2012

Why is There Such a High Concentration of Vertebrate Remains Within a Bone-bed Along Clapp Creek, Williamsburg County, South Carolina?

Jennifer R. Soehner
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WHY IS THERE SUCH A HIGH CONCENTRATION OF VERTEBRATE REMAINS WITHIN A BONE-BED ALONG CLAPP CREEK, WILLIAMSBURG COUNTY, SOUTH CAROLINA?

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

By

JENNIFER R. SOEHNER
B.A., Wright State University, 2009

2012
Wright State University
I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Jennifer R. Soehner ENTITLED Why is There Such a High Concentration of Vertebrate Remains Within a Bone-bed Along Clapp Creek, Williamsburg County, South Carolina? BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT

Soehner, Jennifer Rose. M.S., Department of Earth and Environmental Sciences, Wright State University, 2012. Why is There Such a High Concentration of Vertebrate Remains Within a Bone-bed Along Clapp Creek, Williamsburg County, South Carolina?

A phosphatic bone-bed occurs along Clapp Creek in Kingstree, South Carolina, within the east-central portion of the coastal plain. The location of the research site is within the Chicora Member of the Williamsburg Formation. The paleoenvironment of this site was most likely a complex estuary with microenvironments that included tidal channels, tidal deltas, tidal flats, marshes and subtidal bays. The high diversity and large time span in the bone-bed is explained by the transgressive environment and storm deposits. The phosphate content of the bone-bed is from the calcium phosphate occurring in the coprolites of carnivores and the higher concentration of phosphate present in estuaries. Additionally, the high concentration of coprolites within the bone-bed resulted from the estuary being a feeding and breeding ground for crocodiles.
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Lastly, I owe the most thanks and appreciation to my wonderful and loving partner, Angie Clayton. Without her support and guidance I may not have finished this project. Angie, you were always there when I needed you and you always knew what to say to help me work through my frustrating mind blocks. I cannot thank you enough!
I. INTRODUCTION

The city of Kingstree is located in Williamsburg County within the east-central portion of the South Carolina coastal plain (Figure 1). Along and adjacent to Clapp Creek, a tributary of the Black River, an extremely fossiliferous layer exposes a variety of shark, fish, and reptilian teeth, scales and bones (Weems & Bybell, 1998). The age of the faunal elements within the unit span the Late Cretaceous (Maastrichtian) through the Early Quaternary (Pleistocene). Due to the high concentration of vertebrate and phosphatic material present, this highly fossiliferous layer is referred to as a bone-bed. The fossiliferous sediment is approximately two meters below the surface of the bank at Clapp Creek (Figures 2 & 3). It is believed that approximately fifty cm below this bone-bed is a second bone-bed.

The focus of this research project is to: (1) discuss the age and diversity of the vertebrate material within the bone-bed; (2) define the paleoenvironment of the bone-bed occurring along Clapp Creek in Kingstree, South Carolina; (3) investigate the reason behind the high concentration of coprolites within the bone-bed.
Figure 1: A. Geologic map of South Carolina with Williamsburg County outlined and the position of the field site indicated. B. Geologic map of Williamsburg County with the field site indicated. C. Geologic map of the field site with hydrography and infrastructure shown.
Figure 2: The bone-bed is exposed at the bottom of the shovel in Clapp Creek, Kingstree, South Carolina. The red line indicates where the bone-bed is exposed.
**Figure 3:** Close up of the exposed bone-bed in Clapp Creek. The red line traces the top of the bone-bed.
II. BACKGROUND

The focus of this research was based upon the bone-bed that is present along Clapp Creek in Kingstree, South Carolina. In order to discuss bone-beds, it is important to first have a definition of what a bone-bed is. The definition used for this study is that a bone-bed is the preservation of vertebrate hard parts from more than one individual in a localized area or stratigraphically limited sedimentary unit. The bone material must be denser relative to the adjacent lateral and vertical strata deposits (Rogers, 2007). There are two distinct classifications of bone-beds; these are macrofossil bone-beds and microfossil bone-beds. This paper focuses on macrofossil bone-beds, which are “considered concentrated deposits of skeletal elements from two or more animals in which most bioclasts (>75%, be they isolated elements or entire skeletons) are >5 cm in maximum dimension” (Rogers, 2007).

