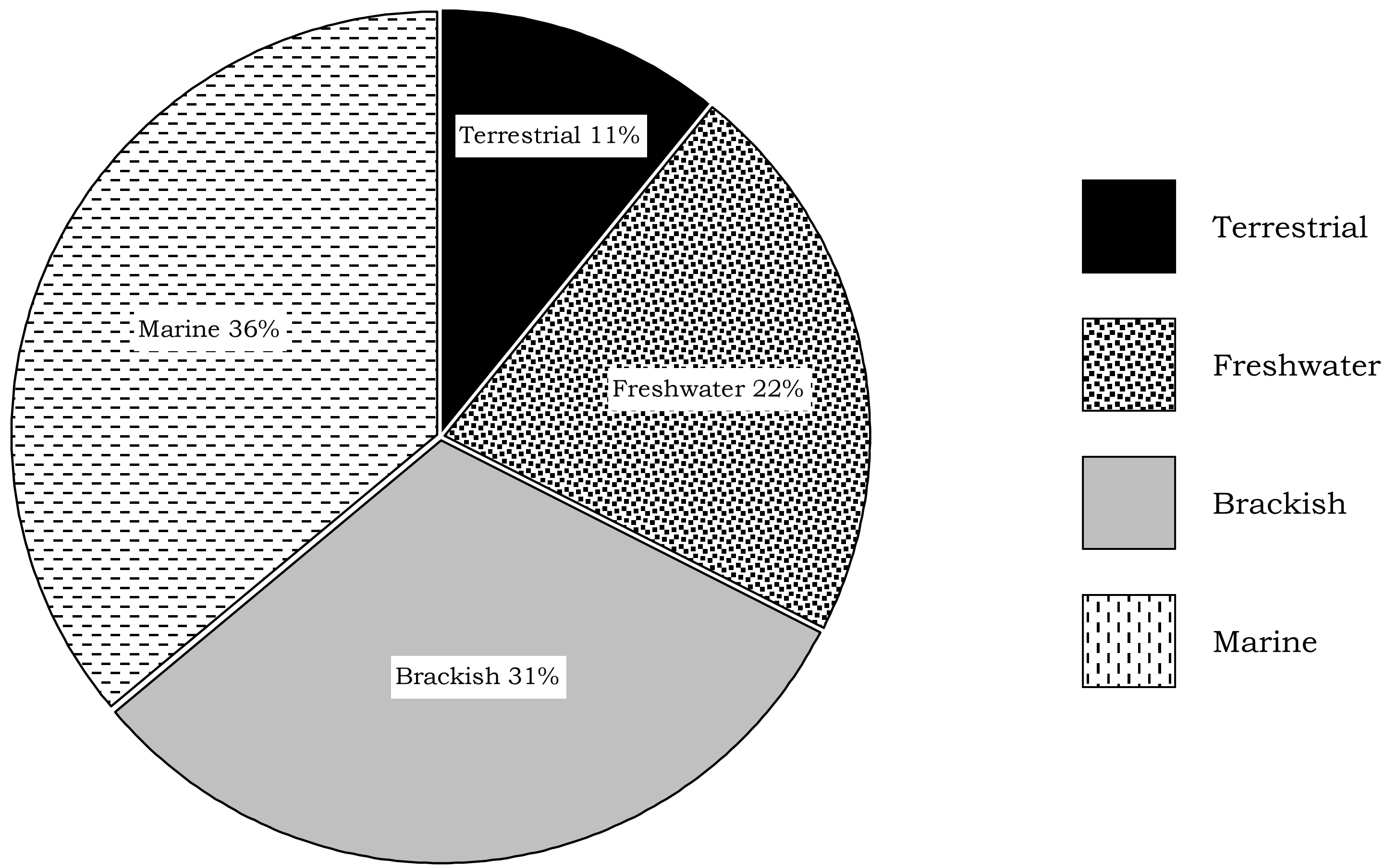


Figure 35. Graphical portrayal of paleoenvironments based on species preferences for particular environments.

5.0 DISCUSSION

5.1 BIOGEOGRAPHY/CORRELATION

The Bladen County Landfill Annex bonebed can be correlated with Campanian bonebeds in New Jersey (Grandstaff et al., 1992; Tashjian, 1990), North Carolina (Miller, 1967), and Georgia (Schwimmer and Case, 1988). The Ellisdale site (New Jersey), the BCLA site, the Phoebus Landing site, and the Hannahatchee Creek site (Georgia) have unconformities directly related to the vertebrate-bearing lag deposits. At the Hannahatchee Creek site, (Blufftown Formation), Georgia, a 30 cm-thick fossiliferous unit lies on an erosional surface (David Schwimmer, personal communication, March, 24, 2011) at the contact between the lower Campanian Blufftown Formation and the upper Campanian Cusseta Sandstone Formation (see Schwimmer and Best, 1989, p. 150, fig. 2). At the Ellisdale site, a five to 15 cm-thick fossiliferous layer (Denton and O'Neil, 1998) containing Campanian age vertebrates lies on an erosional surface between the upper Campanian Marshalltown Formation and the underlying middle Campanian Englishtown Formation (Gallagher et al., 1986). Lastly, the fossiliferous horizon containing the Campanian age vertebrates at the BCLA site lies on an erosional surface near the top of the upper Campanian Bladen Formation (see section 4.1.1).

On a larger scale, the BCLA site shares similar late Campanian faunal affinities with the Aguja Formation (Texas), the Mesaverde Formation (Wyoming), the Oldman Formation Alberta, Canada and the Judith River Formation (Montana) (Fig. 36) (Appendix C). Overall, family level faunal

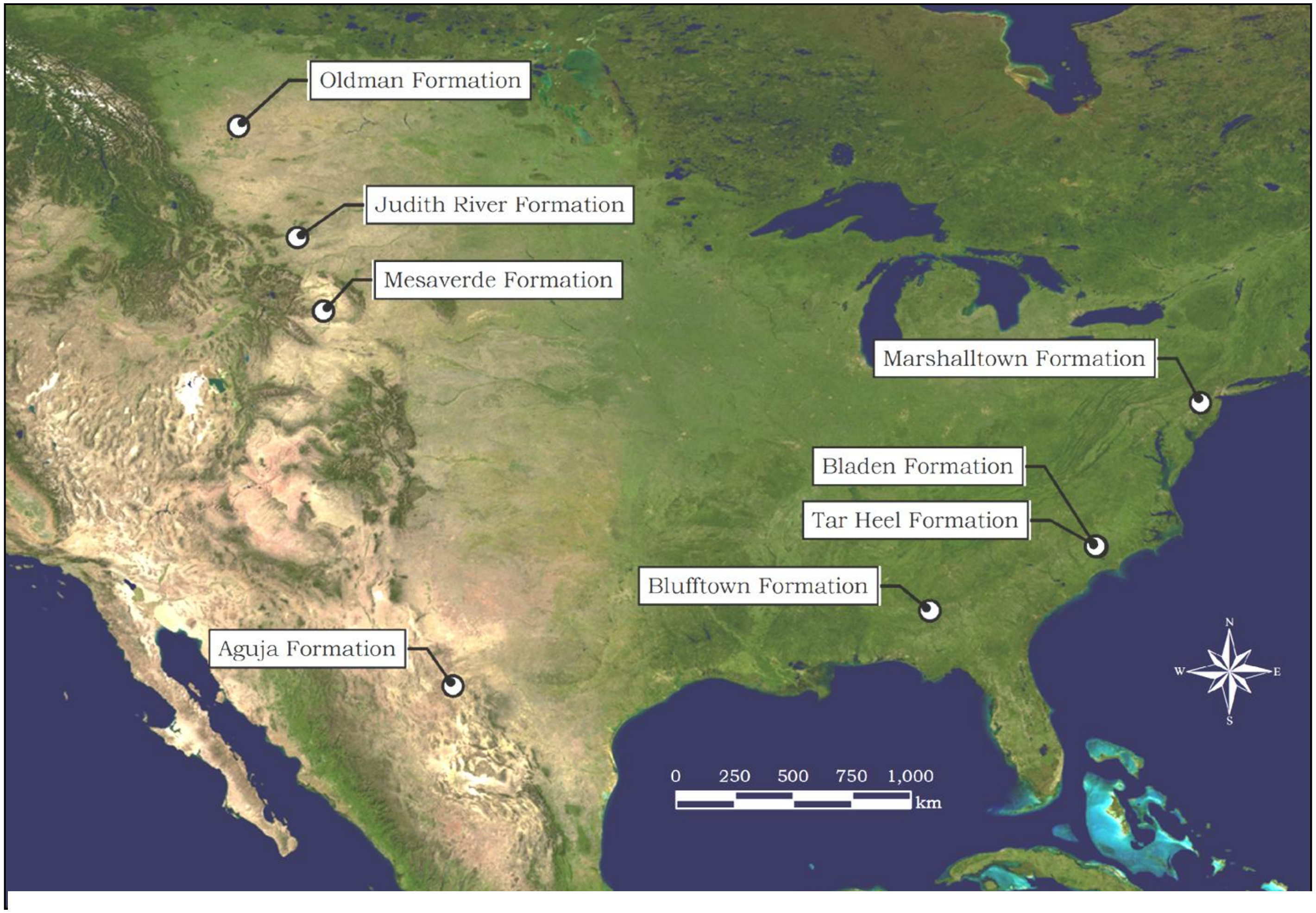


Figure 36. Map showing the locations of age equivalent (Campanian) vertebrate assemblages in North America. Locations include: the Marshalltown Formation (New Jersey); the Bladen Formation and Tar Heel Formation (North Carolina); the Blufftown Formation (Georgia); the Aguja Formation (Texas); the Mesaverde Formation (Wyoming); the Judith River Formation (Montana); and the Oldman Formation (Alberta, Canada). Map source: Blue Marble Next Generation (Stöckli et al., 2005).

similarities depict an area where terrestrial vertebrates (Tyrannosauridae and Hadrosauridae) interacted with freshwater (Trionychidae), estuarine (Lepisosteidae), and marine (Hybodontidae) vertebrates.

5.2 COMPARISON OF THE BCLA AND PHOEBUS LANDING SITES

The Bladen County Landfill Annex and Phoebus Landing sites have similar sedimentological and stratigraphic characteristics. The outcrop at Phoebus Landing has been described in the texts of Emmons (1858), Stephenson (1912), Powers (1951), Miller (1967), and Farrell (1998), yet the only published stratigraphic section of an area near Phoebus Landing was that of Emmons (1858) (section 1.3.3). Miller (1967) gave the most extensive description of the bonebed at Phoebus Landing to date and included a hypothesis as to its formation. In the following section (5.2.1 and 5.2.2), two hypotheses pertaining to the formation and age of the Phoebus Landing bonebed will be presented; Miller (1967) and Crane (this thesis).

5.2.1. <u>The Bonebed at Phoebus Landing; Hypothesis 1: Miller (1967)</u>

Miller (1967) described the bonebed at Phoebus Landing as being within a 1.2 m (4 ft)-thick unconsolidated sand lens lying at the top of the upper Campanian (Cretaceous) shales of the Black Creek Formation (Fig. 37). The unconsolidated sand lens was overlain by a six inch-thick consolidated sandstone bed which was overlain by slumped overburden. According to Miller (1967), the unconsolidated sand lens was a filled channel downcut into the shale bed and was likely to have formed as a component of the Black Creek Formation and not as a later "erosional-depositional intrusive' " (Miller, 1967 p. 220). Miller (1967) also stated that the unconsolidated sand lens lacked spores and pollen, that the majority of the fragmentary and worn vertebrate fossils were originally deposited in the unconsolidated sand lens, and that a few bones appeared to be reworked from an older bed (possibly from the underlying shale) (Miller, 1967, p. 221). Miller (1967) concluded that the vertebrate fossils recovered from Phoebus Landing were from either the unconsolidated sand lens or were lying on the surface of the shale following their erosion from the unconsolidated sand lens.

5.2.2 The Bonebed at Phoebus Landing; Hypothesis 2: Crane (this thesis)

A more recent assessment (this thesis) of the Phoebus Landing site is that the bonebed lies on an erosional surface of the laminated sands and clays of the upper Campanian Tar Heel Formation. The bonebed is overlain by a post-Cretaceous (Cenozoic) unconsolidated sand and modern soil slump (personal observation). Therefore, the fossil-bearing unit is lying on an erosional surface of Tar Heel age but is not part of the Tar Heel Formation. In contrast, the fossiliferous unit at the BCLA (Fig. 37) lies at the base of a sandy-clayey unit directly above the erosional contact of laminated clays and sands of the late Campanian Bladen Formation.

