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CHONDRICHTHYANS FROM THE TALLAHATTA–LISBON FORMATION CONTACT (MIDDLE EOCENE), SILAS, CHOCTAW COUNTY, ALABAMA

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ABSTRACT

In Silas, Alabama, a disconformity with an overlaying lag deposit separates the middle Eocene (Lutetian) Tallahatta and Lisbon Formations along Turkey Creek. This lag deposit consists of blankets and lenses of macrofossil residuum that preserves an unreported assemblage of chondrichthyans represented by at least 13 species. This chondrichthyan assemblage is similar to other contemporaneous nearshore faunas found across North America and elsewhere globally and includes: *Striatolamia acrota* Agassiz, 1843; *Brachycarcharias lerichei* Casier, 1946; *Carcharodon auriculatus* Blainville, 1818; *Otodus obliquus* Agassiz, 1843; *Abdounia recticona* (Winkler, 1873); *Abdounia enniskilleni* (White, 1956); *Galeocerdo eaglesomei* (White, 1955); *Physogaleus secundus* (Winkler, 1874); *Scyliorhinus* sp.; *Rhizoprionodon* sp.; *Pristis* sp.; cf. *Aetomylaeus* sp.; and *Rhinoptera* sp. Additional macrofossils with nearshore affinities occurring in the Turkey Creek lag include bones and teeth from fish, reptiles, and marine mammals as well as mollusc shells. The accumulation and concentration of macrofossils in the Turkey Creek lag are the result of third order eustatic sea level fluctuation prior to late Eocene climatic cooling and global sea level regression associated with the formation of the continental ice sheet on Antarctica. The Turkey Creek assemblage supports prior studies that document evolutionary trends throughout the Cenozoic in which carcharhiniforms become the dominant order of chondrichthyans in the modern oceans.

INTRODUCTION

For over one hundred and fifty years, numerous published reports indicate that the Alabama Coastal Plain Province preserves an abundant and diverse record of fossil chondrichthyans (Morton, 1834; Tuomey, 1858; Leriche, 1942; White, 1956; Thurmond and Jones, 1981; Westgate, 2001). The majority of this record is derived from rivers and associated creeks in the Alabama Coastal Plain such as the Tombigbee, Black Warrior and Conecuh that erode through nearshore, unconsolidated sediments and provide outcrop exposures. In Alabama, lag deposits that drape contacts between glauconitic clay and arenaceous clay sediments occasionally contain chondrichthyan assemblages (Clayton et al., 2013). Such lag deposits reflect third-order sea level events where fossil accumulations are time-averaged and reflect a few million years of diversity (Case and Schwimmer, 1988; Eaton et al., 1989; Ward and Wiest, 1990; Manning and Dockery, 1992; Rogers and Kidwell, 2000; Burris, 2001; Becker et al., 2006).

Chondrichthyan assemblages from the Alabama Coastal Plain are also noteworthy because sediments range from the late Cretaceous to the Miocene and record evolutionary changes in chondrichthyans that traverse the Cretaceous–Paleogene and Eocene–Oligocene global extinction events (Manning, 2003; Raymond et al., 1988). In general, Alabama Coastal Plain chondrichthyan assemblages indicate carcharhiniforms diversified while lamniforms were significantly reduced as earth’s climate transitioned from greenhouse to ice house conditions during the early and middle Cenozoic. This report describes a previously unreported chondrichthyan assemblage from the middle Eocene (Lutetian), Tallahatta–Lisbon Formation contact in Silas, Alabama along Turkey Creek. The Turkey Creek assemblage is dominated by nearshore chondrichthyans concentrated into a lag deposit reflecting a third order sea level fluctuation event. The Turkey Creek chondrichthyan assemblage is similar to other contemporaneous chondrichthyan assemblages occurring in the Atlantic and Gulf Coastal Plains. Comparison of these regional assemblages provides an opportunity to assess general trends in chondrichthyan evolution leading up to the Eocene–Oligocene mass-extinction event.

Institutional Abbreviations—ANSP, Academy of Natural Sciences, Philadelphia.

GEOLOGY OF TURKEY CREEK, CHOCTAW COUNTY, SOUTHWESTERN ALABAMA

Alabama's Cenozoic formations crop out in a belt running east-west through the southern portion of the state (Fig. 1). This outcrop belt curves northward along the state's southwestern border and reflects marine inundation of topographically low lying areas in the Mississippi River Valley Region during the Late Cretaceous and Cenozoic (Toulmin and La Moreaux, 1963; Ivany, 1998; Manning, 2003; Savrda et al., 2005; 2010). Eocene sediments in Alabama are represented by the upper Wilcox, Claiborne and Jackson Groups. These groups are divided from oldest to youngest into the Hatchetigbee, Tallahatta and Lisbon, Yazoo Clay, Crystal River and Moody's Branch Formations as well as numerous members, units and beds. Additional details of state-wide, Alabama Coastal Plain Eocene sedimentology, sequence stratigraphy, and regional correlation with neighboring states are available in Bybell and Gibson, (1985); Szabo et al. (1988); Raymond et al. (1988), Manicini and Tew (1994), and Ivany (1998).

Choctaw County, Alabama is located within the southwestern-most Eocene outcrop belt in the state, and is dissected by numerous creeks that flow to the east into the Tombigbee River. The locality described in this report occurs along Turkey Creek, in Silas, Alabama west of County Road 17. Along this section of Turkey Creek, downcutting and headward erosion has exposed outcrops of the upper Tallahatta and lower Lisbon Formations. These two formations are separated along Turkey Creek by a prominent disconformity exposed along the southern bank and near creek level. In the study area, the upper Tallahatta Formation consists primarily of greenish-gray, siliceous, sandy claystone while the lower part of the Lisbon Formation consists of glauconitic, coarse sands with interbedded, silty and glauconitic claystone. The upper Tallahatta Formation achieves a maximum thickness along this section of Turkey Creek of approximately two meters. The maximum thickness of the lower part of the Lisbon Formation along Turkey Creek is about 20 meters however, the thickness of this unit is highly variable due to extensive physical erosion by numerous smaller tributaries. The two formations are separated by a discontinuous, basal lag deposit that consists of blankets and lenses of macrofossil residuum. The macrofossil lag contains original shell material and steinkerns belonging to oysters, pelecypods, and gastropods in addition to bones and teeth from chondrichthyans, fish, reptiles, and marine mammals. Maximum thickness of the Turkey Creek lag is approximately 10-20 centimeters. The contact between the Tallahatta and Lisbon Formation as studied by Mancini and Tew (1994) in Alabama and Mississippi occurs at the sequence boundary between TAGC 3.1 and TAGC 3.2 sea level cycles (Haq et al., 1988; Clayton et al., 2013). We interpret the prominent disconformity between the upper Tallahatta and lower part of the Lisbon Formation, as well as the chondrichthyan lag, along Turkey Creek to represent the boundary between these two sea level cycles as seen in outcrop.

Multiple sources including: planktonic foraminifera (Bandy, 1949); mollusks (Toulmin, 1977); calcareous nannofossil zonation (Siesser, 1983); core hole data (Bybell and Gibson, 1985); geologic mapping (Szabo et al., 1988), and sequence stratigraphy (Mancini and Tew, 1994; Ivany, 1998) indicated that the age of the upper Tallahatta and lower part of the Lisbon Formations belongs to the lower part of the middle Eocene and Lutetian Stage Boundary. This is also consistent with the known ages and stratigraphic occurrences of chondrichthyans recovered from the Turkey Creek field locality and described in this report. The Gosport Sand, which in southwestern Alabama is also known to contain macrofossils including chondrichthyan teeth, occurs in the uppermost Lisbon Formation and has been documented as Bartonian in age by Thurmond and Jones (1981), Mancini and Tew (1994), CoBabe and Allmon (1994), and other sources cited above. Outcrop exposures of the Gosport Sand were not identified along the westernmost extension of Turkey Creek during this study.

FIELD AND LABORATORY METHODS

Chondrichthyan fossils described in this report were recovered over three field seasons directly from the lag that separates the upper Tallahatta and lower part of the Lisbon Formations along Turkey Creek. Areas in Turkey Creek, immediately adjacent to the Tallahatta–Lisbon Formation contact, were also collected and represent accumulations of chondrichthyan fossils eroded directly out of the lag and hydrodynamically concentrated nearby in deeper pools. Outcrop sediment and creek accumulations were sieved on site with screens ranging from 10.0-5.0 mm.

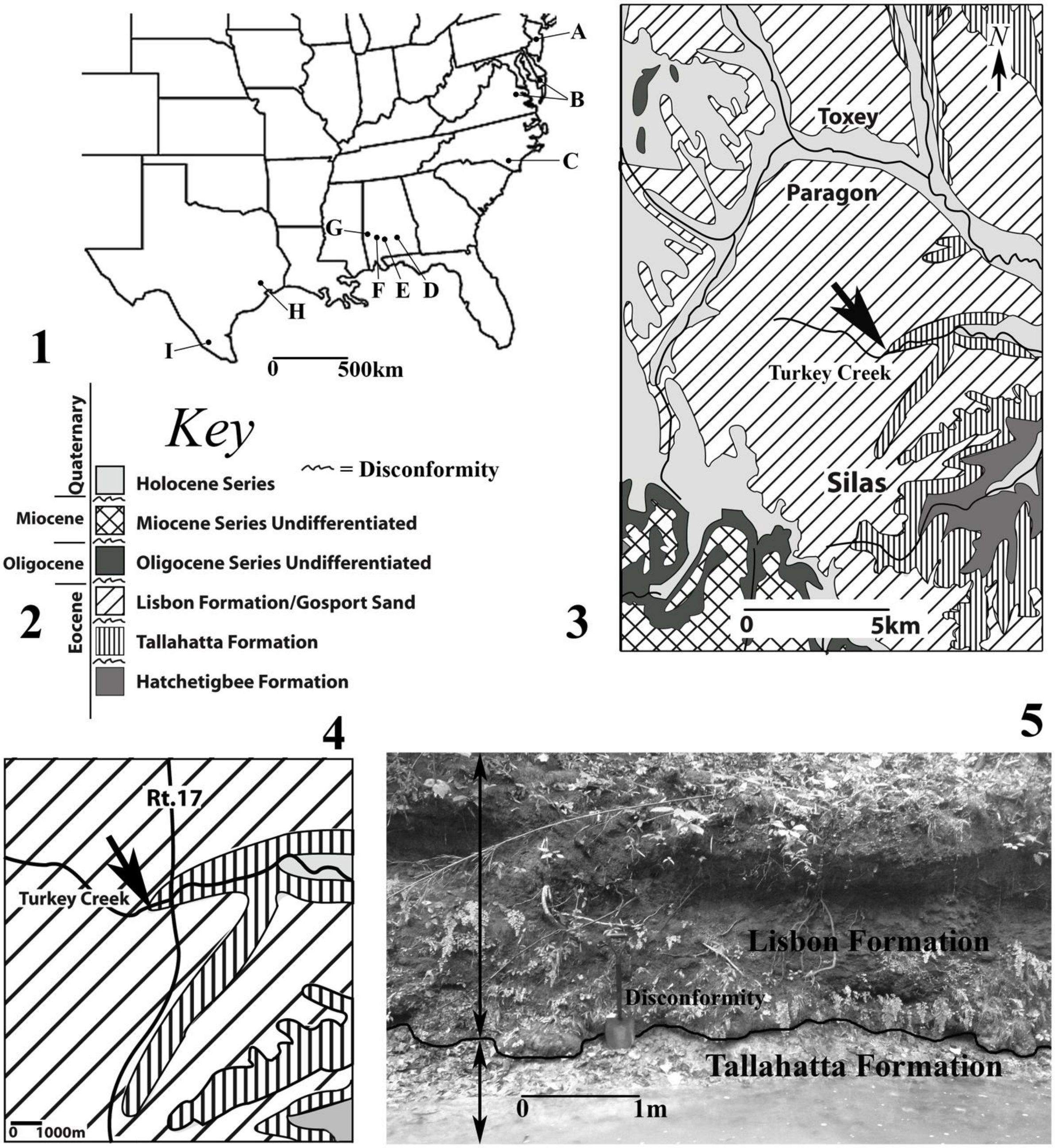

FIGURE 1. Location maps of the Turkey Creek field locality and Tallahatta – Lisbon Formation Contact (middle Eocene), Choctaw County, Silas, Alabama. 1–Middle Eocene Atlantic and Gulf Coastal Plain chondrichthyan localities discussed in this study: A, New Jersey, (Maisch et al., 2013); B, Maryland and Virginia, (Ward and Wiest, 1990; Kent, 1994); C, North Carolina, (Case and Borodin, 2000a); D, southcentral Alabama (Clayton et al., 2013); E, southwestern Alabama (White, 1956); F, southwestern Alabama (Westgate , 2001); G, southwestern Alabama, (this study); H, eastern Texas (Breard and Stringer, 1999); I, western Texas, (Westgate, 1989; 2008). 2 and 3–Stratigraphic column and geologic map of Choctaw County (Eocene) in the southwestern Alabama study area (modified from Osborne et al., 1989). 4–Detailed Geologic Map of the Lisbon–Tallahatta Formation contact along Turkey Creek discussed in text. 5–Outcrop exposure of the lower Tallahatta and upper Lisbon Formations along Turkey Creek, Choctaw County, Silas, Alabama. Note prominent disconformity directly above creek level and 1 meter shovel. Location of the Tallahatta – Lisbon Formation contact (this study) indicated by bold arrows.

Approximately 150 kg of sediment was recovered for laboratory sieve analysis. In the lab, sediment was thoroughly washed through progressively finer meshed screens ranging from 5.0 to 1.0 mm and dried under heat lamps. Teeth were removed using a magnifying glass and imaged directly with an Olympus SZ61 Binocular Microscope attached to an Infinity–2 Digital Camera. Since no new genera or species were identified among the specimens we recovered, abbreviated synonymies are utilized. Chondrichthyan teeth were identified by comparison with well-known regional and international literature including: Thurmond and Jones, 1981, Kent, 1994; 1999a; 1999b; Westgate, 2001; Cappetta, 2012. Reposited chondrichthyan teeth described in this report were selected from an assemblage of over 2000 specimens and are included in the collections of the Academy of Natural Sciences, Philadelphia with the catalogue numbers: ANSP 23404–23428.

SYSTEMATIC PALEONTOLOGY

Class CHONDRICHTHYES Huxley, 1880
Subclass ELASMOBRANCHII Bonaparte, 1838
Cohort EUSELACHII Hay, 1902
Order LAMNIFORMES Berg, 1958
Family ODONTASPIDIDAE Müller and Henle, 1838
Genus *STRIATOLAMIA* Glickman, 1964
Striatolamia macrota Agassiz, 1843
(Figure 2:1–6)

Referred Material—One anterior tooth, one lateral tooth, and one posterior tooth. ANSP 23404–23406.

Description—The crown of the anterior tooth is elongated and narrow with a strongly striated lingual face and smooth labial face. Cutting edges are complete and the cusp is sigmoidal in profile. The anterior tooth has a single reduced cusplet on each shoulder. The root of the anterior tooth is holaucorhizous and the mesial root lobe is commonly elongated. On the dorsal edge of the distal root lobe, a rounded protrusion is present. The crown of the lateral tooth is broad and triangular with a striated lingual face. The lateral tooth possesses wide, triangular to shovel-shaped cusplets. The root of the lateral tooth is holaucorhizous. The crown of the posterior tooth is mesio-distally compressed and antero-posteriorly thickened. Lateral cusplets are highly reduced. The root of the posterior tooth is holaucorhizous and the mesial root lobe is thicker and more rounded than the distal root lobe. A lingual protuberance containing a nutritive groove is present on all teeth.

