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Paleoecological Analysis of the Clayton Formation (Paleocene) near Malvern, Arkansas

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by

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Abstract

The Clayton Formation is a section of the Midway Group immediately above the Cretaceous-Paleogene boundary that contains marine fossils from the Paleocene Epoch. The formation is composed of glauconitic sand, clay, marl, and limestone. Fossils within the formation commonly occur in clay or are concentrated in conglomeratic lag lenses. To assess paleoecology of the region during the Paleocene, the Clayton Formation was sampled for fossil content at a distinctly visible exposure along Interstate 30 near Malvern, Arkansas, that was excavated as part of a landslide mitigation project. Complimentary sites were sampled nearby along the Ouachita River and behind a shopping center. Dark clay sediment was collected from the Interstate 30 site and the bulk matrixes were analyzed for fossil content. The fossil assemblage, complemented by lithologic descriptions at the sites and context with Paleocene geologic history in the Gulf of Mexico basin, was used to infer the paleoecology of the Clayton Formation near Malvern, Arkansas. Fossils from small boney fish, sharks, rays, oysters, small crocodiles, gastropods, decapods, bryozoans, dinoflagellates, and foraminifera indicate a shallow marine setting. The predominance of clay with lag lenses created from tidal channels further hones an interpretation of a protected, mud flat system.

Key Words: Arkansas, Clayton Formation, marine fossils, mud flat, paleoecology

Dedication

Frank Heitmuller, George Phillips, Bryan Farrar, Cindy and Chris Hart

Thank you for your unwavering support and encouragement.

You are the perfect pep squad!

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Lastly, I would like to thank my parents, Cindy and Chris Hart, and my fiancé, Bryan Farrar. I am sure they are tired of hearing about my research but I am thankful for their enduring support.

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List of Abbreviations

Foram(s)	Foraminferan(s)
K-Pg	Cretaceous - Paleogene

Chapter 1: Introduction

Paleoecological research is important for reconstructing ancient environments. Examining fossil remains and the traces organisms left behind are key to interpreting how interactions, communities, and life cycles functioned in their associated natural environment. Those interpretations aid in the recreation of the past ecology, encompassing the type of environment and the affiliated relations of organisms to one another. The study of paleoecology can be used to understand current biodiversity. In many cases, a region's paleoecology may be unknown. During the Paleocene Epoch, Arkansas experienced many changes, with the Ozark and Ouachita Mountains undergoing cyclic erosions and upliftings while the Coastal Plain underwent the advancement and retreatment of the Gulf of Mexico. With so many changes taking place, the area's paleoecology redeveloped alongside. By studying exposures and an outcrop near Malvern, Arkansas, the paleoecology will be interpreted, providing a glimpse of the possible landscape that existed in a time of extensive transformation.

The fossil analysis will mainly consist of extraction, identification, and abundance comparisons to indicate the deposit's biodiversity. The measure of biodiversity can then be used to identify biological patterns indicative of particular ecological niches. The initial objective was to determine the samples' origins as either a marine or terrestrial deposit, which was quickly determined due to an overabundance of shark teeth visible upon the first glance into the raw matrix. Thus, the primary objective of this report is to resolve the marine environment's more precise niche and oceanic zone.

The project's fossil analysis will be complimented by sedimentary facies of the Clayton Formation, which is dominated by clay beds. The site's sediments and strata will support the paleo-ecological analysis. Additionally, two other sites near the excavated slide are similar and are exposed by a river and excavation behind a shopping center. These supplementary sites will be analyzed. Furthermore, the excavation site cannot be fully studied without taking into consideration its geologic age, which is the last major component to the paleoenvironment's description. The formation was formed in the Paleocene and previously published paleogeographic maps can be utilized to determine the advancement of the ancient ocean that once covered the lower half of the present North American continent.

Altogether, the site's stratigraphy, geologic history, and fossils will be used to create the overall image of its particular paleoenvironment in Malvern, Arkansas. The importance of this research project builds on paleontological knowledge of marine niches in specific oceanic zones. The lives of ancient marine fauna, and perhaps flora, could be further understood, in this area of Arkansas, and more understanding of the Paleocene could potentially be gathered from interpretations of the biodiversity and paleo environmental setting.

Purpose and Scope

The purpose of this project is to determine the paleoecology of an excavated site based on two fossiliferous bulk matrix samples from the I-30 Slide Remediation Project in Malvern, Arkansas, which was part of a landslide mitigation plan carried out by the Arkansas Highway and Transportation Department to reduce the slide's driving force where land was moving towards Interstate 30. The paleoenvironment can be determined largely through fossil analysis, but can also be notably aided by studying the lithology and stratigraphy of the Clayton Formation along with its age and that of the bulk matrix samples. The combination of the three geological analyses, with a specialization in paleontological analysis, will be used in this project's research.