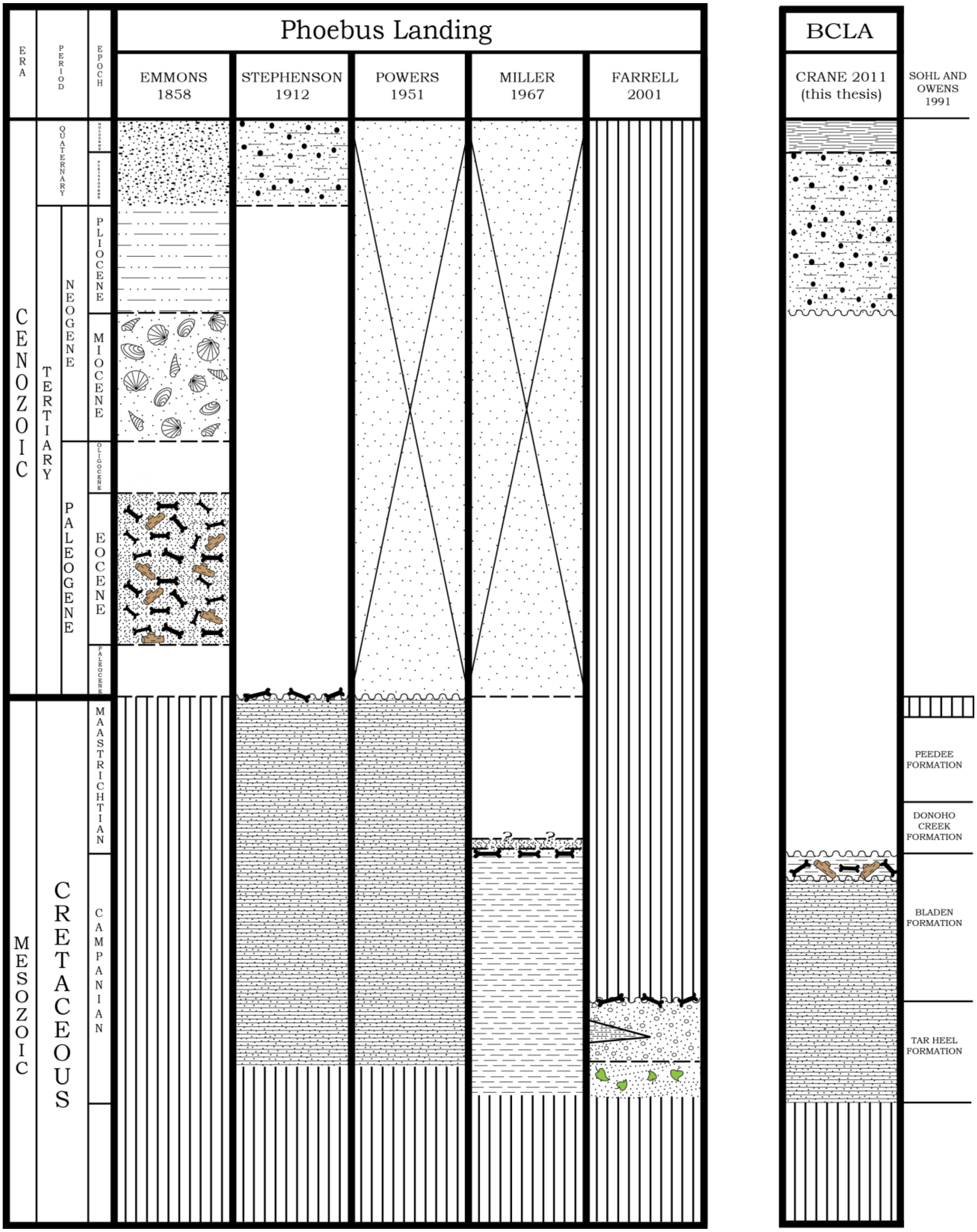


Figure 37. Chart showing the changing interpretations of the age of the Phoebus Landing bonebed. The general lithostratigraphy of the Bladen County Landfill Annex (Crane 2011, and Sohl and Owens 1991) formation names are to the right. Figure 9 provides the key to lithologic symbols.

At Walker's Bluff (Fig. 38A), an escarpment lies along the right bank of the Cape Fear River. When the river overtops its banks, the bluff is eroded (Fig. 38B). The vertebrate fossils at Walker's Bluff occur in a Campanian Bladen Formation bonebed lying at approximately 8-10 m (24-30 ft) up from the base of the bluff (personal observation, August 11, 2009). As the bluff is eroded, blocks of the Bladen Formation laminated sands and clays wedge off and fossils from the overlying bonebed are redeposited on a ledge at the base of the bluff. The vertebrate fossils are then intermixed with the sandy loam, clay and gravel of the overlying Cenozoic units that are also redeposited at the base of the bluff (Fig. 38).

The Bladen County Landfill Annex lies roughly at 36.5 meters (120 feet) above mean sea level and Phoebus Landing lies at approximately 6 meters (20 feet) above mean sea level (USGS, 1987) a roughly 30 meter (100 feet) difference over a horizontal distance of 7 km (4.4 miles). Taking into account the differing stratigraphies at the Phoebus Landing and BCLA localities and the modern-day erosion, slumping, and depositional processes at Walker's Bluff, this thesis proposes a new hypothesis for the formation of the fossil-bearing unit at Phoebus Landing. Laminated sands and clays deposited in an estuarine environment (Sohl and Owens, 1991) formed a thick sequence that spanned the majority of upper Campanian time. The fossil-bearing lag at the BCLA site was subsequently deposited near the end of the Campanian as part of the Bladen Formation.

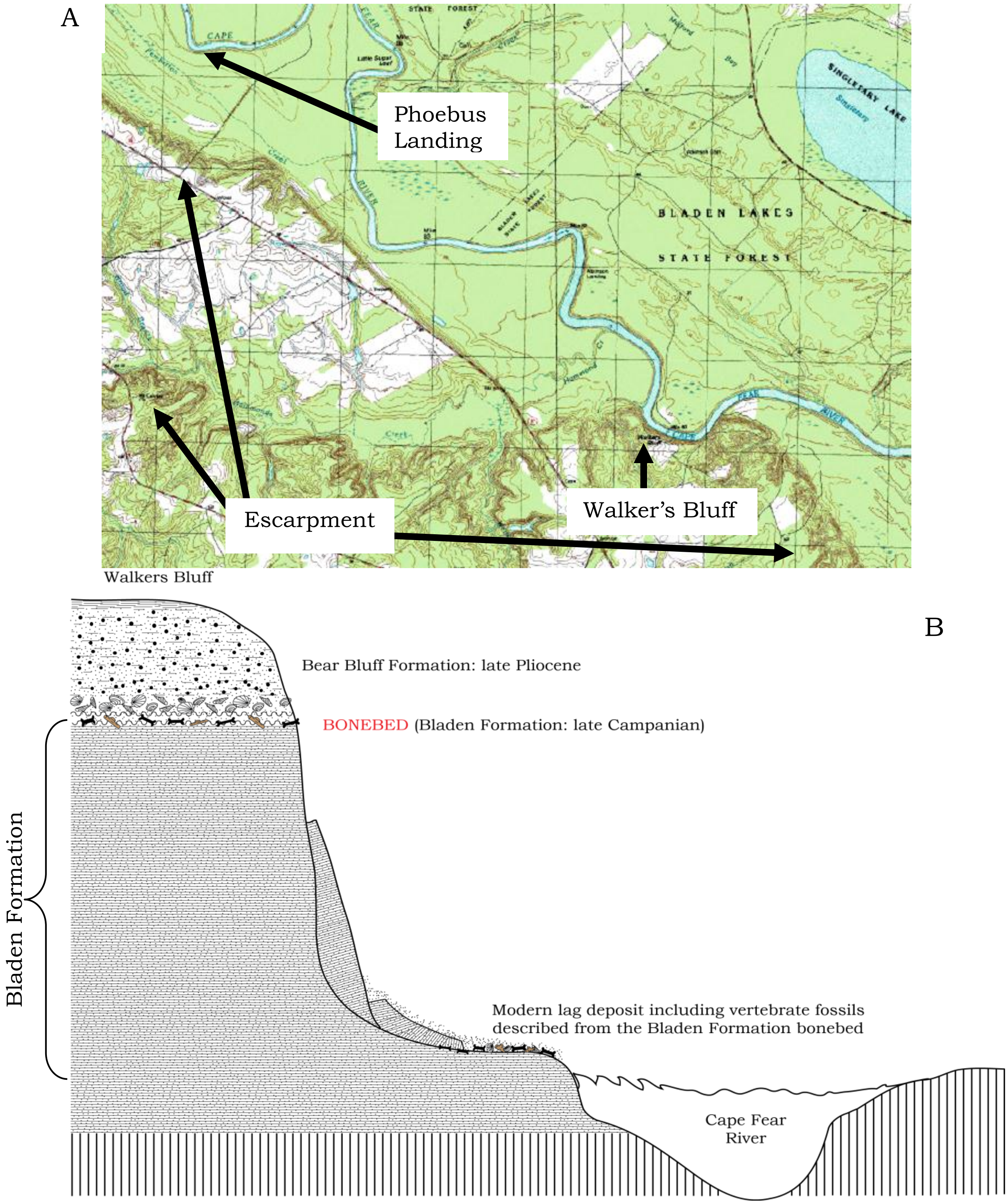


Figure 38. (A) Topographic map of the Bladen County research area with Phoebus Landing, Walker's Bluff, and the NW-SE trending escarpment labeled. (B) Modern-day analog depicting processes that are similar to those that contributed to the formation of the fossil-bearing unit at Phoebus Landing. A similar scenario is occurring at Walker's Bluff (MP 60; right bank of the Cape Fear River), where the river abuts the escarpment (shown in A) and is slowly eroding the bluff resulting in the erosion and redeposition of the higher strata containing the Cretaceous vertebrate fossils. Refer to Figure 9 for key to lithologic symbols.

During the Cenozoic, sea level fluctuations coupled with regional uplift influenced the erosion and deposition of terrace deposits forming prominent escarpments in the Bladen County region. While these escarpments were being formed, fluvial and marine processes were subsequently eroding the fossil-bearing unit and redepositing the vertebrate remains at lower elevations. The modern Cape Fear River has continued to downcut the Cretaceous age laminated sands and clays while the overlying Cenozoic sands are also being eroded. The fossil-bearing lag above the unconformity between the Cretaceous and the Cenozoic strata at Phoebus Landing is thus considered to be a Cenozoic lag, comparable to the modern lag containing Campanian vertebrate fossils at the base of Walker's Bluff. This Cenozoic lag has been eroded by the Cape Fear River and Campanian bones are now part of a modern fluvial lag sitting upon *in situ* Tar Heel Formation sands and clays (Fig. 39). This scenario implies that the fossil assemblages of Walker's Bluff, Phoebus Landing, and the BCLA sites have to be of the same original age and that the fossils were originally deposited at or near the top of the Bladen Formation.

Although microvertebrate material from mammals and amphibians have not been identified from the Phoebus Landing site to date, the faunal assemblages of the Phoebus Landing and BCLA sites are similar (Appendix C: vertebrate faunal data comparisons). The assemblages at the two sites do, however, exhibit differences in preservation. The vertebrate elements recovered from the BCLA site exhibit a wide range of hues, from tawny brown to black, with white and red colorations, and some elements exhibit mottling of multiple colors

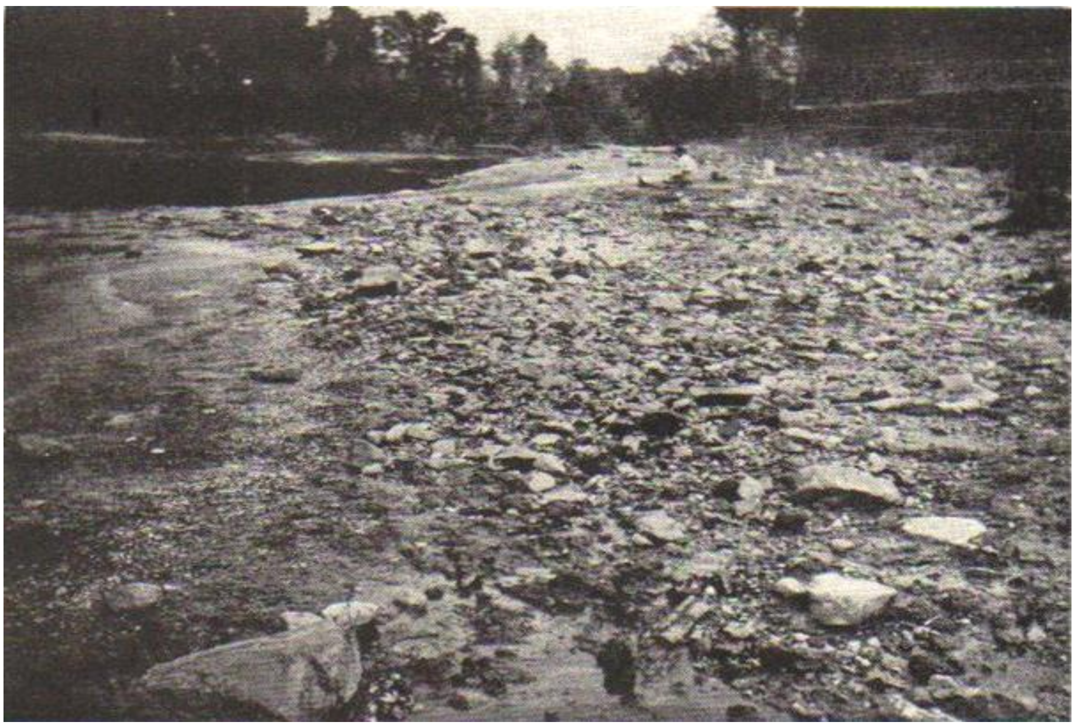


Figure 39. Modern fluvial lag deposit at Phoebus Landing. Campanian bones and other material are derived from the Cenozoic lag exposed in a bluff immediately to the right of this picture. Photograph by Stephenson (1923).

(see plates for color variations). The vertebrate elements from the BCLA site also tend to be better preserved than those of Phoebus Landing. For example, those from the BCLA tend to exhibit sharp (unworn) fracturing and unabraded surfaces. In comparison, the majority of the vertebrate elements collected from Phoebus Landing exhibit a drab gray to black color (based on personal observation of specimens from Phoebus Landing in the collections of the NCMNS) and a high degree of abrasion and rounding.

