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A Miocene Cetacean Vertebra Showing a Partially Healed Compression Fracture, The Result of Convulsions or Failed Predation by the Giant White Shark, *Carcharodon megalodon*

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ABSTRACT

CT scans of a pathological whale vertebra (CMM-V-2194) from the Miocene Chesapeake Group of Maryland, show features characteristic of a compression fracture with comminution. The etiology of the injury suggests a sudden and intense hyperflexion of at least the posterior thoracic vertebrae. The trauma was sufficiently violent to break the lower third of the centrum, including adjacent sections of both epiphyses, away from the main body of the element. A dislocated fragment of the anterior epiphysis became wedged within the principle fracture precluding 'normal' recovery. The trauma was not immediately fatal however as significant fusion of fragmented elements was well underway at the time of death.

The cause of the vertebral hyperflexion and resulting trauma is unknown. Possibilities range from convulsions to a crushing blow delivered by a giant white shark, *Carcharodon megalodon*.

INTRODUCTION

Calvert Cliffs extend for approximately 50 km along the western shore of the Chesapeake Bay, Maryland and form the most nearly complete sequence of marine Miocene sediments exposed on the East Coast of North America. These Miocene age deposits preserve one of the most diverse assemblages of extinct cetaceans known. Both odontocetes (toothed whales) and mysticetes (baleen whales) contribute 30 or so currently valid species to this taxonomically diverse fauna (Gottfried et al, 1994). The remains of cetaceans are amongst the most common vertebrate fossils that erode from the cliffs and their extensions out under the waters of the Chesapeake Bay. Although it is not unusual to recover fossilized tooth-marked cetacean bone (the evidence of shark predation/scavenging), pathological elements are rare indeed. C.T. scans of the pathological cetacean vertebral centrum described herein (CMM-V-2194) revealed features typically associated with vertebral compression fractures and is sufficiently unique to warranted this short note.

CMM-V-2194 was x-rayed on a General Electric HiSpeed Advantage C.T. scanner at the Calvert Memorial Hospital. 3mm helical C.T. scans in both the sagittal and transverse planes of the vertebra were taken at 120 kV and 280 mA.

DESCRIPTION

An isolated mid-dorsal vertebra (Figure 1 A-C) from a Miocene cetothere cetacean was recovered as beach float near Plum Point Beach, Maryland, on the Chesapeake Bay. Although CMM-V-2194 was not found *in situ*, it most likely eroded from either the upper-most Calvert Formation or lower-most Choptank Formation, both of which contribute to cliff exposures along this section of the Bay. Ward (1992) places the boundary between the Calvert and Choptank Formations within the Middle Miocene, a boundary that also corresponds to that separating the Langhian and Serravallian Stages.

That this isolated centrum is fossilized is not in doubt. The weight of the bone as compared with modern representatives of similar proportions indicates that it has been significantly permineralized. The density of the centrum, as measured in Hownsfield Units, is in the 410-420 range (human bone is approximately 1000 Hownsfield Units). Less objective indicators of its Miocene origins include its color, which is consistent with that of other *in situ* fossilized bone from this area, its ceramic-like feel, and "ring" when it is tapped.

The following features suggest that this vertebra (Figure 1) is derived from the mid-thoracic series: 1) there are no facets on the ventral side of the centrum to accommodate a haemal arch, 2) neither is there any development of prominent ventrolateral protuberant parapophyses as would be present in the cervical series, and 3) there are no transverse processes low on the centrum as would be present on lumbar and proximal caudal vertebrae. Unfortunately, this isolated element does not display any diagnostic feature that would allow us to assign it to one of the currently recognized cetacean genera from Calvert Cliffs. At this juncture, we are only able to conclude, based on its overall length and height of 89mm and 84mm respectively, that this cetacean had an overall length of approximately 6m.

The partial vertebra consists of a centrum and the roots for the transverse processes and pedicles for the neural arch. Unfortunately, both the transverse processes and arch were not preserved (Figure 1 A-C). Not unexpectedly, the roots of the transverse processes and neural arch are displaced somewhat towards the anterior end of the vertebra. The centrum is essentially complete, lacking only the smooth periosteal bone over its lateral and ventral surfaces, thereby exposing the spongiosa. Both anterior and posterior epiphyseal plates are, for the most part, well preserved and fused to the centrum although a peripheral suture is still visible. The degree to which the disks have fused to the centrum would indicate that the individual was mature but not of old age at the time of death.

