Cretaceous Research 43 (2013) 145–160

Contents lists available at SciVerse ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

The axial skeleton of the titanosaur *Lirainosaurus astibiae* (Dinosauria: Sauropoda) from the latest Cretaceous of Spain

Verónica Díez Díaz [a,*], Xabier Pereda Suberbiola [a], José Luis Sanz [b]

[a] Universidad del País Vasco/Euskal Herriko Unibertsitatea, Facultad de Ciencia y Tecnología, Apdo. 644, 48080 Bilbao, Spain
[b] Universidad Autónoma de Madrid, Facultad de Ciencias, Dpto. Biología, Ud. Paleontología, 28049 Cantoblanco, Madrid, Spain

ARTICLE INFO

Article history:
Received 8 June 2012
Accepted in revised form 13 March 2013
Available online 12 April 2013

Keywords:
Lirainosaurus
Titanosauria
Vertebrae
Laminae
Fossae
Upper Cretaceous
Spain

ABSTRACT

Lirainosaurus astibiae was originally described by Sanz and collaborators in 1999 on the basis of a skull fragment, isolated teeth, several vertebrae (e.g. the holotypic anterior caudal vertebra) and appendicular bones from the Late Cretaceous of Laño (northern Spain). A review of all the vertebral remains, including new material (cervical, dorsal and caudal vertebrae, dorsal ribs, haemal arch), provides additional information about the axial skeleton of *Lirainosaurus*. A study of the laminae and fossae shows interesting variations in these structures in the axial series, especially concerning the prezygapophyses and diapophyses: e.g. the X-shaped morphology of the centroprezygapophyseal lamina only in the posterior dorsal vertebrae, and the division of the postzygodiapophyseal fossa into two fossae in the posterior dorsal vertebrae and the proximal caudal vertebrae. Two vertebral characters are here considered to be autapomorphic for *L. astibiae*: the presence of a lamina in the interzygapophyseal fossa in the most proximal caudal vertebrae (a postzygodiapophyseal lamina that separates the ventral postzygapophyseal centrodiapophyseal fossa and the dorsal postzygapophyseal spinodiapophyseal fossa), and the spinopostzygapophyseal structure not posteriorly projected in the posterior caudal vertebrae. The combination of characters present in the axial remains of *Lirainosaurus astibiae* supports the idea that it is a derived lithostrotian close to Saltasaurinae.

1. Introduction

In recent years, knowledge of the axial skeleton of sauropod dinosaurs has increased thanks to improvements in the study of their complex laminae and fossae (Wilson, 1999; Salgado et al., 2006; Salgado and Powell, 2010; Wilson et al., 2011; Wilson, 2012), their pneumaticity (e.g. Wedel, 2005), and the description of almost complete vertebral series and/or perfectly preserved and restored vertebrae, especially for diplodocoids (e.g. Harris, 2006; Mannion et al., 2012) and titanosaurs (e.g. Calvo and González Riga, 2003; Martínez et al., 2004; Salgado et al., 2005; Calvo et al., 2007; Filippi and Garrido, 2008; Curry Rogers, 2009). This means that new descriptions of axial remains have to be more detailed in their study of the laminae and fossae, whose topology is very useful when comparing different taxa.

Since the work of Sanz et al. (1999) no more axial remains of *Lirainosaurus astibiae* have been described, except the material from Chera (Valencia, Spain) referred to *L.* cf. *astibiae* by Company et al. (2009) and an isolated caudal vertebra from Guadalajara (Spain) referred to cf. *Lirainosaurus* sp. by Ortega and Pérez García (2009). In this paper, we describe in detail the axial skeleton of *Lirainosaurus astibiae* on the basis of the material found in the type locality of Laño (Condado de Treviño, Spain), and study its diagnostic characters and position within Titanosauria with a view to ascertaining the axial synapomorphies.