This research also focuses on the coprolites occurring in the bone-bed in Kingstree, South Carolina. The term coprolite describes fecal matter that was fossilized after it had left the organism’s body. Coprolites are different from most ichnifossils because they have the ability to be transported by natural processes, such as water. Coprolites commonly occur with other durable items such as teeth, pebbles and nodules. In some localities, bone-beds contain more coprolites than bone material. Such deposits are often phosphatic and can occur in dense accumulations (Thulborn, 1991). One of the criteria that is necessary to be classified as a coprolite is a high calcium phosphate concentration. The phosphate helps mineralize the feces. Most of the phosphate within the coprolite originates from the bones of the animals that have been eaten (Williams,
Carnivore feces have a high preservation potential due to the rich phosphates from the skeletal debris from their prey. The feces then requires little to no mineral enrichment to ensure petrification (Thulborn, 1991). Environments that favor the preservation of coprolites are low-energy depositional settings that have fine sedimentary matrix and a moist climate. Examples of the types of environments that are favorable are quiet streams, floodplains, swamps, lagoons, ephemeral pools and mudflats bordering lakes and estuaries (Vijaya & Singh, 2009).

Coprolites come in many sizes and shapes. These shapes resemble eggs, bullets, kidneys, sausages, ropes and pellets. Coprolites are not branched or multi-lobed (Thulborn, 1991). Coprolites can also contain undigested material. This undigested material is usually the hard parts of the prey the predator had previously eaten or remnants of plants. This material can include bones, teeth, scales, keratin, chitin, woody tissues, cuticles, phytoliths and seeds (Thulborn, 1991). Inclusions of this type can be commonly identified in coprolites and can be used to help identify the type of organism that produced the feces.

The bone-bed along Clapp Creek occurs in unconsolidated sediment and is approximately seventeen centimeters in thickness (Figures 4 & 5). The lithology of the sediment is highly phosphatic and contains abundant amounts of quartz sand. The sediment has a phosphate content of around 50% and the sand is rounded and poorly sorted. When sediments are very rich in phosphates, over 19.5%, they can be termed phosphorites. Those sediments that have a lower phosphate content, between 7.8% and 19.5%, are described as phosphatic (Thulborn, 1991). The Clapp Creek bone-bed contains abundant amounts of coprolites and vertebrate material that ranges in age from
the Late Cretaceous to the Pleistocene. The Black Mingo Group, which is very fossiliferous, is dominantly represented. It is composed of the Rhems Formation, the Williamsburg Formation and the Fishburne Formation (Weems & Bybell, 1998) (Figure 6). In this area, the Rhems and the Williamsburg Formations are present.

The Rhems Formation is composed of the Brown’s Ferry Member which is described as “an arenaceous shale to argillaceous sand” and the Perkin’s Bluff Member which is described as “pelecypod-poor to pelecypod-rich clayey sands” (Muthig & Colquhoun, 1988) (Figure 7). The Brown’s Ferry Member is dominantly grayish white in color, medium to coarse-grained arkosic sands with sandy clays interbedded. There is trough crossbedding and thin, fining-upward beds. Present throughout the unit are beds of thin and thick clay (Muthig & Colquhoun, 1988). The Perkin’s Bluff Member “consists of interbedded sands, silts, clays and thin beds of silicified shell debris” (Muthig & Colquhoun, 1988). The sands are red or yellow in color and are very fine to medium-grained and in some individual beds there is massive, cross-bedded, burrowed, lenticular bedding. The exposed sands are white, gray or black. Shark teeth have been recovered but only in the darker sands (Muthig & Colquhoun, 1988). “The sand deposits grade laterally and vertically to silts and clays. The silts tend to be sandy, bioturbated and commonly exhibit a gray-green color when freshly exposed” (Muthig & Colquhoun, 1988).

The Williamsburg Formation is composed of the “fossiliferous, argillaceous sands of the Lower Bridge member and the fossiliferous, argillaceous sands and molluscan rich bioclastic limestones of the Chicora Member” (Van Nieuwenhuise & Colquhoun, 1982) (Figures 8 & 9). The bottom of the Lower Bridge Member is composed of a fine-grained
limestone that is very shelly and has glauconite grains throughout it. It grades upward into a shale that is sandy and silty and is black to a medium-gray in color. Upward, towards the top of the member, the unit becomes a fine-grained sandstone with some phosphate grains present. The bottom of the Chicora member is described as a gravel bed that is composed of quartz and phosphate pebbles. The unit is fossiliferous with shark, ray and crocodile teeth found throughout it. The surrounding matrix is a medium-grained, poorly sorted, medium-gray sand. The unit grades upward into a fine to medium-grained, well sorted, light gray sand. The sand is planar cross-bedded, has clay lenses and there are woody stem fragments present. Towards the top of the unit, the lithology is a medium to coarse-grained sand that is light-gray to orangish-brown color. Interbedded clay occurs in thin, planar beds. The top of the Chicora Member is a medium-grained sandstone that is interbedded with clay (Weems & Bybell, 1998).