Discussion—The teeth of *S. macrota* are very abundant at the Turkey Creek locality. Although these teeth are frequently fragmentary with only the crown remaining, the cutting edges are sharp, indicating minimal transport occurred during reworking and lag formation (e.g., Becker and Chamberlain, 2012). Morphologically, the teeth of *S. macrota* appear similar to those of *Scapanorhychus sp.* and *Carcharias sp.* Research by Cunningham (2000) suggested the tooth variation and morphology of *S. macrota* is comparable to that seen in the extant sand tiger shark, *Carcharias taurus* (Rafinesque, 1810). Kent (1994) recognized two *Striatolamia* species: *S. striata* (which is defined as having a smaller overall tooth size and longer striations) and *S. macrota*. Due to the variability seen in the teeth of the modern sand tiger shark, *C. taurus*, and their similarity to the teeth of *S. macrota*, we follow Ward and Wiest (1990), who synonymized *S. striata* with *S. macrota*, until further ontogenetic information can be ascertained from the teeth of these extinct sharks. The teeth of *Sylvestrilamia* sp. differ from those belonging to *S. macrota* because anterior teeth are only weakly sigmoidal and only contain folds in the lower portion of the lingual enamel, and lateral teeth are not as broad and have triangular rather than shovel-shaped cusplets (Cappetta and Nolf, 2005; Cappetta, 2012). Additional confusion when identifying *S. macrota* from *Carcharias* sp. such as *Hypotodus verticalis* (Agassiz, 1843) and *C. hopei* (Ward, 1988) may occur if extensive reworking has occurred during lag formation, and in turn, may eliminate the lingual striations on the teeth of *S. macrota* (e.g., Gunnell, 2001). *S. macrota* has a cosmopolitan distribution and has been recovered from Paleocene–Eocene localities including those in: New Jersey (Maisch et al., 2013); Maryland (Ward and Wiest, 1990); Virginia (Cunningham, 2000); North Carolina (Chandler and Timmerman, 1995); South Carolina (Purdy, 1998a); Mexico (Ferrusquia-Villafranca et al., 1999); Texas (Breard and Stringer, 1999; Stidham and Janus, 2008); Georgia (Hulbert et al., 1998; Parmley and Cicimurri, 2003); Alabama (White, 1956; Holman and Case, 1988; Feldmann and Portell, 2007); Mississippi (Case, 1994); Chile (Otero et al., 2012); England (Kemp et al., 1990); France (Adnet, 2006); The Netherlands (Bor, 1985); Belgium (Van den Eeckhaut and De Schutter, 2009) Antarctica (Long, 1992); and Australia (Pledge, 1967). The teeth of *S. macrota* are morphologically similar to those of the modern sand tiger shark, *C. taurus*, which is known to inhabit coastal temperate-tropical waters (Compagno et al., 2005). *S. macrota* may have had similar feeding and habitat preferences.

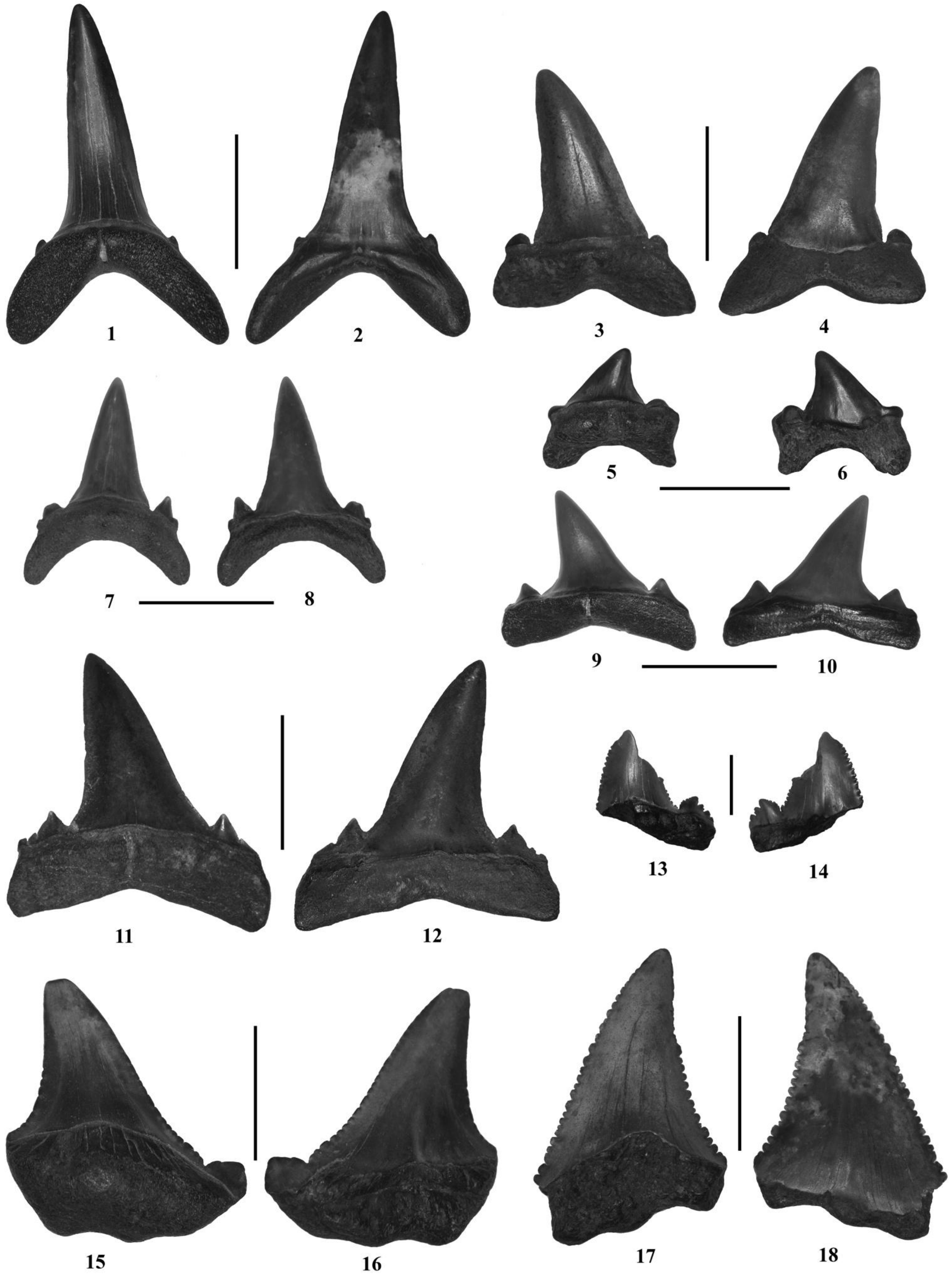

FIGURE 2: Teeth of Lamniforms from the Tallahatta – Lisbon Formation contact, Turkey Creek, Choctaw County, Silas, Alabama. 1–6: *Striatolamia macrota* Agassiz, 1843 (ANSP 23404–23406); 7–12: *Brachycarcharias lerichei* Casier, 1946 (ANSP 23407–23409); 13–18: *Carcharodon auriculatus* Blainville, 1818 (ANSP 23410–23412). Scale bars: 1–18 = 10.0 mm. Orientations: 1, 3, 5, 7, 9, 11, 13, 15, 17 = lingual view; 2, 4, 6, 8, 10, 12, 14, 16, 18 = labial view. Tooth positions: 1, 2, 7, 8 = anterior; 3, 4, 9–12, 15–18= lateral; 5, 6 = posterior.

Genus *BRACHYCARCHARIAS* Cappetta and Nolf, 2005

Brachycarcharias lerichei (Casier, 1946)

(Figure 2:7–12)

Referred Material—One anterior tooth and two lateral teeth. ANSP 23407–23409.

Description—The crown of the anterior tooth is erect and has complete cutting edges. The lingual surface may contain faint striations however, the labial surface is smooth. Large triangular cusplets are present on the mesial and distal tooth shoulders and may be separated from the main cusp by a notch in the enamel. The root of the anterior tooth is holaucorhizous and contains a faint nutritive groove on the lingual surface. Lateral teeth have broad, triangular crowns with smooth lingual and labial surfaces and are angled distally. Broad, triangular cusps are present on the mesial and distal tooth shoulders and may contain a smaller, needle-like secondary cusplet. The root of lateral teeth is broad, holaucorhizous with the lobes widely separated, and the lingual surface is relatively flat.

Discussion—The teeth of *B. lerichei* are frequently recovered from the Turkey Creek locality. These teeth can be differentiated from those of *S. macrota* and other similar species due to the presence of erect, less sigmoidal cusps and more erect and triangular cusplets. The absence of moderately to strongly striated lingual tooth surfaces and shovel-shaped cusplets on lateral teeth of *B. lerichei* can also aid in identification. Kent (1994) described the overall form of *B. lerichei* as similar to that of *Serratolamna* and *Lamna*. Cappetta and Nolf (2005) erected the genus *Brachycarcharias* and considered the tooth morphology to represent that of an odontaspid. Purdy and Francis (2007) compared the teeth of *B. lerichei* to those of the modern porbeagle shark *Lamna nasus* (Bonnaterre, 1788) and suggested that the *B. lerichei* morphology may actually belong to *Lamna*. We follow Cappetta (2012) and assign this species to *B. lerichei* until further analyses are conducted. The teeth of *B. lerichei* have been recovered from Eocene localities including those in: Maryland (Ward and Wiest, 1990); North Carolina (Case and Borodin, 2000a); Alabama (Holman and Case, 1988; Feldmann and Portell, 2007; Clayton et al., 2013); Louisiana (Breard and Stringer, 1995); England (Kemp et al., 1990); Belgium (Leriche, 1905; Casier, 1946; Cappetta and Nolf, 2005; Van den Eeckhaut and De Schutter, 2009); Japan (Tanaka et al., 2006); and Uzbekistan (Case et al., 1996). The teeth of *B. lerichei* resemble those of the modern porbeagle shark, *Lamna nasus*, which is known to inhabit coastal temperate-cool waters (Compagno et al., 2005). *Brachycarcharias lerichei* therefore may have had similar feeding and habitat preferences.

Family LAMNIDAE Müller and Henle, 1838

Genus *CARCHARODON* Smith in Müller and Henle, 1838

Carcharodon auriculatus Blainville, 1818

(Figure 2: 13–18)

Referred Material—One anterior tooth and two lateral teeth. ANSP 23410–23412.

Description—The main cusps of the anterior and lateral teeth are robust with convex lingual surfaces, nearly flat labial surfaces, and have coarsely serrated tooth margins. Lateral teeth are angled distally and have a claw-like appearance. Lateral cusplets are present in all tooth positions, are triangular to round in shape, coarsely serrated, and are separated from the main cusp by a distinct notch in the tooth enamel.

Discussion—The teeth of *C. auriculatus* are infrequently recovered from the Turkey Creek locality. Due to the large size and presence of serrations on these teeth, they are easily distinguished from all other chondrichthyan species in the Turkey Creek Assemblage. *C. angustidens* is morphologically similar to *C. auriculatus*, although overall serration size is smaller and more regular and lateral cusplets are more reduced. *C. sokolowi* (Jaekel, 1895) has been utilized by some researchers as an intermediate form between *C. auriculatus* and *C. angustidens* however, due to varying degrees of ontogenetic heterodonty and general dental morphology seen in the teeth of *Carcharodon* sp., *C. sokolowi* has been synonymized with *C. auriculatus* (e.g., Leriche, 1942; Kent, 1994; Renz, 2002; Adnet, 2006). The late Oligocene–early Miocene form, *C. chubutensis* Ameghino, 1906 (*C. subauriculatus*), differs from both *C. auriculatus* and *C. angustidens* due to the presence of smaller, regularly spaced serrations and reduced lateral cusplets (Kent, 1994; Purdy et al., 2001; Renz, 2002; Parmley and Cicimurri, 2003). This report intends to document the occurrence of mega-toothed sharks in the middle Eocene of Alabama and does not intend to debate taxonomy. We follow the traditional nomenclature of Applegate and Espinosa-Arrubarrena (1996); Gottfried et al. (1996); Hulbert (2001); and Purdy et al. (2001) and utilize the genus *Carcharodon*. For additional discussion regarding the taxonomic classification of *C. auriculatus* and its assignment to *Carcharocles* or *Otodus* see Nyberg et al. (2006); Van den Eeckhaut and De Schutter, 2009; Underwood et al. (2011); Ehret et al. (2012); and Cappetta (2012). *C. auriculatus* has been recovered from Eocene–Oligocene localities including those in: New Jersey (Maisch et al., 2013);

Maryland (Ward and Wiest, 1990); North Carolina (Chandler and Timmerman, 1995); Georgia (Case, 1981; Freile et al., 2001); Alabama (White, 1956; Feldmann and Portell, 2007; Clayton et al., 2013); Mississippi (Dockery and Manning, 1986; Breard, 1991); Louisiana (Breard and Stringer, 1995); Mexico (Ferrusquía-Villafranca et al., 2000); England (Kemp et al., 1990); France (Adnet, 2006); Belgium (Van den Eeckhaut and De Schutter, 2009); Egypt (Underwood et al., 2011); Uzbekistan (Case et al., 1996); Japan (Tanaka et al., 2006); and Australia (Pledge, 1967). *C. auriculatus* has teeth morphologically similar to those of the extant white shark, *C. carcharias*, which is known to be pelagic and inhabit coastal-deep, temperate to tropical waters (Compagno et al., 2005).

Family OTODONTIDAE Glickman, 1964
Genus *OTODUS* Agassiz, 1843
Otodus obliquus Agassiz, 1843
(Figure 3:1–2)

Referred Material—One anterior tooth. ANSP 23413.

Description—The main cusp of the anterior tooth is robust, smooth, and angled distally. The lingual surface is convex and the labial surface is flat. Broad wrinkles are present in the tooth enameloid near the base of the main cusp on the labial surface. A single, well-defined, triangular, and divergent cusplet separated from the main cusp by a distinct notch is present on both the mesial and distal tooth shoulders. A well-defined dental band is present on the lingual surface of the tooth near the base of the main cusp. The root is holaucorhizous with slightly compressed, rounded lobes containing multiple foramina. No nutritive groove is present on the root.

Discussion—The teeth of *O. obliquus* are infrequently recovered from the Turkey Creek locality and are substantially larger and more robust than the teeth of the other chondrichthyan species in the assemblage, excluding *C. auriculatus*. The presence of multiple foramina throughout the root lobes and more narrow and divergent cusplets on lateral teeth of *O. obliquus* readily distinguish this species from *Cretalamna* sp. whereas the lack of serrations distinguishes *O. obliquus* from *C. auriculatus*. The teeth of *O. obliquus* may also appear similar to the teeth of *Jaekelotodus trigonalis* Jaekel, 1895, however, the taller and broader main cusps, lack of a deep concavity on the labial tooth surface, and lack of secondary or partially serrated primary cusplets in *O. obliquus* enables these two species to be distinguished from one another. According to Cappetta (2012) *Otodus* may have arisen from *Cretalamna* and possibly represents the ancestor of some of the larger and later Cenozoic lamniforms therefore justifying the use of the genus *Otodus* for mega-toothed sharks (e.g., Bor et al., 2012; Cappetta, 2012; Ehret et al., 2012). *O. obliquus* has a cosmopolitan distribution and has been recovered from Paleocene–Eocene localities including those in: New Jersey (Fowler, 1911); Maryland (Ward and Wiest, 1990); North Carolina (Chandler and Timmerman, 1995; Case and Borodin, 2000a); South Carolina (Purdy, 1998a); Arkansas (Becker et al., 2011); England (Kemp et al., 1990); Morocco (Arambourg, 1952); and Australia (Pledge, 1967). *O. obliquus* has been documented to have an odontaspid dentition however, its more robust tooth morphology resembles that of *Lamna*, potentially making it similar to modern sand tiger or porbeagle sharks known to inhabit coastal-deep temperate-tropical waters (Applegate and Espinosa-Arrubarrena, 1996; Compagno et al., 2005; Purdy and Francis, 2007).

Order CARCHARHINIFORMES Compagno, 1977
Family CARCHARHINIDAE Jordan and Evermann, 1896
Genus *ABDOUNIA* Cappetta, 1980
Abdounia recticona (Winkler, 1873)
(Figure 3:3–6)

Referred Material—One anterior tooth and one lateral tooth. ANSP 23414–23415.

Description—The crowns of anterior and lateral teeth are smooth with nearly flat labial faces and slightly convex lingual faces. A complete cutting edge is present and up to three coarse, triangular cusplets can be seen on the mesial and distal shoulders of anterior teeth and up to two cusplets can be seen on the lateral tooth. The cusplets are continuous with the main cusp and are not separated by distinct distal and mesial notches on the tooth shoulder. The crown of the lateral tooth is angled distally whereas the crown of the anterior tooth is relatively straight. The root of the anterior tooth is thin, holaucorhizous, transversely extended, and contains a deep nutritive groove while the root base of lateral teeth is slightly thicker. On both anterior and lateral teeth, the basal edge of the labial and lingual root surface is slightly concave.

Discussion—The teeth of *Abdounia recticona* are infrequently recovered from the Turkey Creek locality although they are readily identifiable from other chondrichthyan teeth in the assemblage. The presence of erect main cusps, paired, triangular cusplets and the small overall tooth size of *A. recticona,* enable these teeth to be distinguished from those of *Physogaleus* sp., *Galeocerdo* sp., and other similar species. A similar species, *A. beaugei* (Arambourg, 1935), is also known to occur in North America (Kent, 1994).

