AN OCCURRENCE OF THE PROTOCETID WHALE “EOCETUS” WARDII IN THE MIDDLE EOCENE PINEY POINT FORMATION OF VIRGINIA

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ABSTRACT—Two protocetid whale vertebrae, here referred to “Eocetus” wardii, have been recovered from the riverbed of the Pamunkey River in east-central Virginia. Neither bone was found in situ, but both were found with lumps of lithified matrix cemented to their surfaces. Most of this matrix was removed and processed for microfossils. Specimens of dinoflagellates were successfully recovered and this flora clearly demonstrates that both vertebrae came from the middle Eocene Piney Point Formation, which crops out above and below river level in the area where the bones were discovered. These vertebrae are the oldest whale remains reported from Virginia and are as old as any cetacean remains known from the western hemisphere.

INTRODUCTION

The early record of whale evolution in North America is not well documented. The oldest fossil material from anywhere within the Atlantic and Gulf coastal plains is middle Eocene in age and is from the Blue Bluff unit of Georgia (Hulbert et al., 1998; Hulbert, 1998), the Santee Limestone of South Carolina (Albright, 1996; McLeod and Barnes, 2008), and the Castle Hayne Limestone of North Carolina (McLeod and Barnes, 1990, 1991, 1996, 2008; Uhen, 1999, 2001) (Fig. 1, Table 1). Slightly younger material, still of middle Eocene age, has been reported in South Carolina from the Cross Member of the Tupelo Bay Formation of Geisler et al. (2005), in Alabama from the upper Lisbon Formation (Uhen, 2008), in Mississippi from the Potchetterch Member of the Cook Mountain Formation (Uhen, 2008), and in Louisiana from the Milams Member of the Cook Mountain Formation (Uhen, 1998). Late Eocene whale fossils have been reported from the Atlantic Coastal Plain in the Harleyville Formation of South Carolina (Sanders, 1974), and Oligocene whale fossils have been reported from the Ashley and Chandler Bridge formations of South Carolina (Sanders et al., 1982; Weems and Sanders, 1986; Sanders and Barnes, 2002a, 2002b).

Farther north, in eastern Virginia, remains of Miocene and Pliocene fossil whales have been reported in the scientific literature since early in the nineteenth century (Mitchill, 1818; Lyell, 1842; Wyman, 1850; and numerous papers thereafter). No older material from this region has been reported until now, probably due to the very limited outcrops of appropriately aged sediments. Available evidence suggests that whales evolved in the India-Pakistan region and did not become sufficiently seaworthy to reach North America until sometime during the middle Eocene (Uhen, 1999; Geisler et al., 2005). Although early Eocene deposits of the Nanjemoy Formation are widespread in Virginia and Maryland, these deposits almost certainly are too old to contain cetacean remains. The only strata of an appropriate middle Eocene through Oligocene age that crop out in Virginia occur along a limited stretch of the lower, tidal portion of the Pamunkey River, where middle Eocene strata (Piney Point Formation) and lower Oligocene strata (Old Church Formation) are exposed, and on the south side of the upper tidal portion of the James River east of Hopewell, where the middle Eocene Piney Point Formation occurs (Ward, 1984). Upper Eocene deposits (the Chickahominy Formation) are known from Virginia (Powars and Bruce, 1999; Edwards et al., 2005), but they are deeply buried and therefore virtually inaccessible to exploration for cetacean remains. North of Virginia, beds of middle Eocene through late Oligocene age are known almost entirely from the subsurface of the coastal plain, except for a few middle Eocene outcrops along the Shark River in New Jersey (Self-Trail and Bybell, 1995).

This void in the early cetacean fossil record of the Virginia coastal plain now has been partly filled by the recovery of an anterior thoracic and a posterior lumbar cetacean vertebra of primitive aspect from the bottom of the Pamunkey River near Putneys Mill, about one mile north-northeast of Tunstall, Virginia. Although isolated bones and teeth have been recovered in this region by a number of divers in the past, nearly all of this material has been washed clean of its surrounding sediment, leaving no direct evidence of its stratigraphic context. In both vertebrae described here, however, indurated calcite-cemented quartz-glauconite sand matrix was attached to and partially encased the bones. This matrix, while complicating fossil preparation, was invaluable for microfossil study. In the Pamunkey River valley, calcite-cemented nodules can occur in the Nanjemoy, Piney Point, Old Church, and basal Calvert Formations, so it was important to try to ascertain precisely which stratigraphic unit yielded each specimen through microfossil recovery and analysis. To this end, matrix was removed from each vertebra and processed separately both for calcareous nannofossils and for dinoflagellates.