In a transverse view (Figure 2A), post-trauma bone growth is seen to extend from below the break up the sides of the centrum overlapping pre-

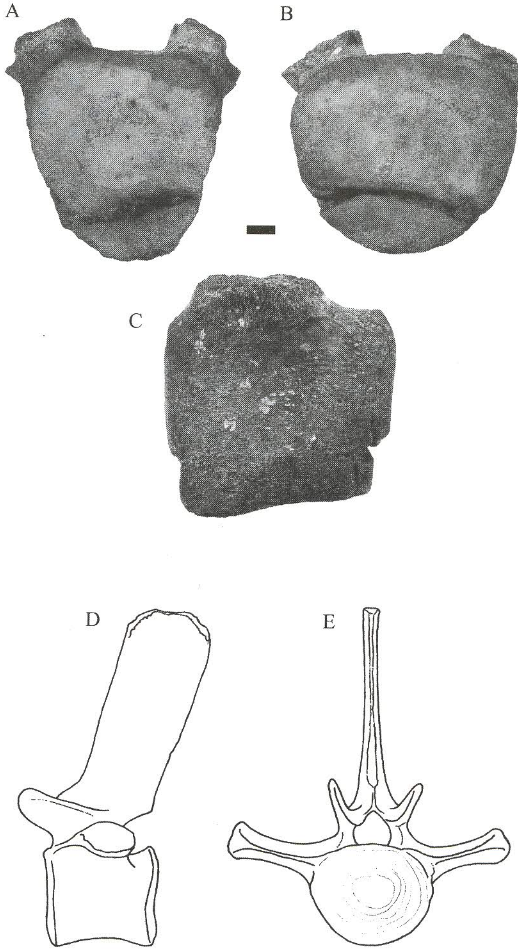

Figure 1. A-C. CMM-V-2194, a Miocene pathological cetacean vertebra seen in anterior, posterior, and left lateral views respectively. Scale bar equals 10mm. D-E. Line drawings of a cetacean vertebra in left lateral and anterior views respectively to show how CMM-V-2194 may have appeared prior to the trauma. (Re-drawn with modifications from Kellogg (1965, Part 1, Fig. 16)).

fracture lateral surfaces. This peripheral bone growth is more prominent towards the anterior end of the centrum. Furthermore, in both transverse and sagittal sections, post-trauma bone is seen to have bridged most of the gap between the pressure-fractured moiety and the remainder of the centrum. The absence of ossification towards the posterior end of the fracture zone suggests that this area was occupied by fibrous connective tissue, which at the time of the cetacean's death had not been invaded by osteocytes. For the most part, bone spicules exposed on the surface of the centrum run parallel to its length. However, in the area of the fracture, some spicules bridge the gap with a vertical orientation whereas others seem to have no preferred orientation. The anterior end of the ventrally displaced segment of the principle fragment was either reabsorbed post-trauma or abraded postmortem, returning the centrum to more normal proportions (Figure 3F).

The posterior epiphysis is 85mm wide, 76mm high, and preserves the smooth periosteal bone of its posterior face. Little or none of the peripheral margin of the posterior disk appears to have been lost through abrasion. Conversely, the anterior disk is 72mm wide and 80mm high as preserved. Although most of the smooth periosteal bone on the anterior face is preserved, some of the periphery of this epiphysis was damaged and lost postmortem. It is no artifact of preservation that the height of the centrum is greater along its anterior margin (a point to which we shall return shortly). Most of the smooth periosteal bone was lost from the lower third of the anterior epiphyseal plate.

CMM-V-2194 differs in several conspicuous ways from a typical mid-thoracic cetothere vertebra (Figure 1 D-E). Superficially, the ventral third of the vertebra, gives the impression that it was strongly compressed lengthwise and both epiphyses are broken into two unequal-sized sections. Furthermore, the dorsal margin of both of these broken lower epiphyseal plates are fused to the main body of the centrum (Figure 1 C).

C.T. scans (Figure 2) show that the lower third of the centrum, including adjacent sections of both epiphyses, was separated from the main body of the element. The large fragment that broke free took slightly more of the left side of the centrum. Therefore, in a transverse section (Figure 2A), the cleavage plane is seen to slope down slightly from left to right. The comminuted fragment was displaced forward relative to the remainder of the centrum (Figure 2B). The anterior end of the fracture gapes open much more widely than the posterior end because a small, dislocated wedge of the anterior epiphysis became lodged within the lumen of the fracture (Figure 3E). New bone growth fixed the fragments in their displaced positions (Figure 3F).