Chapter 2: Literature Review

Study Area

Physiographic Provinces and Geological History

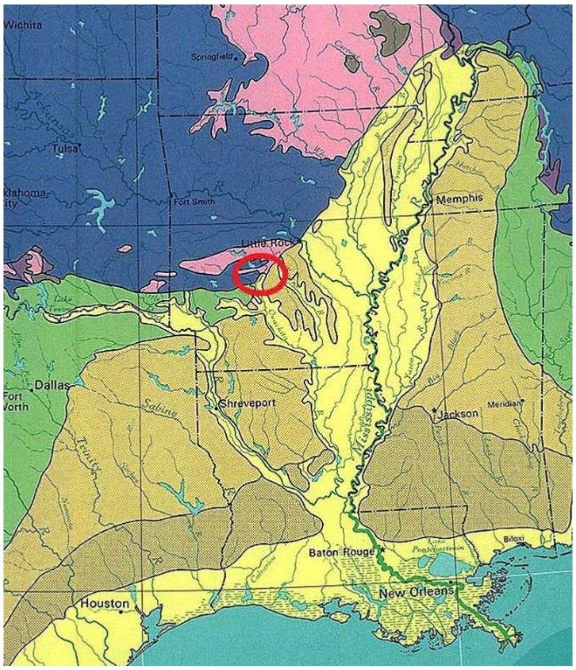

Figure 1: The red circle in the center of the map shows the I-30 slide site near Malvern, Arkansas, where it sits along the Fall Line between two physiographic provinces (Phillips et al., 2015).

The Malvern-Rockport sites in Arkansas occur along the Fall Line between the Ouachita Mountains and the Western Gulf Coastal Plain as shown in Figure 1. The Ouachita Mountains are Paleozoic age sedimentary rocks that are complexly faulted and folded. The sedimentary rocks were originally sediments deposited in a deep marine environment but the continental collision of the late Paleozoic pushed the region up. The highland is predominantly shales, limestones, sandstones, and dolostones, all of Paleozoic age and well-lithified. Due to streams and rivers, the valley floors have younger alluvium consisting of unconsolidated gravel, sands, and clays. The Ouachita Mountains now have east-west trend and the folding was so complex that even local sequences got overturned, whether the sequences were complete or not. The faulting is classified as compressional faulting and is common. Essentially, the Ouachita province is a large anticlinorum with Mississippian and Pennsylvanian sedimentary units expressed at the margins. Late Cambrian and Ordovician units are centered. This province is abruptly bounded to the east by the Gulf Coastal Plain and Mississippi Embayment province shown in figure 2 (Arkansas Geological Survey, 2015).

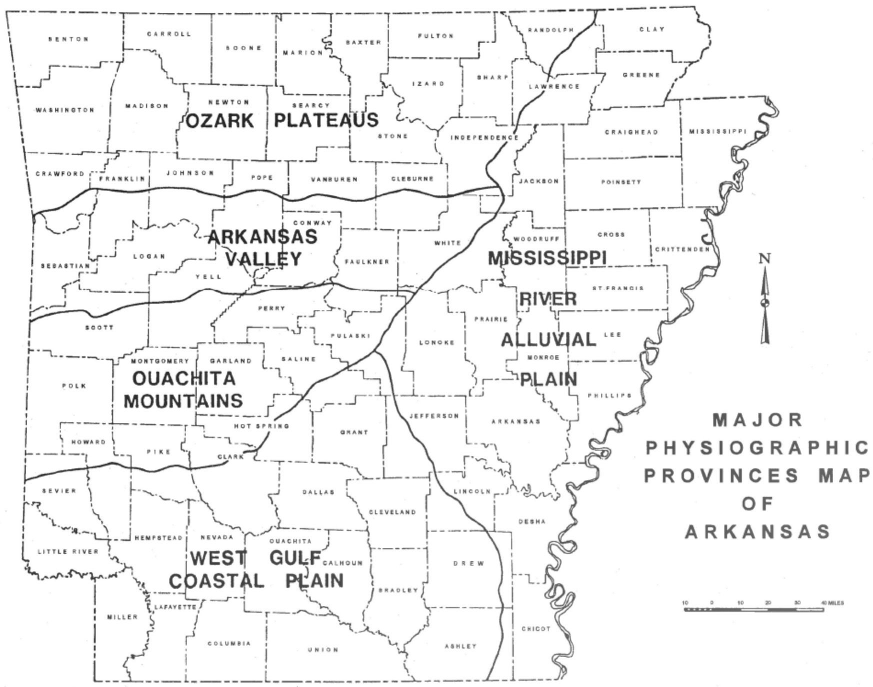

Figure 2: Major physiographic provinces of Arkansas showing the Ouachita Mountains contacting with the West Gulf Coastal Plain (Arkansas Geological Survey, 2015).

The Gulf Coastal Plain and Mississippi Embayment province is in the southern and eastern parts of Arkansas, which have underlying Cretaceous deposits with some Cretaceous age igneous intrusions being present too. The Cretaceous sedimentary deposed exposed in southwestern Arkansas also represent shallow marginal marine environments. Tertiary, coastal plain continental, and Quaternary deposits are in Southern Arkansas. The Tertiary deposits also represent marginal marine depositional environments, and the Quaternary deposits are a thin layer of terrace and alluvium. The thin layer sometimes exposes the Tertiary units underneath. Basically, the region has three terrace levels. The lowland region of Arkansas has sedimentary deposits of unconsolidated gravels, sands, and clays that are Quaternary in age. It also has Tertiary deposits of clay, silt, sand, limestone, and lignite that is poorly consolidated. Cretaceous marl, limestone, chalk, sand, and gravel are present too and are somewhat consolidated in the region. The Mississippi Embayment has a north-south erosional trend with the Quaternary loess is on top, and the Tertiary exposures can be seen along those margins. Conclusively, Ouachita

Mountain province is sharply bounded by the Gulf Coastal Plain and Mississippi Embayment province, which coheres to its steep slopes and occasionally has some missing Paleocene age deposits from the erosion taking place there (Arkansas Geological Survey, 2015).