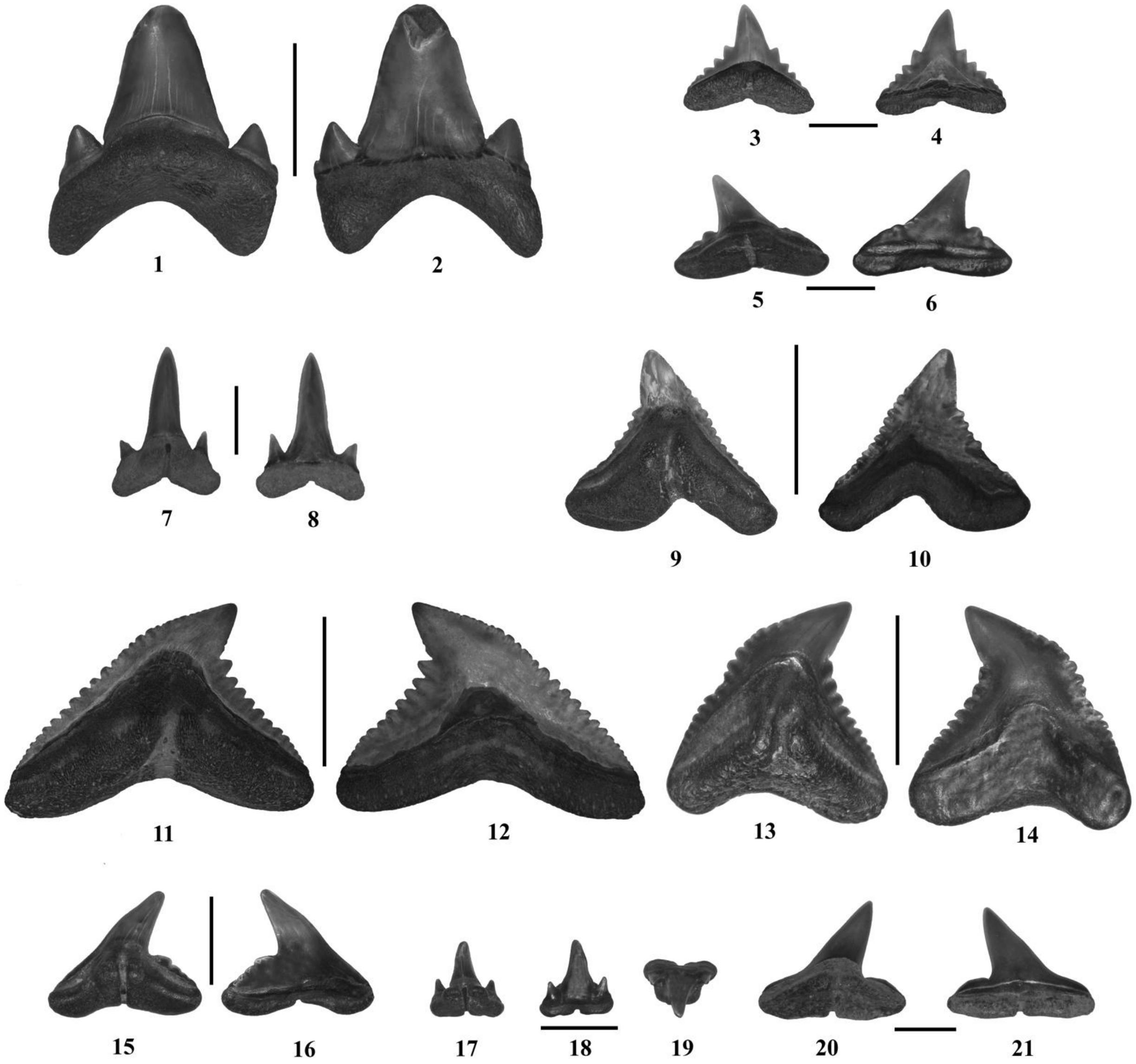

FIGURE 3. Teeth of Lamniforms and Carcharhiniforms from the Tallahatta – Lisbon Formation contact, Turkey Creek, Choctaw County, Silas, Alabama. 1–2: *Otodus obliquus* Agassiz, 1843 (ANSP 23413); 3–6: *Abdounia recticona* (Winkler, 1873) (ANSP 23414–23415); 7–8: *Abdounia enniskilleni* (White, 1956) (ANSP 23416); 9–14: *Galeocerdo eaglesomei* (White, 1955) (ANSP 23417–23419); 15–16: *Physogaleus secundus* (Winkler, 1874) (ANSP 23420); 17–19: *Scyliorhinus* sp. (ANSP 23421); 20–21: *Rhizoprionodon* sp. (ANSP 23422). Scale bars: 1–2; 9–14 = 10.0 mm; 3–8; 15–21= 5.0 mm. Orientations: 1, 3, 5, 7, 9, 11, 13, 15, 17, 20 = lingual view; 2, 4, 6, 8, 10, 12, 14, 16, 18, 21 = labial view; 19 = apical. Tooth positions: 1–4, 7–10, 17–19 = anterior; 5, 6, 11–16, 20, 21= lateral.

However, anterior teeth of *A. beaugei* have two or fewer cusplets, while *A. recticona* has three or more cusplets (Cappetta, 2012). *A. recticona* has a cosmopolitan distribution and has been recovered from Paleocene–Oligocene localities including those in: New Jersey (Maisch et al., 2013); Maryland (Ward and Wiest, 1990); North Carolina (Chandler and Timmerman, 1995; Case and Borodin, 2000a); Alabama (Feldmann and Portell, 2007; Clayton et al., 2013); Texas (Breard and Stringer, 1999); England (Kemp et al., 1990); France (Adnet, 2006; Adnet and Cappetta, 2008); Belgium (Van den Eeckhaut and De

Schutter, 2009); and Uzbekistan (Case et al., 1996). The teeth of *A. recticona* are morphologically similar to those of modern catsharks, which are known to inhabit coastal temperate-tropical waters (Compagno et al., 2005). *Abdounia reticona* therefore may have had similar feeding and habitat preferences.

Abdounia enniskilleni (White, 1956)
(Figure 3:7–8)

Referred Material—One anterior tooth. ANSP 23416.

Description—The crown of the anterior tooth is erect with a nearly flat labial face, convex and weakly striated lingual face, and contains a complete cutting edge. Single, needle-like, divergent cusplets are present on the mesial and distal tooth shoulders and are continuous with the main cusp enamel. The root of the anterior tooth is thick, holaucorhizous, and contains a deep nutritive groove with central foramina on the lingual surface.

Discussion—The teeth of *A. enniskilleni* are infrequently recovered from the Turkey Creek locality, however they are readily distinguished from the teeth of *A. recticona*, *B. lerichei*, and other similar species due to their relatively small size, sharp and erect main cusp with a weakly striated lingual surface, and pair of needle-like and divergent lateral cusplets. The teeth of A. *enniskilleni* appear very similar to those of *A. minutissima* (Winkler, 1874) and *Scyliorhinus* sp. According to Cappetta (2012) the teeth of *A. enniskilleni* do not have crown enamel overhanging the labial root face and have more developed bilobate roots. Such teeth were initially identified as *Scyliorhinus* sp. However, the teeth of *A. enniskilleni* have shorter crown heights and more robust roots with flat, rectilinear basal surfaces. Until further analyses are conducted on the teeth of *A. enniskilleni* and *A. minutissima*, we follow Cappetta (2012) and regard them as two different species. *A. enniskilleni* has been recovered from Eocene localities including those in: North Carolina (Chandler and Timmerman, 1995; Case and Borodin, 2000a); Georgia (Case, 1981; Case and Borodin, 2000b); Alabama (White, 1956; Holman and Case, 1988); Mississippi (Breard, 1991); Louisiana (Manning and Standhardt, 1986; Breard and Stringer, 1995); Arkansas (Westgate, 1984); and Texas (Breard and Stringer, 1999). The teeth of *A. enniskilleni* are morphologically similar to those of modern catsharks, which are known to inhabit coastal temperate-tropical waters (Westgate, 1984; Compagno et al., 2005). *Abdounia enniskilleni* therefore may have had similar feeding and habitat preferences.

Genus *GALEOCERDO* Müller and Henle, 1837
Galeocerdo eaglesomei (White, 1955)
(Figure 3: 9–14)

Referred Material—One anterior tooth and two lateral teeth. ANSP 23417–23419.

Description—The crowns of anterior and lateral teeth are smooth with flat labial surfaces, slightly convex lingual surfaces, and are coarsely serrated. Compound serrations are not present on any of the Turkey Creek teeth. The cusp is angled distally and the angle becomes more acute further from the symphysis. The distal tooth margins contain a well-developed, serrated shoulder, and are concave whereas the mesial tooth margins are nearly straight in anterior teeth and convex in lateral teeth. Serrations are coarsest near the middle of the crown enamel and become progressively smaller in the apical and basal directions. The roots of anterior and lateral teeth are holaucorhizous and contain a short nutritive groove on the lingual surface. The anterior tooth has a thicker root than those of lateral teeth, although the basal, lingual root surface is slightly concave on roots of both tooth positions. The roots are more exposed on the lingual surface.

Discussion—The teeth of *G. eaglesomei* can be readily distinguished from other chondrichthyan teeth in the Turkey Creek assemblage such as *Abdounia recticona*, *Physogaleus secundus*, and *Rhizoprionodon* sp. due to the presence of coarsely serrated tooth margins, relatively thin roots, and a small nutritive groove on the lingual root surface. Previous researchers have described multiple *Galeocerdo* species based on crown angle, serration size, and root thickness (e.g., Leriche, 1942; White, 1955; Purdy et al., 2001; Cappetta, 2012). *G. latidens* Agassiz, 1843, is an Eocene species morphologically similar to the lateral teeth of *G. eaglesomei* although it is defined by having coarse serrations on the distal margin, fine serrations on the mesial margin, a weakly defined distal notch, and a lower overall tooth height and thickness. Manning and Standhardt (1986) synonymized *G. clarkensis* White, 1956, with *G. alabamensis* Leriche, 1942, on the basis that *G. clarkensis* teeth were actually the upper teeth of *G. alabamensis*. Eocene *Galeocerdo* sp. with compound serrations on the distal heel which are also referred to as *G. alabamensis* by Parmley and Cicimurri (2003). *G. eaglesomei* has been recovered from Eocene localities including those in: North Carolina (Case and Borodin, 2000a); Texas (Westgate, 1989; Breard and Stringer, 1999); Belgium (Van den Eeckhaut and De Schutter, 2009); Nigeria (White, 1955); and Egypt (Strougo et al., 2007; Underwood et al., 2011). The extant tiger shark, *G. cuvier*, is known to inhabit coastal, temperate-tropical waters (Compagno et al., 2005).

Genus *PHYSOGALEUS* Cappetta, 1980
Physogaleus secundus (Winkler, 1874)
(Figure 3:15–16)

Referred Material—One lateral tooth. ANSP 23420.

Description—The crown of the lateral tooth is thick, mesio-distally compressed, angled distally, and sigmoidal in profile. The mesial and distal edges of the main cusp are smooth. The base of the mesial cutting edge may contain small serrations and the base of the distal cutting edge that extends onto the tooth shoulder, contains two or more coarse, triangular serrations. The lingual and labial tooth surfaces are convex and the labial surface slightly overhangs the root. The root is holauchorhizous, thick, and contains a large lingual protuberance with a deep nutritive groove. The basal root surface is nearly flat and has a rectilinear appearance.

Discussion—The teeth of *P. secundus* are infrequently recovered from the Turkey Creek locality. The presence of a large lingual protuberance, partly serrated crown and distal shoulder enamel, and convex, sigmoidal main cusps enable the teeth of *P. secundus* to be distinguished from those of morphologically similar *Galeocerdo* and *Abdounia* species even though distinct sexual dimorphism has been documented in the teeth of *P. secundus*. Additionally, the teeth of *P. latus* (Storms, 1894) have more distally angled cusps, weakly serrated or smooth mesial tooth edges, and thinner roots than the teeth of *P. secundus* from the Turkey Creek locality. However, current debate exists on the proper classification of *P. secundus*. The genus *Physogaleus* was erected by Cappetta (1980) who assigned Paleocene and Eocene teeth morphologically similar to *G. contortus* (Gibbes, 1849) to *P. secundus* (Winkler, 1874). Purdy et al. (2001) questioned the identity of *Physogaleus* until the syntypes are found and studied. *P. secundus* teeth, although larger in size, resemble forms of *Paragaleus* sp. as identified from the Miocene of North Carolina by Purdy et al. (2001) and have been assigned to the genus *Physogaleus* by Cappetta (2012). We follow Cappetta (1980; 2012) and assign the Silas teeth to *P. secundus* until further analyses and revised taxonomic classification occurs. *P. secundus* has a cosmopolitan distribution and has been recovered from Eocene localities including those in: New Jersey (Maisch et al., 2013); Maryland (Ward and Wiest, 1990); South Carolina (Parmley and Cicimurri, 2003); Alabama (White, 1956; Clayton et al., 2013); Texas (Breard and Stringer, 1999); England (Kemp et al., 1990); Belgium (Van den Eeckhaut and De Schutter, 2009); Morocco (Cappetta, 1980); and Japan (Tanaka et al., 2006). The teeth of *Physogaleus* species are morphologically similar to those of modern sharpnose and weasel sharks, which are known to inhabit coastal temperate-tropical waters (Compagno et al., 2005). *Physogaleus secundus* therefore may have had similar feeding and habitat preferences.

Family SCYLIORHINIDAE Gill, 1862
Genus *SCYLIORHINUS* Blainville, 1816
Scyliorhinus sp.
(Figure 3:17–19)

Referred Material—One anterior tooth. ANSP 23421.

Description—The crown of the anterior tooth is erect, thin, and short with a nearly flat labial face, convex lingual face, and a complete cutting edge. Single, needle-like, erect cusplets are present on the mesial and distal tooth shoulders and are continuous with the main cusp enamel. The root of the anterior tooth is thick, holaucorhizous, and contains a deep nutritive groove extending from the labial to lingual face with central foramen on the lingual surface and additional foramina throughout the root. The root base is flat, heart-shaped, and wider on the labial face and no vertical folds or striations are present on the enamel near the root base.

Discussion—The teeth of *Scyliorhinus* sp. are infrequently recovered from the Turkey Creek locality. These are the smallest chondrichthyan teeth recovered from Turkey Creek and are readily distinguished from other teeth in the assemblage due to their short, thin crowns, and robust root with flat basal surfaces that are roughly heart-shaped in appearance. The teeth of *A. enniskilleni* are morphologically similar to those of *Scyliorhinus* sp., however, they are larger in size, have a more erect main cusp with divergent cusplets, and a more well-defined bilobate root structure that is not as thick, or flat on the basal surface as the root of *Scyliorhinus* sp. Cappetta (2012) identified a tooth similar to those found at the Turkey Creek locality as *Premontreia (Oxyscyllium) subulidens* while Bor et al. (2012) identified another nearly identical tooth as *Pachyscyllium dachiardii* (Lawley, 1876). Due to the highly variable morphology seen in *Scyliorhinus* teeth and scarce occurrence of these teeth at Turkey Creek, we refrain from higher level taxonomic classification. Similar *Scyliorhinus* sp. have been recovered from Eocene localities including those in: Maryland (Ward and Wiest, 1990); Georgia (Case, 1981); France (Adnet, 2006); and Uzbekistan (Case et al., 1996). The teeth of *Scyliorhinus* species are morphologically similar to those of modern catsharks, which are known to inhabit coastal temperate-tropical waters (Compagno et al., 2005). *Scyliorhinus* species therefore may have had similar feeding and habitat preferences.

Genus *RHIZOPRIONODON* Whitley, 1929
Rhizoprionodon sp.
(Figure 3:20–21)

Referred Material—One lateral tooth. ANSP 23422.

Description—The crown of lateral teeth is short and broad with a complete cutting edge. The cusp is sigmoidal to slightly concave, bent distally and a pronounced, unserrated, distal heel is present. The labial tooth face slightly overhangs the root and displays a convex ridge parallel to the root base while the lingual face is nearly flat. The root is holauchorhizous and rectilinear in appearance and contains a deep nutritive groove.