Therefore, because of the differences in the preservational nature of the fossils, elevation, and sedimentologic characteristics between the two sites, the Phoebus Landing fossils were probably eroded from the Bladen Formation (located at the higher elevation) to form a Cenozoic lag lying atop the Tar Heel Formation at a lower elevation. In turn, this lag material is currently being eroded to form a modern lag on the laminated sediments of the Tar Heel Formation that form a platform along the river (i.e. the Landing; Fig. 39). Contrary to the observations of Miller (1967; Fig. 37), vertebrate fossils have not been observed unequivocally by the present author within the Cretaceous sediments at Phoebus Landing.

5.3 PALEOENVIRONMENTS AND TAPHONOMY OF THE BCLA SITE

The fossil elements from the Bladen County Landfill Annex represent a parautochthonous faunal assemblage that lived within close proximity of their final resting place. A short (or zero) transport distance is indicated by the high proportion of unabraded elements (Behrensmeyer, 1982), with many exhibiting intact external laminar bone and tooth serrations (see Plates IV-C Fig. 4a and IV-F, Fig. 10c for examples). The Bladen Formation is considered to represent a delta to shelf depositional system (Sohl and Owens, 1991). The mixed assemblage of taxa from terrestrial and various aquatic habitats (freshwater, brackish, and marine) indicates an area where terrestrial and freshwater vertebrates lived in close proximity to a brackish estuarine environment (section 4.2.2). The heterogeneous nature of the sediments, ranging in size from silt to cobble size suggests that the fossiliferous horizon at the BCLA site is a channel-lag deposit where the fossil elements were transported as bedload and concentrated by deposition in the estuarine section of a fluvial system (Eberth, 1996).

A possible modern analog for the depositional environment of the BCLA assemblage is the coastal plain region of southeastern South Carolina that encompasses Saint Helena Sound to the north and Port Royal Sound to the south (Fig. 39). This is a region where fluvial and marine environments converge producing an estuarine environment with varying salinities that support a wide range of salt-tolerant to freshwater species (Riekerk, 2011).

Multiple low relief meandering rivers with extensive flood plains are affected by frequent flood events which cause river avulsions and meander cut-offs.

Although the general depositional environment of the Bladen Formation is considered estuarine-deltaic (Sohl and Owens, 1991), it is possible to consider sub-environments within that larger setting. There are two probable scenarios for the formation of the fossiliferous horizon at the BCLA site: a fluvial-estuarine (estuarine-dominated) environment (Eberth and Brinkman, 1997) or an avulsive-floodplain-bank collapse (fluvial-dominated) environment (after Rogers and Brady, 2010). These two depositional environments most likely alternated during the Cretaceous as a result of marine transgressive and regressive events (Hancock and Kauffman, 1979).

The fluvial-estuarine scenario would feature an estuary situated where an interplay of tidal and river processes occur (Fig. 20) (Eberth and Brinkman, 1997). This interplay would contribute to reduced velocities and bedload carrying capacities, thus resulting in deposition of woody material and vertebrate elements. During periods of high discharge (Bull, 1979), vertebrate and woody material located within a short distance upstream would be subjected to transport downstream into the fluvial/estuarine interface region (Eberth, 1996). The sedimentological record of this area would be represented by laminated clays and muds with interbedded gravelly, woody, vertebrate-bearing strata (Dalrymple et al., 1992).

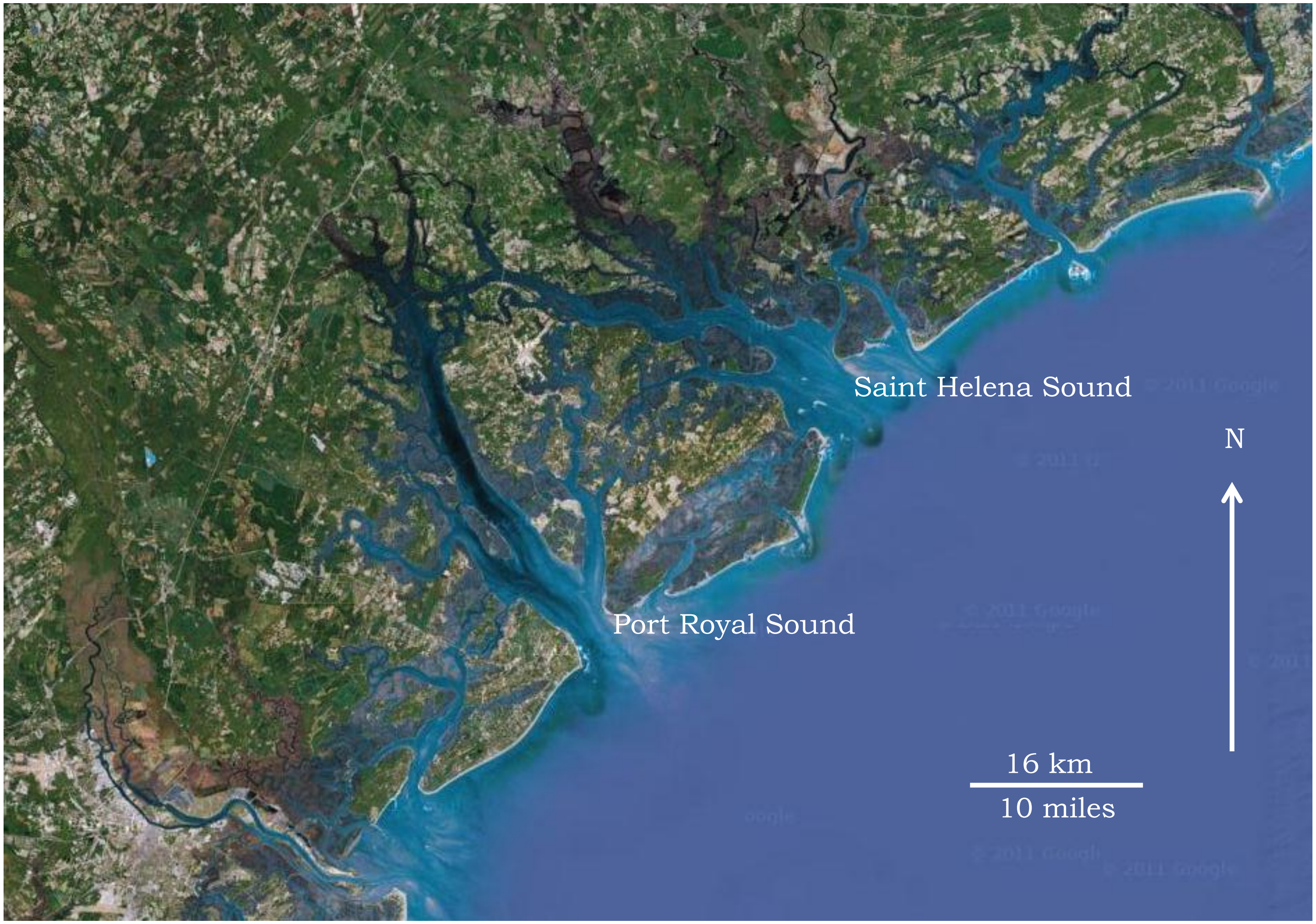


Figure 40. Aerial image of Saint Helena Sound and Port Royal Sound, southeastern South Carolina. (from Google Maps).

An avulsive-floodplain-bank collapse scenario would occur in localized areas within an environment where anastomosing channels formed as a result of bank overtopping, levee breaching, or channel pattern migration (Galloway and Hobday, 1983; Farrell, 2001). This would result in a build-up of woody and vertebrate matter on the floodplain immediately adjacent to a levee breech (Nanson and Croke, 1992) or along chute bars (Galloway and Hobday, 1983). Kaolinite and montmorillite-rich clays, (representing ancient soil horizons, Heron, 1958) would accumulate over the woody and vertebrate material. Over time, fluvial processes and river channel adjustments would contribute to bank collapses, producing channel-bed accumulations of the woody and vertebrate material (Schumm, 1985 and Behrensmeyer, 1982).

The fossiliferous unit of the BCLA was deposited in a localized area at an interface between fluvial and estuarine environments. Fluvial processes were likely to have been the dominating mechanism for transport of the micro- and macro-vertebrate fossil elements. This is suggested by the abundance of woody material and the presence of sand to cobble sized, angular to subrounded detrital clasts. The well preserved nature of the fossil elements from the BCLA site suggests that local secondary re-entrainment, transport, and re-burial were likely to have occurred primarily during episodic flood events; thus resulting in minimal damage to the fossils.

6.0 SUMMARY

6.1 HISTORY OF WORK AND DEBATE

Research on Cretaceous vertebrates in North Carolina has a long but sporadic history. Since the mid 1800s a handful scientists have probed the Bladen County segment of the Cape Fear River. This includes geologists seeking economically useful materials (Emmons) to recent work on interpreting depositional environments. Even fewer researchers were interested in the vertebrate paleontology of the area (Emmons, Kerr, Stephenson, Miller, Baird and Horner, Robb, and Gaffney et al.). Until this work, no research has integrated the depositional environments, stratigraphy, vertebrate paleontology, and taphonomy of a fossiliferous site in Bladen County. This work was intended to combine past research and new methods to produce a broad scientific picture of the Bladen County region and its vertebrate microfossil assemblages during late Cretaceous (upper Campanian) time.

6.2 AGE OF THE SEDIMENTS AT THE BCLA SITE

Pollen analysis of samples from the BCLA site indicated that the strata are most likely of late Campanian age. Laminated sands and clays underlying the fossiliferous unit are determined to belong to the Bladen Formation based on similar lithologic and stratigraphic characteristics to those at the type area, as described and named by Owens (1989).

6.3 FORMATION OF THE FOSSILIFEROUS UNIT AT THE BCLA SITE

The fossil-bearing horizon at the BCLA site is interpreted as an estuarine-hosted accumulation ("lag") deposit. This interpretation is based on the well-preserved nature of the fossil elements and the nearby source of the elements. The assemblage represents a mixed population of organisms that are indicative of various environments (terrestrial, freshwater, brackish water, and marine). Because the lag is intermixed with angular to sub-rounded fine sand to cobble clasts, as well as coprolites, and woody material, the lag is interpreted to have formed in an estuarine environment where a high energy fluvial system meets a low energy estuarine/back-barrier system.

6.4 TAPHONOMY OF THE BCLA FOSSILIFEROUS UNIT

The vertebrate fossil elements were transported as bedload and concentrated in a local reach of the fluvial-estuarine system over an extended length of time. A short (or zero) transport distance is indicated by the high proportion of unabraded elements (some exhibiting intact external laminar bone and others possessing sharp edged serrations) and a mixed assemblage of taxa representative of various habitats. This suite of fossil elements represents a parautochthonous faunal assemblage that lived in close proximity to its final resting place.

6.5 COMPOSITION OF THE BCLA VERTEBRATE ASSEMBLAGE

The vertebrate fossil assemblage represents a mix of terrestrial, freshwater, brackish water, and marine organisms. Marine organisms (particularly cartilaginous fish (sharks)) dominate the assemblage. Freshwater and brackish organisms such as gars (freshwater) and sawfish (brackish water) also occur. The large crocodylian *Deinosuchus,* which thrived in estuarine to swampy regions, is also recorded. Turtle and small crocodylian species are also well represented in the assemblage including the freshwater turtle *Bothremys* and the crocodylian *Borealosuchus.* Dinosaurs are present with hadrosaurs (duckbill dinosaurs) being the dominant type. Rare theropoda (Dromaeosaur and Albertosaur) fossils are also represented. A fraction of the fossils within the BCLA assemblage have been preliminarily identified as amphibian (family Albanerpetontidae), mammal (family Cimolomyidae), lizard (incertae sedis), and a snake (family Aniliidae). These are some of the first records of these taxa in the Campanian of the Atlantic Coast of North America.

6.6 COMPARISON OF THE BCLA SITE TO PHOEBUS LANDING

The fossiliferous lag unit at the BCLA site compares well with the lag at the Phoebus Landing locality in terms of species composition. Miller (1967) considered the vertebrate fossils at Phoebus Landing as being deposited within and derived from a channel-fill within the Black Creek Formation. An alternative hypothesis is that the bonebed at Phoebus Landing is a Cenozoic lag deposit, the result of erosion and deposition that concentrated vertebrate fossils derived from the Campanian Bladen Formation.

6.7 PALEOECOLOGY

The fossil assemblage of the BCLA consists of species that inhabited various habitats within a fluvial to back-barrier/estuarine environment. This region included marshy areas as well as river channels that could support a range of saline-tolerant to freshwater aquatic organisms as well as organisms such as giant crocodylians and large freshwater turtles. Terrestrial organisms flourished especially larger organisms such as the hadrosaurs. The occurrence of hadrosaur tooth elements of various age groups (from baby to adult) indicates that hadrosaurs were likely indigenous.

A modern-day analogue of a fluvial-estuarine environment (sans dinosaurs) is the Saint Helena Sound and Port Royal Sound region of South Carolina. This area consists of a non-barrier island sound/estuarine region with multiple fluvial channels, swampy regions, and in-channel island bars. This environment supports various aquatic organisms from different saline to freshwater habitats as well as semi-aquatic to fully terrestrial organisms.