Formations and Sites

The Clayton Formation is part of the Midway Group, which stretches from Texas to Georgia, inclusive of all states bordering the Mississippi Embayment. In Arkansas, the Midway Group's distribution is from central to southwestern Arkansas with an isolated outcrop in the northeastern part of the state, and its age correlates with the Paleocene Epoch. Sequences of the Midway Group that are exposed in Arkansas are representative of marginal marine depositional environments, which occur between continental depositional zones and open marine depositional zones. Marginal marine areas are modified by wave, tidal, and river processes. Generally, marginal marine areas include tidal flats, deltas, estuaries, lagoons, barrier islands, and beaches, which span a range from high-energy and current driven to quiescent, low-energy settings. The sites in this study do not appear to be estuarine as marine fish fossils have been identified and gar scales are notably absent (Harris, 1894, 1896).

The Midway Group, though not generally separated, is divided into two formations in Arkansas: the lower Clayton Formation and the upper Porters Creek Formation. The Clayton Formation is characterized by calcareous and sand lithologies including calcareous shale, arenacous limestones, glauconitic sandstone, conglomerates, and light to dark clay shales. The Porters Creek Formation is characterized by shale and silty shale. The thickness of the Midway Group outcrop ranges from about 40 meters to mere centimeters, though its downdip units are generally much thicker (McFarland, 2004). The fauna found in the Midway Group are marginal marine, containing all that has been previously mentioned as well as brachiopods and bryozoans (Harris, 1894, 1896).

Three key sites in the Malvern-Rockport area of Hot Springs County, Arkansas, were used for this research. The main excavated site is about 4.3 miles west of Malvern and about a mile south of the Highway 48 intersection close to Rockport along the west side of Interstate 30. To reduce the land sliding, approximately 400,000 m^3 of material was removed, resulting in a 440-meter-long exposure, as seen in Image 1, some of which is now covered with vegetation. The early Paleocene (Danian) Clayton Formation of the Midway Group was exposed.

Image 1: This is a picture taken of the I-30 slide excavation site that became the primary collection site for paleoecological research (Phillips et al., 2015)

The Clayton Formation is generally separated into four simple stratigraphic layers as seen in Figure 3. According to Stone and Sterling (1965), the Clayton Formation can be described as 55-foot-thick lenticular beds of calcareous, glauconitic sand, clay, marl, and limestone. From the bottom, it has a clayey basal sand that represents the K-Pg event of Cretaceous (Maastrichtian) age. Above the sand, is a large clay unit. It is predominantly calcareous marine clay, which makes up about 90% of the

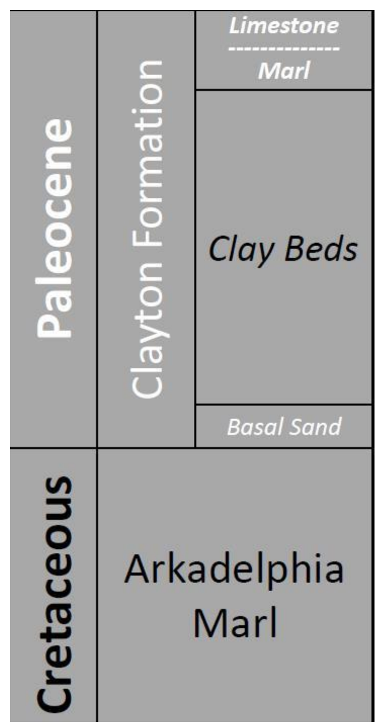

Figure 3: Stratigraphic column representation of the Clayton Formation (Phillips et al., 2015).

formation. The clay is overlain by a sandy calcareous marl and then a light gray calcarenite limestone.

At the primary site, the basal sand is not found. The site's lithology consists of about 22 meters of the Clayton Formation with roughly 15 meters of it being the clay beds. The mostly dark gray claystone contains numerous thin, lighter colored, fossiliferous lag deposit lenses, as shown in Image 2. The fossils collected included weathered shells, shark, ray, crocodile, and fish teeth, crab carapaces, otoliths, bivalves, gastropods, and foraminifera. The lenses are laden with rounded phosphate pebbles intermixed with the fossils. Because of this, the lag seams are densely compressed, fossiliferous conglomeratic lenses. Above the clay near the top of the exposure occurs silicified limestone boulders up to the size of small cars. A terrace deposit of novaculite and gravel lies above this, presumably from the overlying Wilcox Group.

Image 2: This picture shows one of the fossiliferous, conglomeratic, lag lenses present at the I-30 slide locality within the clay (Phillips et al., 2015).

The second site is located along the Ouachita River, which is about 200 meters east of the main collection site mentioned above. The river location is the only place of the three different sites that the Cretaceous – Paleogene boundary is visible. Importantly, the river locality is also the only one where sand from the K-Pg meteor impact is present, known as the event sand, and the Arkadelphia Formation, which underlies the Clayton Formation, are exposed. An outcrop on the upstream end of the river has a 9-meter continuous section of the Arkadelphia Formation and the basal Clayton Formation (Becker et al., 2006, 2010).