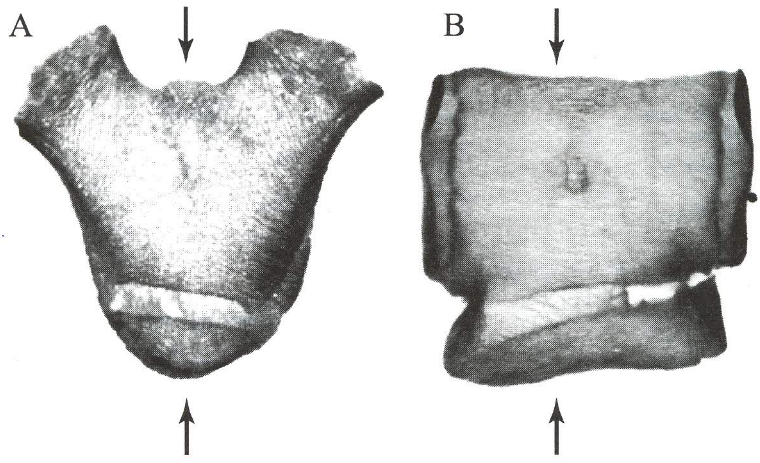

Figure 2. A-B. CT scans through CMM-V-2194 in transverse and sagittal planes respectively. The arrows in A mark the location of the sagittal-plane scan seen in B, and the arrows in B mark the location of the transverse-plane scan seen in A. The small black dot on the posterior end of the vertebra in B is a metal orientation bead.

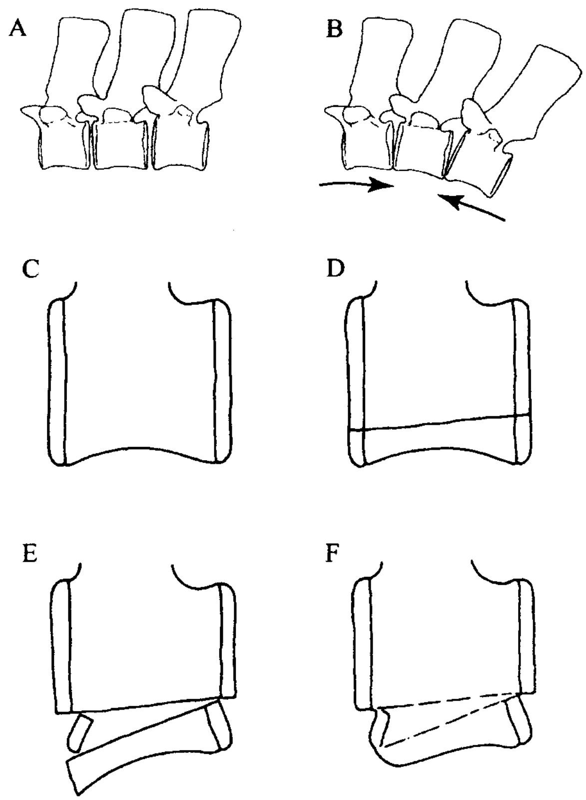

Figure 3. A. Three naturally articulated cetothere thoracic vertebrae. B. The same vertebrae in hyperflexion. The arrows represent compressive forces applied to the centrum that resulted in the compression fracture with comminution. C-F. A series of drawings showing the possible etiology of the vertebral pathology: C. The centrum prior to the trauma. D. A roughly horizontal fracture extends through the lower third of the centrum and adjacent epiphyseal plates. E. The lower third of the centrum breaks free and is pushed forward relative to the main body of the centrum. A small section of the anterior epiphyseal plate becomes lodged within the lumen of the fracture. F. The dorsal margins of the broken epiphyses fuse to the diaphysis of the centrum. The anterior lower-most angular portion of the centrum is either reabsorbed by the living whale or eroded postmortem.