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8.0 PLATES

8.1 PLATE I: CLASS CHONDRICHTHYES

8.1.1 PLATE I-A: FAMILY HYBODONTIDAE

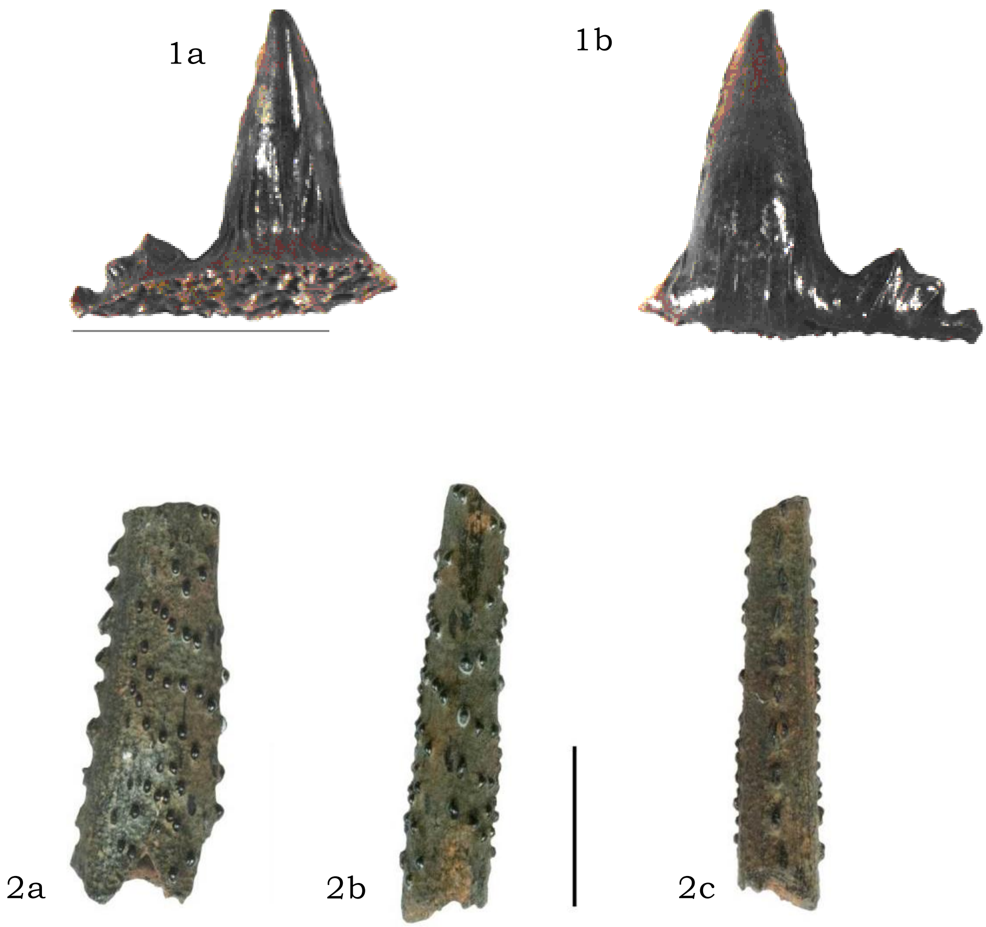


Figure 1a-2c: *Hybodus* sp.
Tooth (1a-b) scale = 5 mm
1a: lingual view; 1b: labial view

Fin spine (2a-c) scale = 1 cm
2a: lateral view; 2b: anterior view; 2c: posterior view

Refer to section 4.2 for descriptions

8.1.2 PLATE I-B: FAMILY LONCHIDIIDAE

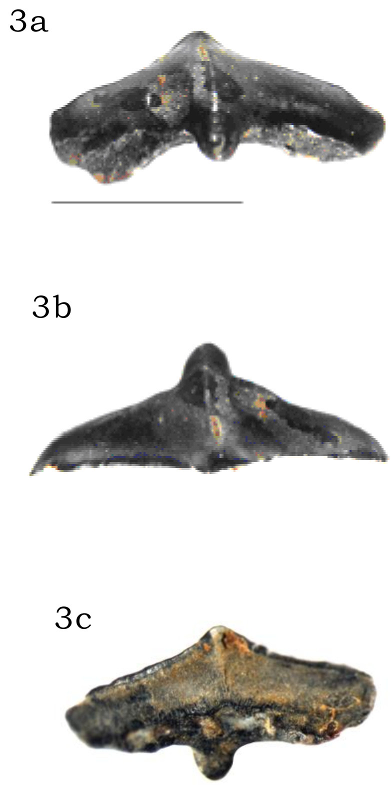


Figure 3a-c: *Lonchidion selachos*
Tooth scale = 2 mm
3a: labial view
3b: occlusal view
3c: lateral view

Refer to section 4.2 for descriptions

8.1.3 PLATE I-C: FAMILY MITSUKURINIDAE

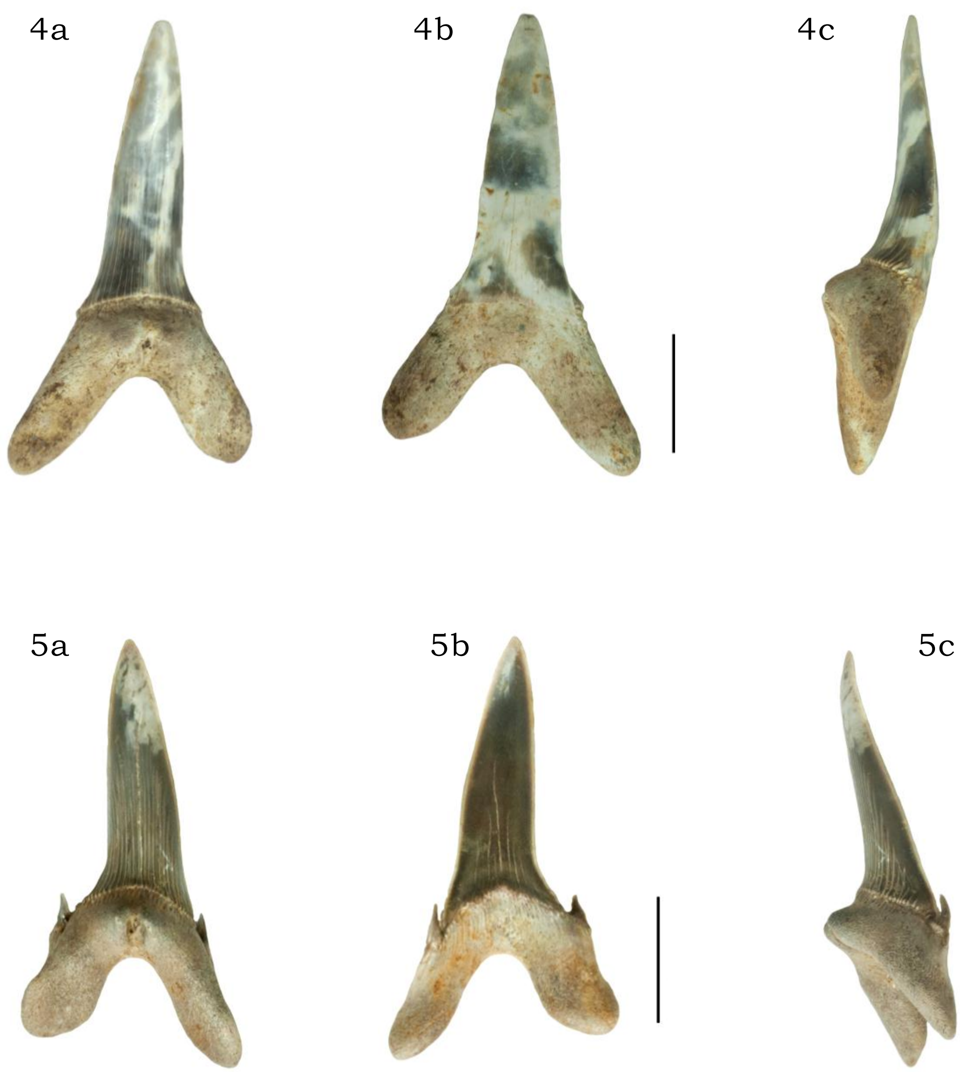


Figure 4a-5c: *Scapanorhynchus texanus*
Anterior teeth: scale = 1 cm
4a, 5a: lingual view
4b, 5b: labial view
4c, 5c: distal view

Refer to page 78 for description

8.1.4 PLATE I-D: FAMILY MITSUKURINIDAE

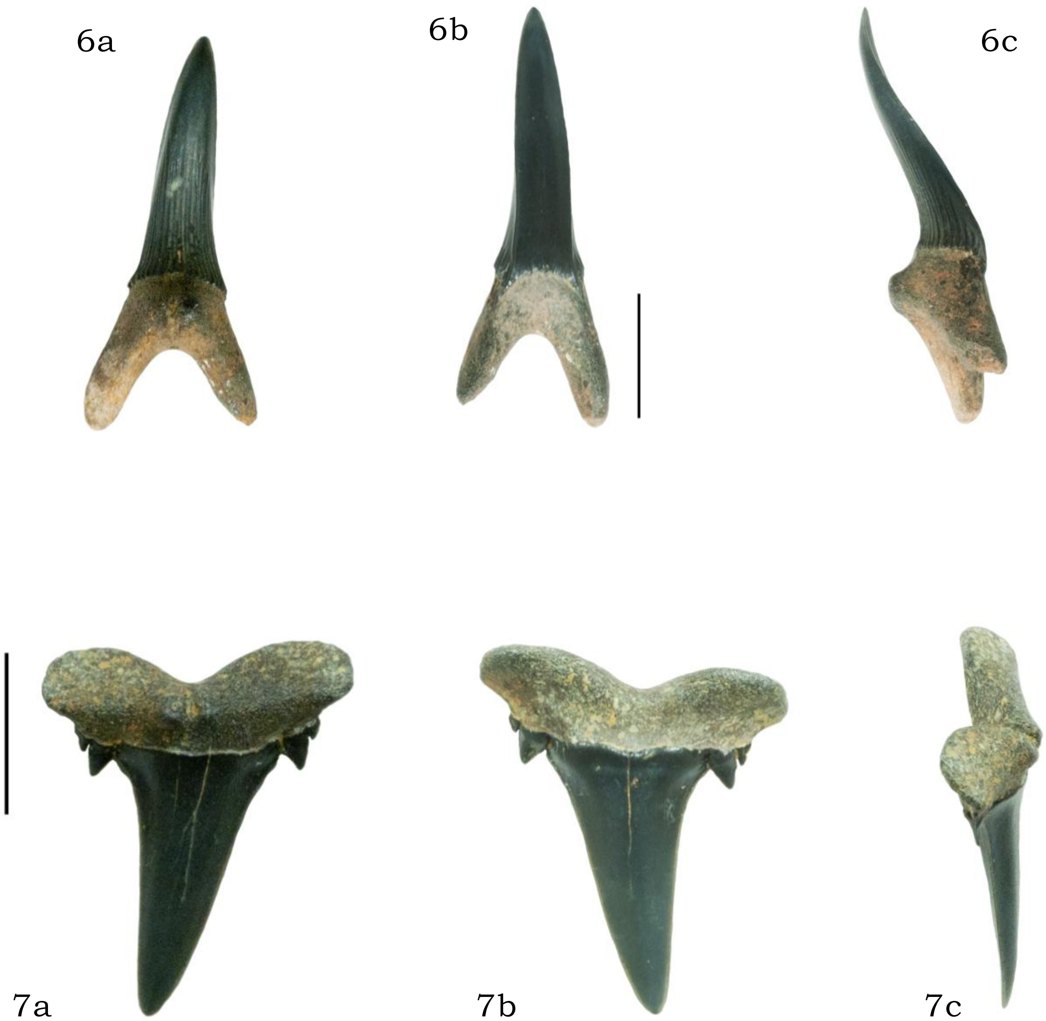


Figure 6a-7c: *Scapanorhynchus texanus*
6a-c: Anterior tooth: scale = 1 cm
7a-c: Lateral tooth: scale = 1 cm

6a, 7a: lingual view
6b, 7b: labial view
6c: distal view
7c: mesial view

Refer to section 4.2 for description

8.1.5 PLATE I-E: FAMILY CRETOXYRHYINIDAE

8a

8b

Figure 8a-b: *Cretolamna appendiculata lata*
Tooth: scale = 1 cm
8a: lingual view
8b: labial view