Discussion—The teeth of *Rhizoprionodon* sp. are frequently recovered from the Turkey Creek locality and can be distinguished from those belonging to *Sphyrna* sp., by the presence of narrower, more sigmoidal main cusps and well-defined distal heels. *Rhizoprionodon* sp. teeth can also be distinguished from those of *Scoliodon* sp. by the lack of labial tooth enamel overhanging the root. Recent analyses on teeth from the extant genera: *Scoliodon*, *Loxodon*, and *Rhizoprionodon* have shown dental morphology to be very similar (Springer, 1964; Cappetta, 2012). Additional complications documented in identifying the teeth of *Rhizoprionodon* sp. include varying degrees of sexual dimorphism and ontogenetic heterodonty. We refrain from lower level taxonomic classification until further studies are conducted on the teeth of *Rhizoprionodon* sp. *Rhizoprionodon* has a cosmopolitan distribution and has been recovered from Eocene-recent localities including those in: Delaware (Purdy, 1998b); North Carolina (Case, 1980; Chandler and Timmerman, 1997; Case and Borodin, 2000a as *Physogaleus* sp.; Purdy et al., 2001); South Carolina (Cicimurri and Knight, 2009); Georgia (Case, 1981); Louisiana (Breard and Stringer, 1995); Florida (Hulbert, 2001); Alabama (Clayton et al., 2013); Texas (Manning, 1990; Stidham and Janus, 2008); Panama (Pimiento et al., 2013); Brazil (Fernandes dos Reis, 2005); Malta (Ward and Bonavia, 2001); Egypt (Case and Cappetta, 1990; Adnet et al., 2011; Underwood et al., 2011); Pakistan (Case and West, 1991; Adnet et al., 2007); and Uzbekistan (Case et al., 1996). Extant *Rhizopriondon* species are known to inhabit coastal, temperate-tropical waters (Compagno et al., 2005).

Suborder *PRISTIOIDEI* Cappetta, 1980

Family PRISTIDAE Bonaparte, 1838
Genus *PRISTIS* Linck, 1790
Pristis sp.
(Figure 4:1–3)

Referred Material—One rostral tooth. ANSP 23423.

Description—The rostral tooth from the Turkey Creek locality is fragmentary however, the anterior edge of the tooth is rounded and the apex is slightly curved in the posterior direction. The posterior edge of the tooth is nearly flat although a U-shaped groove may be seen on this surface. Lateral grooves are present on the dorsal and basal surface and extend from the tooth base to the tooth apex. The tooth base exposes spongy, cancellous tooth matrix.

Discussion—The rostral teeth of *Pristis* sp. are infrequently recovered from the Turkey Creek locality and are usually abraded and fragmentary. Some rostral teeth, thought to belong to juvenile sawfish, may lack a groove along the posterior edge; indicating that ontogenetic heterodonty may be present in *Pristis* sp. (Purdy et al., 2001). Additionally, many *Pristis* sp. have been named from isolated rostral teeth leaving their validity in question until further studies are conducted (Cappetta, 2012). Due to the fragmentary nature of the Turkey Creek specimens, we refrain from higher level taxonomic classification. *Pristis* has a cosmopolitan distribution and has been recovered from Eocene-recent localities including those in: New Jersey (Leidy, 1877; Fowler, 1911; Maisch et al., 2013); Maryland (Ward and Wiest, 1990); North Carolina (Case and Borodin, 2000a; Purdy et al., 2001); South Carolina (Purdy, 1998a; Cicimurri, 2007); Georgia (Case, 1981; Case and Borodin, 2000b); Florida (Olsen, 1964); Alabama (Holman and Case, 1988; Clayton et al., 2013); Mississippi (Breard, 1991; Stringer and Miller, 2001); Louisiana (Manning and Standhardt, 1986; Breard and Stringer, 1995; Stringer et al., 2001); Arkansas (Westgate, 1984); Texas (Westgate, 1989; Breard and Stringer, 1999); England (Kemp et al., 1990); France (Cappetta, 1973); Belgium (Van den Eeckhaut and De Schutter, 2009); Egypt (Case and Cappetta, 1990; Underwood et al., 2011); Uzbekistan (Case et al., 1996); and Antarctica (Kriwet, 2005). The extant sawfish, *P. pectinatus* is known to inhabit coastal, temperate-tropical waters (Bigelow and Schroeder, 1953).

Superorder BATOMORPHII Cappetta, 1980
Order MYLIOBATIFORMES Compagno, 1973
Family MYLIOBATIDAE Bonaparte, 1838
Genus *AETOMYLAEUS* Garman, 1908
cf. *Aetomylaeus* sp.
(Figure 4:7–12)

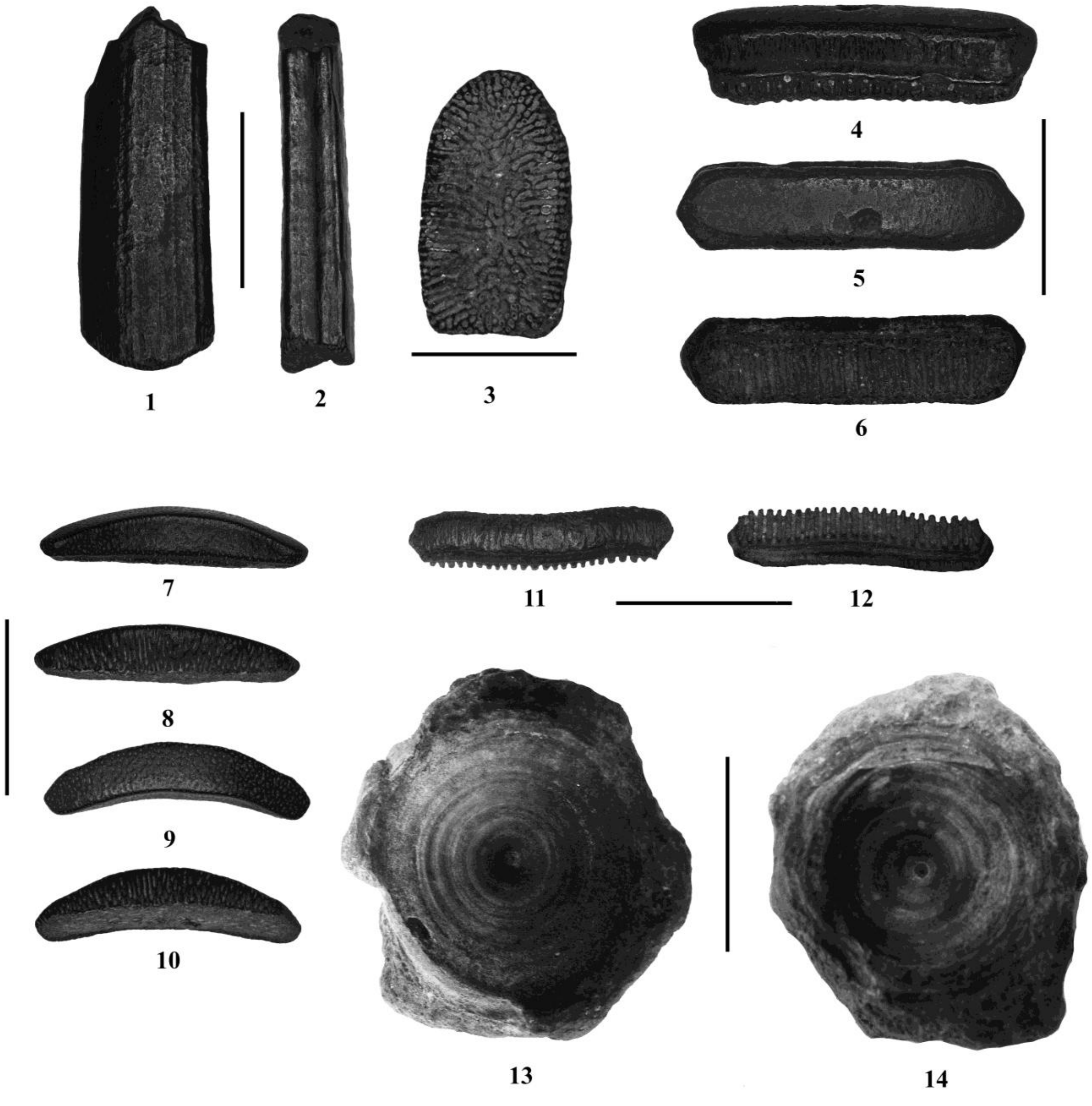

FIGURE 4. Teeth of Myliobatiforms, Pristiforms, and carcharhinoid-type vertebral centrum from the Tallahatta – Lisbon Formation contact, Turkey Creek, Choctaw County, Silas, Alabama. 1–3: *Pristis* sp., (ANSP 23423); 4–6:*Rhinoptera* sp., (ANSP 23424); 7–12: cf. *Aetomylaeus* sp., (ANSP 23425–23427); 13–14: Carcharhinoid-type vertebral centrum (ANSP 23428). Scale bars: 1–2, 4–12 = 10.0 mm; 3 = 5.0 mm; 13–14 = 20.0 mm. Orientations: 1 = ventral view; 2 = posterior tooth side; 3, 6, 10, 12 = basal view; 4, 8 = labial view; 5, 9, 11 = occlusal view; 7 = lingual view; 13–14 = articular surface view.

Referred Material—Two median pavement teeth. ANSP 23425–23426.

Description—The crowns of the pavement teeth are smooth, arcuate in occlusal view, convex in labial and lingual view, and broader than they are long. The median tooth from the center of the dental plate has a crown that overhangs the labial face of the root and has angular edges. The median tooth from the posterior region of the dental plate is more arcuate and has distal tooth edges that are rounded. The root is polyaulacorhizous and contains equidimensional nutritive grooves.

Discussion—The median teeth of cf. *Aetomylaeus* sp. are infrequently recovered from Turkey Creek. These teeth can be distinguished from other Silas batoid teeth due to crowns that are not uniform in thickness, and are elongated and arched in occlusal view. The batoids *Pteromylaeus* sp. Garman, 1913, *Myliobatis* sp. Cuvier, 1817, *Rhinoptera* sp. Cuvier, 1829, and *Aetobatus* sp. Blainville, 1816 bear some resemblance to *Aetomylaeus* from the Turkey Creek assemblage. However, the median pavement teeth of *Pteromylaeus* sp. are roughly seven times longer than their width, and upper median teeth retain the hexagonal outline as seen in *Myliobatis* and *Rhinoptera* while lower median teeth are gently arched (McEachran and Capapé, 1984; Cappetta, 2012). The median and lateral teeth of *Myliobatis* sp. have low, uniform crown thicknesses, angular tooth edges, are hexagonal in outline, and are not as broad as those of *Aetomylaeus*. The teeth of *Rhinoptera* sp. resemble those of *Myliobatis* sp. although, they have thick crowns that are uniform in thickness and median teeth that are not distinctly larger than lateral teeth. *Aetobatus* sp. have pavement teeth that are chevron to gently arched in shape and taper to rounded points as the genus does not contain lateral tooth rows (Bigelow and Schroeder, 1953). Analyses on the spatiotemporal distribution of *Aetomylaeus* by Cappetta (1987; 2012) suggest the genus has a greater extent than previously documented owing to its confusion with the teeth of *Myliobatis* sp. and *Pteromylaeus* sp. Due to the uncertain distribution of *Aetomylaeus* in the Gulf Coastal plain and the infrequent occurrence in the Silas assemblage, we refrain from definitive genus and species assignment until further studies are conducted on fossil and extant specimens. *Aetomylaeus* has a cosmopolitan distribution although is currently only documented from Miocene-recent localities including those in: New Jersey (Fowler, 1911 as *Myliobatis*); Florida (Hulbert, 2001); Cuba (Iturralde-Vinent et al., 1998); France (Cappetta, 1970 as *Pteromylaeus*); Portugal (Antunes et al., 1999 as *Pteromylaeus*). Extant *Aetomylaeus* species are known to inhabit the Red Sea and coastal, temperate-tropical waters of the Pacific and Indian Oceans (Cappetta, 2012).

Family RHINOPTERIDAE Jordan and Evermann, 1896
Genus *RHINOPTERA* Cuvier, 1829
Rhinoptera sp.
(Figure 4:4–6)

Referred Material—One median pavement tooth. ANSP 23424.

Description—The crown of the pavement tooth has a nearly flat and smooth hexagonal occlusal surface, uniform thickness, and is mesiodistally elongated. The base of the crown overhangs the root on all but the lingual side and contains numerous longitudinal ridges. The root is polyaulacorhizous and contains equidimensional nutritive grooves.

Discussion—The pavement teeth of *Rhinoptera* sp. are frequently recovered from the Turkey Creek locality and can be distinguished from other batoid teeth in the Silas assemblage by their nearly flat, hexagonal occlusal surfaces, uniform crown thickness, mesiodistally elongated form, and similarly sized median and lateral teeth (Nishida, 1990; Hulbert, 2001; Purdy et al., 2001; Cappetta, 2012). Median teeth of *Rhinoptera* have angular edges that correspond with the articular surfaces of adjoining, similarly sized and shaped lateral teeth. The batoids *Pteromylaeus* Garman, 1913, *Aetomylaeus* Garman, 1908 and *Myliobatis* Cuvier, 1817 bear some resemblance to *Rhinoptera* sp. from the Turkey Creek assemblage. However, according to McEachran and Capapé (1984) the median pavement teeth of *Pteromylaeus* are roughly hexagonal and seven times longer than their width, have lateral teeth that are much smaller than median teeth, and the labial and lingual tooth faces contain numerous pits and grooves. *Aetomylaeus* has median pavement teeth that are also noticeably longer than the corresponding lateral teeth although, the crowns are centrally thickened, yielding a convex form in addition to a slightly arched appearance in occlusal view. *Myliobatis* pavement teeth appear very similar to those of *Rhinoptera* however, they are slightly arched when viewed in labial or lingual view, have thinner crown heights, and have a greater size difference between median and lateral teeth. The highly variable dental morphology of pavement teeth belonging to extant genera including: *Myliobatis*, *Rhinoptera*, *Aetomylaeus*, and *Pteromylaeus* make the identification of isolated median and lateral pavement teeth extremely difficult (Nishida, 1990; Herman et al., 2000; Cappetta, 2012). The Turkey Creek *Rhinoptera* sp. pavement teeth resemble those of *R. bonasus* Mitchill, 1815 and *R. sherboni* White, 1926 however, we refrain from higher level taxonomic classification until more detailed analyses are conducted on the pavement teeth of fossil and extant *Rhinoptera* sp. *Rhinoptera* has a cosmopolitan distribution and has been recovered from Paleocene–recent localities including those in: Delaware (Purdy, 1998b); North Carolina (Case, 1980; Purdy et al., 2001); South Carolina (Purdy, 1998a; Cicimurri and Knight, 2009); Georgia (Case, 1981); Florida (Hulbert, 2001);

Louisiana (Breard and Stringer, 1995); Alabama (Thurmond and Jones, 1981; Feldmann and Portell, 2007; Clayton et al., 2013); Mississippi (Case, 1994); Texas (Westgate, 1989; Breard and Stringer, 1999; Stidham and Janus, 2008); Panama (Gillette, 1984; Pimiento et al., 2013); England (Kemp et al., 1990); France (Cappetta, 1970); Morocco (Arambourg, 1952; Adnet et al., 2010); Nigeria (White, 1926); Germany (Freess, 1992; Gille et al., 2010); Switzerland (Agassiz, 1843); Egypt (Adnet et al., 2011; Underwood et al., 2011); India (Sahni and Mehrotra, 1981); Pakistan (Case and West, 1991); and Uzbekistan (Case et al., 1996). Extant *Rhinoptera* species are known to inhabit coastal, temperate-tropical waters (Rogers et al., 1990; Gilbert and Williams, 2002).

Vertebral Centrum
(Figure 4: 13–14)

Referred Material—One vertebral centrum. ANSP 23428.

Description—The vertebral centrum face is roughly circular in outline, has a concave articulation surface that is 38 mm in diameter, and contains multiple concentric lamella and a centrally-located birthmark. Large foramina for basal cartilage can be seen in dorso-lateral view.

Discussion—In addition to the chondrichthyan teeth, a vertebral centrum was also recovered. Carcharhinoid-type vertebral centra lack paired foramina, are more solid, and lack distinctive septa when compared to lamnoid-type vertebral centra which have many septa and large, paired basidorsal and basiventral foramina (Shimada, 1997; Blanco-Piñón et al., 2005; Becker et al., 2007). The association of isolated chondrichthyan vertebra with a particular genus or species is problematic as demonstrated by the well-known late Cretaceous lamniform, *Squalicorax* sp. In this species, teeth and associated tooth tissues are that of a lamniform but vertebral centra are more similar to that of a carcharhiniform (e.g., Shimada and Cicimurri, 2005; Becker et al., 2007). In this regard, the Turkey Creek carcharhinoid-type vertebral centrum is no exception and little is known about the skeletal anatomy of Paleogene chondrichthyans in North America.

