New *Carcharodon* scavenging evidence on Pliocene whale bones remains from Northern Appennines

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Abstract

Here is report the finding of a large *Carcharodon* tooth among the fossil remains of *Cetotherium capellinii* (MPP – 47), previously discovered in the Castell'Arquato Plio-Pleistocene Basin (CAB; Northern Apennines, Italy). The taphonomy of this assemblage indicates that the cetacean has probably been scavenged by *Carcharodon*. This may indicate that, as in the present, white sharks actively preyed upon small prey and scavenged the large whale carcasses.

Keywords: Pliocene, Cetacea, Castell'Arquato Plio-Pleistocene Basin, scavenging, *Cetotherium capellinii*, *Carcharodon carcharias*.

Riassunto

Nuove tracce fossili di* scavenging *di* Carcharodon *su reperti di misticete del Bacino Plio-Pleistocenico di Castell'Arquato.
È segnalato un dente di squalo in resti fossili di *Cetotherium capellinii* (MPP - 47) scoperti nel Bacino Plio-Pleistocenico di Castell'Arquato (CAB; Appennino settentrionale, Italia). Il dente appartiene ad una grande *Carcharodon*. La tafonomia del ritrovamento indica che la carcassa del cetaceo è stata probabilmente sottoposta a *scavenging* da parte del *Carcharodon*.

Parole chiave: Pliocene, Cetacea, Bacino Plio-Pleistocenico di Castell'Arquato, *scavenging*, *Cetotherium capellinii*, *Carcharodon carcharias*.

Introduction

From an actualistic perspective, the exceptional combination of selachimorph teeth associated with fossil whales could indicate scavenging of the carcasses by sharks (Capellini, 1865; Borselli & Cozzini, 1992; Bianucci *et al.*, 2000; Danise & Dominici, 2014). Furthermore, the presence on the bone surfaces of striae, grooves and abrasions closely matching extant shark bites represents a direct paleontological evidence of trophic interaction (Deméré & Cerutti, 1982; Cigala-Fulgosi, 1990; Noriega *et al.*, 2007; Pobiner, 2008; Bianucci *et al.*, 2010; Govender, 2015). Even in the geological past the sharks have been holding the same ecological function as scavengers (Schwimmer *et al.*, 1997).
Here, I describe new Pliocene (5.3 - 2.5 Ma) scavenging evidence on incomplete whale skeletons discovered in the Castell'Arquato Plio-Pleistocene Basin (hereinafter referred as to CAB; Monegatti *et al.*, 2001). Evidence of trophic interactions (predation or scavenging) between *Carcharodon carcharias* and cetaceans was discovered in other fossils in the CAB.

Geologial setting

The Castell'Arquato Basin is located in the foothills of the northern Apennines and its main building up phases are from Oligocene onward (Monegatti *et al.*, 2001). The Plio-Pleistocene sequences include rich marine invertebrate and vertebrate faunas, recovered in several sections of this unit. More recent studies led to a substantial revision of the stratigraphic framework (Roveri *et al.*, 1998; Monegatti *et al.*, 2001; Roveri & Taviani, 2003).
The *Cetotherium capellinii* MPP-47 was discovered by Giovanni Podestà in the nineteenth century in Monte Falcone outcrop (2.7 - 2.5 Ma. Castell'Arquato, Piacenza. Northern Apennines) and is now hosted at the Museo Paleontologico Parmense (Università degli Studi di Parma) (Cigala-Fulgosi, 1980; Freschi, 2014).

Materials and method

We analyzed the skeletal fragments of *Cetotherium capellinii* MPP – 47 (Cetacea, Mysticeti *incertae sedis*) (Strobel, 1881; Cigala-Fulgosi, 1980; Freschi, 2014) hosted in the "Museo Paleontologico Parmense". The specimen is fragmentary and still partially embedded in a matrix of highly cemented sandy mudstone rich in bioclasts made by bivalves and bryozoans (Fig. 1 and 2). The skeletal remains consist of scapula, sternum, both radii, cubits, eight phalanges and metacarpals, 24 ribs and 22 vertebrae. The specimen was studied by Strobel (1881) and classified as *Cetotherium capellinii*. Strobel (1881) estimated that the specimen had to reach a total body length of 9.25 m. After Strobel (1881), this specimen has not been reviewed. In

