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A sternal plate of a large-sized sauropod dinosaur from the Late Jurassic of Portugal

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Introduction

Sauropods of the Late Jurassic of Portugal are *Lusotitan atalaiensis, Dinheirosaurus lourinhanensis, Turiasaurus riodevensis, Lourinhasaurus alenquerensis*, and possibly *Apatosaurus* (Antunes and Mateus, 2003; Mateus, 2009; Mannion et al., 2011). The skeletal remains consist of incomplete specimens. Only one sternal plate has yet been reported (Lapparent and Zbyszewski, 1957: p. 41), but was neither figured nor can it be located in any collection at present. An isolated, second, left sternal plate (ML 684) from Lage Fria (Atalaia, Lourinhã, Western Portugal), is herein described. It is the longest sternal plate reported from Europe, almost reaching the size of the elements known from *Giraffatitan* or *Alamosaurus* (Gilmore 1946; Janensch, 1961). It is partly damaged anteromedially and was recovered from the Sobral Unit of the Lourinhã Formation (Tithonian, Late Jurassic).

Description

The sternal plate ML 684 is 100 cm long, 43.5 cm wide, and about 2 cm thick medially. It is reniform in outline, with a weakly concave lateral and a convex medial margin (Fig. 1). It is flat dorsally, and bears a weak, broad ridge ventrally. The ridge extends close to the lateral edge, following its curvature. The lateral side of the ridge is steeper than the medial one. The sternal plate is thinner medially than laterally. The margins are rugose, only the central-most portion of the lateral edge is smooth. No lateroanterior process (Sanz et al., 1999) is present. The posteromedial corner of the sternal plate bears a thin and rugose, subtriangular extension, as in the elements of *Haplocanthosaurus delfsi* CMNH 10380 (McIntosh and Williams, 1988) or *Camarasaurus lentus* WDC BS-104 (Wilhite, 2005). Whereas the dorsal surface of this extension is smooth, the ventral one is highly irregular and pitted. Without this extension, the posterior edge of the sternal plate would be rounded. The ventral surface of the plate bears some circular pits. The pits are up to 11 mm in diameter and 8 mm deep.

Comparison and discussion

Due to its posteromedial extension, the sternal plate ML 684 resembles the one of *Haplocanthosaurus delfsi* CMNH 10380, or *Camarasaurus lentus* WDC BS-104 (McIntosh and Williams, 1988; Wilhite, 2005). However, the rugose surface and a faint suture between the extension and the plate indicates that the former does not belong to the main plate. It is located where the sternal ribs are thought to attach and its rugose surface implies a cartilage covering (Borsuk-Bialynicka, 1977). As sternal ribs are usually cartilaginous, this extension most probably represents a partly ossified sternal rib that fused with the sternal plate. The extensions in *H. delfsi* CMNH 10380, and *C. lentus* WDC BS-104 might thus be sternal ribs as well. Ignoring the extension, ML 684 most resembles the sternal plates of *Camarasaurus supremus* AMNH 5761, *Giraffatian brancai* MB.R. S II, *Apatosaurus ajax* NSMT-PV 20375, *Turiasaurus riodevensis* or *Losillasaurus giganteus* (Osborn and Mook, 1921; Janensch 1961; Casanovas et al., 2001; Upchurch et al., 2004a; Royo-Torres et al., 2006).

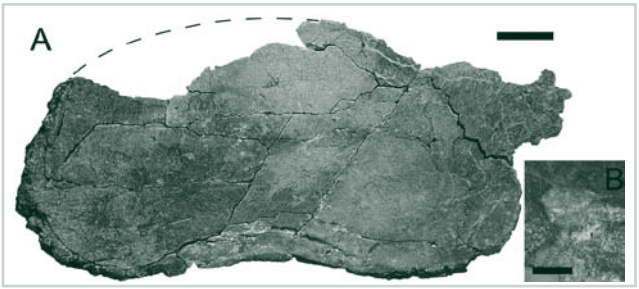

Figure 1. Sauropod sternal plate ML 684 in dorsal view (A) and detail of a circular pit in cross-section. Scale bars=10 cm (A), and 1 cm (B). (planned for column width).