DISCUSSION

Composition and Paleoecology of the Turkey Creek Chondrichthyan Assemblage—A list of chondrichthyan genera occurring in the Turkey Creek lag is compiled in Table 1. Also included in this table are middle Eocene Gulf Coastal Plain chondrichthyan assemblages reported by: White (1956); Bread and Stringer (1999); Westgate (1989, 2008); and Clayton et al. (2013). These five middle Eocene chondrichthyan assemblages occur across 1400 km of the Gulf Coastal Plain. The data in Table 1 indicate that eleven Turkey Creek genera occur in all other assemblages and the most wide-spread genera include: *Striatolamia, Physogaleus, Abdounia, Galeocerdo, Rhinoptera,* and *Pristis*. No chondrichthyans with distinct, deep water and open ocean affinities such as *Isurus* sp., *Alopias* sp., and *Hexanchus* sp. were recovered (Hulbert, 2001; Compagno et al., 2005; Adnet, 2006; Maisch, et al., 2013). However, the availability of deeper ocean water to the south in Alabama and neighboring states is documented by the occurrence of *Carcharodon* (Breard and Stringer, 1995; Manning, 2003).

The genera in Turkey Creek also occur in the middle Eocene of the Atlantic Coastal Plain (Ward and Wiest, 1990; Kent, 1994; Case and Borodin, 2000a; Maisch et al., 2013). These observations suggest that the Turkey Creek chondrichthyans were highly mobile, nektonic predators and scavengers that had broad geographic ranges across the entire middle Eocene shoreline of North America. This geographic distribution continued into the late Eocene in all inundated Gulf and Atlantic Coastal Plains states (Case, 1981; Westgate, 1984; Breard, 1991; Kent, 1994; 1999a; b; Breard and Stringer, 1995; Stidham and Janus, 2008).

The middle Eocene chondrichthyan assemblages in Table 1 derive from glauconitic sand and clay that contains oysters, gastropods and pelecypods diagnostic of coastal environments and consistent with a nearshore or beach facies community. This interpretation is reinforced by the occurrence of reptiles, amphibians and birds with coastal affinities within these chondrichthyan assemblages. Additionally, the shoreline and shallow marine environments of the Gulf Coastal Plain during the middle Eocene were known to have mangrove palm swamps, bays, and lagoons separated by offshore marine sandbar complexes and tidal channels emptying into a nearshore, marine environment (Westgate, 1989; 2008). According to Westgate (1989), water temperatures greater than 24 degrees Celsius and higher than normal marine salinity existed as far west as the Rio Grande Embayment along the middle Eocene Gulf Coastal Plain. Middle-late Eocene chondrichthyan species from the Atlantic and Gulf Coastal Plains also compare favorably with those found in Tethyan faunas of Africa, Egypt, Western Europe and elsewhere globally (See discussions in systematic paleontology). Similar marine conditions may have prevailed across the Atlantic and Gulf Coastal Plains throughout the Eocene (Miller et al., 2008) and substantial bay and shoreline habitat loss throughout the Mississippi

TABLE 1. Geographic distribution of middle Eocene chondrichthyan localities in the Gulf Coastal Plain discussed in this report. Notes: Only definitive genus assignments from cited authors are included in Table 1. *Carcharodon* is equivatlent to *Carcharocles* as identified by Clayton et al. (2013); *Striatolamia macrota* is equivalent to *Odontaspis macrota* as identified by White (1956).

Order	**Conecuh River, near Andalusia, Alabama (Clayton et al., 2013)**	**Claiborne, Alabama “Red Sands” White (1956)**	**Little Stave Creek, Jackson, Alabama (Westgate, 2001)**	**Turkey Creek Silas, Alabama (This Report)**	**Brazos River, near Bryan, Texas (Breard and Stringer, 1999)**	**Lake Casa Blanca, near Laredo, Texas (Westgate (1989; 2008)**
ORECTOLOBI-FORMES	*Nebrius*					
	Squatiscyllium					
LAMNIFORMES	*Carcharodon*			*Carcharodon*		
	Hypotodus					
				Otodus		
					Carcharias	
	Striatolamna	*Striatolamia*	*Striatolamia*	*Striatolamia*	*Striatolamia*	*Striatolamia*
		Odontaspis				
	Brachycarcharias			*Brachycarcharias*		
	Sylvestrilamia					
	Jaekelotodus					
CARCHARHINI-FORMES	*Physogaleus*	*Physogaleus*		*Physogaleus*	*Physogaleus*	
	Abdounia		*Abdounia*	*Abdounia*	*Abdounia*	
	Galeocerdo		*Galeocerdo*	*Galeocerdo*	*Galeocerdo*	*Galeocerdo*
	Pachygaleus					
		Galeorhinus				
		Negaprion	*Negaprion*		*Negaprion*	
			Hemipristis			
					Scoliodon	
				Scyliorhinus		
	Rhizoprionodon			*Rhizoprionodon*		
					Carcharhinus	*Carcharhinus*
MYLIOBATI-FORMES						
	Leidybatis					
					Anoxypristis	
	Myliobatis				*Myliobatis*	*Myliobatis*
	Rhinoptera			*Rhinoptera*	*Rhinoptera*	*Rhinoptera*
	Coupatzia					
	Dasyatis					*Dasyatis*
	Gymnura					
	Jacquhermania					
RAJIFORMES	*Rhinobatos*				*Rhinobatos*	*Rhinobatos*
PRISTOFORMES	*Pristis*			*Pristis*	*Pristis*	*Pristis*

Embayment across the Eocene/Oligocene Boundary has been documented by Manning (2003).

Chondrichthyan Faunal Turnover and Extinction in the Gulf Coastal Plain: Evidence from Turkey Creek—Faunal assemblages from Gulf Coastal Plain localities such as Turkey Creek provide some general patterns by which chondrichthyan evolution at the genus-level and higher order taxonomy in the Cenozoic can be analyzed. Detailed species level chondrichthyan taxonomy is limited due to well-known and ongoing splitting and lumping problems (e.g., Fowler, 1911; Ward, 1988; Hubbell, 1996; Purdy et al., 2001; Hulbert, 2001; Cappetta and Nolf, 2005; Cappetta, 2012). Additional limitations cited by taphonomists include: areas of exposure, differential habitat preferences, and diagenesis (e.g., Brett and Baird, 1986; Kidwell, 1986; Behrensmeyer et al., 2000; Manning, 2003; Labs-Hochstein and MacFadden, 2006). It is also important to note that many Late Cretaceous and Cenozoic chondrichthyan assemblages from the Gulf Coastal Plain and throughout North America, including this report, derive from lag deposits

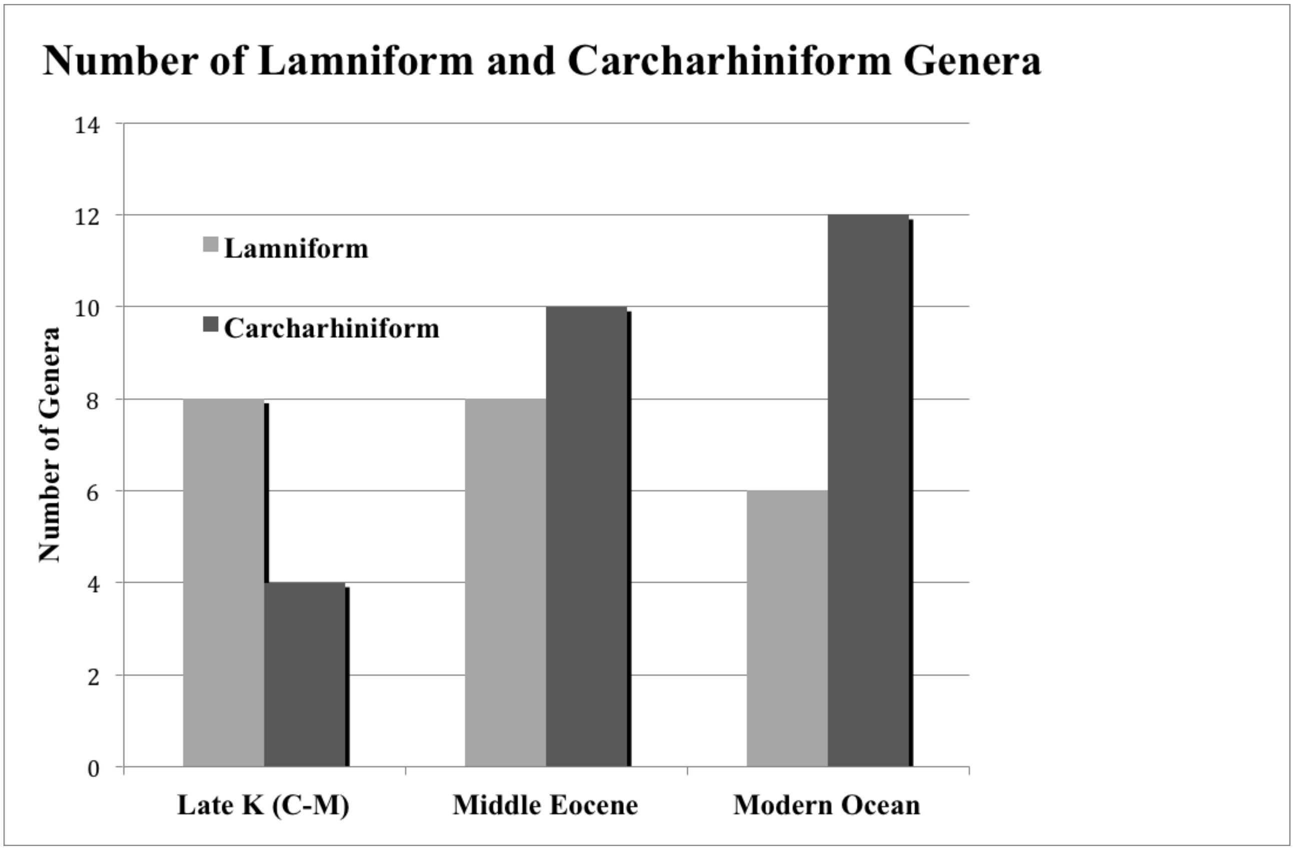

FIGURE 5. Graph displaying the number of lamniform and carcharhiniform genera from the Late Cretaceous (Campanian–Maastrichtian), middle Eocene, and modern Atlantic and Gulf coastal plains of the United States. Sources utilized: Gulf Coastal Plain (White, 1956; Westgate, 1989; 2001; 2008; Manning and Dockery, 1992; Welton and Farish, 1993; Case and Cappetta, 1997; Breard and Stringer, 1999; Clayton et al., 2013; This report). Atlantic Coastal Plain (Ward and Wiest, 1990; Gallagher, 1993; Hartstein et al., 1999; Case and Borodin, 2000a; Chamberlain et al., 2005). Modern Atlantic and Gulf Coastal Plains (Compagno, 1988; Compagno et al., 2005).

(e.g., Manning and Dockery, 1992; Becker et al. 1998; 2006; Breard and Stringer, 1999; Shimada et al., 2006; Clayton et al., 2013; Maisch et al., 2013). The degree of localized reworking during sea level fluctuation may be the products of episodic storm influence, shoreface bathymetry and coastline configuration (Kidwell, 1985; 1986; Morton, 1988; CoBabe and Allmon, 1994; Becker et al., 1996). In this regard, compilations of assemblages, such as those provided in Table 1, are time-averaged, middle Eocene snapshots of diversity trends of chondrichthyan genera across a given region such as the Gulf Coastal Plain (Flessa et al., 1993). Considering these limitations, chondrichthyans from middle Eocene Gulf Coastal plain localities cited and discussed in this report show: 1) an overall decrease in the number of lamniform genera compared to the Late Cretaceous; 2) an overall increase in the number of carcharhiniform genera compared to the Late Cretaceous; and 3) the appearance large sharks, with large teeth, belonging to the genus *Carcharodon* (See Figure 5).

Reports on county to state-wide Late Cretaceous chondrichthyan assemblages in the Gulf Coastal Plain list numerous lamniform genera. Conversely, only several genera of carcharhiniforms have been reported from these same localities and many well-known Late Cretaceous localities report none (e.g., Manning and Dockery, 1992; Welton and Farish, 1993; Gallagher, 1993; Case and Cappetta, 1997; Hartstein et al., 1999; Chamberlain et al., 2005). By the middle Eocene, many chondrichthyan assemblages like those reported in Table 1, document lamniform diversity loss and contain an almost equal number of lamniform and carcharhiniform genera (e.g., White, 1956; Westgate, 1989; 2001; 2008; Ward and Wiest, 1990; Breard and Stringer, 1999; Case and Borodin, 2000a; Clayton et al., 2013; This report; Figure 5). This pattern has continued through to the modern Atlantic Ocean and Gulf of Mexico (Compagno, 1988; Compagno et al., 2005).

Over the last two decades, the evolution of *Carcharodon* in North American and global localities has been intensely studied (e.g., Dockery and Manning, 1986; Uyeno et al., 1989; Kent, 1994; Gottfried et al., 1996; Hubbell, 1996; Applegate and Espinosa-Arrubarrena, 1996; Purdy, 1996; Purdy et al., 2001; Hulbert, 2001; Freile et al., 2001; Gottfried and Fordyce, 2001; Renz, 2002; Nyberg et al., 2006; Ehret et al., 2009; 2012; Cappetta, 2012). Intense debate still exists with regard to *Megalodon* ancestry and the usage of the genera, *Carcharodon*, *Carcharocles*, *Megaselachus*, and *Otodus*. However, the generally accepted evolutionary history links *Cretalamna appendiculata* in the Late Cretaceous with the intermediate middle Eocene form, *Carcharodon auriculatus*, seen in the Turkey Creek assemblage and throughout the Atlantic and Gulf coastal plains, to *Carcharodon megalodon*'s last appearance in the Pliocene. A summation of this debate is as follows: 1) Casier (1960) concluded that the mega-tooth line from *Carcharodon auriculatus-Carcharodon megalodon* was not related to the modern white shark, *Carcharodon carcharias* (Linnaeus, 1758), and erected the genus *Procarcharodon* for species with large teeth and fine serrations and the genus *Palaeocarcharodon* for Paleocene species with smaller teeth and larger serrations. 2) *Procarcharodon* was challenged by Glickman (1964), who attributed the Eocene–Oligocene teeth of *Carcharodon auriculatus* and *Carcharodon angustidens*, containing coarser serrations and larger lateral cusplets, to *Otodus obliquus*. This superficial grouping resulted in the creation of the genus *Megaselachus* Glickman (1964) for large teeth with regular serrations and lack of lateral cusplets. However, studies have shown some teeth of *Carcharodon* sp., including *Carcharodon carcharias*, to have lateral cusplets in early and later development, making Glickman's classification method unwarranted. Additional work by Purdy et al. (2001), using reconstructed tooth sets of both *Otodus* and *Carcharodon*, has documented greater morphological differences between the teeth of these genera than previously assumed. 3) Jordan and Hannibal (1923) created the genus *Carcharocles* for teeth with large, serrated cusplets. Cappetta (1987) synonymized *Procarcharodon* and *Megaselachus* with *Carcharocles* and 4) Cappetta (2012) further revised mega-toothed shark nomenclature (sensu Zhelezko and Kozlov, 1999) and grouped *Carcharocles* and *Megaselachus* with *Otodus*. Ehret et al. (2012) described an articulated dentition from Peru and erected the species *Carcharodon hubbelli* for a transitional species between broad-toothed mako sharks (*Carcharodon hastalis*) and the great white shark (*Carcharodon carcharias*) and also interpreted the *Megalodon* lineage as belonging to *Otodus*. Applegate (1967) and Compagno (1988) documented that serrations have developed several times in sharks and that the loss of lateral cusplets is a general evolutionary trend. This inhibits the use of these characteristics in the construction of phylogenetic scenarios (Purdy et al., 2001). Although controversy exists regarding the exact phylogeny, data indicate that the total body length and tooth size of *Carcharodon* increased throughout the Cenozoic (e.g., Gottfried et al., 1996; Applegate and Espinosa-Arrubarrena, 1996; Purdy et al., 2001). These evolutionary changes in body and tooth size are thought to reflect middle Cenozoic climatic cooling and predation on larger marine mammals (e.g., Purdy, 1996; Hulbert et al., 1998; Uhen, 1998; 1999; Noriega et al., 2007; Berger, 2007; Weems et al., 2011).