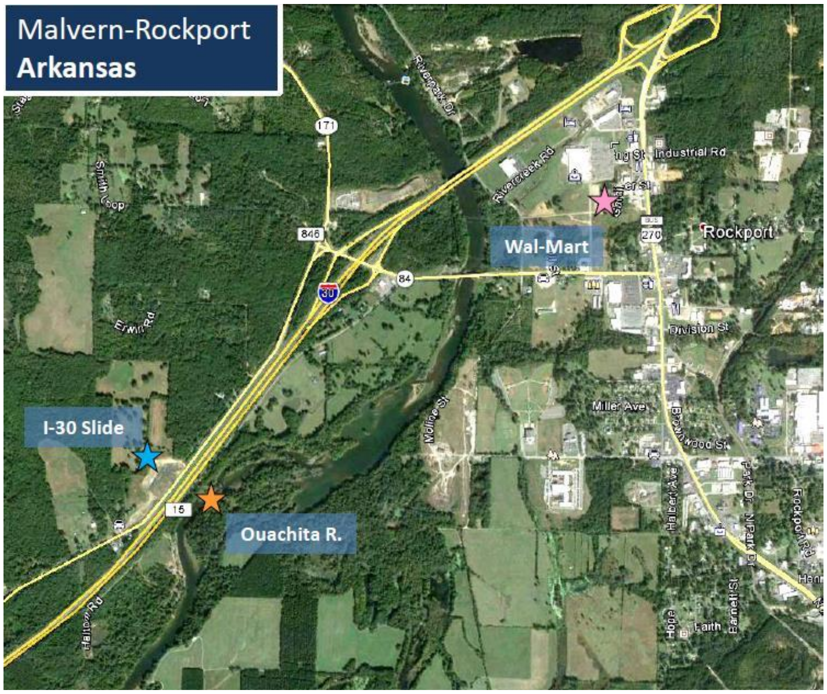

Figure 4: This aerial view shows the three fossil collection sites: the I-30 slide site, the Walmart site, and the Ouachita River site - which have exposures of the Clayton Formation near the Malvern-Rockport, Arkansas, area (Phillips et al., 2015).

The second site, which can be found in Figure 4, is located along the Ouachita River, about 200 meters east of the main collection site mentioned above. The river location is the only place of the three different sites that the K-Pg boundary is visible, where the Cretaceous age Arkadelphia Formation underlies the basal sand of the Paleocene age Clayton Formation. An outcrop on the upstream end of the river has a 9-meter continuous section of the Arkadelphia Formation and the basal Clayton Formation (Becker et al., 2006, 2010).

The Arkadelphia Formation is a marl of the Upper Cretaceous or Maastrichtian and includes 4 thin layers of intermixed limestone. Two of the layers are 7.5 meters below the K-Pg boundary and the other two are about 4 meters below the boundary. All the layers are approximately 5 to 15 centimeters thick. An abrupt contact with no evidence of bioturbation is the underlying Arkadelphia Marl meets the basal sand.

Importantly, the river locality is also the only one where sand from the Cretaceous - Paleogene meteor impact is present, known as the event sand. The approximately 0.6-meter-thick basal sand includes numerous glass spherules created from the K-Pg meteoric impact. Furthermore, the spherule bed is quartz-rich, unsorted, and contains rip up clasts of the Arkadelphia Marl in the lower 10 cm of the sand bed, which supports the interpretation of a tsunami event following the K-Pg meteor impact that brought backwash to the near shore sands. According to Carson Sloan (written commun., 2017) of the Arkansas Highway and Transportation Department, the spherules can be found throughout the sand, and as concentrated laminations. Spherule sand clasts observed in parts of the Clayton Formation in Missouri indicate that the sand layer is a twice-reworked bed. The initial meteor impact and tsunami would have caused a failed and scarped beach zone. Then, the resulting beach zone recovered, presumably from a series of transgressions as evidenced by foraminifera. Furthermore, Cretaceous fossils can be found at the second site in the reworked sand but are not found at the primary collection site. At the river, clay beds of the Clayton Formation are found about 4.5 meters above the top of the sand. Including the approximate 15 meters of clay beds at the collection site and the approximate 4.5 meters at the river, clay bed thickness is about 20 meters.

The third and final site, shown Image 3, is located behind the local Walmart in Malvern, Arkansas, that was exposed from construction. Only the upper 1.2 meters of the clay was exposed. The upper clay contained the intermittent fossiliferous lag

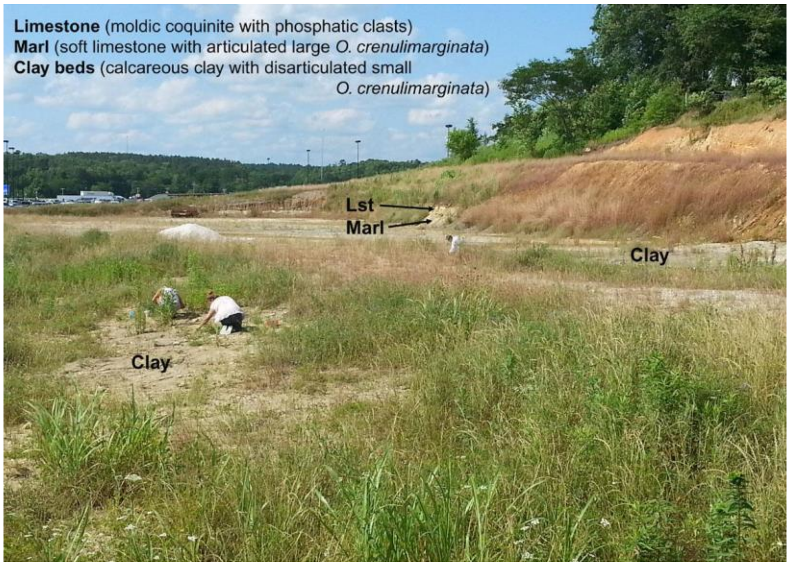

Image 3: This is a picture taken of the excavated site behind the Walmart shopping center in the Malvern-Rockport area of Arkansas, displaying the clay, marl, and limestone beds (Phillips et al., 2015).