2. Geological setting

The Laño quarry is located between the villages of Laño and Albaina in the Condado de Treviño, an enclave of Alava that belongs politically to the province of Burgos in the north of the Iberian Peninsula (Fig. 1). From a geological point of view, Laño and the adjacent region lie within the Sub-Cantabrian Synclinorium in the southeastern part of the Basque-Cantabrian Region (Baceta et al., 1999). Laño has yielded a diverse continental vertebrate assemblage of Late Cretaceous (probably late Campanian to early Maastrichtian) age, including fossil remains of bony fishes, amphibians, lizards, snakes, turtles, crocodilians, pterosaurs, dinosaurs and mammals (Astibia et al., 1990, 1999; Pereda-Suberbiola et al., 2000). The continental fossiliferous beds (called L1A, L1B and L2) of the

* Corresponding author.
E-mail address: diezdiaz.veronica@gmail.com (V. Díez Díaz).

0195-6671/$ – see front matter
http://dx.doi.org/10.1016/j.cretres.2013.03.002

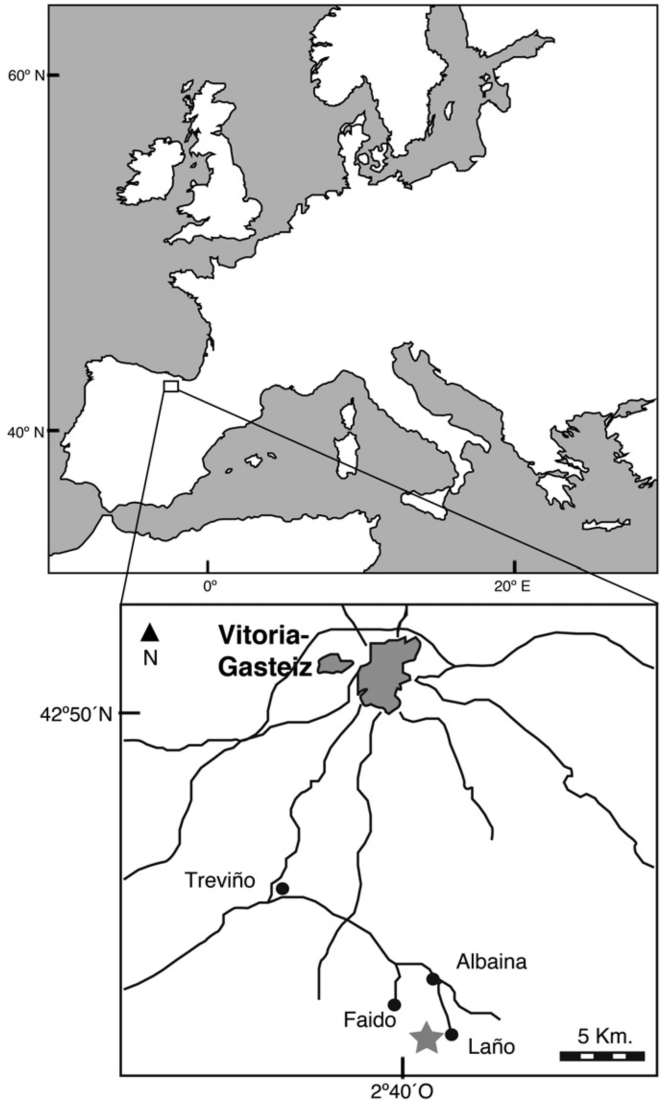

Fig. 1. Location map of the Laño quarry.

Laño quarry were deposited in an alluvial system composed primarily of fluvial sands and silts. The sedimentary structures are consistent with channel areas within an extensive braided river (Astibia et al., 1990, 1999).

Lirainosaurus, a small to medium-sized sauropod (about 4–6 m in length sensu Díez Díaz, 2013), is the largest vertebrate in the Laño association (Pereda-Suberbiola et al., 2000). Sanz et al. (1999) erected *L. astibiae* on the basis of a fragment of skull, several isolated teeth and a set of postcranial elements. New cranial remains, including basicranial material and teeth, have recently been described by Díez Díaz et al. (2011, 2012).

