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Distributional patterns of enchodontoid fishes in the Late Cretaceous

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ABSTRACT

Enchodontoidei are extinct marine teleost fishes with a long temporal range and a wide geographic distribution. We propose here to apply Parsimony Analysis of Endemicity (PAE), Track Analysis and Brooks Parsimony Analysis (BPA) to analyze the distributional patterns of these fishes during the Late Cretaceous. Matrices were built according to their respective geological age in the Late Cretaceous. The occurrence data of enchodontoids produced consistent results for the Cenomanian, Turonian, and Santonian. The generalized track found for the Cenomanian (GT 1) can be associated to oceanic currents, whereas for the Turonian the generalized tracks (GT 2, GT 3 and GT 4) were associated with eutrophication/sedimentation effects. During the Santonian, the third Oceanic Anoxic Event (OAE 3) promoted vicariant events that could explain the generalized track found therein (GT 5). The BPA recovered the area formed by Middle East and Europe, which is congruent with GT 1 and GT 5.

1. Introduction

†Enchodontoid (Fig. 1) are extinct aulopiform fishes generally characterized by an elongate body, and a long and narrow rod-like maxilla included in the mouth gape (Silva, 2011; Silva and Gallo, 2011). They had a long temporal range that extended from the Early Cretaceous to Early Eocene, i.e. *Apateodus* sp. from Akli Formation, India (Rana et al., 2005), although they were more diversified in the Late Cretaceous. The group occurs in strata of South America, Africa, Asia, Europe, and North America (e.g., Goody, 1969; Chalifa, 1996; Fielitz, 2004; Figueiredo and Gallo, 2006). In Brazil, enchodontoids have been recorded in strata ranging from the Barremian to the Maastrichtian (Rebouças and Silva Santos, 1956; Gallo and Coelho, 2005; Figueiredo and Gallo, 2006; Gallo et al., 2007b; Silva, 2011; Silva and Gallo, 2011). These fishes are important members of the Cretaceous marine fauna, and represent a significant tool in the reconstruction of Late Cretaceous biogeographic patterns. Although no analytical method has been previously applied to the study of enchodontoid fishes, various biogeographical hypotheses have been proposed for the group (e.g., Fielitz, 2004; Cavin, 2008; Cavin et al., 2012).

According to the recent systematic review of this marine group, Silva and Gallo (2011) recognized five of the nine families previously proposed by Nelson (1994, 2006): Ichthyotringidae, Dercetidae, Enchodontidae, Eurypholidae, and Halecidae.

Fielitz (2004) proposed a phylogenetic hypothesis of Enchodontoidea, including some living and extinct members of Aulopiformes. The author concluded that Enchodontoidea was a monophyletic sister group of Cimolichthyidae, and this clade in turn was the sister group of living Alepisauridae. In addition, it was presented a resolved area cladogram and generalizations about the paleobiogeography of *Enchodus*. According to him, this genus originated in the mid-Tethyan Ocean (nowadays Middle East), with some endemic and widespread species recorded in this area. Moreover, one clade comprising three other species from North America is the sister group of a species from the Northwestern region of the Tethys Ocean (nowadays Western Germany). This clade, in turn, is the sister group of a species from the Western edge of the Tethys Ocean (nowadays Morocco) and North America.

Silva and Gallo (2007) applied Parsimony Analysis of Endemicity (PAE) to analyze the distributional patterns of enchodontoids in the Cenomanian. Two areas of endemism were delimited, one of them formed by Morocco + Southern Italy, representing the North African region of the Tethys Ocean; and another one formed by Lebanon + Israel, which is in the mid-Tethyan Ocean.