deposit lenses observed at the main collection site. Disarticulated oyster bivalves were common. The overlying marl, with a thickness of about 1.6 meters, was soft and contained many oysters. The upper limestone of the Clayton Formation was visible and approximately a meter thick. The hard limestone was a sparry coquinite composed of many mollusks, vertebrate fish fragments, and phosphate clasts. Many of the shells were also pseudomorphs that had been dolomized and formed rudstones. The top of the limestone was vuggy and infilled with a green clay. The cohesive green clay found is interpreted to have come from the upper Porter Creek Formation; however, at the primary collection site, the Porters Creek Formation is absent from erosion.

Chapter 3: Methods and Materials

The study sites were assessed for lithology and collected fossils. A Jacob's staff was used for lithology thickness, and a hand lens aided primary determination of the lithology types. At the main collection site, a shovel was used to scoop fossiliferous materials into water-tight field bags, which were labeled with a unique field identification number. Unique, cinder block-sized concretions with oyster growths on all sides were hand collected. Larger fossils, loose and on the surface, were picked up by hand and placed in labeled bags. Fossils were hand-picked in this manner at the Ouachita River and Walmart sites, instead of bulk matrix samples being collected. At the Ouachita River locality, additional limestone boulders embedded with fossils were collected. All fossils were transported to labs at the Mississippi Museum of Natural Science and the Department of Geology and Geography at The University of Southern Mississippi.

The fossiliferous sediment was screen washed, because some of the matrix clumps were hard and consolidated. A large, standing metal bin with a draining well in the corner, was filled with water and a large sifting screen was inspected to ensure that no sediments from previous projects remained. A smaller plastic bin was subsequently submerged in the water. The fossiliferous bulk matrixes were either carefully emptied into a water-filled, multi-gallon bucket for a pre-soak or were directly emptied into the sifting screen that was placed above the submerged plastic bin. The harder consolidated matrixes were pre-soaked to disaggregate their contents.

After the matrix sediment was poured onto the metal screen, it was gently submerged in the water above the plastic bin and lightly shaken. Any floating material was collected. Once brought back up to the surface, a gentle stream of water from a hose was applied to the sediment filled screen. The material was gently sifted and agitated to unconsolidated it. The purpose of the metal bin was merely to hold enough water for the wet screening to take place and the submerged plastic bin served to capture fine matrix material that sifted through the screen.

The above process was repeated several times until the matrix material was sufficiently unconsolidated. Occasionally, the hose would be removed to collect obvious loose fossils, which were placed into separate containers. Upon completion, the screen was removed and placed to dry at an angle small enough so that no material fell out. Additionally, fine sediment collected in the plastic bin would be collected or rinsed out, depending on the likelihood of fossils being present. If hard, consolidated matrix chunks remained, they were placed into a water-filled, multi-gallon bucket with dish soap for several days to break up the clods. The metal bin was drained and rinsed to complete the wet screening/sifting process.

Image 4: This is a picture taken of one of the bulk matrix samples after being sifted and dried and before being picked through (Hart, 2017)

Image 5: All the fossils picked from the bulk matrix were placed in individual identification boxes (Hart, 2017).

After all matrix material was dry, sediments were poured into plastic containers, shown in Image 4, and the screen was picked through using toothpicks to ensure no material remained. Medium to large sized fossil specimens, visible with the naked eye, were picked out with tweezers or forceps and were carefully placed into a labeled identification box. Collection of smaller fossil specimens required the aid of a microscope. A small scoop was used to transfer the bulk matrix material to the microscope. Fossils were gently picked through using sharp, curved-tip forceps, and were placed in separate identification boxes, shown in Image 5. For example, shark teeth were placed in one box whereas fish spines were placed in a separate box. All fossil boxes and material containers were covered to prevent contamination from dust or any other sediment. No acid was applied to ensure fossil preservation. Any fossils that included clingy matrix and were needed for further investigation were re-soaked and/or a dental pick was used for cleaning and separating of the unwanted matrix as seen in Image 6.

Image 6: Picking clingy sediment off a fossil shark tooth with a dental pick, with the aid of the microscope (Hart, 2017).

Non-fossils, except for phosphate pebbles and spherules, were discarded into a zip lock bag. The process described above was continued until the entire bulk matrix container was empty. This was done for two separately collected bulk matrix samples from the slide mitigation site: Sample A- MMNS Reg. No. 10251.2, which weighed 3.24 kg, and Sample B - MMNS Reg. No. 10262.0, which weighed 3.70 kg. Finally, fossils were identified and relative abundances were compared to interpret the past paleoenvironment from the fossil assemblage.

Chapter 4: Results

All the fossils collected at all three sites were marine based. No terrestrial organisms, other than the partially aquatic and land-living crocodile, were found. Furthermore, all "flora" collected were poorly preserved dinoflagellates from the clay beds, which presently remain unidentified. Starting at the base of the Clayton Formation, marine based Cretaceous fossils are only observed in the spherule sand at the Ouachita River locality due to re-working and occurrence in rip-ups.