Refer to section 4.2 for description

8.1.6 PLATE I-F: FAMILY ANACORACIDAE

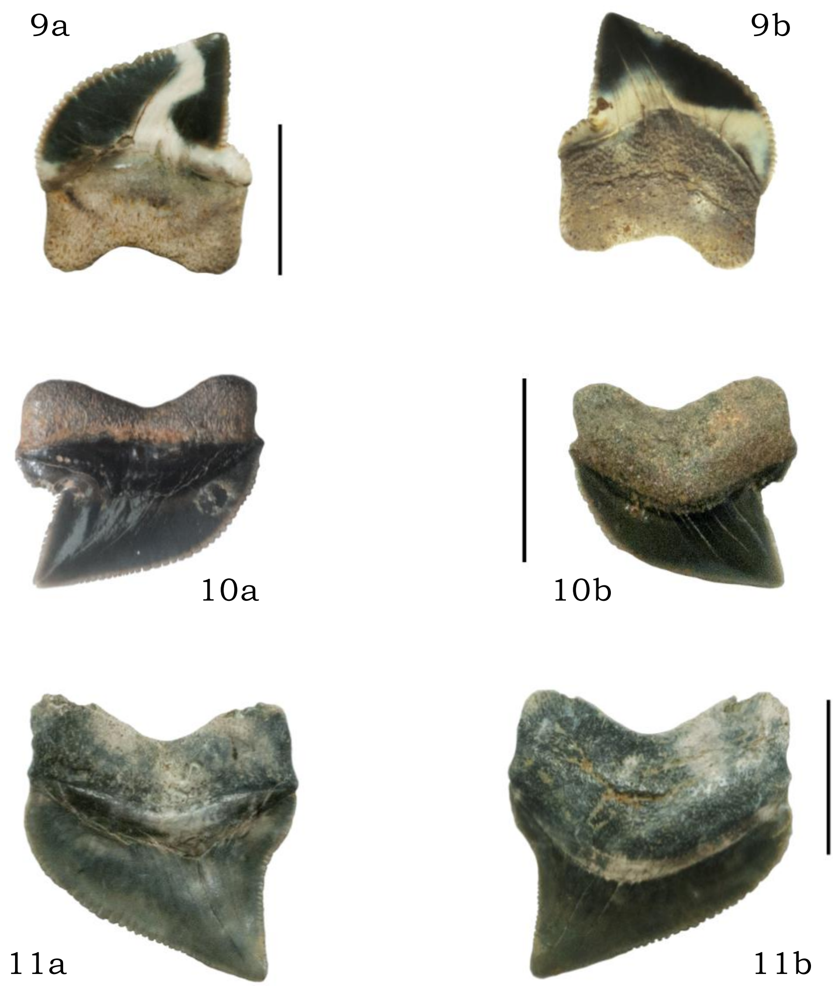


Figure 9a-10b: *Squalicorax kaupi*
Teeth: scale = 1 cm
9a, 10a: labial view
9b, 10b: lingual view
Refer to section 4.2 for description

Figure 11a-b: *Squalicorax pristodontis*
Tooth: scale = 1 cm
11a: labial view
11b: lingual view
Refer to section 4.2 for description

8.1.7 PLATE I-G: FAMILY SQUATINIDAE

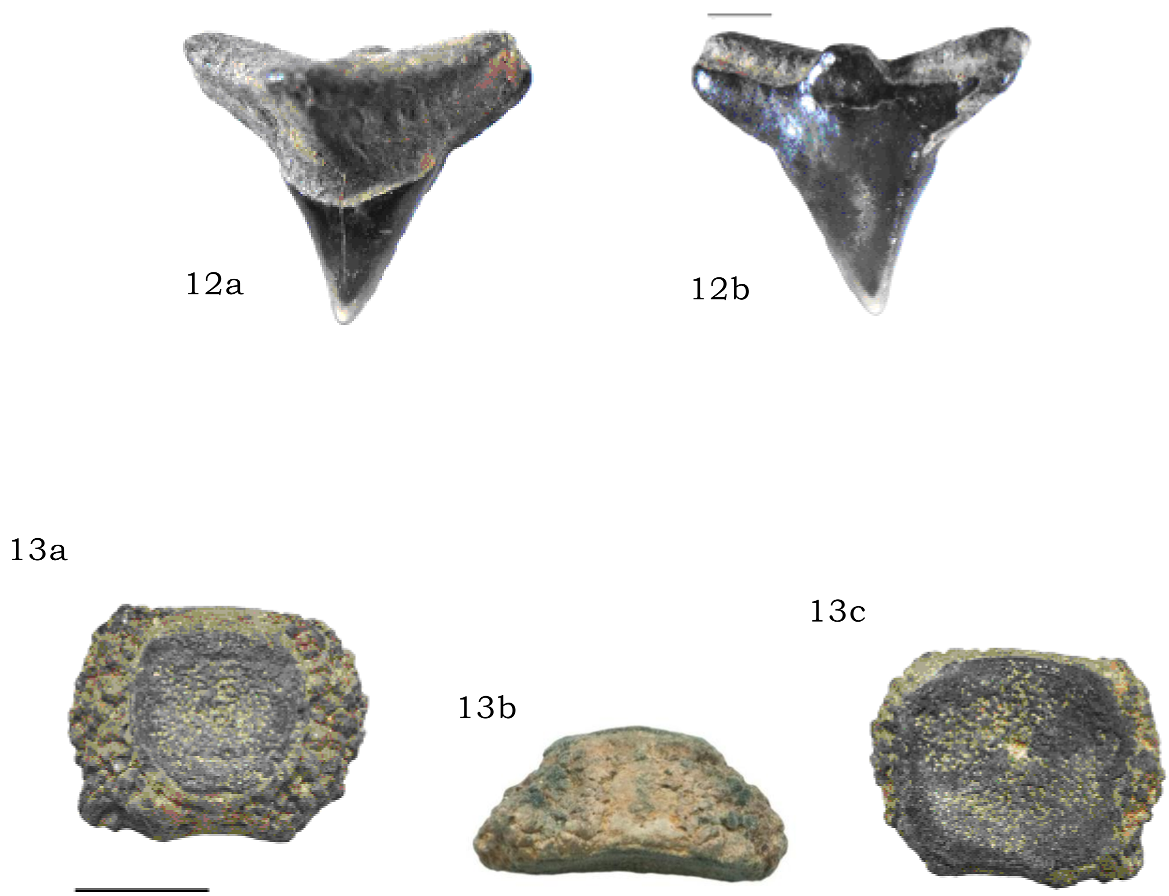


Figure 12a-13c: *Squatina hassei*
12a-b Tooth: scale = 1mm
12a: lingual view
12b: labial view

13a-c Vertebra: scale = 1 cm
13a: anterior view
13b: ventral view
13c: posterior view

Refer to section 4.2 for descriptions

8.1.8 PLATE I-H: FAMILY GINGLYMOSTOMIDAE

14a

14b

14c

Figure 14a-c: *Ginglymostoma globidens*
Tooth: scale = 5 mm
14a: labial view
14b: basal view
14c: apical view

Refer to section 4.2 for description

8.1.9 PLATE I-I: FAMILY SCLERORHYNCHIDAE

15a

Figure 15a: *Borodinopristis schwimmeri*
Rostral tooth: scale = 2 mm
15a: dorsal view

Refer to section 4.2 for description

8.1.10 PLATE I-J: FAMILY SCLERORHYNCHIDAE

16a

16b

Figure 16a-b: *Ischyrhiza avonicola*
Rostral tooth: scale = 5 mm
16a: anterior view
16b: posterior view

Refer to section 4.2 for description

8.1.11 PLATE I-K: FAMILY SCLERORHYNCHIDAE

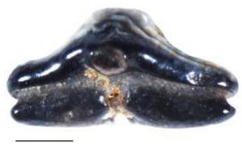
Figure 17a-18c: *Ischyrhiza mira*
17: Oral tooth: scale = 1 mm
17a: apical view; 17b: labial view; 17c: basal view; 17d: distal view

18: Rostral tooth: scale = 1 cm
18a: dorsal view; 18b: anterior view; 18c: posterior view

Refer to section 4.2 for description

8.1.12 PLATE I-L: FAMILY incertae sedis

19a



19b

19c

19d

Figure 19a-d: *Ptychotrygon triangularis*
Oral tooth: scale = 1 mm
19a: labial view; 19b: occlusal view; 19c: basal view; 19d: occlusal view

Refer to section 4.2 for description

8.1.13 PLATE I-M: FAMILY DASYATIDAE

20a

20b

20c

Figure 20a-c: *Dasyatis* sp.
Tooth: scale = 5 mm
20a: lingual view; 20b-c: basal view

Refer to section 4.2 for description

8.1.14 LATE I-N: FAMILY MYLIOBATIDAE

21a

21b

21c

Figure 21a-c: *Brachyrhizodus wichitaensis*
Pavement tooth: scale = 1 cm
21a: occlusal view; 21b: lateral view; 21c: basal view

Refer to section 4.2 for description

8.1.15 PLATE I-O: FAMILY RHOMBODONTIDAE

22a

22b

22c

Figure 22a-c: *Rhombodus binkhorsti*
Pavement tooth: scale = 1 mm
22a: lingual view
22b: basal view
22c: occlusal view

Refer to section 4.2 for description

8.2 PLATE II: CLASS OSTEICHTHYES

8.2.1 PLATE II-A: FAMILY LEPISOSTEIDAE

1a

Figure 1a: *Lepisosteus* sp.
1a: Scale: scale = 1 cm
1a: occlusal view

Refer to section 4.2 for description

8.2.2 PLATE II-B: FAMILY PYCNODONTIDAE

Figure 2a-4b: *Anomoeodus phaseolus*
2a-c: Fragmentary splenial jaw section with two crusher teeth: scale = 1 cm
2a: occlusal view; 2b: lateral view; 2c: basal view

3a-b: Isolated mandibular tooth: scale = 1 cm
3a: occlusal view; 3b: basal view

4a-b: Isolated anterior vomerine tooth: scale = 1 mm
4a: occlusal view; 4b: basal view

Refer to section 4.2 for description

8.2.3 PLATE II-C: FAMILY PHYLLODONTIDAE

Figure 5a-7b: *Paralbula casei*
5a-6a: Isolated crushing teeth: scale = 1 mm
5a-6a: occlusal view

7a-b: Fragmentary mouth plate: scale = 1 mm
7a: occlusal view
7b: basal view

Refer to section 4.2 for description

8.2.4 PLATE II-D: FAMILY ALBULIDAE

Figure 8a-c: *Albula* sp.
Isolated crusher tooth: scale = 1 mm
8a: occlusal view
8b: basal view
8c: lateral view

Refer to section 4.2 for description

8.2.5 PLATE II-E: FAMILY ENCHODONTIDAE

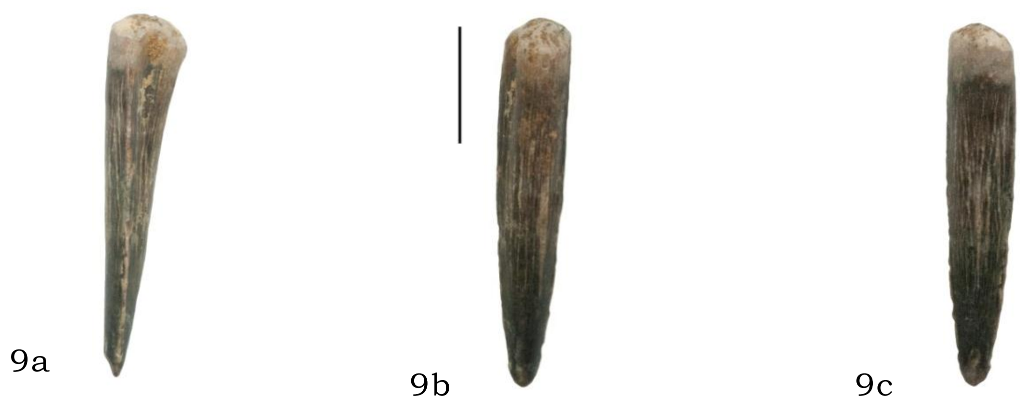


Figure 9a-c: *Enchodus* cf. *E. petrosus*
Palatine fang: scale = 1 cm
9a: lingual view; 9b: posterior view; 9c: anterior view

Refer to section 4.2 for description

8.2.6 PLATE II-F: FAMILY ICHTHYODECTIDAE

10a

10b

Figure 10a-b: *Xiphactinus vetus*
Tooth: scale = 1 cm
10a: labial view; 10b: anterior view

Refer to section 4.2 for description

8.2.7 PLATE II-G: FAMILY HADRODONTIDAE

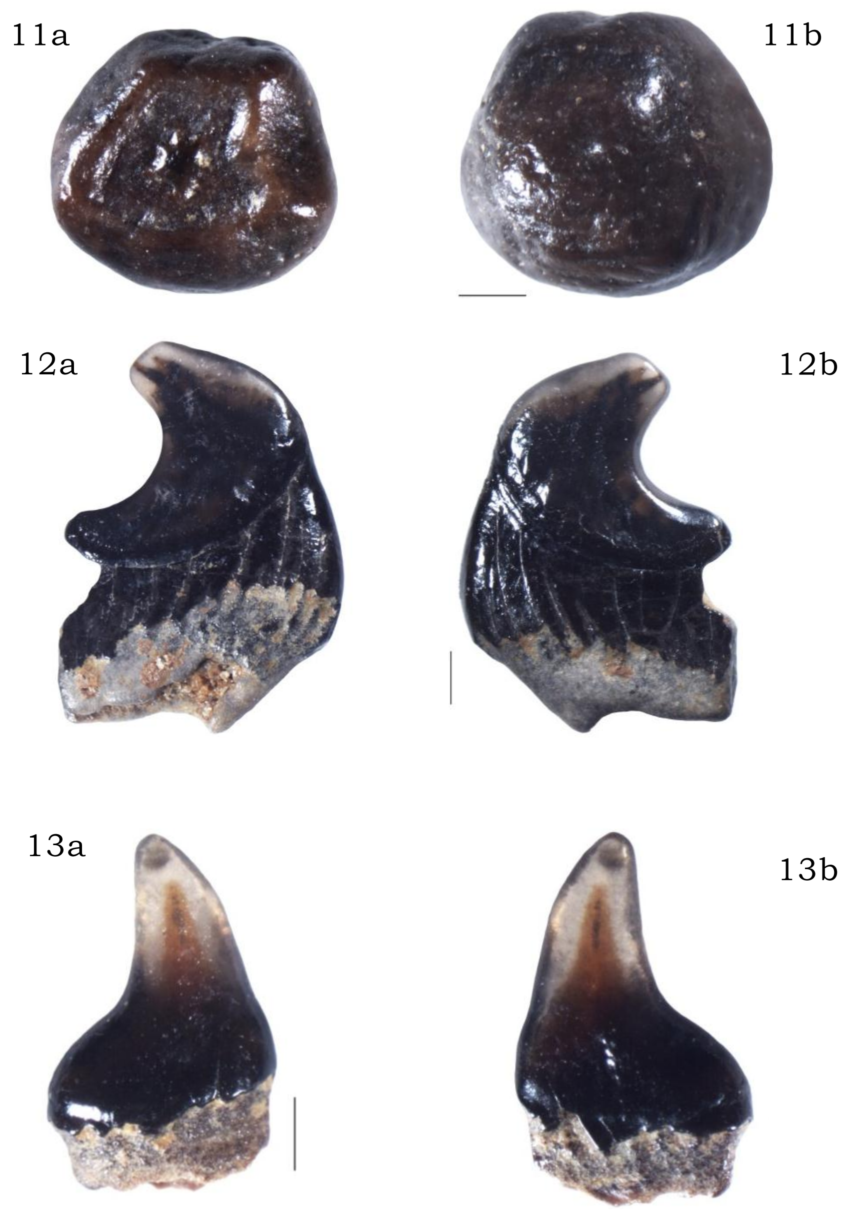


Figure 11a-13b: *Hadrodus priscus*
11a-b: Vomer crushing tooth: scale = 1 mm
11a: basal view; 11b: occlusal view