MICROFOSSIL RESULTS

Paleogene stratigraphic units in the Pamunkey River valley often yield abundant nannofossil floras (e.g., DiMarzio, 1984; Bybell and Gibson, 1994), but none were recovered from either sample discussed here. In all probability, the chemical processes that induced calcite-cementation in this material also resulted in recrystallization of any nannofossils that originally may have been present. In contrast, dinoflagellates were unharmed by the cementation process and yielded floras that, while not extremely abundant or diverse, nevertheless were stratigraphically diagnostic for each specimen. The flora recovered from each sample is shown in Table 2.

The sample from the posterior lumbar vertebra was more abundant and diverse than the sample recovered from the anterior thoracic vertebra, but both were adequate to show that their contained flora is middle Eocene (late Lutetian to Bartonian) in age. In eastern Virginia, the only outcropping
unit known to fall within this age range is the Piney Point Formation. The Piney Point is the same age as the Comfort Member of the Castle Hayne Formation in North Carolina, the Santee Limestone in South Carolina, and the Blue Bluff unit in Georgia (Weems et al., 2004). These age-equivalent units have yielded the oldest reported remains of protocetid whales from anywhere within the Atlantic and Gulf coastal plains (Albright, 1996; Hulbert et al., 1998; Uhen, 1999, 2001; McLeod and Barnes, 2008) (Table 2).

<table>
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<tr>
<th>Stage</th>
<th>Georgia</th>
<th>South Carolina</th>
<th>North Carolina</th>
<th>Virginia</th>
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<tbody>
<tr>
<td>Bartonian (NP 17)</td>
<td>Caroliacetus gingerichi</td>
<td>Cross Member, Tupelo Bay Fm.</td>
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<td></td>
<td>Georgiacetus vogtelenisis</td>
<td>Georgiacetus aff. G. vogtelenisis</td>
<td>“Eocetus” wardii</td>
<td>“Eocetus” wardii</td>
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<tr>
<td></td>
<td>Blue Bluff unit</td>
<td>Santee Limestone</td>
<td>Comfort Member, Castle Hayne Fm.</td>
<td>Piney Point Formation</td>
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<th>STRATIGRAPHIC CONTEXT</th>
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<td>Based on the age of the associated dinoflagellate flora, the only unit in this region from which these specimens could have come is the middle Eocene (upper Lutetian to lower Bartonian) Piney Point Formation. A core hole drilled at Putneys Mill, Virginia (Fig. 2), which is within a mile of where these bones were found, recovered a 38-foot section of the Piney Point between the lower Eocene Nanjemoy Formation and the mid-Oligocene Old Church Formation (Edwards, 1982, 1984; Bybell and Gibson, 1994). Throughout the Pamunkey River valley region the Piney Point has been subdivided into three beds by Ward (1984, 1985), which he designated as A, B, and C from oldest to youngest. Morrell (1984) assigned all of these beds to the middle Eocene (Claibornian) Cubitostrea sellaeformis zone, which can be...</td>
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recognized as far south and west as Texas. Beds A and B can be confidently assigned to nanofossil Zone NP16, but bed C (the uppermost three feet of the unit) probably was deposited during nanofossil zone NP 17 (Bybell and Gibson, 1994). The dinoflagellate flora from the Putneys Mill core also supports an early Bartonian age for bed C (Edwards, 1984; Ward, 1984). Ward (1984) described calcite-cemented nodules in bed A and calcite-cemented oyster layers in bed B, but no one has reported any calcite cementation in bed C. This suggests that the specimens described here in all likelihood come from bed A or B, though this cannot be rigorously demonstrated.