Turiasaurus riodevensis and *Losillasaurus giganteus* are Late Jurassic Iberian sauropods. The Portuguese sauropod taxa mentioned above and the Spanish form *Galvesaurus herreroi* complete the reported Jurassic Iberian sauropod record. *G. herreroi* is distinct from ML 684 in having a dorsal instead of a ventral ridge, and a straight posterior border (Barco, 2009). The large size of ML 684 makes an identification as *Lourinhasaurus alenquerensis* and *Losillasaurus giganteus* improbable as well: while the latter has a sternal only 60% the length of ML 684 (Casanovas et al., 2001), *L. alenquerensis* does not preserve sternal elements. However, being in the same size class as the closely related *Camarasaurus* (Barco, 2009), ML 684 can be compared to the largest, morphologically similar *Camarasaurus* sternal (AMNH 5761, length 67,5 cm; Osborn and Mook, 1921). For both *L. giganteus* and *L. alenquerensis*, an approximate size increase of more than 50% would thus be needed to have an individual large enough to carry ML 684.

As a diplodocid sauropod (Mannion et al., 2011), one would expect a typical triangular plate for *Dinheirosaurus lourinhanensis*, markedly different from ML 684. On the other hand, given the similar element of *Apatosaurus ajax* NSMT-PV 20375, an assignment of ML 684 to *D. lourinhanensis* seems possible. However, comparing the sizes of the sternals of NSMT-PV 20375 and ML 684 an individual almost 20% bigger than the only known specimen of *D. lourinhanensis* ML 414 would be needed to carry a sternal plate as ML 684. An assignment of ML 684 to this species is thus unlikely.

Lusotitan atalaiensis is a brachiosaurid about the size of *Giraffatitan brancai* (Antunes and Mateus, 2003). In addition to *G. brancai*, also the brachiosaurs *Paluxysaurus jonesi* and *Cedarosaurus weiskopfae* preserve sternal plates. All these elements are similar to ML 684 in outline. However, *G. brancai* has a thicker anterior corner (Janensch, 1961), *P. jonesi* has an acute anterior end (Rose, 2007), and *C. weiskopfae* has more elongate plates than ML 684 (V. Tidwell, pers. comm.). Like ML 684, *L. atalaiensis* was found in the Sobral Unit of Lourinhã Fm. in Atalaia (Antunes and Mateus, 2003). As the morphological differences concern widely varying features (see below), an assignment of ML 684 to *L. atalaiensis* is possible.

The sternal plate of the eusauropod *Turiasaurus riodevensis* is reniform, but more slender than ML 684 (Royo-Torres et al., 2006). With a length of 950 mm, it almost reaches the size of ML 684. Finally, also the stratigraphic level of *T. riodevensis* coincides with the level of ML 684 (Royo-Torres et al., 2006). The most probable identification of ML 684 is thus *T. riodevensis* or *Lusotitan atalaiensis* - awaiting the find of a sternal plate undoubtedly belonging to the latter taxon.

The pits on the ventral face of ML 684 resemble boring holes caused by dermestid or silphid beetles, as reported from bones in the Morrison Formation (Britt et al., 2008). However, the borings in ML 684 are slightly larger.