The high concentration of phosphate in the bone-bed is indicative of an anoxic environment. Most phosphorite deposits occur in shallow water with depths of 60 to 400 meters (Miller, 1982). Phosphorites are most commonly associated with shallow marine continental shelf deposits (Nichols, 2007). Phosphorus most commonly occurs in the Earth’s crust as species of the apatite group, $\text{Ca}_{10}(\text{PO}_4, \text{CO}_3)_6(\text{F, Cl, OH})_2$. Apatite is soluble in neutral to alkaline waters (McKelvey, 1967). The pH of the water controls the precipitation of phosphate. Phosphate precipitates at a pH of 7.0-7.5 (Miller, 1982).

Most phosphorus is carried to the ocean in the form of phosphate minerals. The phosphate content of most rivers range from about 0.01-0.5 parts per million (ppm) and highly saline alkaline lake waters contain 200-900 ppm. Estuaries often contain a higher phosphate concentration than rivers or sea water (McKelvey, 1967).
The vertebrate material present includes several species of crocodiles, fish, turtles, sharks, as well as terrestrial mammals. There is also a high concentration of coprolites in this area. These coprolites are presumed to be mostly crocodilian in origin (Sawyer, 1998). There is very little carbonate-shelled invertebrate fauna represented in this area. The conditions that create “thick phosphate-dominated vertebrate deposits may diminish the preservation potential of carbonate-shelled invertebrate fauna” (Tapanila et al., 2004).
Figure 4: Core taken at Clapp Creek in Kingstree, South Carolina. The red lines indicate the extent of the bone-bed.

Figure 5: Close up of the bone-bed within the core taken at Clapp Creek in Kingstree, South Carolina. The red lines indicate the extent of the bone-bed.
Figure 6: Stratigraphic column of the Black Mingo Group modified from Van Nieuwenhuiise and Colquhoun, 1982.
Figure 7: Stratigraphic column of the Rhems Formation modified from Van Nieuwenhuise and Colquhoun, 1982.
Figure 8: Stratigraphic column of the Chicora Member in the Williamsburg Formation modified from Van Nieuwenhuise and Colquhoun, 1982.

Figure 9: Stratigraphic column of the Lower Bride Member in the Williamsburg Formation modified from Van Nieuwenhuise and Colquhoun, 1982.
III. METHODS

Field work was performed at Kingstree, South Carolina in order to collect an abundant amount of bulk material to analyze its contents. Approximately ten trips to Kingstree were conducted to collect the bulk material to screen both at the site and in the lab. The material was collected along the banks of Clapp Creek in a pit that was previously dug by a backhoe. Collection of the material was done by climbing into the pit and digging out the bone-bed material where it has been previously exposed (Figures A.1 & A.2). This material was placed into five-gallon buckets and transported down to the creek to be screened. The screening process consisted of the bulk material being poured into a system of two screens. The top screen box had screen openings of 5 mm and sat within a bottom screen box that had screen openings of 3 mm. The material was sifted by placing the screen boxes into the creek and shaking them back and forth to remove the excess sediment (Figure A.3 & A.4). Bone-bed material was then collected from the screens and brought back to the lab for analysis. Several buckets of bulk material were also taken back to the lab for analysis. The bulk material was processed by sieving it through a system of three screens. The first screen had openings of 5 mm, the second screen had openings of 3 mm and the third screen had openings of 1 mm. The bone-bed material was recovered from the screens and the unconsolidated matrix was removed and saved from each screen size (Figures B.1, B.2, B.3 & B.4). The unconsolidated matrix was then used to identify the formation present at the Kingstree locality.

Several cores were taken at the locality to identify the extent of the bone-bed, to determine if there was a second bone-bed below the first one, and to clarify the
stratigraphy of the area. The tubing used to take the cores were automobile muffler pipes with an internal diameter of two inches. The cores were taken by pounding the muffler pipe into the sediment in the vicinity of the pit. The cores were pounded into the ground using a ten pound sledge and a two by four piece of wood on top of the muffler pipe to help drive it into the ground. The core was removed by digging down to the bottom of the core and sliding a flat shovel underneath the bottom of the core to ensure that the sediment was not disturbed. A foam filler was used to plug the tops of the cores and both the tops and the bottoms of the cores were secured by placing duct tape over the ends to prevent the sediment from falling out. After the cores were transferred to the lab, they were cut open to analyze the bone-bed thickness and the stratigraphy of the area.