We interpret the composition of the Turkey Creek chondrichthyan assemblage to represent evolutionary changes created by the Cretaceous–Paleogene mass extinction, shallow marine habitat losses and climate cooling. By the middle Eocene, Kriwet and Benton (2004) documented the global recovery of chondrichthyan communites after the Cretaceous–Paleogene mass extinction event. Their research indicates six widespread lamniform families go extinct along with the genera *Scapanorhynchus*, *Paranomotodon*, *Archaeolamna*, and *Squalicorax*. These families were replaced by those with similar ecological roles and include the appearance of the Carcharhinidae, Isuridae, and Torpedinidae (Kriwet and Benton, 2004). The Carcharhinidae or requiem sharks are the most abundant genera and commonly occurring teeth in the Turkey Creek assemblage.

Paleoshoreline reconstructions of the Late Cretaceous indicate that a shallow, marine seaway extended hundreds of kilometers inland and covered more than half the state of Alabama (Smith et al., 1994; Kennedy et al., 1998). Late Cretaceous chondrichthyans occurring in Alabama have been found throughout the Atlantic and Gulf Coastal plain states as well as the Western Interior Seaway (e.g., Cappetta and Case, 1975; Gallagher et al., 1986; Case and Schwimmer, 1988; Manning and Dockery, 1992; Welton and Farish, 1993; Hoganson et al., 1996; 1997; Case and Cappetta, 1997; Cicimurri, 1998; Becker et al., 1998; 2006; Hartstein et al., 1999; Hoganson and Murphy, 2002). By the middle Eocene, this shallow marine habitat had been drastically reduced to a small region within the Mississippi Embayment and a marine shelf that fringed the Atlantic and Gulf coastal plains (e.g., Toulmin and La Moreaux, 1963; Ward et al., 1978; Case and

Borodin, 2000a; Bybell and Gibson, 1985; Ward and Wiest, 1990; Mancini and Tew, 1994; Ivany, 1998; Smith et al., 1994; Savrda et al., 2005; 2010; Miller et al., 2008; Maisch et al., 2013). The Turkey Creek chondrichthyans existed as earth's climate transitioned between greenhouse and ice house conditions and experienced carbon dioxide levels more than twice that of the modern times (Norris et al., 2013). Continental glaciation of Antarctica and cooling of the Arctic may have begun in the early Eocene and was responsible for global sea level regression (Pagani et al., 2011; Pearson et al., 2009; Liu et al., 2009). The Alabama Coastal Plain provides an excellent record for studying late Mesozoic and Cenozoic chondrichthyan evolution during substantial sea level lowering and climate changes. Future investigations are necessary to determine how a rapidly warming modern world may again determine the direction of chondrichthyan evolution in local, regional and global populations.

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LITERATURE CITED

Adnet, S. 2006. Nouvelles faunes de Sélaciens (Elasmobranchii, Neoselachii) de l'Éocène moyen des Landes (Sud−Ouest, France). Implication dans la connaissance des communautés de sélaciens d'eaux profondes. Palaeo Ichthyologica 10:5–128.

Adnet, S., P. Antoine, S. Hassan Baqri, J. Crochet, L. Marivaux, J. Welcomme, and G. Métais. 2007. New tropical carcharhinids (Chondrichthyes, Carcharhiniformes) from the late Eocene–early Oligocene of Balochistan, Pakistan: paleoenvironmental and paleogeographic implications. Journal of Asian Earth Sciences 30:303–323.

Adnet, S., and H. Cappetta. 2008. New fossil Triakidae (chondrichthyes, carcharhiniformes) from the Upper Ypresian of Prémontré (Aisne, France) with comments on the fossil record of family. Acta Palaeontologica Polonica 53:433–448.

Adnet, S., H. Cappetta, and R. Tabuce. 2010. A Middle–Late Eocene vertebrate fauna (marine fish and mammals) from southwestern Morocco; preliminary report: age and palaeobiogeographical implications. Geological Magazine 147:860–870.

Adnet, S., H. Cappetta, S. Elnahas, and A. Strougo. 2011. A new Priabonian chondrichthyans assemblage from the Western desert, Egypt: correlation with the Fayum oasis. Journal of African Earth Sciences 61:27–37.

Agassiz, L. 1833-1844. Recherches sur les Poissons fossiles. Imprimerie de Petitpierre. Neuchâtel and Soleure, Switzerland, 1-5, 1,420 pp.

Ameghino, F. 1906. Les formations sédimentaires du Crétacé Supérieur et du Tertiaire de Patagonie avec un parallelé entre leurs faunes mammalogiques et celles de l'ancien continent. Anales del Museo Nacional de Buenos Aires (tercera serie) 8:1–568.

Antunes, M., A. Balbino, and H. Cappetta. 1999. Sélaciens du Miocène terminal du bassin d'Alvalade (Portugal) Essai de synthèse. *Ciências da Terra* 13: 115–129.

Applegate S. 1967. A survey of shark hard parts; pp. 37–65 in P. Gilbert, R. Mathewson, and D. Rall (eds.) Sharks, Skates, and Rays. Baltimore, Johns Hopkins.

Applegate, S., and L. Espinosa-Arrubarrena. 1996. The fossil history of *Carcharodon* and its possible ancestor, *Cretolamna*: A study in tooth identification. Pp. 19–36 in A. Klimley and D. Ainley (eds.), Great White Sharks: The Biology of *Carcharodon carcharias*. Academic Press, San Diego.

Arambourg, C. 1935. Poissons fossiles du Bassin serimentarie du Gabon (avec la Collaboration de D. Schneegans). Annales de Paléontologie. Invertébrés 24:139–160.

Arambourg, C. 1952. Les Vertébrés fossiles des Phosphates (Maroc-Algerie-Tunisie). Service Géologique Maroc. Notes and Mémoirs 92:372 pp.

Bandy, O. 1949. Eocene and Oligocene foraminifera from Little Stave Creek, Clarke County, Alabama. Bulletin of American Paleontology 32:210 pp.

Becker, M., W. Slattery, and J. Chamberlain Jr. 1996. Reworked Campanian and Maastrichtian macrofossils in a sequence bounding, transgressive lag deposit, Monmouth County, New Jersey. Northeast Geology and Environmental Science 18:234–252.

Becker, M., W. Slattery, and J. Chamberlain Jr. 1998. Mixing of Santonian and Campanian chondrichthyan and ammonite macrofossils along a transgressive lag deposit, Greene

County, western Alabama. Southeastern Geology 7:1–12.

Becker, M., J. Chamberlain Jr., and G. Wolf. 2006. Chondrichthyans from the Arkadelphia Formation (Upper Cretaceous: late Maastrichtian) of Hot Spring County, Arkansas. Journal of Paleontology 80:700–716.

Becker, M., R. Chamberlain, and J. Chamberlain Jr. 2007. Large carcharhinoid-type shark vertebrae in the Upper Cretaceous of New Jersey: evidence for an anacoracid origin. Northeastern Geology and Environmental Science 30:118–129.

Becker, M., L. Smith, and J. Chamberlain Jr. 2011. Chondrichthyans from the Clayton Limestone Unit of the Midway Group (Paleogene: Paleocene) of Hot Spring County, Arkansas. Cainozoic Research 8:1–15

Becker, M., and J. Chamberlain Jr. 2012. *Squalicorax* chips a tooth: a consequence of feeding-related behavior from the lowermost Navesink Formation (Late Cretaceous: Campanian–Maastrichtian) of Monmouth County, New Jersey, U.S.A. Geosciences 2:109–129.

Behrensmeyer, A., S. Kidwell, and R. Gastaldo. 2000. Taphonomy and paleobiology. Paleobiology, 26: 103–147.

Berg, L. 1958. System rezenten und fossilen Fischartigen und Fisch, Hochschulbücher für Biologie, Berlin 4:1–310.

Berger, W. 2007. Cenozoic cooling, Antarctic nutrient pump, and the evolution of whales. Deep-Sea Research II 54:2399–2421.

Bigelow, H., and W. Schroeder, W. 1953. Sawfishes, guitarfishes, skates, and rays. Memoir of the Sears Foundation for Marine Research 1: xv + 588 pp., 127 figures.

Blainville, H.D. 1816. Prodrome d’une nouvelle distribution systematique de regne animal. Bulletin de Sciences de la Société Philomatique de Paris part 8:113–124.

Blainville, H.D. 1818. Sur les ichthyolites ou les poissons fossils. Nouveau Dictionnaire d’Histoire Naturelle 37:310–395.

Blanco-Piñon, A., K. Shimada, and Gonzalez-Barba, G. 2005. Lamnoid vertebrae from the Agua Nueva Formation (Upper Cretaceous: Lower Turonian), northeastern Mexico. Revista Mexicana de Ciencias Geológicas, Universidad Nacional Autónoma de Mexico 22:19-23.

Bonaparte, C. 1832–1841. Iconografia della fauna Italica, per le quattro classi degli animali vertebrati. 3 (Pesci). Rome, Tipographia Salviucci, 78 color plates.

Bonnaterre, J. 1788. Tableau encyclopedique et methodique de trios regnes de la Nature. Ichthyologie. Panckoucke, Paris LVI+251pp.

Bor, T. 1985. Elasmobranch teeth (Vertebrata, Pisces) from the Dongen Formation (Eocene) in the Netherlands. Mededelingen van de Werkgroep voor Tertiaire en Kwartaire Geologie 22:73–122.

Bor T., T. Reinecke, and S. Verschueren. 2012. Miocene Chondrichthyes from Winterswijk – Miste, the Netherlands. Palaeontos 21:136pp.

Breard, S., Jr. 1991. Paleoecology of a late Eocene (Bartonian) vertebrate fauna, Moodys Branch Formation, Techeva Creek, Mississippi. Transactions of the Gulf Coast Association of Geological Societies 41:43–55.

Breard, S., and G. Stringer. 1995. Paleoenvironment of a diverse marine vertebrate fauna from the Yazoo Clay (Late Eocene) at Copenhagen, Caldwell Parish, Louisiana. Transactions of the Gulf Coast Association of Geological Societies 45:77–85.

Breard, S., and G. Stringer. 1999. Integrated paleoecology and marine vertebrate fauna of the Stone City Formation (middle Eocene), Brazos River section, Texas. Transactions of the Gulf Coast Association of Geological Societies 49:132–142.

Brett, C., and G. Baird. 1986. Comparative taphonomy: a key to paleoenvironmental interpretation based on fossil preservation. Palaios 1:207–227.

Buckland, W. 1837. Geology and Mineralogy considered with special reference to natural theology. University of Oxford, London 1–580.

Burris, J. 2001. Reworked Cretaceous elasmobranch teeth and provenance of the Paleocene Hanna Formation (Hanna Basin, Wyoming). Rocky Mountain Geology 36:37–48.

Bybell, L., and T. Gibson. 1985. The Eocene Tallahatta Formation of Alabama and Georgia: Its lithostratigraphy, biostratigraphy, and bearing on the age of the Claiborne Stage. U.S. Geological Survey Bulletin B 1615, p 1–20.

Cappetta, H. 1970. Les sélaciens du Miocène de la région de Montpellier. Paleovertebrata, Mémoire extraodinaire, 139pp.

Cappetta, H. 1973. Les selaciens du Burdigalien de Lespignan (Herault). Geobios 6:211–223.

Cappetta, H. 1980. Modification du statut générique de quelques espèces de sélaciens crétacés et tertiares. Palaeovertebrata 10:29–42.

Cappetta, H. 1987. Chondrichthyes (Mesozoic and Cenozoic Elasmobranchii) in H. Schultze (ed.), Handbook of Paleoichthyology, Gustav Fisher Verlag, Stuttgart Vol. 3B pp. 193.

Cappetta, H. 2012 Chondrichthyes (Mesozoic and Cenozoic Elasmobranchii: Teeth) in H. Schultze (ed.), Handbook of Paleoichthyology, Vol. 3E pp. 512. München: Verlag F. Pfeil.

Cappetta, H., and G. Case. 1975. Contributions a l' etude des sélaciens du groupe Monmouth (Campanian-Maastrichtian) du New Jersey. Paleontographica 5:146 pp.

Cappetta, H., and D. Nolf. 2005. Revision de quelques Odontaspidae (Neoselachii: Lamniformes) du Paleocene et de l'Eocene du Bassin de la mer du Nord. Bulletin de l'institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre 75:237–266.

Case, G. 1967. The Eocene fossils of the Aquia Formation (Virginia). Earth Science 20:211–214.

Case, G. 1980. A selachian fauna from the Trent Formation; lower Miocene (Aquitanian) of eastern North Carolina. Palaeontographica A 171:75–103.

Case, G. 1981. Late Eocene selachians from South-Central Georgia. Palaeontographica Abt.A, Bd. 176:52–79.

Case, G. 1994. Fossil fish remains from the Late Paleocene Tuscahoma and Early Eocene Bashi Formations of Meridian, Lauderdale County, Mississippi. Palaeontographica Abt. A 230:97–138.

Case, G. and D. Schwimmer. 1988. Late Cretaceous fish from the Blufftown Formation (Campanian) in western Georgia. Journal of Paleontology 62:290–301.

Case, G., and H. Cappetta. 1990. The Eocene selachian fauna from the Fayum Depression in Egypt. Palaeontographica Abteilung A, Paläozoologie-Stratigraphie 212:1–30.

Case, G., and R. West. 1991. Geology and paleontology of the Drazinda Shale Member of the Khirthar Formation, Central Western Pakistan; Part II Late Eocene fishes. Tertiary Research 12:105–120.

Case, G., N. Udovichenko, L. Nessov, A. Averianov, and P. Borodin. 1996. A Middle Eocene selachian fauna from the White Mountain Formation of the Kizylkum Desert, Uzbekistan, C.I.S. Palaeontographica A 242:99–126.

Case, G., and H. Cappetta. 1997. A new selachian fauna from the late Maastrichtian of Texas. Münchener Geowissenschaften Abhandlungen 34:131–189.

Case, G., and P. Borodin. 2000a. A Middle Eocene selachian fauna from the Castle Hayne Limestone Formation of Duplin County, North Carolina. Munchner Geowissenschaften Abhandlungen 39:17–32.

Case, G., and P. Borodin. 2000b. Late Eocene selachians from the Irwington Sand Member of the Barnwell Formation (Jacksonian) WKA Mines, Gordon, Wilkinson County, Georgia. Munchner Geowissenschaften Abhandlungen 39:5–16.

Casier, E. 1946. La faune ichthyologique de l'Yprésien de la Belgique. Mémoire du Musée royale d' Histoire naturelle de Belgique 104:1–267.

Casier, E. 1960. Note sur la collection des poissons paléocènes et éocènes de l'Enclave de Cabinda (Congo). Annales du Musée Royal du Congo Belge series A. 3(1)2:1–48.

Chaffee, R. 1939. A new eagle ray from the lower Eocene of New Jersey. Notulae naturae of the Academy of Natural Sciences of Philadelphia 30:1–4.

Chamberlain, J., Jr., M. Becker, and M. Garb. 2005. Sharks from the basal Hornerstown Formation, Monmouth County, New Jersey: implications for a severe chondrichthyan extinction at or near the K/T boundary. Geological Society of America Abstracts with Programs 37:82.

Chandler, R., and J. Timmerman. 1995. Cretaceous and Paleogene fossils of North Carolina: a field guide. North Carolina Fossil Club 70pp.

Chandler, R., and J. Timmerman. 1997. Neogene fossils of North Carolina: a field guide. North Carolina Fossil Club 42 pp.

Cicimurri, D. 1998. Fossil elasmobranchs of the Cretaceous System (Neocomian Maestrichtian), Black Hills Region, South Dakota and Wyoming. Unpublished M.S. thesis, South Dakota School of Mines and Technology, Rapid City, 197 pp.

Cicimurri, D. 2007. A partial rostrum of the sawfish *Pristis lathami*, from the Eocene of South Carolina. Journal of Paleontology 81:597–601.

Cicimurri, D., and J. Knight. 2009. Late Oligocene sharks and rays from the Chandler Bridge Formation, Dorchester County, South Carolina, USA. Acta Palaeontologica Polonica 54:627–647.

Clayton, A., C. Ciampaglio, and D. Cicimurri. 2013. An inquiry into the stratigraphic occurrence of a Claibornian (Eocene) vertebrate fauna from Covington County, Alabama. Bulletin of the Alabama Museum of Natural History 31:60–73.

CoBabe, E., and W. Allmon. 1994. Effects of sampling on paleoecologic and taphonomic analyses in high-diversity fossil accumulations; an example from the Eocene Gosport Sand, Alabama. Lethaia 27:167–178.

