The fossil record as a tool for studying the convergent evolution of deep diving abilities in beaked whales and sperm whales

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Abstract

Occurring multiple times in the evolutionary history of tetrapods, the return to an aquatic environment resulted in the colonization of varied environments, from oceanic tropical regions to freshwater systems and from polar seas to upwelling-related temperate regions. Adding a vertical component further increases this environmental diversity, with bentho-pelagic to benthic areas visited by members of different tetrapod clades. Although some pinnipeds, sea turtles, and even a few seabirds are known to regularly undertake deep dives, the most iconic deep divers are odontocetes (= echolocating toothed whales). Together with a few true dolphins, beaked whales (family Ziphiidae, 22 species) and the sperm whale (Physeteroidea, *Physeter macrocephalus*) perform some of the deepest (record up to 3000 m) and longest (over 2 hours) dives, to catch benthic and bentho-pelagic squid and fish.

As the paleontological record of beaked whales and sperm whales progressively improves (from the middle Miocene and latest Oligocene respectively), could the available fossils provide clues about the timing, context, drivers, and impact of this major ecological shift?

Different datasets are currently used. First, phylogenetic bracketing allows inferring ecological traits for extinct species of crown Ziphiidae; it results in a tentative middle Miocene minimum age for the acquisition of a deep diving ecology in the latter. Secondly, skeletal morphology gives useful indications about the feeding and locomotion abilities of extinct beaked whales and sperm whales (e.g., presumably macroraptorial species among the latter), to be compared with the suction feeding and deep diving skeletal specializations of extant forms. Furthermore, the discovery of fossil crown ziphiids in deep-sea deposits vs. stem ziphiids in shelf deposits is an additional indication for a shift occurring at around the stem-crown transition. Finally, such contrasted fossil records can be combined with data on the associated faunas and paleoenvironments, revealing competitors and potential prey (together with the analysis of extremely rare fossil evidence of predator-prey relationships).

Although the analysis of bone pathologies related to decompression syndrome (i.e. avascular osteonecrosis) did not yet reveal any pattern among fossil beaked whales and sperm whales, several other research fields may help further elucidating this process: bone histology (in relation with locomotion and buoyancy) and stable isotope analyses (C, O) of mineralized tissues (bones and teeth).