One thin section was prepared for a “typical” coprolite and one cross section was prepared using a “typical” phosphate nodule. The thin section was prepared to study the internal features of the coprolite. The first step in the thin sectioning process was to take a cross section of the coprolite by cutting it in half. Next, the sample was adhered to a microscope slide that was 76.5 mm by 51 mm and 1.2 mm thick. The coprolite was mounted by using a mixture of 5 parts Epothin Epoxy Resin and 1.95 parts of Epothin Epoxy Hardener was used. After the adhesive had set, the coprolite was then cut further and polished down to create the thin sections. When completed, the thin section was approximately 30 microns thick. No staining was needed for the thin section. The cross section was prepared to determine the composition of the nodule. In order to produce the cross section of the phosphate nodule, the nodule was first cut in half. Next, it was polished using a series of sand paper, in progressively finer grades, to smooth the surface. The type of sand paper that was used was silicon carbide waterproof paper. Water was
placed on each of the different sizes of sand paper and then the cut end was polished in a circular motion for approximately 2-3 minutes. The nodule was first polished on sand paper with a grit size of 80. It was then polished with a series of sand papers with grit sizes of 120, 220, 400, 600, 800 and lastly 1000. After the phosphate nodule was polished, it was examined under a microscope.

Lastly, to discuss the diversity of the bone-bed different methods were used. First, a diverse array of vertebrate material and coprolites were selected and identified. In order to show the diversity using this method, the vertebrate material and coprolites were mounted on pieces of clay and a photograph of each individual fossil was taken. Plates were then made from the individual photographs to show the diversity of the bone-bed at Kingstree, South Carolina (Figures 10, 11, &12). Second, four 5 gallons buckets of bulk material were screened and the vertebrate material and coprolites were collected, categorized and counted (Table 4 & Figures 13 & 14). Lastly, a fauna list was created from the vertebrate material that has been found at Kingstree, South Carolina (Table 5). The identification of the vertebrate material was done using *Chondrichthyan Fishes from the Paleocene of South Carolina* (Purdy, 1998), *Actinopterygian Fish Remains from the Paleocene of South Carolina* (Weems, 1998), *Paleocene Turtle Remains from South Carolina* (Hutchison, 1998), and *Crocodilians of the Black Mingo Group (Paleocene) of the South Carolina Coastal Plain* (Erickson, 1998).
IV. DIVERSITY

There is high vertebrate diversity in the bone-bed present in Clapp Creek. The vertebrate remains occurring in the bone-bed span approximately 98 million years from the Late Cretaceous to the Early Quaternary. Both marine and terrestrial fauna are present in the bone-bed with reptilian remains being the most common. There is also a high concentration of coprolites in the bone-bed with the majority of them being crocodilian in origin.

The high diversity and large time span of the bone-bed can be explained by a transgressive environment with relatively low energy. Many of the specimens show little abrasion and most likely experienced little to no reworking after their initial deposition. This supports the interpretation that deposition occurred during a transgressive event (Clayton, 2011). During a transgressive event, finer sediment will be transported whereas larger bioclasts (vertebrate remains) will remain in place. The process of carrying sediment and depositing bioclasts also occurs in tidal channels that are commonly within estuaries (Nichols, 2007). Storm deposits can also play a role in removing sediment and re-deposition of bioclasts. The combination of the transgressive processes, tidal channels and storms would support the accumulation of a bone-bed with a large time span represented.

Figures 10-12 show a broad sampling of some of the vertebrate remains found in the bone-bed at Kingstree, South Carolina. A few invertebrate remains were also recovered from the bone-bed but are not represented in the figures below. The invertebrate remains are very uncommon in the bone-bed. However, the presence of
invertebrate organisms, such as gastropods and bivalves, can be inferred from the borings illustrated in figure 12.E. A boring is an excavation created in a hard substrate such as wood or bone (Tapanila et al., 2004). Tables 1-3, which respectively follow figures 10-12, describe and identify the broad sampling of vertebrate remains occurring in the Kingstree bone-bed.