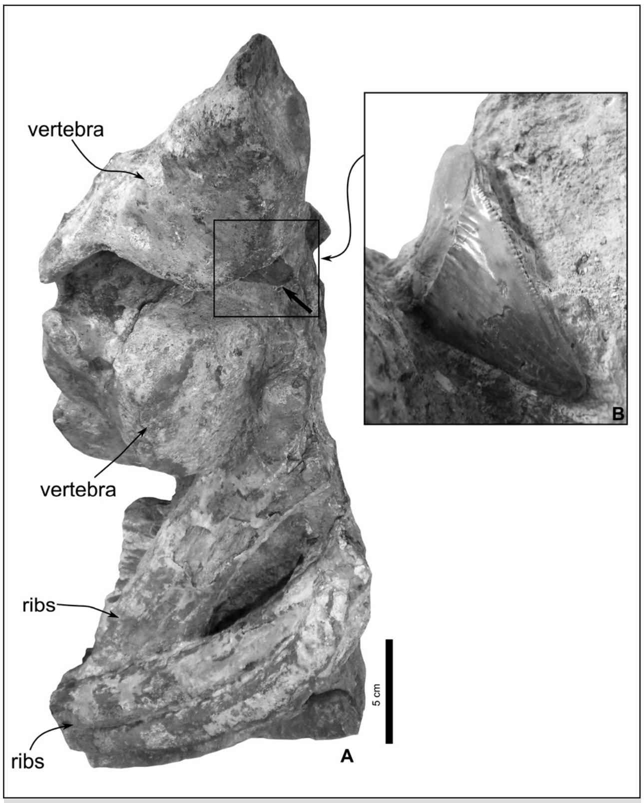

Fig. 1. Skeletal remains of *C. capellini* (MPP-47) from Monte Falcone section (Castell'Arquato, Piacenza). Dislocated ribs and thoracic, lumbar (?) and caudal vertebrae embedded in the sediment (A). The arrow indicates the position of *Cacharodon* tooth (B) between the fossil bones.

the present study, we keep the original taxonomic assignment by Strobel (1881).

The study of fossil traces of predation or scavenging on cetaceans by sharks was addressed by Capellini (1865), Portis (1883), Frenguelli (1928). However, their interpretations were significantly improved by Cigala-Fulgosi (1990) & Bianucci *et al.* (2000, 2010): their analyses of the bite action of sharks indicate four types of damage left on bones by serrated and unserrated teeth. Here, we follow the above authors in the nomenclature of shark feeding traces.

Results and discussions

Description and identification of the shark bite marks

The specimen includes dislocated thoracic, lumbar and caudal vertebrae and thoracic ribs, A shark tooth is exposed among the vertebral portion of *C. capellini* MPP – 47. Both size and denticulate edge support the referral of this tooth to *Carcharodon carcharias* (Fig. 1 - B).

Two phalanges (Fig. 2) of *C. capellini* MPP-47 are scarred by scrape marks of biogenic origin. Ribs and vertebrae appear to have no tooth marks. In the central part of the first phalanx (Fig. 2 - A), a cutting scraped-surface is well evident. This feature is compatible with the cutting action of a shark tooth on the bone surface. This type of track is produced through dragging of the tooth edge perpendicularly to the dental axis (Cigala-Fulgosi, 1990; Bianucci *et al.*, 2010). The size of the track is congruous with the tooth marks made by *Carcharodon*, *Cosmopolitodus* and *Isurus*. It is noteworthy that the morphology of the marks left by these taxa allows to distinguish the former genus from the others: *Carcharodon* has denticulately-edged teeth and produces serrate tooth marks, while *Cosmopolitodus* and *Isurus* have smooth-edged teeth and produce tooth marks characterized by smooth grooves (Cigala-Fulgosi, 1990; Bianucci *et al.*, 2010). In MPP-47, the cut surface is slightly abraded and thus cannot be attributed to *Cosmopolitodus* or to *Isurus*. A series of striae, a few mm in width, run along the distal end of another phalanx (Fig. 2 - B).