Evolution of sauropod sternal plates

Isolated sauropod sternal plates are difficult to identify (Wilhite, 2005). However, some trends can be observed in their morphology (Fig. 2): basal Eusauropoda like *Shunosaurus lii* usually show rounded sternal plates, some with thickened anterior corners (Zhang, 1988). More derived Eusauropoda have reniform plates, often with shallow dorsal or ventral ridges (Casanovas et al., 2001). Within Diplodocoidea, Rebbachisauridae show crescentic (Calvo and Salgado, 1995), and Diplodocidae subtriangular to triangular plates with dorsoventrally thick anterior ends (Hatcher, 1901). Somphospondylia mirror the evolution of rebbachisaurs, developing crescentic sternal plates. Some taxa as *Alamosaurus* or *Malawisaurus* have straight posterior edges (Gilmore, 1946; Gomani, 2005). Advanced titanosaurs like *Alamosaurus* or *Opisthocoelicaudia* evolve very long sternal plates compared to humerus length (Gilmore, 1946; Borsuk-Bialynicka, 1977). Whereas shallow ridges or expanded anteroventral corners appear convergently in various groups, a prominent anteroventral ridge only occurs in derived titanosaurs like *Lirainosaurus* or *Neuquensaurus* (Huene, 1929; Sanz et al., 1999).

Based on this review, four additional characters are suggested that were not included in the phylogenetic analyzes of Salgado et al., (1997); Upchurch, (1998); Sanz et al., (1999); González Riga, (2002); and Upchurch et al., (2004b): 1) sternal plate, general shape: short or elongate; 2) sternal plate, anteromedial corner: gently curved or

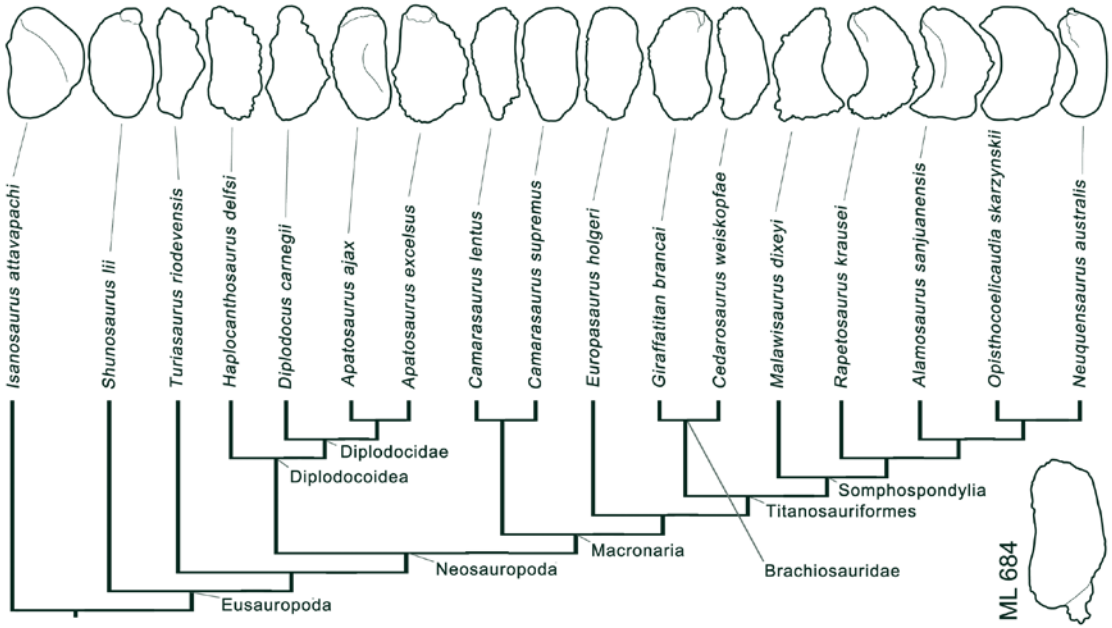

Figure 2. Compiled phylogeny with sternal plates of the respective taxa scaled to the same length. ML 684 for comparison in the lower right corner, not to scale. (planned for two columns).

forming a distinct corner; 3) sternal plate, dorsoventrally expanded anterior end, not followed by ridge: absent or present; 4) sternal plate, anteroventral ridge: absent/shallow or prominent.

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