Table 4 and Figures 13 & 14 show a count of the vertebrate remains that have been recovered from bulk material found in the bone-bed at Kingstree, South Carolina. The remains came out of 20 gallons of bulk material that was collected at the Kingstree site. Only vertebrate remains that could be identified were used in the counts. Table 5 is a comprehensive faunal list of the remains that have been found at Kingstree, South Carolina. The list shows the wide diversity of remains recovered from the bone-bed at Kingstree, South Carolina.
Figure 10: Plate number 1 of vertebrate material.
<table>
<thead>
<tr>
<th>Letter</th>
<th>Dimensions</th>
<th>Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.7 cm wide &amp; 4 cm tall</td>
<td>Great White shark tooth</td>
</tr>
<tr>
<td>B</td>
<td>1.9 cm wide &amp; 1.7 cm tall</td>
<td>Tiger shark tooth</td>
</tr>
<tr>
<td>C</td>
<td>1.0 cm wide &amp; 3.1 cm tall</td>
<td>Sawfish tooth</td>
</tr>
<tr>
<td>D</td>
<td>1.5 cm long &amp; 1.0 cm tall</td>
<td>Stingray tooth</td>
</tr>
<tr>
<td>E</td>
<td>Diameter of 3.8 cm</td>
<td>Stingray plate</td>
</tr>
<tr>
<td>F</td>
<td>1.6 cm wide &amp; 2.2 cm tall</td>
<td>Fish plate</td>
</tr>
<tr>
<td>G</td>
<td>4.5 cm wide &amp; 4.0 cm tall</td>
<td>Cephalic shark spine</td>
</tr>
<tr>
<td>H</td>
<td>1.0 cm wide &amp; 3.0 cm tall</td>
<td>Stingray barb</td>
</tr>
<tr>
<td>I</td>
<td>Diameter of 2.4 cm</td>
<td>Shark vertebrae</td>
</tr>
<tr>
<td>J</td>
<td>Diameter of 2.6 cm</td>
<td>Turtle vertebrae</td>
</tr>
<tr>
<td>K</td>
<td>1.0 cm wide &amp; 1.6 cm tall</td>
<td>Drumfish plate</td>
</tr>
<tr>
<td>L</td>
<td>1.3 cm wide &amp; 2.0 cm tall</td>
<td>Dermal denticle</td>
</tr>
</tbody>
</table>

**Table 1:** Identification of vertebrate material A-L from Figure 10.
Figure 11: Plate number 2 of vertebrate material.
<table>
<thead>
<tr>
<th>Letter</th>
<th>Dimensions</th>
<th>Identification</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>11.5 cm long &amp; 6.3 cm tall</td>
<td>Crocodile jaw bone with tooth in position</td>
</tr>
<tr>
<td>B</td>
<td>1.7 cm wide &amp; 2.8 cm tall</td>
<td>Crocodile tooth</td>
</tr>
<tr>
<td>C</td>
<td>1 cm wide &amp; 3.4 cm tall</td>
<td>Marine reptile tooth</td>
</tr>
<tr>
<td>D</td>
<td>7.1 cm long &amp; 5.0 cm tall</td>
<td>Crocodile scoot</td>
</tr>
<tr>
<td>E</td>
<td>9 cm long &amp; 6.0 cm tall</td>
<td>Crocodile vertebrae</td>
</tr>
<tr>
<td>F</td>
<td>1.2 cm wide &amp; 3.7 cm tall</td>
<td>Marine reptile tooth</td>
</tr>
<tr>
<td>G</td>
<td>10.5 cm long &amp; 8 cm tall</td>
<td>Partial turtle shell</td>
</tr>
<tr>
<td>H</td>
<td>2 cm wide &amp; 1.8 cm tall</td>
<td>Vertebrate ball joint</td>
</tr>
<tr>
<td>I</td>
<td>5 cm wide &amp; 6 cm tall</td>
<td>Vertebrate ball joint</td>
</tr>
<tr>
<td>J</td>
<td>2.0 cm wide &amp; 6.8 cm tall</td>
<td>Two-toed horse tooth</td>
</tr>
<tr>
<td>K</td>
<td>1.4 cm wide &amp; 4.6 cm tall</td>
<td>Three-toed horse tooth</td>
</tr>
</tbody>
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**Table 2:** Identification of vertebrate material A–K from Figure 11.
Figure 12: Plate number 3 of vertebrate material.
<table>
<thead>
<tr>
<th>Letter</th>
<th>Dimensions</th>
<th>Identification</th>
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<tbody>
<tr>
<td>A</td>
<td>3.2 cm wide &amp; 5.5 cm tall</td>
<td>Unidentified coprolite</td>
</tr>
<tr>
<td>B</td>
<td>1.5 cm wide &amp; 4.4 cm tall</td>
<td>Crocodile coprolite</td>
</tr>
<tr>
<td>C</td>
<td>2.5 cm wide &amp; 5.6 cm tall</td>
<td>Crocodile coprolite</td>
</tr>
<tr>
<td>D</td>
<td>5.0 cm wide &amp; 4.8 cm tall</td>
<td>Dinosaur coprolite</td>
</tr>
<tr>
<td>E</td>
<td>2.5 cm wide &amp; 10.7 cm tall</td>
<td>Borings in bone material</td>
</tr>
</tbody>
</table>