The depositional environment of the Pinney Point was a shallow, open marine shelf environment at about 60 to 120 ft water depth based on foraminifera (Bybell and Gibson, 1994), mollusks (Strickland, 1984; Ward, 1984), and ostracodes (Deck, 1984). Müller (1999) has documented 19 species of sharks, 9 species of rays, and 57 otolith species of bony fish from the Pinney Point. These vertebrates also indicate deposition in a shallow neritic environment. The molluscous fauna indicates a mild to warm temperate marine environment during the middle Eocene in the eastern Virginia region (Ward, 1984). The palaenmorph assemblage reported from this unit by Frederiksen (1984) is dominated by extinct genera and species of the Fagaceae (which today includes oaks, beech, and chestnuts) with lesser amounts of pollen produced by extinct species of the Juglandaceae (which today includes walnuts, pecans, and hickories). Ferns, palms and tupelo (Nyssa) are also present. Together, these other palynomorphs indicate a winter-dry tropical climate onshore in this region during the middle Eocene (Frederiksen, 1984). The sediments of the middle Eocene are clastic-poor throughout the southeastern United States, indicating that inland areas in this region had very low relief at that time, were well vegetated, and provided very little sediment input into the tropical to subtropical Atlantic and Gulf coastal plain regions (Weems et al., 2004).

MATERIAL
Specimens include two vertebrae, an anterior thoracic (CMM-V-4334) and a posterior lumbar (CMM-V-4335), both lacking ephiphes and the greater part of their transverse processes and neural arches. Both specimens were collected on 18 July 2009 (by Jason Osborne and Aaron Alfrod) on the riverbed of the Pamunkey River in the vicinity of Putneys Mill (37.604 N, 77.092 W), north-northeast of Tunstall, Virginia. In this region, the Pamunkey River is the boundary line between New Kent and King William counties, Virginia. Specimens are from the Pinney Point Formation and are probably late Lutetian but possibly early Bartonian in age. Both specimens are now held at the Calvert Marine Museum, Solomons, Calvert County, Maryland.

TAXONOMIC ASSIGNMENT
The lumbar vertebra illustrated here (Fig. 3) is exceptionally large for a protocetid whale, and only “Eocetus” wardii Uhen is known to reach a comparable or somewhat larger size (Hulbert et al., 1998; Uhen, 1999, 2001; Geisler et al., 2005). Additionally, the distinctive pock-marked external texture of the bone, the presence of dense layered cortical bone, and the exceptional elongation of the centrum and basal transverse processes are all features unique to material assigned to Eocetus among protocetid whales (Uhen, 1999, 2001). Thus, based on size, bone texture, and the exceptional antero-posterior elongation of its centrum and transverse processes, the lumbar vertebra can be confidently assigned to “E.” wardii.

The mid-thoracic vertebra is quite different in its overall length (Fig. 4), but in “Eocetus” wardii there is an exceptional elongation of the vertebral series starting in the thoracic region and continuing back toward the lumbar region. This degree of vertebral elongation in the lumbar region is greater than that found in any other known protocetid whale. In the type specimen of “E.” wardii, a far anterior thoracic vertebra has a ventral centrum length of 59.5 mm, whereas a far posterior lumbar vertebra has a ventral centrum length of 183 mm (Uhen, 1998, 2001). This is slightly greater than the difference in values for the specimens at hand, which have a preserved ventral centrum length of 63 mm and 143 mm, respectively. Neither Pinney Point vertebra has ephiphes attached to its centrum, so each is from a subadult animal and both of these centra would have been slightly but comparably longer when complete. Both bones have a size relative to each other that is comparable to correlative bones in the vertebral series of “Eocetus” wardii, and the thoracic vertebra also has the distinctive pock-marked surface texture found in “E.” wardii. Therefore, the thoracic vertebra also can be referred confidently to this taxon. As both bones were found along the same stretch of riverbed, have a comparable relative size, and show a similar degree of maturity, it seems quite possible that they came from a single individual.