DISCUSSION

Intolerable strain imposed on the vertebra in hyperflexion was sufficient to cleave the lower third of the centrum, including adjacent sections of both epiphyses, away from the main body of the element (Figure 3A-B). A sudden compressive or unidirectional blow to the base of the centrum produced the cleavage plane running the length of the bone. Unfortunately, the cause of the hyperflexion that produced the compression fracture with comminution is unknown. Possibilities range from convulsions induced by toxic shock, to a collision with a floating object (like a tree carried out to sea), the sea bottom, or another organism. A variation on the latter possibility is the one that we consider most likely. An encounter between this cetacean and *Carcharodon megalodon*, the most common giant predatory shark species within the Chesapeake Group (Figure 4), cannot be proven, but it is by no means unreasonable. The large serrated teeth of *C. megalodon* are found throughout the Chesapeake Group (Kent, 1994), evidence that they were present within the waters of the Salisbury Embayment. From tooth-marked bone in the collection of the Calvert Marine Museum, we know that *C. megalodon* was consuming cetaceans in this area during the Miocene (see also Kent, 1994). Elsewhere, *C. megalodon*-bitten whale bones are relatively common in the Pliocene of Lee Creek, North Carolina (Purdy, 1996). Hulbert (2001) and Renz (2002) report similar finds in Florida. Deméré & Cerutti (1982), Martin & Rothschild (1989), Everhart et al. (1995), Becker et al. (2000), Purdy et al. (2001), Hanks & Shimada (2002), Shimada et al. (2002), and Godfrey (2003) describe other examples of prehistoric shark predation. Living great white sharks (*Carcharodon carcharias*) are not known to attack living prey larger than themselves (Long & Jones, 1996). Gottfried et al. (1996) estimate that *C. megalodon* attained lengths over 12m, thus no Chesapeake Group cetacean would have been beyond their grasp.

Living great whites attack cetaceans from below or behind with a swift initial bite that is intended to kill or disable their prey (Long & Jones, 1996). The caudal peduncle or the abdomen, are favored initial strike locations. If the predatory strategies of *C. megalodon* were at all similar to

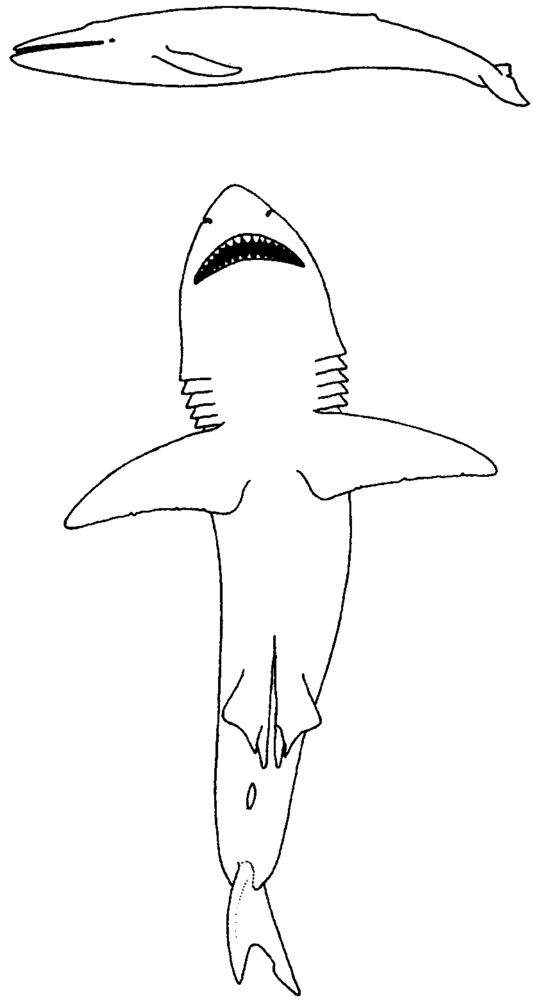

Figure 4. Possible origin of the vertebral pathology: *Carcharodon megalodon* attacking a small Miocene baleen whale from below. The attack could also have come from behind.

those of modern white sharks, then it is easy to imagine that this vertebral pathology came about as a result of a sudden and violent bone-splitting blow to the whale delivered by one of these colossal predators. We suggest that the impact hyper-flexed the vertebral column into a tight arc compressing adjacent centra up against the one described herein. That the comminuted fragment was displaced forward relative to the remainder of the centrum suggests an attack from behind. The partially healed vertebra shows that in spite of the severity of the injury, the whale survived this crush with death. From time to time, extant marine mammals survive *C. carcharias* attacks (Long & Jones, 1996; Long et al., 1996). Indeed, this centrum testifies that substantial headway was made in restoring the integrity of the vertebra prior to the cetacean's demise, of which we know not the cause(s).

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