**Table 3:** Identification of vertebrate material A-E from Figure 12.
Table 4: Counts of vertebrate remains and coprolites from 20 gallons of bulk material from Kingstree, South Carolina.
Figure 13: Faunal diversity recovered from 20 gallons of bulk material from Kingstree, South Carolina.
Figure 14: Ratio of the amount of crocodile remains to the amount of coprolites. The majority of the coprolites are crocodilian in origin.
Comprehensive Faunal List

Chondrichthyan Fish

Order Myliobatiformes
Family Myliobatidae
*Myliobatis* sp.

*Rhinoptera* sp.

Order Pristiformes
Family Pristidae
*Pristis* sp.

Order Orectoloboformes
Family Ginglymostomatidae
*Nebrius* sp.

Order Lamniformes
Family Odontaspididae
*Carcharias*
*Odontaspis*

Family Otodontidae
*Otodus*

Family Cretoxyrhinidae
*Cretolamna*

Family Lamnidae
*Carcharodon*

Order Carcharhiniformes
Family Scyliorhinidae

Family Triakidae

Order Chimaeriformes
Family Chimaeridae
*Ischyodus* sp.
Fish

Class Osteichthyes
Subclass Actinopterygii
Order Lepisosteiformes
Family Lepisosteidae
*Lepisosteus* sp.

Order Pycnodontiformes
Family Pycnodontidae
*Pycnodus* sp.

Order Elopiformes
Family Albulidae
*Albula*

Family Phyllodontidae
*Egertonia*

*Phylloodus*

Order Tetraodontiformes
Family Ostraciidae

Family Diodontidae
*Progymnodon*

Turtles

Class Reptilia
Order Chelonia
Suborder Pleurodira
Family Pelomedusidae
Subfamily Bothremydinae
*Taphrosphys*

*Bothremys*

Suborder Cryptodira
Family Adocidae
*Adocus*

Family Kinosternidae
*Kinosternidae*

*Agomphus*
Family Trionychidae

Aspideretes

Superfamily Cheloniioidea
Family Toxochelyidae
Subfamily Toxochelyinae

Family Cheloniidae
Subfamily Osteopyginae

**Crocodiles**

Order Crocodylia
Suborder Mesosuchia
Family Dryosauridae

*Hyposaurus*

Suborder Euschia
Family Crocodylidae

*Bottosaurus*

*Thoracosaurus*

Suborder Eusuchia

*Alligator*

**Dinosaur**

Order Ornithischia
Suborder Ornithopoda
Family Hadrosauridae

Order Theropoda
Family Dromaeosaur

**Mammals**

Order Perissodactyla
Family Equidae

Order Rodentia
Family Castoridae
V. RESULTS

The sediment recovered along the banks of Clapp Creek indicates that the Williamsburg Formation, more specifically the Chicora Member, is present at this location. Evidence from screening (Figures B.1, B.2, B.3 & B.4) shows predominantly quartz sand that is very coarse to medium in size. The screening process also revealed the presence of woody and clay material. The description of the Chicora Member lithology is identical to the sedimentary lithology recovered from the site and the type of vertebrate remains recovered also indicate that the Chicora Member is present at this locality.

The city of Kingstree is located in the east-central portion of the South Carolina coastal plain. Stratigraphic and fossil evidence indicate that the paleoenvironment of Kingstree was shallow, nearshore marine (Weems & Bybell, 1998). Evidence from the cores (Figures 4 & 5) and from the sediment collected from screening (Figures B.1, B.2, B.3 & B.4) suggest a nearshore marine paleoenvironment. The fossil evidence provides insight on the type of environment by the high diversity of fauna and the types of remains that have been preserved. The presence of both marine and terrestrial organisms indicates that the environment was nearshore and not wholly marine. The abundance of coprolites also indicates that the environment was shallow and characterized by low energy. The types of vertebrate remains recovered in this study and the above evidence indicate that the paleoenvironment of Kingstree was estuarine in nature.