Uhen (1998, 2001) assigned “E.” wardii to the genus Eocetus, which was originally described from Egypt. The type species (E. schweinfurthi) is based on a somewhat damaged skull, with two vertebrae assigned to it that were inferred to belong to this form but were not directly associated with the type material. Geisler et al. (2005), noting the lack of direct association of the type skull with the referred vertebrae and the poor preservation of the posterior portion of the type skull, have questioned the assignation of “E.” wardii to the genus Eocetus and recommended that this species be designated as “Eocetus” wardii until such time as more complete material of Eocetus schweinfurthi can clarify just how closely related these two species are. We follow this recommended designation, but note that even if future discoveries of better material of E. schweinfurthi prove that the American material is distinctive enough to belong in its own genus, referral of our material to the species wardii remains firm.

DISCUSSION
The lower Eocene Nanjemoy Formation, which spans calcareous nanofossil Zones NP 10 and NP 13, is extensively exposed in both Virginia and Maryland. These outcrops have been searched extensively for fossils for well over one hundred years (e.g., Clark, 1896), and a considerable vertebrate fauna has been recovered from this unit (e.g., Weems and Grimsley, 1999), but not one tooth or scrap of bone referable to a cetacean has been found. A scapula of a putative primitive whale (Anglocetus beatusi) was reported from the age-equivalent lower Eocene London Clay of England by Tarlo (1964), but that specimen was referred to the primitive leatherback sea turtle Eosphyagris gigas (Halstead, 1984). Except for this one now refuted claim, no whale material ever has been reported from the London Clay despite more than two hundred years of intensive collecting. As neither the lower Eocene Nanjemoy Formation nor the lower Eocene London Clay has yielded any whale remains, it seems virtually certain that cetaceans were not present either in the northern Atlantic
Coastal Plain or in the London Basin region during early Eocene time.

The oldest and most primitive remains of whales found anywhere occur in lower Eocene to lower middle Eocene sediments in Pakistan and western India, and are referable to the families Pakicetidae, Ambulocetidae, and Remingtonocetidae. (Sahni and Mishra, 1975; Gingerich et al., 1995). These were all rather small animals that were only partly adapted to an aquatic existence. This stock gave rise to the family Protocetidae, which was much better adapted to marine life and spread throughout the Tethys Sea region and then to eastern North America during the middle Eocene (Uhen, 1999; Geisler et al., 2005). The occurrence of whale remains in the Piney Point Formation, the Comfort Member of the Castle Hayne Formation, and the Santee Limestone, all of which contain middle Eocene (upper Zone NP16) calcareous nannofossils, demonstrates that whales had reached eastern North America by late Lutetian time. The material from the Santee Limestone additionally indicates that at least two and perhaps three different species were present (Albright, 1996; Geisler et al., 2005, p. 52). Therefore, the time of the earliest cetacean dispersal to eastern North America was no earlier than the latest early Eocene (early Zone NP14) and no later than late middle Eocene (early Zone NP16). This is a firm but fairly large window of time within which protocetid whales spread from the Tethys region to southeastern North America (approximately 49 to 42 million years ago, or latest Ypresian through early Lutetian time; Gradstein et al., 2004).

The Congaree and Warley Hill Formations in South Carolina are among the few outcropping strata in the southeastern United States that are referable to the lower or middle Lutetian (calcareous nannofossil Zones upper NP14, NP 15, and lower NP 16), and no whale remains have been reported from either unit. Because outcrops are sparse, however, there is no way to be sure if protocetid whales are absent from these strata or if insufficient time has been spent prospecting them to provide a reasonable chance for finding whale remains. Thus, for now, it is not certain exactly when within this time interval protocetid whales first arrived offshore of North America. However, it is interesting to note that there was a major change in the depositional regime throughout the Atlantic and Gulf coastal plains of the
southeastern United States around the lower-middle Eocene boundary, which was the basis for establishing the boundary between the Ancora and Trent Supergroups (Weems et al., 2004). Deposition regionally changed from a clastic-dominated regime in the Ancora Supergroup to a carbonate-dominated regime in the Trent Supergroup, and this corresponds to the time at which the climate within the northern North Atlantic basin (and elsewhere) changed from exceptionally warm and stable in the early Eocene to relatively cooler and much more unstable in the middle and late Eocene (Wade and Kroon, 2002, 2003). Because these strong shifts in climate, depositional regime, and oceanic circulation pattern occurred in the North Atlantic region at or close to the early-middle Eocene boundary, we suggest that this change in climate and circulation pattern may have been the event that provided the initial opportunity for whales to cross the Atlantic Ocean and become established in the southeastern United States.