12a-13b: Pharyngeal teeth: scale = 1 mm
12a, 13a: lingual view
12b, 13b: lateral view

Refer to section 4.2 for description

8.3 PLATE III: CLASS REPTILIA

8.3.1 PLATE III-A: FAMILY MOSASAURIDAE

1a

1b

2a

2b

Figure 1a-2b: *Tylosaurus* sp.
1a-b: Isolated tooth: scale = 1 cm
1a: labial view
1b: lingual view

2a-b: Cervical vertebra: scale = 1cm
2a: ventral view
2b: dorsal view

Refer to section 4.2 for description

8.3.2 PLATE III-B: FAMILY EMASMOSAURIDAE

Figure 3a-d: Family Elasmosauridae gen. et sp. indet.
3a-d: Isolated vertebra: scale = 1 cm
3a: anterior view
3b: ventral view
3c: posterior view
3d: dorsal view

Refer to section 4.2 for description

8.3.3 PLATE III-C: FAMILY CROCODYLIDAE

4a

4b

5a

Figure 4a-5a: *Borealosuchus* sp.
4a-b: Isolated tooth: scale = 1 cm

5a: Mandible fragment: scale = 1cm
5a: occlusal view

Refer to section 4.2 for description

8.3.4 PLATE III-D: FAMILY CROCODYLIDAE

Figure 6a-7b: *Deinosuchus rugosus*
Isolated teeth: scale = 1 cm

Refer to section 4.2 for description

8.3.5 PLATE III-E: FAMILY CROCODYLIDAE

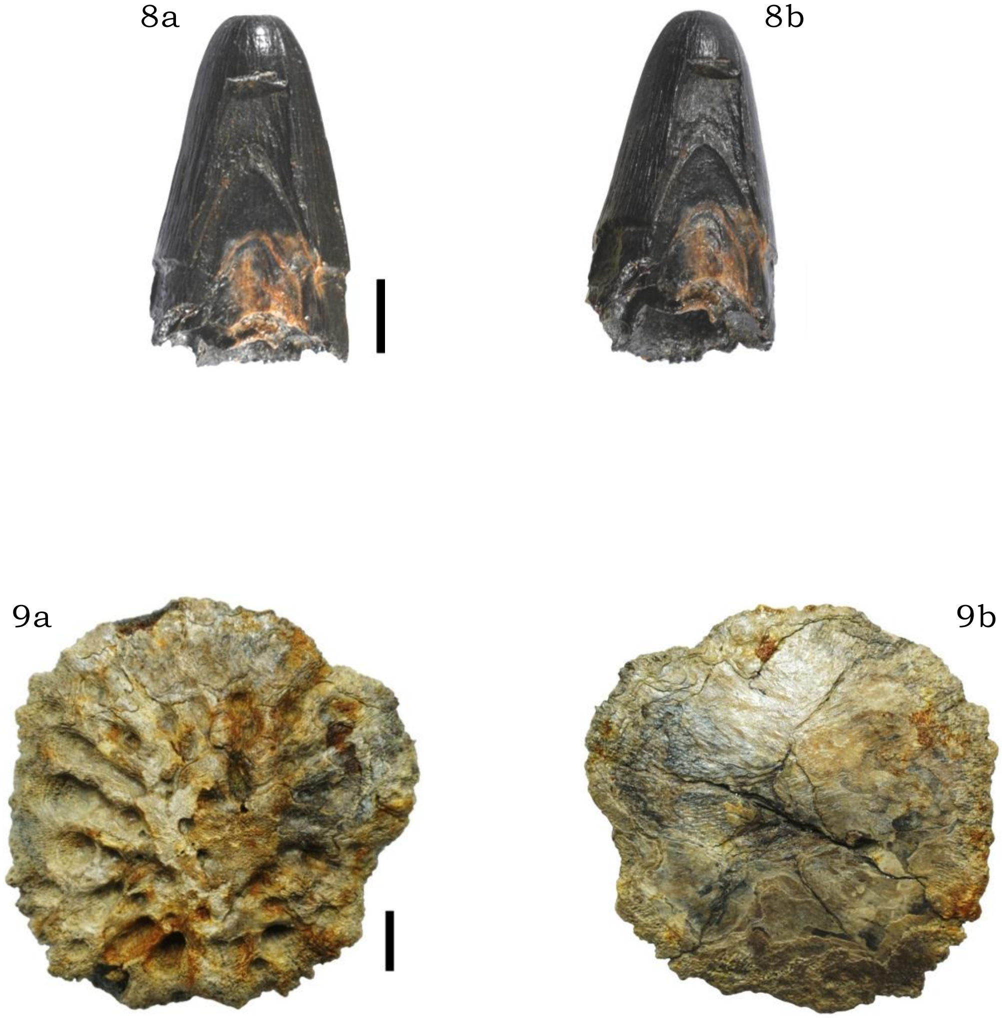


Figure 8a-9b: *Deinosuchus rugosus*
8a-b: Isolated tooth exhibiting feeding shear: scale = 1 cm

9a-b: Osteoderm element: scale = 1cm
9a: dorsal view
9b: ventral view

Refer to section 4.2 for description

8.3.6 PLATE III-F: FAMILY CROCODYLIDAE

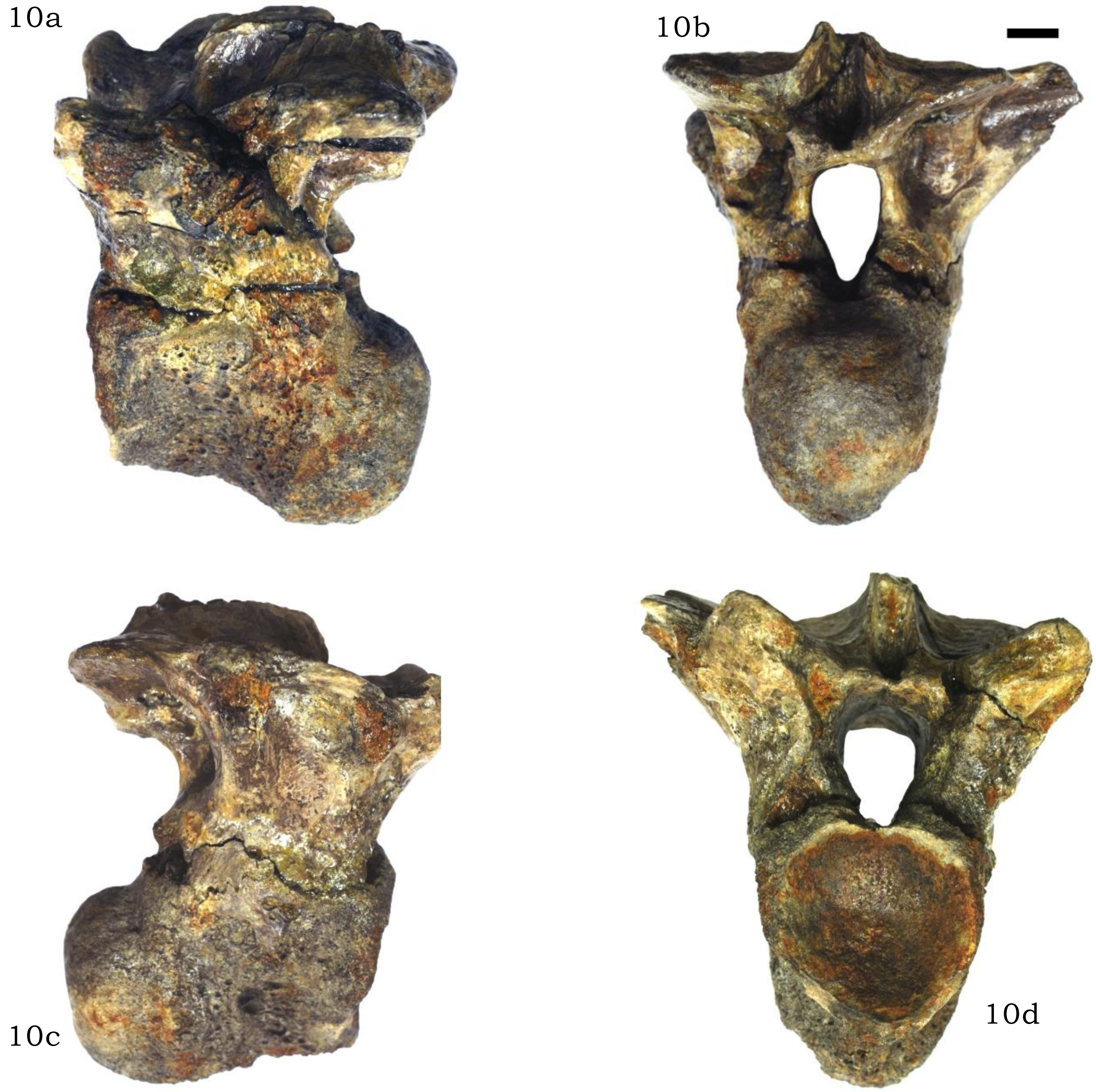


Figure 10a-d: *Deinosuchus rugosus*
Isolated vertebra: scale = 1 cm
10a: left lateral view
10b: posterior view
10c: right lateral view
10d: anterior view

Refer to section 4.2 for description

8.4 PLATE IV: CLASS DINOSAURIA

8.4.1 PLATE IV-A: FAMILY ORNITHOMIMIDAE

Figure 1a-2b: *Ornithomimus* sp.
1a-b: Isolated pedal phalanx: scale = 1 cm
1a: right lateral view
1b: ventral view

2a-b: Fragmentary manual ungula: scale = 1 cm
2a: ventral view
2b: right lateral view

Refer to section 4.2 for description

8.4.2 PLATE IV-B: FAMILY DROMAEOSAURIDAE

3a

3b

3c

Figure 3a-c: Family Dromaeosauridae gen. et sp. indet.
3a-c: Isolated tooth: scale = 1 cm
3a: labial view
3b: lingual view
3c: basal view

Refer to section 4.2 for description

8.4.3 PLATE IV-C: FAMILY TYRANNOSAURIDAE

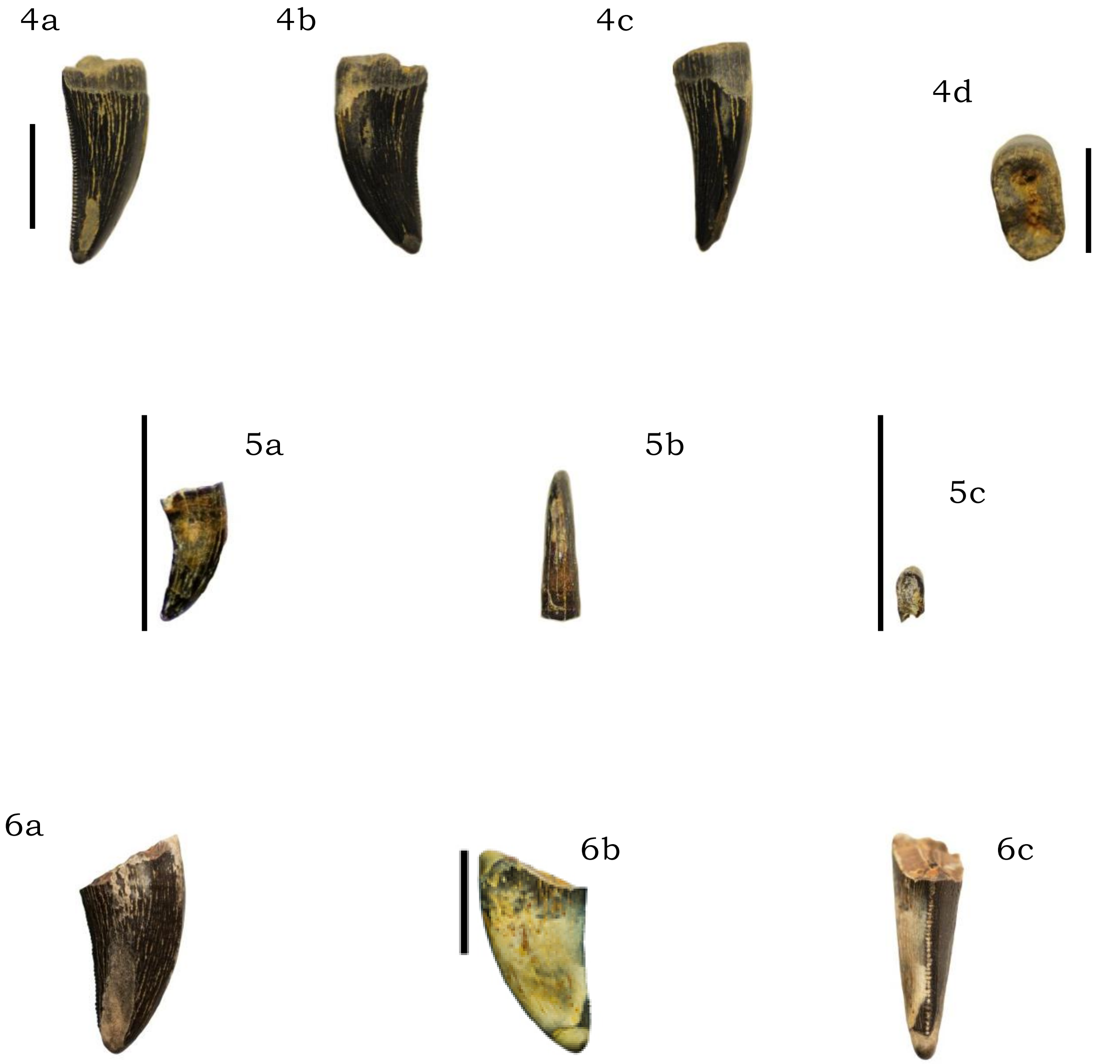


Figure 4a-6d: Family Tyrannosauridae gen. et sp. indet.
Isolated teeth: scale = 1 cm
4a: lingual view; 4b: labial view; 4c: anterior view; 4d: basal view
5a: lingual view; 5b: anterior view; 5c: basal view
6a: lingual view; 6b: labial view; 6c: posterior view