The fossils of *Lirainosaurus astibiae* come from three fossiliferous strata and correspond to several different individuals. Elements with the same morphology, such as caudal vertebrae, iliac fragments and fibulae, have been found in two or in the three beds, strengthening the hypothesis of the presence of a single titanosaurian taxon in Laño. As a whole, indeed, the remains of *L. astibiae* found in Laño are quite homogeneous and show few osteological variations, indicating that they belong to the same species (Sanz et al., 1999; Díez Díaz et al., 2011). Besides Laño, titanosaurian vertebrae referred to *Lirainosaurus* have been described from two other Iberian localities (Company et al., 2009; Ortega and Pérez García, 2009).

3. Material and methods

Osteological descriptions are organized as follows: vertebrae, ribs and haemal arches. Each major anatomical subdivision (cervical, dorsal and caudal vertebrae) is described sequentially. For the anatomical structures we use "Romerian" terms (Wilson, 2006) for the structures (e.g. "centrum", not "corpus") and their orientation (e.g. "anterior", not "cranial'"). The landmark-based terminology for vertebral laminae (Wilson, 1999) and fossae (Wilson et al., 2011) is utilized in the discussion of vertebral anatomy and in Figs. 2–7. For the haemal arches we use the nomenclature proposed by Otero et al. (2011). All vertebral measurements are provided in Table 1.

A revised and more accurate definition of the caudal vertebrae of titanosaurs is proposed, based on the articulated and almost complete titanosaurian caudal series of *Baurutitan britoi* (Kellner et al., 2005), *Trigonosaurus pricei* (Campos et al., 2005) and *Alamosaurus sanjuanensis* (Gilmore, 1946), and personal observation of those of *Andesaurus delgadoi* (Calvo and Bonaparte, 1991; Mannion and Calvo, 2011), *Pellegrinisaurus powelli* (Salgado, 1996), *Rinconsaurus caudamirus* (Calvo and González Riga, 2003), *Neuquensaurus australis* (Huene, 1929; Salgado et al., 2005), *Epachthosaurus sciuttoi* (Martínez et al., 2004) and other non-articulated titanosaurian caudal vertebrae.

1. Anterior caudal vertebrae: we differentiate the most proximal vertebrae from the other anterior caudals. The first caudal vertebrae (depending on the taxon, the first one, two, three and/or four) have triangular or wing-shaped transverse processes, as in *Baurutitan britoi*, *Trigonosaurus pricei*, *Neuquensaurus australis*, *Epachthosaurus sciuttoi*, *Narambuenatitan palomoi* (Filippi et al., 2011; V.D.D., personal observation) and *Alamosaurus sanjuanensis*, with more or less complex neural spines (with lamination), and without haemal arch facets. The

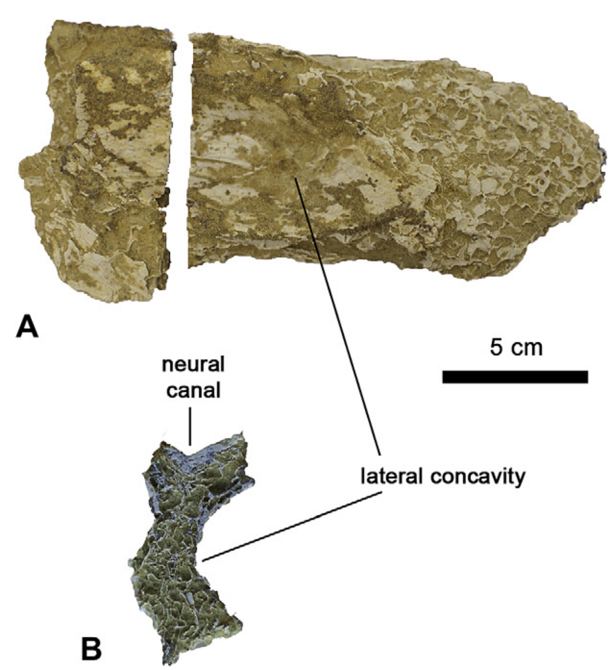

Fig. 2. Anterior cervical vertebra (MCNA 14429) of the titanosaurian sauropod *Lirainosaurus astibiae* from the Late Cretaceous of Laño (northern Spain). A, left lateral view; B, detail of the somphospondylous internal structure of the centrum.