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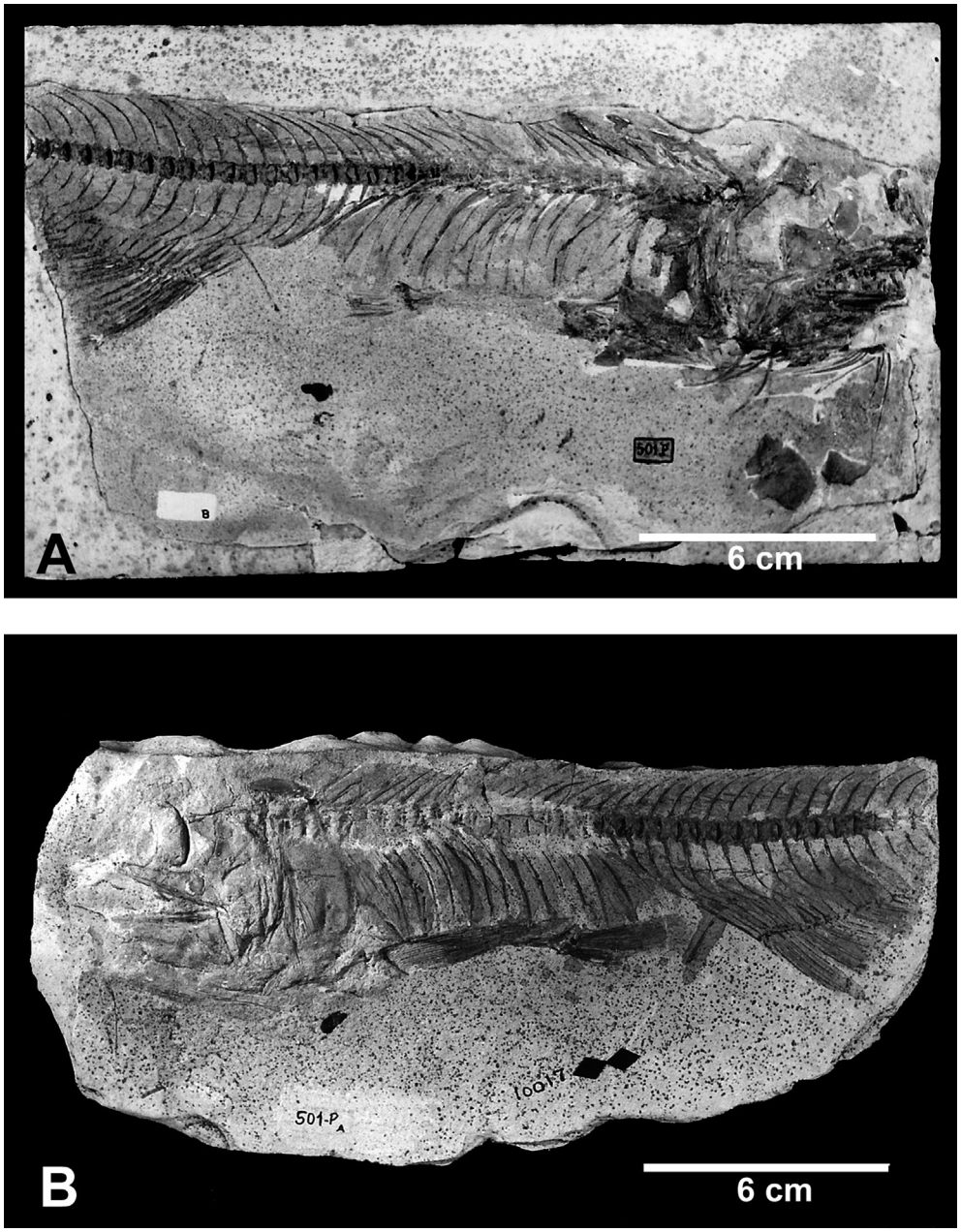

Fig. 1. *Enchodus longipectoralis*, DGM 501-P, an extinct aulopiform fish from the Upper Cretaceous of Brazil, preserved in part (A) and counterpart (B).

Cavin (2008) proposed a sequence of biogeographic events (vicariance–radiation) based on phylogenies of Fielitz (2004) for enchodontids and by Gallo et al. (2005) for dercetids, with suggestions of Taverne (2005a, 2005b).

Cavin et al. (2012) described *Enchodus* cf. *dirus* from the Middle to Upper Maastrichtian of the Island of Gavdos, Greece. A phylogenetic analysis was also employed and the systematic position of *Parenchodus* was discussed. Moreover palaeobiogeographic and paleoecology assumptions were formulated.

We propose here to apply PAE as a panbiogeographical tool, following Echeverry and Morrone (2010), in order to analyze the distributional patterns of enchodontoids during the Late Cretaceous as a preliminary step (Morrone, 2014, 2015). In addition, we employed a method of Cladistic Biogeography, the Brooks Parsimony Analysis (BPA) (Wiley, 1988), in order to find the secondary biogeographic homologies.

2. Material and methods

The analysis was performed by directed observation of specimens of enchodontoids and extant Aulopiformes housed at Paleontological and Ichthyological collections of the American Museum of Natural History, New York, USA; Muséum national d'Histoire naturelle, Paris, France; Natural History Museum, London, United Kingdom; and Smithsonian Institution National Museum of Natural History, Washington DC, USA (Appendix A). We also used distributional data taken from the literature (Table 1A–F) supplemented by the available records of online databases of some scientific institutions.

Individual tracks for the enchodontoid taxa were constructed by plotting their occurrences on maps according to their respective geological age in the Late Cretaceous with ArcView GIS v3.2 (ESRI, 1999) and connecting them by minimum spanning trees (Page, 1987) using the Trazos2004 extension (Rojas, 2007).

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