Refer to section 4.2 for description

8.4.4 PLATE IV-D: FAMILY HADROSAURIDAE

Figure 7a-8b: Family Hadrosauridae gen. et sp. indet.
7a-8b: Isolated teeth: scale = 1 cm
7a, 18a: lingual view
7b: anterior view
8b: labial view

Refer to section 4.2 for description

8.4.5 PLATE IV-E: FAMILY HADROSAURIDAE

9a

Figure 9a: Family Hadrosauridae gen. et sp. indet.
9a: Fragmentary left dentary: scale = 1 cm
9a: lingual view

Refer to section 4.2 for description

8.4.6 PLATE IV-F: FAMILY HADROSAURIDAE

Figure 10a-c: Family Hadrosauridae gen. et sp. indet.
Isolated thoracic vertebra: scale = 1 cm
10a: anterior view; 10b: posterior view; 10c: right lateral view

Refer to section 4.2 for description

8.4.7 PLATE IV-G: FAMILY HADROSAURIDAE

Figure 11a-d: Family Hadrosauridae gen. et sp. indet.
Isolated vertebra: scale = 1 cm
11a: right lateral view; 11b: left lateral view; 11c: posterior view;
11d: anterior view

Refer to section 4.2 for description

8.4.8 PLATE IV-H: FAMILY HADROSAURIDAE

Figure 12a-b: Family Hadrosauridae gen. et sp. indet.
Isolated ungual: scale = 1 cm
13a: ventral view
13b: dorsal view

Refer to section 4.2 for description

APPENDIX A: ABUNDANCE DATA OF VERTEBRATE FOSSIL ELEMENTS UTILIZED IN ANALYSIS

Counts of vertebrate fossil tooth elements from less than 6.4 mm (1/4 in) and greater than 6.4 mm (1/4 in) sediment fraction per each bucket (A-D).

.	Bucket A	Bucket B	Bucket C	Bucket D	Total
Sharks and Rays	529	403	477	383	1792
Crocodylians	97	65	64	71	297
Fish	76	49	62	62	249
Dinosaurs	8	1	4	6	19

Counts of vertebrate fossil element of fossil specimens greater than 6.4 mm (1/4 in) per each bucket (A-D).

.	Bucket A	Bucket B	Bucket C	Bucket D	Total
Turtle Elements	120	93	101	115	429
Bone fragments	148	94	118	60	420
Shark Teeth	121	86	87	112	406
Crocodylian Teeth	13	5	2	1	21
Fish Teeth	6	3	2	4	15
Ray Teeth	7	1	3	0	11
Fish Vertebrae	0	0	0	2	2
Dinosaur Teeth	0	0	1	1	2
Gar Scales	0	1	0	0	1

Counts of fossil vertebrate elements less than 6.4 mm (1/4 in).

.	Bucket A	Bucket B	Bucket C	Bucket D	Total
Albula sp. (tooth)	19	18	21	16	74
Anomoedus sp.	9	15	12	16	52
Anoxypristis sp. (rostral)	0	1	0	0	1
Borodinopristis schwimmeri	0	1	0	0	1
Brachyrhizodus wichitaensis	0	0	1	3	4
Chondrichthian (vertebra)	39	33	40	34	146
Coprolite	2	2	6	0	10
Cretorectolobus sp.	0	0	0	2	2
Crocodilia (scute)	0	4	10	0	14
Crocodilia (tooth)	84	60	62	70	276
Cylindracanthus sp. (spine)	0	0	0	1	1
Dasyatis (barb)	0	0	0	1	1
Dasyatis (tooth)	1	2	0	1	4
Dermal denticle	1	2	2	3	8
Enchodus petrosus	11	6	3	16	36
Fish (fused vertebrae)	1	0	0	1	2
Ginglymostoma globidens	2	1	1	0	4
Hybodus sp. (tooth)	15	5	2	5	27
Hybodus sp. (cephalic hook)	1	1	0	0	2
Indet. Dinosaurian (tooth)	3	0	0	1	4
Ischyrhiza mira (oral tooth)	4	13	9	13	39
Ischyrhiza mira (rostral)	1	5	1	0	7
Ischyrhiza sp. (oral tooth)	0	1	0	0	1
Lonchidion selachos	0	1	4	4	9
Onchopristis sp. (rostral)	0	1	0	0	1
Ornithopoda (tooth)	5	1	3	3	12
Osteichthian (vertebra)	14	6	9	10	39
Paralbula casei (jaw fragment)	0	0	1	1	2
Paralbula casei (tooth)	6	1	9	1	17
Pristis? (tooth)	0	0	0	3	3
Protosphyraena sp. (tooth)	0	1	0	0	1
Pseudohypolophus sp. (tooth)	0	2	0	0	2
Pseudohypolophus sp. (dermal denticle)	0	1	1	0	2
Ptychotrygon sp. (rostral spine)	2	0	0	0	2
Ptychotrygon sp. (tooth)	29	39	33	26	127
Ray teeth (indet.)	46	47	71	32	196

Reptilian (vertebra)	0	0	0	1	1
Rhinobatos casei	3	0	0	0	3
Scales (gar)	0	0	2	0	2
Scales (indet.)	20	17	7	7	51
Schizorhiza sp.	0	0	0	1	1
Chondrichthian teeth (indet.)	298	196	265	181	940
Squatina hassei	2	1	0	0	3
Hadrodus priscus	3	0	2	3	8
Theropoda	0	0	0	1	1
Xiphactinus vetus	22	5	13	6	46

Tooth counts of fossil elements less than 6.4 mm (1/4 in) grouped by Order.

	Bucket A	Bucket B	Bucket C	Bucket D
Hybodontiformes	16	7	6	9
Lamniformes	298	196	265	181
Squatiniformes	2	1	0	0
Orectolobiformes	2	1	1	2
Rajiformes	85	110	115	75
Myliobatiformes	1	2	1	5
Lepisosteiformes	0	0	2	0
Pycnodontiformes	9	15	12	16
Elopiformes	25	19	31	18
Salmoniformes	11	6	3	16
Ichthyodectiformes	22	5	13	6
Perciformes	0	0	0	1
Pleuronectiformes	3	0	2	3
Crocodilia	84	64	72	70
Saurischia	0	0	0	1
Ornithischia	8	1	3	4

Environmental preference data with 0 to 1 ranking of each taxon. A ranking of 1 indicates an environment in which particular taxa could function, a 0 ranking indicates an environment where a particular taxa could not survive.

Taxa	Terrestrial	Freshwater	Brackish	Marine
Chondrichthyes				
Hybodus sp.	0	1	1	1
Lonchidion selachos	0	1	1	1
Squatina hassei	0	0	1	1
Ginglymostoma globidens	0	0	1	1
Scapanorhynchus texanus	0	0	0	1
Cretolamna appendiculata lata	0	0	1	1
Cretolamna sp.	0	0	1	1
Squalicorax kaupi	0	0	0	1
Squalicorax pristodontis	0	0	0	1
Galeorhinus sp.	0	1	1	1
Rhinobatos casieri	0	0	1	1
Protoplatyrhina sp.	0	0	1	1
Ischyrhiza mira	0	1	1	1
Ischyrhiza avonicola	0	1	1	1
Borodinopristis schwimmeri	0	1	1	1
Schizorhiza sp.	0	1	1	1
Ptychotrygon triangularis	0	1	1	1
Dasyatis sp.	0	1	1	1
Brachyrhizodus wichitaensis	0	0	0	1
Rhombodus binkhorsti	0	0	0	1
Osteichthyes				
Anomoedus phaseolus	0	1	1	0
Lepisosteus sp.	0	1	1	1
Xiphactinus vetus	0	0	1	1
Cylindracanthus sp.	0	0	0	1
Hadrodus priscus	0	1	1	1
Albula sp.	0	1	1	1
Paralbula casei	0	1	1	1
Enchodus cf. *E. petrosus*	0	0	0	1
Reptilia				
Deinosuchus rugosus	1	1	1	0
Borealosuchus sp.	1	1	1	0
Tylosaurus sp.	0	0	1	1
Coniophis sp.	1	0	0	0
Plesiosauria	0	1	1	1

Cimolomys sp.	1	0	0	0
Dinosauria				
Tyrannosauridae	1	0	0	0
Dromaeosauridae	1	0	0	0
Ornithomimus sp.	1	0	0	0
Hadrosauridae	1	0	0	0
Amphibia				
Albanerpeton sp.	1	1	0	0

	Terrestrial	Freshwater	Brackish	Marine
Counts of score 1	9	18	25	29

APPENDIX B: X-RAY DIFFRACTION DATA OF DIAGENETIC MINERAL CONSTITUENTS OF A THEROPOD BONE FRAGMENT, A *DEINOSUCHUS* TOOTH, AND A COPROLITE.

X-ray diffraction (XRD) data for a theropod bone from the Bladen County Landfill Annex at Elizabethtown, NC.
[°2Th]: 2 Theta angle
d-spacing: Space between the layers of atoms, measured in Angstroms
Rel. Int.: Relative Intensity
I%: Intensity percent
Δd: Difference between derived d-spacing and known d-spacing

Mineral	Position [°2Th]	Derived d-spacing [Å]	Counts per second (peak height)	Relative Intensity [%]	Known d-spacing from reference file [Å]	Known Intensity from reference file [%]	Δd
Fluorapatite	31.845	2.81	207	100	2.81	100	0.00
Fluorapatite	33.056	2.71	124	60	2.71	60	0.00
Fluorapatite	46.791	1.94	60	29	1.94	40	0.00
Fluorapatite	49.526	1.84	78	38	1.84	60	0.00
Fluorapatite	52.207	1.75	138	67	1.75	30	0.00
Fluorapatite	53.159	1.72	58	28	1.72	30	0.00

Pyrite	33.056	2.71	124	60	2.71	100	0.00
Pyrite	37.080	2.42	34	16	2.42	58	0.00
Pyrite	40.731	2.22	39	19	2.21	43	0.00
Pyrite	56.202	1.64	67	32	1.63	74	0.01
Pyrite	64.205	1.45	33	16	1.45	13	0.00

X-ray diffraction (XRD) data for a *Deinosuchus* tooth from the Bladen County Landfill Annex at Elizabethtown, NC.