Compagno, L. 1973. Interrelationships of living elasmobranchs. Journal of the Linnean Society (Zoology) 53:63–98.

Compagno, L. 1977. Phyletic relationships of living sharks and rays. American Zoologist 17:303–322.

Compagno, L. 1988. Sharks of the order *Carcharhiniformes*. Princeton, New Jersey. Princeton University Press. 486 pp. and 35 plates.

Compagno, L., M. Dando, and S. Fowler. 2005. A field guide to the sharks of the world. Harper and Collins Publishers Ltd., London. 368 pp.

Cook, T., A. Murray, E. Simons, Y. Attia, and P. Chatrath. 2010. A Miocene selachian fauna from Moghra, Egypt. Historical Biology 22:78-87.

Cuvier, G. 1817. Le Règne animal distribué d'après son organisation, pour servir de base à l'histoire naturelle des animaux et d'introduction à l'anatomie comparée 1–4.

Cuvier, G. 1829. Le Règne Animal, distribué d'après son organisation, pour servir de base à l'histoire naturelle des animaux et d'introduction à l'anatomie comparée. Règne Animal 2 (2) i-xv + 1–406.

Cunningham, S. 2000. A comparison of isolated teeth of early Eocene *Striatolamia macrota* (Chondrychthyes, Lamniformes), with those of a Recent sand shark, *Carcharias Taurus*. Tertiary Research 20:17-31.

Dockery, D., III, and E. Manning. 1986. Teeth of the giant white shark *Carcharodon auriculatus* from the Eocene and Oligocene of Mississippi. Mississippi Geology 7:7–19.

Eastman, C. 1904. Pisces, in Maryland Geological Survey: Miocene. Baltimore: Johns Hopkins University Press. I-clv+543 pp.

Eaton, J., J. Kirkland, and K. Doi. 1989. Evidence of reworked Cretaceous fossils and their bearing on the existence of Tertiary dinosaurs. Palaios 4:281–286.

Ehret, D., G. Hubbell, and B. MacFadden. 2009. Exceptional preservation of the white shark *Carcharodon* (Lamniformes, Lamnidae) from the early Pliocene of Peru. Journal of Vertebrate Paleontology 29:1–13.

Ehret, D., B. MacFadden, D. Jones, T. Devries, D. Foster, and R. Salas-Gismondi. 2012. Origin of the white shark Carcharodon (Lamniformes: Lamnidae) based on recalibration of the upper Neogene Pisco Formation of Peru. Palaeontology 55:1139–1153.

Feldmann, R., and R. Portell. 2007. First Report of *Costacopluma* Collins and Morris, 1975 (Decapoda: Brachyura: Retroplumidae)from the Eocene of Alabama, U.S.A. Journal of Crustacean Biology 27:90–96.

Fernandes dos Reis, M. 2005. Chondrichthyan fauna from the Pirabas Formation, Miocene of Northern Brazil, with comments on paleobiogeography. Anuário do Instituto de Geociências 28:31–58.

Ferrusquía-Villafranca, I., S. Applegate, and L. Espinosa-Arrubarrena. 1999. First Paleogene selachifauna of the middle American-Caribbean-Antillean region, La Mesa de Copoya, West-Central Chiapas, Mexico, systematics and paleontological significance. Revista Mexicana de Ciencias Geológicas, Universidad Nacional Autónoma de México, Instituto de Geología; y Sociedad Geológica Mexicana México, D.F. 16:155–174.

Ferrusquía-Villafranca, I., S. Applegate, and L. Espinosa-Arrubarrena. 2000. First Paleogene selachifauna of the middle America-Caribbean-Antillean region, La Mesa de Copoya, West-Central Chiapas-geologic setting. Revista Mexicana de Ciencias Geológicas, Universidad Nacional Autónoma de México, Instituto de Geología, México, D.F. 17:1–23.

Flessa, K., A. Cutler, and K. Meldahl. 1993. Time and taphonomy: quantitative estimates of time-averaging and stratigraphic disorder in a shallow marine habitat. Paleobiology 19:266–286.

Fowler, H. 1911. A description of the fossil fish remains of the Cretaceous, Eocene and Miocene formations of New Jersey. New Jersey Geological Survey Bulletin 4:1–192.

Freess, W. 1992. Haie, rochen und chimären aus dem mitteloligozänen Meeressand von Leipzig. Aufschluss 43:195–214.

Freile, D., M. Devore, and D. Parmley. 2001. The first report of *Carcharocles auriculatus* from the Oligocene of Georgia in the context of previous Gulf coast records. Georgia Journal of Science 59:128–136.

Gallagher, W. 1993. The Cretaceous–Tertiary mass extinction event in the northern Atlantic Coastal Plain. The Mosasaur 5:75–154.

Gallagher, W., D. Parris, and E. Spamer. 1986. Paleontology, biostratigraphy, and depositional environments of the Cretaceous–Tertiary transition in the New Jersey coastal plain. The Mosasaur 3:1–35.

Garman, S. 1908. New Plagiostomia and Chismopnea. Bulletin of the Museum of Comparative Zoology 51:249–256.

Garman, S. 1913. The Plagiostomia. Memoirs of the Museum of Comparative Zoology at Harvard College 36: 578 pp. and plates 1–75.

Gibbes, R. 1849. Monograph of the fossil squalidae of the United States. Journal of the Academy of Natural Sciences of Philadelphia series 2, 1:139–147, 191–206, plates 18–21, 25–27.

Gilbert, C., and J. Williams. 2002. National Audubon Society Field Guide to Fishes: North America, Knopf, 607 pp.

Gill, T. 1862. Analytical synopsis of the order Squali; and revision of the nomenclature of the genera. Annals of the Lyceum Natural History of New York 7:371–408.

Gille, D., A. Gille, and J. Fichter. 2010. Verbreitung und Zusammensetzung der Elasmobranchierfauna im Kasseler Meeressand (Oberligozän, Chattium, Kassel-Formation) Nordhessens, insbesondere im Ahnetal bei Kassel (GK25, Bl. 4622 Kassel West). Geologisches Jahrbuch Hessen 136:5–33.

Gillette, D. 1984. A marine ichthyofauna from the Miocene of Panama, and the Tertiary Caribbean faunal province. Journal of Vertebrate Paleontology 4:172–186.

Glickman, L. 1964. Sharks of Paleogene and their stratigraphic significance. Nauka Press. Moscow, 229 pp.

Gottfried, M., L. Compagno, and C. Bowman. 1996. Size and skeletal anatomy of the giant ‘‘megatooth’’ shark *Carcharodon megalodon*. Pp. 55–66 in A. Klimley and D. Ainley (eds) Great white sharks: the biology of *Carcharodon carcharias*. San Diego, CA, USA: Academic Press.

Gottfried, M., and R. Fordyce. 2001. An associated specimen of *Carcharodon angustidens* (Chondrichthyes, Lamnidae) from the late Oligocene of New Zealand, with comments on *Carcharodon* interrelationships. Journal of Vertebrate Paleontology 21:730–739.

Gunnell, G. (ed.) 2001. Eocene biodiversity: unusual occurrences and rarely sampled habitats. Kluwer Academic/Plenum Publishers, New York. 442 pp.

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

Hartstein, E., L. Decina, and R. Keil. 1999. A Late Cretaceous (Severn Formation) vertebrate assemblage from Bowie, Maryland. The Mosasaur 6:17–24.

Hay, O. 1902. On a collection of Upper Cretaceous fishes from Mount Lebanon, Syria, with descriptions of four new genera and nineteen new species. Bulletin of the American Museum of Natural History 19:395–452.

Herman, J., M. Hovestadt-Huler, D. Hovestadt, and M. Stehmann. 2000. Contributions to the study of the comparative morphology of teeth and other relevant ichthyodorulites in living superaspecific taxa of Chondrichthyan fishes. Part B: Batomorphii 4c: Order: Rajiformes-Suborder Myliobatoidei-Superfamily Dasyatoidea-Family Dasyatididae-Subfamily Dasyatinae-Genus: *Urobatis*, Subfamily Potamotrygoninae-Genus: *Pomatotrygon*, Superfamily Plesiobatoidea-Family Plesiobatidae-Genus: *Plesiobatis*, Superfamily Myliobatoidea-Family Myliobatidae Subfamily Myliobatinae- Genera: *Aetobatus*, *Aetomylaeus*, *Myliobatis*, and *Pteromylaeus*, Subfamily Rhinopterinae-Genus: *Rhinoptera* and Subfamily Mobulinae-Genera: *Manta* and *Mobula*. Addendum 1 to 4a: erratum to Genus *Pteroplatytrygon*. Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Biologie 70:5–67.

Hoganson, J., M. Erickson, and F. Holland. 1996. Vertebrate paleontology of the Timber Lake Member, Fox Hills Formation (Maastrichtian), North Dakota. Journal of Vertebrate Paleontology 16:41A.

Hoganson, J., M. Erickson, A. Cvancara, and F. Holland. 1997. Terminal Cretaceous extinction event documented by marine cartilaginous fishes from the Fox Hills (Maastrichtian) and Cannonball (Danian/ Thanetian) formations, North Dakota. Geological Society of America Abstracts with Programs 17:53A.

Hoganson, J., and E. Murphy. 2002. Marine Breien Member (Maastrichtian) of the Hell Creek Formation in North Dakota: stratigraphy, vertebrate fossil record, and age. Pp. 247–269 in J. Hartmann, K. Johnson, and D. Nichols (eds.), The Hell Creek Formation and the Cretaceous–Tertiary Boundary in the Northern Great Plains: an integrated record of the end of the Cretaceous. Geological Society of America Special Paper 361.

Holec P., M. Hornáček, and M. Sýkora. 1995. Lower Miocene shark (Chondrichthyes, Elasmobranchii) and whale faunas (Mammalia, Cetacea) near Mučín, Southern Slovakia. Geologické Práce, Správy 100:37–52.

Holman, J., and G. Case. 1988. Reptiles from the Eocene Tallahatta Formation of Alabama. Journal of Vertebrate Paleontology 8:328–333.

Hubbell, G. 1996. Using tooth structure to determine the evolutionary history of the White Shark. Pp. 9–18 in A. Klimley and D. Ainley (eds.), Great White Sharks: The Biology of *Carcharodon carcharias*. Academic Press, San Diego.

Hulbert, R. (ed.). 2001. Fossil vertebrates of Florida. University Press of Florida Press, Gainesville, Florida. 350 pp.

Hulbert, R., R. Petkewich, G. Bishop, D. Burkry, and D. Aleshire. 1998. A new middle Eocene protocetid whale (Mammalia: Cetacea: Archaeoceti) and associated biota from Georgia. Journal of Paleontology 72:907–927.

Huxley, T. 1880. On the application on the laws of evolution to the arrangement of the vertebrata and more particularly of the Mammalia. Zoological Society of London, Scientific Memoirs 4:457–472.

Itturalde-Vinent, M., C. Mora, R. Rojas, and M. Gutierrez. 1998. Myliobatidae (Elasmobranchii: Batomorphii) del Terciario de Cuba. Review of the Mexicana Society of Paleontology 8:135–145.

Ivany, L. 1998. Sequence stratigraphy of the Middle Eocene Claiborne Stage, US Gulf Coastal Plain. Museum of Paleontology and Department of Geological Sciences University of Michigan 38:1–20.

Jaekel, O. 1895. Unter-Tertiäre selachier aus Süderrussland. Mem. Comité Géol. St. Petersbourg 9:19–35.

Jordan, D., and H. Hannibal. 1923. Fossil Sharks and Rays of the Pacific Slope of North America. Bulletin of the Southern California Academy of Sciences 22:27–63, plates 1-9.

Jordan, D., and B. Evermann. 1896. The fishes of North and Middle America: a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the Isthmus of Panama. Bulletin of U.S. National Museum 5:1240 pp.

Kemp, D., L. Kemp, and D. Ward. 1990. An illustrated guide to the British Middle Eocene vertebrates. London (Ward) 59 pp.

Kennedy, W., N. Landman, W. Christensen, W. Cobban, and J. Hancock. 1998. Marine connections in North America during the late Maastrichtian: palaeogeographic and palaeobiologic significance of *Jeletzkytes nebrascensis* zone cephalopod fauna from the Elk Butte Member of the Pierre Shale, SE South Dakota and NE Nebraska. Cretaceous Research 19:745–775.

Kent, B. 1994. Fossil sharks of the Chesapeake Bay Region. Egan, Rees and Boyer Publishers, Baltimore, Maryland, 146 pp.

Kent, B. 1999a. Sharks from the Fisher/Sullivan Site. Pp. 11–38 in R. Weems, and G. Grimsley (eds.), Early Eocene vertebrates and plants from The Fisher/Sullivan Site (Nanjemoy Formation) Stafford County, Virginia. Virginia Division of Mineral Resources 152.

Kent, B. 1999b. Rays from the Fisher/Sullivan Site. Pp. 39–52 in R. Weems, and G. Grimsley (eds.), Early Eocene vertebrates and plants from The Fisher/Sullivan Site (Nanjemoy Formation) Stafford County, Virginia. Virginia Division of Mineral Resources 152.

Kidwell, S. 1985. Palaeobiological and sedimentological implications of fossil concentrations. Nature, 318:457–460.

Kidwell, S. 1986. Models for fossil concentrations: paleobiologic implications. Paleobiology 12:6–24.

Kriwet, J. 2005. Additions to the Eocene selachian fauna of Antarctica with comments on Antarctic selachian diversity. Journal of Vertebrate Paleontology 25:1–7.

Kriwet, J., and M. Benton. 2004. Neoselachian (Chondrichthyes, Elasmobranchii) diversity across the Cretaceous–Tertiary boundary. Palaeogeography, Palaeoclimatology and Palaeoecology 214:181–194.

Labs-Hochstein, J., and B. MacFadden. 2006. Quantification of diagenesis in Cenozoic sharks: elemental and mineralogical changes. Geochimica et Cosmochimica Acta 70:4921–4932.

Lawley, R. 1876. Nuovi studi sopra ai pesci ed altri vertebrati fossili delle colline Toscane. Firenze, Tipografia dell' Arte della Stampa 1-122.

Leidy, J. 1877. Description of vertebrate remains, chiefly from the phosphate beds of South Carolina. Journal of the Academy of Natural Sciences of Philadelphia 2:209–261, plates 30–34.

Leriche, M. 1905. Les poisons tertiaires de la Belgique. II. Les poissons eocenes. Memoires Musee Royal d'Histoire Naturelle Beligique 11:49–228.

Leriche, M. 1942. Contribution à l'étude des faunes ichthyologiques marines des terrains Tertiaires de la Plaine Côtière Atlantique et du centre des Etats Unis. Mémoire de la Société Géologique de France 43:1–111.

Linck, H. 1790. Versuch einer Eintheilung der Fische nach den Za¨hnen. Magazin für das Neueste aus der Physik und Naturgeschichte 4:28–38.

Linnaeus, C. 1758. Systema Naturae per Regna Tria Naturae, Secundum Classes, Ordines, Genera, Species cum Characteribus, Differentiis, Synonymis, Locis. Tomus I. Editio decima, reformata. Stockholm 824 pp.

Liu, Z., M. Pagani, D. Zinniker, R. DeConto, M. Huber, H. Brinkhuis, S. Shah, R. Leckie, and A. Pearson. 2009. Global cooling during the

Eocene-Oligocene climate transition. Science 323:1187–1190.

Long, D. 1992. Sharks from the La Meseta Formation (Eocene) Seymour Island, Antarctic Peninsula. Journal of Vertebrate Paleontology 12:11–32.

Maisch, H., IV, M. Becker, and J. Chamberlain Jr. 2013. Chondrichthyan remains from the Shark River Formation (Middle Eocene) and Kirkwood Formation (Early Miocene) lag deposit Monmouth County, New Jersey. 73rd Meeting, Society of Vertebrate Paleontology, Los Angeles, California, Programs and Abstracts p. 169.

Mancini, E., and B. Tew. 1994. Claiborne-Jackson Group contact (Eocene) in Alabama and Mississippi. Gulf Coast Association of Geological Societies Transactions 44:431–439.

Manning, E. 1990. The late Early Miocene Sabine River. Transactions of the Gulf Coast Association of Geological Societies 40:531–549.

Manning, E. 2003. The Eocene/Oligocene transition in marine vertebrates of the Gulf Coastal Plain; pp. 366–385 in D. Prothero, L. Ivany, and E. Nesbitt (eds.), From Greenhouse to Icehouse, the marine Eocene-Oligocene transition. Columbia University Press, New York.