The primary collection site includes an oyster, *Ostrea crenulimarginata*, which is quite common in the clay beds where they are small. This is also seen in the upper meter or so of the clay exposed at the Walmart site. Furthermore, the clay beds at the slide mitigation locality have *O. crenuimarginata* in two forms: encrusting and non-encrusting. The non-encrusting oyster is cotyloid in form and occurs in the lower facies than those observed at the Walmart site. The same is true for the encrusting oyster that was observed congregated on clay slabs and/or concretions. The concretions include oyster growth on all sides, indicating that currents were strong enough to roll over these large, heavy concretions so that a new growth colony of oysters were initiated on a fresh surface of the concretion. Nuculanid bivalves, many of them identified as *Venericardia* and *Jupiteria*, were also collected in lag lenses in the clay beds (Phillips et al., 2015). The *Jupiteria* mud clam is seen in Image 7.

Image 7: Jupiteria mud clams are visible clustered throughout a lag lens in the clay at the I-30 slide locality (Phillips et al., 2015).

Most of the fossils in the Clayton Formation occur in the clay beds with high concentrations in the lenses. Among the findings in the clay bulk matrix from the I-30 site include vertebrate and invertebrate skeletal constituents. Common vertebrate fossils were shark and ray teeth and vertebra, including those belonging to the selachians of the *Brachycarcharias* and *Rhinoptera* genera, respectively, which were identified by the state paleontologist, George Phillips, from the Mississippi Museum of Natural Science. The poorly preserved dinoflagellates in the clay beds were analyzed by Nina Baghai-Riding from Delta State University, who found an assortment of dinoflagellates in the bulk clay matrix. Additionally, in the overlying marl, *Ostrea crenulimarginata* is much larger in form, reaching the size of a splayed hand. With the decrease in sediment deposition and turbidity, the oyster is able to live longer, thus growing larger.

Teeth, otoliths, and bone fragments of various bony fish species were collected. The fish teeth are generally black and rounded in a circular or bullet shape. Otoliths, visible in Image 8, are rounded calcium carbonate structures from the inner ears of fish, which are used as balance regulators, sound, vibration, and directional indicators. The otoliths were generally orange to tan in color and were much less common than the fish teeth or bone fragments. The fish bone fragments were highly variable, with many small fragments unable to be precisely identified due to the lack of bone structure preserved; however,

Image 8: Tan-orange otoliths are scattered throughout a clay matrix from the I-30 slide locality (Phillips et al., 2015).

some fish vertebrae and spines were wholly intact or at least identifiable from individual fragments.

The less commonly observed vertebrate based fossils in the clay were crocodile teeth and coprolites. The crocodile teeth were less abundant than the coprolites and uncommon in general, which is not entirely unexpected as crocodiles are known to be seafaring in the search for food but do not live in the ocean. The large coprolites, also uncommon, could have derived from sharks or crocodiles. The more common coprolites were small, thin cylinders ranging from 1 to 3 millimeters in length, and could have belonged to fish decapods (Phillips, written commun., 2017)

Regarding macroinvertebrates, many shell fragments from *Turritella* gastropods, articulated and disarticulated bivalves, and crap carapaces and appendages were collected from the clay beds. Most of the gastropods were steinkerns, which formed when mud or other sediment entered the hollow cavity of the shell and cemented. Later, the shell fell apart and the cast remained, leaving phosphatic steinkerns that either remained whole or broke into fragments. The bivalve shells were either calcitic or aragonitic. In general, the smaller specimens remained intact with complete valves but larger valve specimens were fragmental. Decapod fragments are primarily from *Costacopluma*, or small mud crabs. Additionally, benthic forams, bryozoans, and brachiopods were present in the clay beds.

Phosphate pebbles were mixed throughout and varied from rounded discoids, ellipsoids, and sub-cylinders. They ranged in size from a fraction of a millimeter to about 28 millimeters in diameter. The average diameter was about 5 millimeters. The small pebbles were 1 to 3 mm in size and were sub-cylindrical, which might be either phosphate pebbles or coprolites (Phillips, written commun., 2017).

Many of the conglomeratic fossiliferous layers, which diminish laterally, are comprised of mollusk shells, bone fragments, and phosphatic pebbles. The clasts are either flattened or rounded, and the shark teeth are commonly eroded due to smoothing at their edge. Despite roundness of the amorphous pebbles, reworking of the clasts was nevertheless apparent as indicated from the presence of aragonitic bivalves. As initially noted by George Phillips, the valves must have been in good condition before burial.

At the Walmart site, the marl included fragments of a heart urchin known as *Schizaster alabamensis*, which is a burrowing echinoderm of the order Spatangoida, which was also identified by paleontologist, George Phillips. Above the marl, high mollusk diversity in the upper coquinite included many dolomized pseudomorph shells. The shelly composition also includes echinoid fragments from two unidentified regular urchins and many phosphatic clasts included vertebrate marine fragments. The tables shown below provide some of the organismal data that has been mentioned in this chapter.

Fossil Types	Raw Counts of Collected Fossils	Classification
Fish Teeth and Spines	94 Teeth & 16 Spines	Vertebrate
Selachian Teeth and Vertebra	622 Teeth & 240 Vertebra	Vertebrate
Coprolites	411	Vertebrate
Crocodile Teeth	NA (not in matrix)	Vertebrate
Bivalves	723	Invertebrate
Gastropods	1106	Invertebrate
Decapods	NA (fragmented)	Invertebrate
Foramineferans	NA (poorly perserved)	Invertebrate
Dinoflagellates	NA (poorly perserved)	Invertebrate
Brachiopods	NA (fragmented)	Invertebrate
Bryozoans	NA (fragmented)	Invertebrate
Otoliths	19	Vertebrate

Table 1: Raw counts of collected fossil specimens from both I-30 bulk matrix samples

Table 1 displays the raw counts of the fossils collected from both I-30 slide matrix samples. Some of the samples were too fragmented or too poorly preserved for counting.