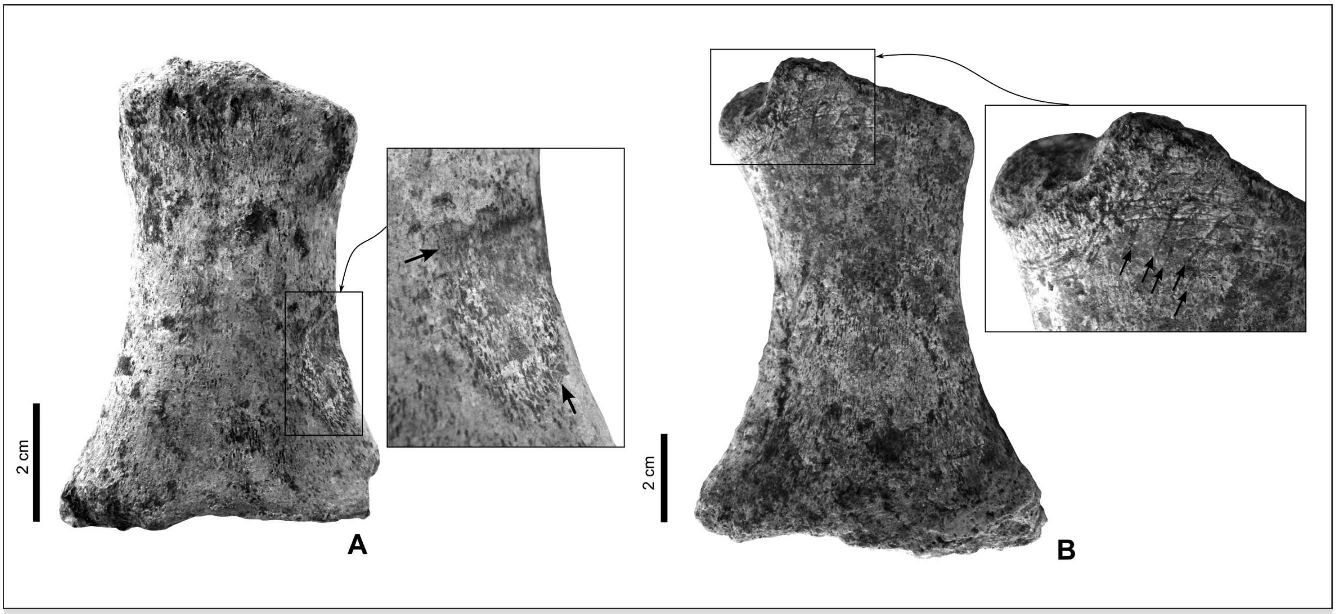

Fig. 2. Phalanges of *C. capellini* (MPP-47) with large scraped surface (A) and subparallel bite marks (B).

They do not look like the typical streaks left by the action of the serrated edge of *Carcharodon*, usually bearing evident and deep grooves. They were probably produced by the action of pointed teeth, and may be referred to relatively small marine vertebrate (Boessenecker & Fordyce, 2015).
On the other bone portions, tooth marks are not observed. It is particularly noticeable that bite marks are absent from the ribs, because shark bite marks are largely found in these bones (Cigala-Fulgosi, 1990; Bianucci *et al.*, 2000; Bianucci *et al.*, 2010).

Shark scavenging evidence

Great white sharks commonly prey upon small tooted wales and pinnipeds but never attack baleen whales (Long & Jones, 1996; Collareta *et al.*, 2017). The modern great white shark only attacks cetacean individuals that are considerably smaller than him, and never actively preys upon animals from its own size class (Long & Jones, 1996). Although the adult baleen whales are not suitable for predation, their carcasses represent a large part of *C. carcharias* diet (Carey *et al.*, 1982; Long & Jones, 1996; Curtis *et al.*, 2006; Dicken *et al.*, 2008; Fallows *et al.*, 2013).
The teeth of white sharks are often present in mixture with large Pliocene whale skeletons, especially balaenopteroid, with a estimated length between 7 and 10 m (Bianucci *et al.*, 2000). The MPP-47 mysticete is estimated to be 9.25 m in length and fits into this category (Strobel, 1881). Furthermore, bite marks are more frequently found on fossil bones of delphinids and small mysticetes (Cetotheriidae s.s. and s.l.) (Bianucci *et al.*, 2000). The most compelling cases of probable direct predation on cetaceans were described for two Pliocene delphinids, i.e. *Astadelphis gastaldii* and *Hemisyntrachelus cortesii*. These species measure less than 4 m (Cigala-Fulgosi, 1990; Bianucci, 1997a; Bianucci *et al.*, 2010).
Two additional examples of probable scavenging have been described from the Castell'Arquato Plio-Pleistocene Basin remains. The first is a *Protororqualus cuvieri* whose body measured 7 m and was associated with a large number of shark teeth (Cortesi, 1819; Bisconti, 2007; Danise & Dominici, 2014; Freschi & Cau, 2015). The second is represented by a large rorqual-like whale about 8 m in length that was found near Salsomaggiore Terme (Parma province) (Bianucci, 1997b; Freschi & Raineri, 2014) bearing three white shark teeth.
Although this qualitative observation is recurrent, it is difficult to define what relationship exists between the size of the carcasses and the traces of predation or scavenging. In all these cases, by comparing the adult size of *Carcharodon* (3.5 - 5 m) (Compagno, 2001) with the *C. capellini* (MPP-47) and other large Pliocene mysticetes associated with teeth, the observed difference of dimensions is twice. However, the white shark feeding behavior changes over time on the basis of ontogenesis (Estrada *et al.*, 2006) and is not able to attack and kill large prey such as whales. Probably, as in the present, during the Pliocene, adults white shark mainly actively preyed small-sized prey and scavenged on the large whale carcasses.

Conclusions

The results of this study confirm the ecologic role of great white sharks in Castell'Arquato Plio-Pleistocene Basin.
The nature of the find did not allow to discriminate between active predation and scavenging. Considering the long series of whale fossils, estimated at around 10 m, it is possible to hypothesize that adult white sharks, as in the present, were eating large carcasses of whales. Future studies might seek to respond to this observation by comparing the fossil data and the current of the great white sharks diet.

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