Feldmann et al. (1998) noted that there was an extensive dispersal of decapod crustaceans from the Tethys region to North Carolina in the middle Eocene, and they suggested that this occurred due to a major change in ocean currents at the beginning of the middle Eocene that created a strong westward flowing north-equatorial current. Uhen (1999), citing their work, suggested that the initial cetacean colonization of North America occurred by coastal migration along the northern coast of Africa and then by riding across the Atlantic to northeastern South America on this north-equatorial current into the Caribbean region and then to the southeastern United States. However, Geisler et al. (2005) have disputed the likelihood of this scenario on the grounds that protocetid whales were still poorly adapted to marine life at that time and probably could not have survived a direct trans-Atlantic crossing between Africa and South America, even considering the much narrower breadth of the Atlantic between these continents in the middle Eocene (Smith et al., 1994). Instead, they argued strongly that the more likely path of migration was by way of shallow marine shelf waters around the rim of the North Atlantic, hopping across short stretches of deep water between Britain and Greenland and between Greenland and North America, then migrating down the coast of eastern North America. This route would have required much shorter
hops across deep water than a southern dispersal across a single long trans-Atlantic gap.

Both routes have their appeal. However, in view of the fact that the Piney Point, Castle Hayne, Santee, and Blue Bluff whale remains are of late Lutetian to perhaps early Bartonian age, both routes for now suffer from a complete absence of evidence for fossil whales of Lutetian age in either northwestern Europe or northeastern South America. In Europe the oldest known whale remains are from the upper middle Eocene Bartonian stage, above the Lutetian. In Germany a protocetid whale has been reported from the Stockletten Formation of Bavaria (Uhen and Berndt, 2008), and in England two relatively advanced species of basilosaurids have been reported (Prozeuglodon (now Dorudon) and Basilosaurus) (Seeley, 1876; Andrews, 1907; Halstead and Middleton, 1972; McLeod and Barnes, 2008). This does not suggest an abundance of archaeocetes in this region during the middle Eocene, even after the Lutetian. In northeastern South America, no whale remains have been reported from any part of the middle Eocene. This could be due to lack of outcrop and/or collecting, however, because middle Eocene protocetids recently have been reported from southern Peru (Uhen et al., 2008). For now, the exact path of migration to eastern North America by protocetid whales remains undocumented, and it is by no means impossible that the earliest whales came to North America around the rim of the North Pacific and through the then-open Central American seaway. In any case, by the late Lutetian protocetid whales were well established along the eastern seaboard of the present United States and even then were represented by several immigrant species.

Uhen (2001) has noted that, despite intensive searching in South Carolina, Georgia, Alabama, and Mississippi, no remains of “Eocetus” wardii have been found. One could argue that “E.” wardii became extinct by the end of middle Eocene calcareous nannofossil Zone NP16, and that this would explain why its remains are not found among the relatively common whale remains recovered in strata that were deposited during the time of late middle Eocene Zone NP17. This, however, still would not explain why “E.” wardii has not been reported from the demonstrably age equivalent and whale bone-bearing Santee Limestone in South Carolina (Geisler et al., 2005) and the Blue Bluff unit in Georgia (Hulbert et al., 1998). The fact that “E.” wardii now has been recovered much farther north from age-equivalent strata in Virginia shows that this species is not endemic to only a single region in southeastern North Carolina, but rather seems to have been a species with a broad but more northerly range than other known North American protocetids. This suggests that, even at this early date in whale evolution, there already was a latitudinal division between mild- to warm-temperate whale faunas versus subtropical to tropical whale faunas along the east coast of North America, comparable to differences documented for the molluscan fauna in those two areas (Ward, 1984). If the ancestor of “E.” wardii perhaps reached North America via a counterclockwise northern route, while Geogiacetus and Carolinacetus came via a clockwise southern route on a west-flowing equatorial current, then such a latitudinal boundary also might reflect the point at which two different but concurrent waves of migration met. Obviously, more complete and geographically more widespread material will be needed to answer these intriguing questions concerning the biogeography of the earliest cetacean inhabitants of the western North Atlantic and Caribbean regions.

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REFERENCES


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