Estuaries are semi-enclosed coastal bodies of water that are connected to the ocean and contain seawater that is diluted as a result of fluvial input. Estuaries are
associated with transgressive settings having good preservation potential. Estuaries are complex because they encompass several coastal and shallow marine environments. Estuaries contain many subenvironments that include tidal channels, tidal deltas, tidal flats, marshes and subtidal bays (Reinson, 1992). Due to the wide range of microenvironments occurring in estuaries, the dominant sediment type ranges from coarse-grained sands to fine sands with interspersed deposits of mud and clay derived from local tidal areas (Nichols, 2007). This type of environment would have supported and preserved the diverse fauna present in the Kingstree locality.

A high concentration of phosphate occurs in the bone-bed in Clapp Creek. Estuaries contain a higher concentration of phosphate than rivers and sea water (McKelvey, 1967) which would explain this abundance of phosphate occurring in the bone-bed. In cases where a reducing environment results from the microbial decay of organic matter, phosphorus can be released into the pore waters and may be incorporated into bones and scales (Northwood, 2005). The majority of the coprolites present in the bone-bed are crocodilian in origin (Sawyer, 1998). Coprolites from carnivores contain abundant calcium phosphate derived from the bone material occurring within them. The coprolites that were broken down and the feces that were not preserved would be another source of phosphate in the bone-bed. There is also a high concentration of phosphate nodules in the bone-bed. The phosphate nodules may have formed from gelatinous nodules in the sediment that became phosphatized. During this phosphatization, some minerals are depleted and other minerals are taken up. Other nodules could be broken coprolites that appear to be pebbles or nodules (Thulborn, 1991). A cross section of a nodule was made to investigate their origin (Figure 15). The inside of the nodule does
not appear to be coprolitic in nature. There are several cracks on the inside that have trace amounts of pyrite in them. This nodule formed through phosphatization and took up pyrite during the process.

The bone-bed also contains a high concentration of coprolites. As discussed above, these coprolites are mostly crocodilian in origin. Other coprolites present in this area have originated from turtles, sharks and dinosaurs. A thin section of a coprolite was made (Figures 16 & 17) and due to the lack of phosphate and the presence of organic matter, the coprolite is thought to originate from a terrestrial turtle. The lack of phosphate indicates that the organism was not carnivorous. Terrestrial turtles would have eaten a variety of organic matter and would not have calcium phosphate in their feces.

In order for feces to be preserved, several conditions must be met. Feces can be preserved if they are buried rapidly or occur in current-free, oxygen-depleted water. Feces can also be preserved if deposited in marginal environments such as floodplains, swamps, lagoons, mudflats and estuaries. This is due to the occasional flooding that occurs in these environments that would then rapidly bury the feces, allowing them to become preserved. Feces deposited on dry land will shrink and dry out and are subject to being destroyed by environmental and biological factors (Thulborn, 1991). An estuary is an ideal place for feces to be preserved because of the low energy environment, the fine-grained sediment that would bury it, and the occasional flooding to cause rapid burial.

While an estuarine environment allows feces to be preserved, its preservation potential alone does not explain the abundance of coprolites present at the Kingstree locality. The reason for the abundance of coprolites, with the majority being crocodilian, is that the estuary was a feeding and breeding ground for crocodiles. Crocodiles are
carnivores that eat a variety of organisms that would all have been supported by an estuarine environment. Juvenile crocodiles eat a variety of small prey that include fish, frogs, and insects. Adult crocodiles are known to eat sharks, deer, snakes, turtles, other reptiles, and even other crocodiles (Alderton, 2004). One possible explanation for the accumulation of coprolites and vertebrate remains in the Kingstree setting is that crocodiles can be responsible for the accumulation of microvertebrate material that has been defecated or regurgitated (Fisher, 1981).

Saltwater crocodiles have a high salt tolerance but commonly live in brackish and freshwater environments. They typically reside in streams and swamps but during dry seasons they relocate to estuaries (Alderton, 2004). During breeding, a female crocodile will build a nest in tidal rivers. The female crocodile stays with the nest during the incubation period, which is approximately 80-90 days. After the offspring have hatched, the female will watch over them for a few months (Alderton, 2004). This dedication to their young would produce a high concentration of feces in one area by both the female crocodile and the hatchlings. Estuaries were also used as nurseries for extant sharks due to the highly productive shallow waters and abundant food (Purdy, 1998).
Figure 15: Inside of the polished nodule. Diameter of the nodule is approximately 2 cm.
Figure 16: Thin section of coprolite at low magnification.