Abundance Ranking	
Gastropods	1
Selachian	2
Bivalves	3
Fish	4
Coprolites	5
Decapods	6
Dinoflagellates	7
Foramineferans	8
Otoliths	9
Bryozons	10
Brachiopods	11
Crocodile	12

Table 2: This is an abundance ranking of the collected fossil specimens, ranging from 1 (most common) to 12 (least common).

Diversity Ratios	
Ray Teeth Vs. Shark Teeth	3:1
Gastropods Vs. Bivalves	1.5:1
Ray Teeth Triangular Vs. Flat	36:1
Oyster Vs. Nuculanid	41.5:1

Table 3: Diversity ratios of particular organisms were calculated based on the fossils collected from both bulk matrix samples from the I-30 site.

Table 2, which is an estimated biodiversity abundance ranking, is not completely based on the counts observed in Table 1 because the fragmented and poorly preserved specimens were taken into consideration. For example, many sundry fish fragments, which were not counted because there was no way to differentiate between individual fishes, were still recognized as making up a large portion of the fossils collected. As for Table 3, the diversity ratios of particular organism were calculated based only on the fossils collected. They depict there being more rays to sharks, more gastropods to bivalves, and more oysters to mud clams in the paleoenvironment.

Chapter 5: Discussion

The fossil organisms collected at the three study sites were marine based, but their exact ecological niches are largely inferred from their living descendants present today, or from similar modern organisms. First, shark teeth, like the one seen in Image 9, belonging to the genus *Brachycarcharias* were very common, which are closely related to sand tiger sharks that commonly inhabit estuaries, sandy nearshore environments, and shelves in tropical and subtropical regions to a maximum depth of approximately 198 meters in modern waters (Cappetta and Nolf, 2005). Also, "Several odontaspidids, a ginglymostomatid, and two triakids constitute the commonest sharks" (Phillips et al., 2015). The fossil ray teeth belong to the genus *Rhinoptera*, or cownose rays of the eagle ray family, which are found in brackish and marine waters up to depths of about 21 meters. Some urchin fragments were collected, which have an expansive oceanic range and temperature tolerance. The observed burrowing heart urchin, *Schizaster alabamensis*, is a deposit feeder found on coastlines and in shallow subtidal zones. As for the abundance of fish, none of the various bone fragments, teeth, or otoliths belong to large fish, and as is general in today's oceans, smaller fish reside nearer to the shore.

Image 9: Shark teeth were quite common in the matrix samples from the I-30 slide locality (Phillips et al., 2015).

Many crab carapaces were interpreted as belonging to the genera *Costacopluma*, which is the modern equivalent to mud crabs (Phillips et al., 2015). Mud crabs are known to inhabit estuaries, mangroves, and tidal flats where they scavenge for food. The nocturnal organisms commonly migrate to intertidal zones to scavenge for food during high tide and retreat back to the subtidal zone at low tides. A commonly identified bivalve was the oyster *Ostrea crenulimarginata*, which was a stationary suspension feeder known to inhabit coastal zones, shallow sub-tidal environments, and marine and carbonate zones (Phillips et al., 2015). Many gastropod fragments were identified, which are sea snail mollusks. These marine mollusks are quite common in mud flats. Brachiopod shells, though not as commonly identified at this site, indicate zones absent of strong currents and waves on either slopes and rocky overhangs along the ocean floor or the continental shelf. Also less commonly identified were bryozoans, which filter food particles in shallow tropical waters. The general inhabited depths are the less than 91 meters.

The last three fossil types identified, crocodile teeth, foramaniferans, and dinoflagellates, were also rarely collected from the matrix. Besides rivers, crocodiles can commonly inhabit brackish settings like estuaries and other coastal environments. Occasionally, small crocodiles, most often juveniles, cannot compete for food and/or territory against their larger adult competitors that have claimed the upper streams and rivers, forcing the smaller crocodiles into brackish environments such as deltas, lagoons, swamps, and estuaries. Although large crocodiles can thrive in those environments, they hunt for larger prey farther out in the ocean, leaving the smaller prey to the smaller crocodiles closer to shore. Consequently, large crocodile teeth are often absent in the near shore settings.

As for the few specimens of foraminferans, which are single-celled protists with shells and can either be benthic or planktonic, they are too weathered to make an accurately identify at this point and will need further study. Dinoflagellates are eukaryotic protists with flagella and most are photosynthetic and marine dwelling. Though generally useful as environmental indicators, the assemblage collected is too weathered for proper identification and have been sent to Nina Baghai-Riding of Delta State University for determination.

From all fossil organisms collected and described at the three sites, the paleoecology of the Paleocene near Malvern, Arkansas, is interpreted as a tidally influenced mud flat that is rich in vertebrate and invertebrate life utilizing the brackish marginal marine environment. Due to the muddy composition of the clay beds, it is also interpreted that a river discharged to the ocean nearby and sediments were dispersed through longshore currents, but the site is not an actual delta, nor is it a typical estuary. The Midway group of the Paleocene is known to have recognizable fluvial and deltaic complexes around the rim of the Gulf of Mexico, which were overlain by early late Paleocene and early Eocene strand-plain-barrier-bar systems belonging to the Wilcox Formation (Salvador, 1991). Thus, a nearby river discharging muddy sediment is not unexpected.