[°2Th]: 2 Theta angle

d-spacing: Space between the layers of atoma, measured in Angstroms

Rel. Int.: Relative Intensity

I%: Intensity percent

Δd: Difference between derived d-spacing and known d-spacing

Mineral	Position [°2Th]	Derived d-spacing [Å]	Counts per second (peak height)	Relative Intensity [%]	Known d-spacing from reference file [Å]	Known Intensity from reference file [%]	Δd
Fluorapatite	31.986	2.80	162	100	2.78	40	0.02
Fluorapatite	33.019	2.71	79	49	2.71	60	0.00
Fluorapatite	34.187	2.62	49	31	2.63	30	-0.01
Fluorapatite	46.839	1.94	51	31	1.94	40	0.00
Fluorapatite	48.278	1.89	34	21	1.89	10	0.00
Fluorapatite	49.578	1.84	105	65	1.84	60	0.00
Fluorapatite	52.315	1.75	27	17	1.75	30	0.00
Fluorapatite	53.121	1.72	41	26	1.72	30	0.00
Quartz	26.665	3.34	55	34	3.34	100	0.00
Quartz	42.419	2.13	12	7	2.13	6	0.00
Quartz	60.214	1.54	5	3	1.54	9	0.00
Quartz	63.966	1.46	39	24	1.45	2	0.01

X-ray diffraction (XRD) data for a coprolite from the Bladen County Landfill Annex at Elizabethtown, NC.
[°2Th]: 2 Theta angle
d-spacing: Space between the layers of atoms, measured in Angstroms
Rel. Int.: Relative Intensity
I%: Intensity percent
Δd: Difference between derived d-spacing and known d-spacing

Mineral	Position [°2Th]	Derived d-spacing [Å]	Counts per second (peak height)	Relative Intensity [%]	Known d-spacing from reference file [Å]	Known Intensity from reference file [%]	Δd
Fluorapatite	32.008	2.80	203	100	2.78	40	0.02
Fluorapatite	33.128	2.70	89	44	2.71	60	-0.01
Fluorapatite	46.871	1.94	52	26	1.94	40	0.00
Fluorapatite	49.584	1.84	79	39	1.84	60	0.00
Fluorapatite	50.779	1.80	14	7	1.80	30	0.00
Fluorapatite	52.457	1.74	21	11	1.75	30	-0.01
Fluorapatite	53.074	1.73	47	23	1.72	30	0.01

Pyrite	33.128	2.70	89	44	2.71	100	0.00
Pyrite	37.035	2.43	36	18	2.42	58	0.00
Pyrite	56.226	1.64	80	40	1.63	74	0.00
Pyrite	59.211	1.56	1	0	1.56	11	0.00
Pyrite	64.023	1.45	22	11	1.45	13	0.01

APPENDIX C: THE OCCURRENCE OF CRETACEOUS VERTEBRATES WITHIN CAMPANIAN AGE STRATA AT LOCALITIES IN THE UNITED STATES AND CANADA.

Taxa	BCLA, NC: Crane (2011)	Aguja Formation, West Texas: Rowe et al (1992), Sankey (2005), Gates et al., (2010)	Blufftown Formation, Georgia: Schwimmer (1986, 1997), Case and Schwimmer (1988), Schwimmer et al., (1993)	Phoebus Landing, NC: Miller (1967, 1969), Baird and Horner (1979), Robb (1989a, 1989b), and Gaffney et al., (2009)	Mesaverde Formation, Bighorn Basin, Wyoming: DeMar and Breithaupt (2006, 2008)	Oldman Formation, Alberta, Canada: Brinkman (1990), Eberth and Brinkman (1997)	Demopolis Chalk, Mississippi: King et al., (1988), Schwimmer et al., (1997)	Marshalltown Formation, New Jersey: Gallagher et al., (1986), Grandstaff et al., (1992), Schwimmer et al., (1997)	Judith River Formation, Central Montana: Gates et al., (2010), Fiorillo (1989)	Marshalltown Formation, Delaware: Lauginiger and Hartstein (1983)
CLASS REPTILIA	x	x	x	x	x	x	x	x	x	
ORDER Testudinata	x	x		x	x		x	x	x	
FAMILY Bothremydidae	x	x		x				x		
GENUS Bothremys	x	x		x				x		
Bothremys sp.	x	x	x	x						
GENUS *Chedighaii*	x							x		
Chedighaii sp.	x							x		
FAMILY Trionychidae	x	x	x	x	x	x		x	x	
GENUS *Trionyx*	x	x	x	x	x			x	x	
Trionyx sp.	x	x	x	x	x				x	
ORDER Crocodylia	x	x	x	x	x	x		x	x	
FAMILY Crocodylidae	x	x	x	x	x			x	x	
GENUS *Deinosuchus*	x	x	x	x	x			x	x	
Deinosuchus rugosus	x		x	x				x		
Leidyosuchus	x			x		x		x	x	
ORDER Squamata	x	x	x	x	x	x		x		
FAMILY Mosasauridae	x		x	x	x			x		
Tylosaurus sp.	x			x	x					
ORDER Plesiosauria	x				x				x	
CLASS DINOSAURIA	x	x	x	x	x	x	x	x	x	
SUBORDER Theropoda	x	x	x	x	x	x	x	x	x	
FAMILY Tyrannosauridae	x	x	x	x	x	x	x	x	x	
FAMILY Ornithomimidae	x	x	x	x	x				x	
SUBORDER Sauropodomorpha	x			x						
FAMILY incerta	x			x						

Hypsibema crassicauda	x			x						
SUBORDER Ornithopoda	x	x	x	x	x	x		x	x	
FAMILY Hadrosauridae	x	x	x	x	x	x		x	x	

CLASS AMPHIBIA	x	x			x	x		x		
ORDER Allocaudata	x	x								
FAMILY Albanerpetontidae	x	x								
Albanerpeton sp.	x	x								

CLASS CHONDRICHTHYES	x	x	x	x	x	x	x	x	x	x
ORDER Hybodontiformes	x	x	x	x	x	x		x	x	x
FAMILY Hybodontidae	x	x	x	x	x	x		x	x	x
Hybodus sp.	x	x	x	x	x			x	x	x
FAMILY Polyacrodontidae	x	x	x					x		
Lissodus sp.	x	x	x					x		
ORDER Squatiniformes	x		x	x	x			x		x
FAMILY Squatinidae	x		x	x	x			x		x
GENUS *Squatina*	x		x	x	x			x		x
Squatina hassei	x		x	x				x		x
ORDER Orectolobiformes	x	x	x		x			x		x
FAMILY Ginglymostomatidae	x	x	x		x			x		x
Ginglymostoma globidens	x		x		x					x
ORDER Lamniformes	x	x	x	x	x		x	x		x
FAMILY Odontaspididae	x	x	x	x	x			x	x	x
FAMILY Mitsukurinidae	x	x	x	x	x		x	x		x
Scapanorhynchus texanus	x	x	x	x	x		x	x		x
FAMILY Cretoxyrhinidae	x	x	x		x		x	x	x	x
Cretolamna appendiculata	x	x	x		x		x	x		x
FAMILY Anacoracidae	x	x	x	x	x		x	x	x	x
Squalicorax kaupi	x	x	x	x	x		x	x	x	x
Squalicorax pristodontis	x			x	x					x
ORDER Rajiformes	x	x		x	x		x		x	x
FAMILY Rhinobatidae	x	x			x				x	x
GENUS *Rhinobatos*	x				x					x
Rhinobatos casieri	x				x					x
Rhinobatoidei incertae sedis	x									
Protoplatyrhina renae	x				x				x	
FAMILY Sclerorhynchidae	x	x	x	x	x		x	x	x	x
GENUS *Ischyrhiza*	x	x	x	x	x		x	x	x	x
Ischyrhiza avonicola	x	x			x				x	

Ischyrhiza mira	x	x	x	x	x		x	x	x	x
GENUS *Ptychotrygon*	x	x	x		x			x	x	x
Ptychotrygon triangularis	x									
ORDER Myliobatiformes	x	x	x	x				x		x
FAMILY Myliobatidae	x		x	x				x		x
GENUS *Brachyrhizodus*	x		x	x				x		x
Brachyrhizodus wichitaensis	x		x	x				x		x
FAMILY Rhombodontidae	x		x	x						x
GENUS *Rhombodus*	x		x	x						x
Rhombus binkhorsti	x									
FAMILY Dasyatidae	x	x			x					
GENUS *Dasyatis*	x	x								
Dasyatis sp.	x									
CLASS OSTEICHTHYES	x	x	x	x	x	x	x	x		
ORDER Pycnondontiformes	x		x	x	x		x	x		
FAMILY Pycnodontidae	x		x	x	x		x	x		
GENUS *Anomoeodus*	x		x	x				x		
Anomoeodus phaseolus	x		x	x						
ORDER Lepisosteiformes	x	x	x	x	x	x		x	x	
FAMILY Lepisosteidae	x	x	x	x	x	x		x	x	
Lepisosteidae indet.	x		x	x				x	x	
ORDER Ichthyodectiformes	x		x	x	x			x		
FAMILY Ichthyodectidae	x		x	x	x			x		
GENUS *Xiphactinus*	x		x	x	x			x		
Xiphactinus vetus	x		x	x	x		x	x		x
ORDER Perciformes	x			x	x			x		
ORDER Semionotiformes	x		x	x						
FAMILY Hadrodontidae	x		x	x						
GENUS *Hadrodus*	x		x	x						
Hadrodus priscum	x		x	x						
ORDER Elopiformes	x		x	x	x	x		x	x	
FAMILY Albulidae	x		x	x	x	x				
GENUS *Albula*	x		x	x						
Albula sp.(**) = *Batoidea* sp. (*)	x		**	**	*	*			*	
FAMILY Paralbulinae	x		x	x	x	x		x	x	
GENUS *Paralbula*	x		x	x	x	x		x	x	
Paralbula casei	x		x	x	x	x		x	x	
ORDER Salmoniformes	x		x	x	x	x	x	x		

FAMILY Enchodontidae	x		x	x	x		x	x		
GENUS *Enchodus*	x		x	x	x		x	x	x	
Enchodus cf. *E. petrosus*	x		x	x	x			x	x	

APPENDIX D: LIST OF VERTEBRATES RECORDED AT THE BCLA SITE NEAR ELIZABETHTOWN, BLADEN COUNTY, NORTH CAROLINA

CLASS CHONDRICHTHYES

Order SELACHII
Family Hybodontidae
Genus *Hybodus*
Hybodus sp.
Family Lonchidiidae
Genus *Lonchidion*
Lonchidion selachos Estes, 1964

Order EUSELACHII
Family Mitsukurinidae
Genus *Scapanorhynchus*
Scapanorhynchus texanus (Roemer, 1852)
Family Cretoxyrhyinidae
Genus *Cretolamna*
Cretolamna appendiculata lata (Agassiz, 1843)
Cretolamna sp.
Family Anacoracidae
Genus *Squalicorax*
Squalicorax kaupi (Agassiz, 1843)
Squalicorax pristodontis Agassiz, 1843

Order CARCHARHINIFORMES
Family Triakidae
Galeorhinus sp.
Family Odontaspididae
gen. and sp. indet.

Order SQUATINIFORMES
Family Squatinidae
Genus *Squatina*
Squatina hassei Leriche, 1929

Order ORECTOLOBIFORMES
Family Ginglymostomatidae
Genus *Ginglymostoma*
Ginglymostoma globidens Cappetta and Case, 1975

Order RAJIFORMES
Family Rhinobatidae
Genus *Rhinobatos*
Rhinobatos casieri Herman, 1977
Protoplatyrhina sp.
Rhinobatoidei incertae sedis
Family Rajidae
gen. and sp. indet.
Family Sclerorhynchidae
Genus *Borodinopristis*
Borodinopristis schwimmeri Case, 1987
Genus *Ischyrhiza*
Ischyrhiza avonicola Estes, 1964
Ischyrhiza mira Leidy, 1856
Genus Schizorhiza
Schizorhiza sp.

Order BATOIDEA
Family incertae sedis
Genus *Ptychotrygon*
Ptychotrygon triangularis (Reuss, 1844)
Family Dasyatidae
Genus *Dasyatis*
Dasyatis sp.

Order MYLIOBATIFORMES
Family Myliobatidae
Genus *Brachyrhizodus*
Brachyrhizodus wichitaensis Romer, 1942
Family Rhombodontidae
Genus *Rhombodus*
Rhombus binkhorsti Dames, 1881

CLASS OSTEICHTHYES

Order LEPISOSTEIFORMES
Family Lepisosteidae
Genus *Lepisosteidae*
Lepisosteus sp.

Order PYCNONDONTIFORMES
Family Pycnodontidae
Genus *Anomoeodus*
Anomoeodus phaseolus (Hay, 1899)

Order ELOPIFORMES
Family Phyllodontidae
Genus *Paralbula*
Paralbula casei Estes, 1969
Family Albulidae
Genus *Albula*
Albula sp.

Order SALMONIFORMES
Family Enchodontidae
Genus *Enchodus*
Enchodus cf. *E. petrosus* Cope, 1874

Order ICHTHYODECTIFORMES
Family Ichthyodectidae
Genus *Xiphactinus*
Xiphactinus vetus Schwimmer, Stewart & Williams, 1997

Order SEMIONOTIFORMES
Family Hadrodontidae
Genus *Hadrodus*
Hadrodus priscus Leidy, 1857

CLASS AMPHIBIA

Order CAUDATA
Family Albanerpetontidae
Genus *Albanerpeton*
Albanerpeton sp.

CLASS REPTILIA

Order TESTUDINES
Family Bothremydidae
Genus *Bothremys*
Bothremys sp.
Genus *Chedighaii*
Chedighaii sp.
Family Trionyxchidae
Genus *Trionyx*
Trionyx sp.

Order SQUAMATA
Family Mosasauridae
Genus *Tylosaurus*

Tylosaurus sp.

Order SERPENTES
Family Aniliidae
Coniophis sp.

Order PLESIOSAURIA
Superfamily Plesiosauroidea
Family Elasmosauridae
gen. and sp. indet.

Order CROCODYLIA
Family Crocodylidae
Subfamily Crocodylinae
Genus *Borealosuchus*
Borealosuchus sp.
Genus *Deinosuchus*
Deinosuchus rugosus (Emmons, 1858)

CLASS DINOSAURIA

Suborder THEROPODA
Family Ornithomimidae
Genus *Ornithomimus*
Ornithomimus sp.
Family Dromaeosauridae
gen. and sp. indet.
Family Tyrannosauridae
gen. and sp. indet.

Suborder SAUROPODOMORPHA
Family incerta
Hypsibema crassicauda (Cope, 1869)

Order ORNITHOPODA
Family Hadrosauridae
gen. and sp. indet.

CLASS MAMMALIA

Order MULTITUBERCULATA
Family Cimolomyidae
Genus *Cimolomys*
Cimolomys sp.