Figure 17: Thin section of coprolite at high magnification.
VI. CONCLUSION

This research has provided insight into the phosphatic bone-bed occurring along Clapp Creek, Williamsburg County, South Carolina. The results support the following conclusions:

1. The bone-bed present in Kingstree, South Carolina has vertebrate remains that range from the Late Cretaceous to the Early Quaternary. Among the remains, coprolites are the most abundant material occurring in this bone-bed. The concentration of this material is supported by the estuarine environment by tidal channels carrying sediment rich in vertebrate material that drops out of suspension creating bone-beds (Nichols, 2007). The transgressive processes that create estuaries would have removed the fine sediment allowing the vertebrate material to collect. Storm deposits would have also removed the fine sediment while leaving the larger bioclasts. This is a possible explanation for why there is such a large time span represented by this bone-bed.

2. The paleoenvironment of the Kingstree area was a coastal environment. More specifically, the bone-bed was probably deposited in an estuary with both fluvial and marine environments present. This environment would have supported both the marine and terrestrial fauna occurring at this locality. Stratigraphic evidence also suggests that the bone-bed is present in the Williamsburg Formation.

3. Modern day crocodiles feed and breed in estuarine environments. The majority of the coprolites occurring in the bone-bed were crocodilian in origin. An explanation for the high concentration of coprolites within the
bone-bed is that the area was an estuary where crocodiles fed and bred. The estuarine environment would also support the occurrences of both marine and terrestrial remains and would have also preserved feces from these organisms.
VII. FUTURE WORK

Future work could be conducted at the Kingstree locality to further investigate the coprolite chemistry. A mass spectrometric analysis of the coprolites and phosphate nodules could be used to identify the calcium and phosphate concentrations to further support the analysis of the coprolites. An analysis of the calcium and phosphate concentrations can lead to a better understanding of the diet of the faunal feeding niche.

Microvertebrate remains could be collected and analyzed to help support the theory that coprolites are primarily crocodilian in origin. The microvertebrate remains could justify that crocodiles were a source of the accumulation of the vertebrate remains occurring in the area. They could also be used to support the depositional environment of an estuary.

Another important future direction would be to map the lateral extent of the bone-bed. Future pilot cores could be taken systematically in a twenty mile radius to determine direction, length and depth of the bone-bed. It would be important to know where the bone-bed is located and how far it extends. This could indicate a large region of feeding and breeding grounds.

Investigation into the possible second bone-bed would also yield important information. This second bone-bed, located approximately one half of a meter below the first one, may contain the same type of material as the one that was investigated in this thesis. This would show a break or change in environment over a period of time. The second bone-bed could possibly contain different amounts or types of vertebrate material. This could indicate a different depositional environment than the first bone-bed.
Lastly, further investigation into the stratigraphy of the Kingstree area can be performed to support that the depositional environment was estuarine in nature. Several systematic cores could be taken to investigate the stratigraphy of the area and a correlation could possibly be made with the St. Stephen site, which is approximately sixteen miles away and is where a very detailed stratigraphic column was created during the building of a hydroelectric dam.
REFERENCES


Figure A.1: Pit on the banks of Clapp Creek, Kingstree, South Carolina where the bulk material from the bone-bed was taken.
Figure A.2: Close up of the pit that the bulk material was collected from. The bone-bed is located below the water line. The water line is indicated by the red line.
Figure A.3: Screening process showing the bulk material being sieved through the top 5 mm screen and the bottom 3 mm screen.
Figure A.4: Bone-bed material being picked out of the screens after the bulk material went through the screening process.
Appendix B.1: Sediment collected from the three different screen sizes. Sediment A came from the screen with the 5 mm openings. Sediment B came from the screen with 3 mm openings. Sediment C came from the screen with 1 mm openings.
Figure B.2: Sediment A from the screen with 5 mm openings. Sediment is sandy, coarse grained and poorly sorted.
Figure B.3: Sediment B from the screen with 3 mm openings. Sediment is a coarse sand and moderately sorted.
Figure B.4: Sediment C from the screen with 1 mm openings. Sediment is medium sand and well sorted.