Manning, E., and B. Standhardt. 1986. Late Eocene sharks and rays of Montgomery Landing, Louisiana. Pp. 133–161 in J. Schiebout and W. van den Bold (eds), Montgomery Landing site, marine Eocene (Jackson) of central Louisiana. Gulf Coast Association of Geological Societies, Symposium Proceedings.

Manning, E., and D. Dockery III. 1992. A guide to the Frankstown vertebrate fossil locality (Upper Cretaceous), Prentiss County, Mississippi. Mississippi Department of Environmental Quality, Office of Geology Circular 4:43 pp.

McEachran, J., and C. Capapé. 1984. Myliobatidae; pp. 205–207 in P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielson, and E. Tortonese, Fishes of the North-eastern Atlantic and the Mediterranean. Paris: Unesco.

Miller, K., J. Browning, M. Aubry, B. Wade, M. Katz, A. Kulpecz, and J. Wright. 2008. Eocene–Oligocene global climate and sea-level changes: St. Stephens Quarry, Alabama. Geological Society of America Bulletin 120:34–53.

Minch, J., K. Schulte, and G. Hofman. 1970. A Middle Miocene age for the Rosarito Beach Formation in Northwestern Baja California, Mexico. Geological Society of America Bulletin 81:3149–3154, 2 figs.

Mitchill, S. 1815. The fishes of New York, described and arranged. Transactions of the Literary and Philosophical Society of New York 1:355–492.

Monsch, K. 1998. Miocene fish faunas from the northwestern Amazonia basin (Colombia, Peru, Brazil) with evidence of marine incursions. Palaeogeography, Palaeoclimatology, Palaeoecology 143:31–50.

Morton, R., 1988, Nearshore responses to great storms, GSA Special Papers 229:7–22.

Morton, S. 1834. Synopsis of the organic remains of the Cretaceous Group of the United States: Key and Biddle, Philadelphia, 88pp., 19 plates.

Müller, J., and J. Henle. 1837. On the generic characters of cartilaginous fishes with descriptions of new genera. Magazine of Natural History 2:1–91.

Müller, J., and J. Henle 1838-41 [1838]. Systematische Beschreibung der Plagiostomen. Berlin, n.p.

Nishida, K. 1990. Phylogeny of the suborder Myliobatoidei. Memoirs of the Faculty of Fisheries Hokkaido University, 37:1–108.

Noriega, J. A. Cione, and F. Aceńolaza. 2007. Shark tooth marks on Miocene balaenopterid cetacean bones from Argentina. Neues Jahrbuch fur Geologie und Paläeontologie. Abhandlungen 245:185–192.

Norris, R., S. Kirtland-Turner, P. Hull, and A. Ridgwell. 2013. Marine ecosystem responses to Cenozoic global change. Science 341:492–498.

Nyberg, K., Ciampaglio, C., and G. Wray. 2006. Tracing the ancestry of the great white shark, *Carcharodon carcharias*, using morphometric analyses of fossil teeth. Journal of Vertebrate Paleontology 26:806–814.

Olsen, S. 1964. The stratigraphic importance of a lower Miocene vertebrate fauna from North Florida. Journal of Paleontology 38:477–482.

Osborne, W., M. Szabo, C. Copeland, and T. Neathery. 1989. Geologic Map of Alabama: Geological Survey of Alabama, scale 1:500,000.

Otero, R., T. Torres, J. Le Roux, F. Hervé, C. Fanning, R. Yuri-Yáñez, and D. Rubilar-Rogers. 2012. A late Eocene age proposal for the Loreto Formation (Brunswick Peninsula, southernmost Chile), based on fossil cartilaginous fishes, paleobotany and radiometric evidence. Andean Geology 39:180–200.

Pagani, M., M. Huber, Z. Liu, S. Bohaty, J. Henderiks, W. Sijp, S. Krishnan, and R. DeConto. 2011. The role of carbon dioxide during the onset of Antarctic glaciation. Science 334:1264–1264.

Parmley, D., and D. Cicimurri. 2003. Late Eocene sharks of the Hardie Mine local fauna of

Wilkinson County, Georgia. Georgia Journal of Science 61:153–179.

Pearson, P., G. Foster, and B. Wade. 2009. Atmospheric carbon dioxide through the Eocene-Oligocene climate transition. Nature 461:1110–1113.

Pimiento, C., G. Gonzalez-Barba, D. Ehret, A. Hendy, B. MacFadden, and C. Jaramillo. 2013. Sharks and rays (chondrichthyes, elasmobranchii) from the late Miocene Gatun Formation of Panama. Journal of Paleontology 87:755–774.

Pledge, N. 1967. Fossil elasmobranch teeth of South Australia and their stratigraphic distribution. Transactions of the Royal Society of South Australia 91:135–160.

Purdy, R. 1996. Paleoecology of fossil white sharks. Pp. 67–78 in A. Kimley, and D. Ainley (eds.), Great White Sharks: the Biology of *Carcharodon carcharias*. San Diego, California: Academic Press.

Purdy, R. 1998a. Chondrichthyan fishes from the Paleocene of South Carolina. Transactions of the American Philosophical Society, New Series 88:122–146.

Purdy, R. 1998b. The Early Miocene fish fauna from the Pollack Farm Site, Delaware; pp. 133–139 in R. Benson (ed.), Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21.

Purdy, R., V. Schneider, S. Applegate, J. McLellan, R. Meyer, and R. Slaughter. 2001. The Neogene sharks, rays, and bony fish from Lee Creek Mine, Aurora, North Carolina. Pp. 71–202 in C. Ray and D. Bohaska (eds.) Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology, No. 90. Smithsonian Institution Press, Washington D.C.

Purdy, R., and M. Francis. 2007. Ontogenetic development of teeth in *Lamna nasus* (Bonnaterre, 1758) (Chondrichthyes: Lamnidae) and its implications for the study of fossil shark teeth. Journal of Vertebrate Paleontology 27:798–810.

Radwański, A. 1965. A contribution to the knowledge of Miocene elasmobranchii from Pinczow (Poland). Acta Palaeontologica Polonica 10:267–276, with 2 plates.

Rafinesque, C. 1810. Caraterri di alcuni nuovi generi e nuove specie di animali piante Della Sicilia. Palermo 105 pp.

Raymond, D., W. Osborne, C. Copeland, and T. Neathery. 1988. Alabama stratigraphy. Geologic Survey of Alabama, Circular 140 Tuscaloosa, Alabama p. 42, 83–84.

Renz, M. 2002. *Megalodon*: hunting the hunter. Paleopress. Leheigh Acres, Florida. 1–159 pp.

Rogers, C., C. Roden, R. Lohoefener, K. Mullin, and W. Hoggard. 1990. Behavior, distribution, and relative abundance of cownose ray schools *Rhinoptera bonasus* in the Northern Gulf of Mexico. Northeast Gulf Science 11:69–76.

Rogers, R., and S. Kidwell. 2000. Associations of vertebrate skeletal concentrations and discontinuity surfaces in terrestrial and shallow marine records: a test in the Cretaceous of Montana. Journal of Geology 108:131–154.

Sahni, A., and D. Mehrotra. 1981. The elasmobranch fauna of coastal Miocene sediments of peninsular India. Vertebrate Palaeontology Series, Biological Memoir 5:83–121.

Savrda, C., J. Counts, O. McCormick, R. Urash, J. Williams. 2005. Log-Grounds and *Teredolites* in transgressive deposits, Eocene Tallahatta Formation (Southern Alabama, USA). Ichnos 12:47–57.

Savrda, C., J. Counts, E. Bigham, and S. Martin. 2010. Ichnology of siliceous facies in the Eocene Tallahatta Formation (Eastern United States Gulf Coastal Plain): implications for depositional conditions, storm processes, and diagenesis. Palaios 25:642–655.

Shimada, K. 1997. Periodic marker bands in vertebral centra of the Late Cretaceous lamniform shark, *Cretoxyrhina mantelli*. Copeia 1997:233–235.

Shimada, K., and D. Cicimurri. 2005. Skeletal anatomy of the Late Cretaceous shark *Squalicorax*, (Neoselachii: Anacoracidae). Paläontologische Zeitschrift 79: 241–261.

Shimada, K., B. Schumacher, J. Parkin, and J. Palermo. 2006. Fossil marine vertebrates from the lowermost Greenhorn Limestone (Upper Cretaceous: Middle Cenomanian) in southeastern Colorado. Journal of Paleontology Memoir 63:1–45.

Siesser, W. 1983. Paleogene calcareous nannoplankton biostratigraphy Mississippi, Alabama, and Tennessee, Mississippi Department of Natural Resources Bureau Geology Bulletin 125:61 pp.

Smith, A., D. Smith, and B. Funnell. 1994. Atlas of Mesozoic and Cenozoic coastlines. Cambridge University Press, Cambridge, 109 pp.

Springer, S. 1964. A revision of the carcharhinid shark genera *Scoliodon*, *Loxodon*, and *Rhizoprionodon*. Proceedings of the U.S. Notational Museum 115:559–632.

Stevens, N., J. Eastman, S. Odunze, L. Cooper, and G. Obi. 2011. Paleocene ichthyofauna and paleoenvironmental setting, Imo Formation, southeastern Nigeria. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 260:289–296.

Stidham, T., and T. Janus. 2008. New vertebrates from the Paleogene of eastern Texas. Transactions of the Gulf Coast Association of Geological Societies, Extended Abstract, 58:853–855.

Storms, R. 1894. Trioisiéme note sur les poissons du terrain rupélian. Bulletin de la Société Belge de Géologié, de Paléontologie, et d'Hydrologie 8:67–82.

Stringer, G., and M. Miller. 2001. Paleoenvironmental interpretations based on vertebrate fossil assemblages: an example of their utilization in the Gulf Coast. Transactions-Gulf Coast Association of Geological Societies 51:329–338.

Stringer, G., S. Breard, and M. Kontrovitz. 2001. Biostratigraphy and paleoecology of diagnostic invertebrates and vertebrates from the type locality of the Oligocene Rosefield Marl Beds, Louisiana. Transactions of the Gulf Coast Association of Geological Societies 51:321–328.

Strougo, A., H. Cappetta, and S. Elnahas. 2007. A remarkable Eocene ichthyofauna from the ElGedida glauconitic sandstone, Bahariya Oasis, Egypt, and its stratigraphic implications. M.E.R.C. Ain Shams University, Earth Science Series 21:81–98.

Suarez, M., A. Encinas, and D. Ward. 2006. An early Miocene elasmobranch fauna from the Navidad Formation, Central Chile, South America. Cainozoic Research 4:3–18.

Szabo, M., E. Osborne, C. Copeland Jr., and T. Neathery. 1988. Geologic Map of Alabama, Geological Survey of Alabama Special Map 220, scale 1:250,000.

Tanaka, T., Y. Fujita, and S. Morinobu. 2006. Fossil shark teeth from the Namigata Formation in Ibara City, Okayama Prefecture, Central Japan and their biostratigraphical significance. Bulletin of the Mizunami Fossil Museum 33:103–109.

Thurmond, J., and D. Jones. 1981. Fossil vertebrates of Alabama. University of Alabama Press. Tuscaloosa, 244 pp.

Tomita, T., and T. Oji. 2010. Habitat reconstruction of Oligocene elasmobranchs from Yamaga Formation, Ashiya Group, western Japan. Paleontological Research 14:69–80.

Toulmin, L. 1977. Stratigraphic distribution of Paleocene and Eocene fossils in the eastern Gulf Coast region, Alabama Geological Survey, Monograph 13:602 pp.

Toulmin, L. and P. La Moreaux. 1963. Stratigraphy along Chattahoochee River, connecting link between Atlantic and Gulf coastal plains. Bulletin of the American Association of Petroleum Geologists, 47:385–404.

Tuomey, M. 1858. Descriptions and figures of *Ctenacanthus elegans*, *Cladodus newmani*, *C. magnificus*. Second biennial Report of the Geology of Alabama, J. W. Mallett (ed.), XIX + 292 pp.

Uhen, M. 1998. New protocetid (Mammalia, Cetacea) from the Late Middle Eocene Cook Mountain Formation of Louisiana. Journal of Vertebrate Paleontology 18:664–668.

Uhen, M. 1999. New Species of protocetid Archaeocete whale, *Eocetus wardii* (Mammalia: Cetacea) from the Middle Eocene of North Carolina. Journal of Paleontology 73:512–528.

Underwood, C., D. Ward, C. King, S. Antar, I. Zalmout, and P. Gingerich. 2011. Shark and ray faunas in the Middle and Late Eocene of the Fayum Area, Egypt. Proceeding of the Geological Association of London 122:47–66.

Uyeno, T., O. Sakamoto, and H. Sekine. 1989. Description of an almost complete tooth set of *Carcharodon megalodon* from a middle Miocene bed in Saitama Prefecture, Japan. Bulletin of the Saitama Museum of Natural History 7:73–85.

Van den Eeckhaut, G., and P. De Schutter. 2009. The elasmobranch fauna of the Lede Sand Formation at Oosterzele (Lutetian, Middle Eocene of Belgium). Palaeofocus 1: 57pp.

Ward, D. 1988. *Hypotodus verticalis* (Agassiz 1843), *Hypotodus robustus* Leriche (1921) and *Hypotodus heinzelini* (Casier 1967), Chondrichthyes, Lamniformes, junior synonyms of *Carcharias hopei* (Agassiz 1843). Tertiary Research 10:1–12. Leiden.

Ward, D., and R. Wiest. 1990. A checklist of Paleocene and Eocene sharks and rays (Chondrichthyes) from the Pamunkey Group, Maryland and Virginia, USA. Tertiary Research 12:81–88.

Ward, D., and C. Bonavia. 2001. Additions to, and a review of, the Miocene shark and ray fauna of Malta. The Central Mediterranean Naturalist 3:131–146.

Ward, L., D. Lawrence, and B. Blackwelder. 1978. Stratigraphic Revision of the Middle Eocene, Oligocene, and Lower Miocene Atlantic Coastal Plain of North Carolina: contributions to stratigraphy. United States Geological Survey, Bulletin 1457-F, 23pp.

Weems, R., L. Edwards, J. Osborne, and A. Alford. 2011. An occurrence of the protocetid whale *Eocetus wardii* in the middle Eocene Piney

Point Formation of Virginia. Journal of Vertebrate Paleontology 85:271–278.

Welton, B., and R. Farish. 1993. The collector's guide to fossil sharks and rays from the Cretaceous of Texas. Lewisville, Texas: Before Time, 204 pp.

Westgate, J. 1984. Lower Vertebrates from the Late Eocene Crow Creek Local Fauna, St. Francis County, Arkansas. Journal of Vertebrate Paleontology 4:536–546.

Westgate, J. 1989. Lower vertebrates from an estuarine facies of the Middle Eocene Laredo Formation (Claiborne Group), Webb County, Texas. Journal of Vertebrate Paleontology 9:282–294.

Westgate, J. 2001. Paleoecology and biostratigraphy of marginal marine Gulf Coast Eocene vertebrate localities. Pp. 263–397 in Gunnel, G. (ed.) Eocene Biodiversity: Unusual Occurences and Rarely Sampled Habitats. Kluwer Academic/ Plenum, New York.

Westgate, J. 2008. Vertebrates from a middle Eocene estuarine mangrove community in the Rio Grande Embayment. Geological Society of America Abstracts with Programs 40:3.

White, E. 1926. Eocene fishes from Nigeria. Bulletin of the Geological Survey of Nigeria 10:1–82.

White, E. 1955. Notes on African Tertiary Sharks. Bulletin of American Palaeontology 5:319–325.

White, E. 1956. The Eocene fishes of Alabama. Bulletin of American Palaeontology 36:123–152.

Whitley, G. 1929. Addition to the check list of the fishes of New South Wales. Australian Zoology 5:353–357.

Winkler, T. 1873. Mémoire sur des dents de poissons du terrain Bruxellien. Archives du Musée Teyler 3:10 pp.

Winkler, T. 1874. Deuxième Mémoire sur des dents de poisons du terrain Bruxellien. in: Archives du Musée Teyler, 1878. Vol. IV. Les Héritiers Loosjes, Haarlem, Belgium. pp. 16–48.

Woodward, A. 1889. Catalogue of the fossil fishes in the British Museum. British Museum of Natural History, London 1:474 pp.

Zhelezko V., and V. Kozlov. 1999. Elasmobranchii and biostratigraphy of the Palaeogene of the Trans-Urals and Middle Asia [in Russian]; pp. 1–324 in E. Amon (ed.), Materialy po stratigrafii i paleontologii Urala, 3. UrO RAN, Ekaterinburg