Furthermore, the mud flat was protected or sheltered from direct wave action, possibly due to a buildup of sand dropped by the river that formed a bar or spit, creating a bay. Without direct wave action, the area was of lower energy. Low-energy environments typically have gentle ramps and an absence of barrier reefs and shoals (Salvador, 1991). Although the sea would have been warm and shallow at the study sites, they lacked reef material and there were no sandy ridges or bars. The absence of gar specimens in the matrix is also indicative that the area was not a typical estuary or delta, which they would have inhabited and there is an absence of gastropods particular to these environments (Phillips, written commun., 2017).

The study sites would have been part of the intertidal zone and would have been very shallow. According to Phillip Heckel (1972), “Shallow marine sedimentary environments correspond to the sub littoral benthonic zone that floors the coastal shelf off major land masses”.

The zone lies beneath neritic water, extending from the lowest tide line to the edge of the continental shelf. The shelf's edge is commonly recognized to be at 183 meters in depth. The sublittoral zone also has the photic zone because sunlight always reaches the bottom (Heckel, 1972).

Interpretively, the environment was rich in food with its numerous small, bony fish, attracting predators like sand tiger sharks and small crocodiles. Filter feeders and detritivores were thriving here. Incoming tides would cover the mud flat, bringing with them extra food and nutrients, and the retreating tide would expose the mud flats. This repetitive action formed the fossiliferous and conglomeratic lens layers seen in the clay beds via tidal channel beds. Fossiliferous conglomerates were made by low tides, and covered up again by the hightides, causing the overlying muddy clay bed and keeping with the alternating cycle observed at the primary collection site. No flaser, wavy, or lenticular bedding, which is usually indicative of tidal current influences within mud flats, was observed due to the structures being destroyed by sediment compaction with the muddy clay. It is also conclusive from the oyster coated concretions that the channel currents must have been quite strong to roll over the large concretions and allow for new growth to begin on the other side of the concretion. Many concretions were covered on all sides, having been rolled around frequently. At the lowest part of the intertidal zone, bioturbation was observed by many trace fossils including burrowed tubes or tunnels, many 2 to 3 inches thick.

The paleoenvironment interpretation of the Clayton Formation near Malvern, Arkansas, has been observed before in an older formation in the east-central Mexico region. For the Clayton Formation, there was a drop in sea level and a basinward retreat of the Gulf of Mexico near the end of the Cretaceous, resulting in a shallow sea at the beginning of the Paleocene. As the amount of terrigenous coarse clastics were dwindling in supply during the early Paleocene, a transgressive sequence of mostly shale can be observed over most of the northern parts of the Gulf of Mexico basin. The transgressive sequence of shale is the Midway Group and the deposition did not have related grow faulting. The closer to the Mississippi Embayment and southern Alabama, the sander the lower Paleocene section becomes, whereas the Florida panhandle has carbonates at the base of the lower Paleocene, which is the Clayton Formation (Salvador, 1991).

The similar paleoenvironment to the Clayton Formation in Mexico occurred at the eastern part of the corridor that connected the Gulf of Mexico basin and the Pacific Ocean experienced continuous marine deopostion until the middle to late Jurassic. The late Jurassic transgression advanced over shallow ramps and shelves along the early Gulf of Mexico and terrigenous sediments declined in supply. Mid-Oxfordian mudstones and limestones of the lower Smackover and Zuloaga Formations covered the basal sandstones and lag deposits. "They all reflect deposition under low-energy, severely restricted conditions—intertidal mud flats or coastal areas where the development of algal mats alternated with deposition of carbonate muds" (Salvador, 1991).

In summary, there is a high degree of certainty of the paleoenvironment represented by the collected fossils near Malvern, Arkansas. An entire brackish ecosystem thrived there, with organisms along the food chain having easy access to food including sustenance from the nutrient rich sediments and from filtration of the water. This ancient mud flat flourished for various species during the earliest epoch of the Cenozoic.

Chapter 6: Conclusion

In conclusion, the study sites in the Clayton Formation near Malvern, Arkansas represents a mud flat during the early Paleocene Epoch (65.5 - 61.7 Ma). The mud flat was very shallow as interpreted from fossils in clay lenses of the Clayton Formation. There were no large sharks of the *Otodus* genus, and only small sharks, *Brachycarcharias*, commonplace in sheltered shallow waters were present. Other than small fish-eating crocodile genera, there were no large bony fish predators, which is expected of marginal marine habitats. The shallow water habitat was also rich in macroinvertebrates, including *Costacopluma*, or mud flat crabs. Nuculanid bivalves, or small, saltwater clams typical of shallow waters were also identified. Oysters, *Ostrea crenulimarginata*, attaching onto lithified mud also constitutes as shallow, tidal habitat indicators. In addition to biotic paleoenvironmental constituents, sedimentary structures aid in the same interpretation. Laminated clay intermixed with fossiliferous lenses containing shallow water organisms affirms there were tidal creeks in the mud flat that remained in place long enough for oysters to grow on the lithified mud concretions and clay slabs. The Paleocene environment near Malvern, Arkansas, was an ecologically rich mud flat.

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