Cretaceous Research 82 (2018) 83–98

Contents lists available at ScienceDirect

Cretaceous Research

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

New plesiosaurian specimens (Reptilia, Plesiosauria) from the Upper Cretaceous (Turonian) of Goulmima (Southern Morocco)

Rémi Allemand [a, b, *], Nathalie Bardet [a], Alexandra Houssaye [b], Peggy Vincent [a]

[a] Centre de Recherches sur la Paléobiodiversité et les Paléoenvironnements, CR2P – UMR 7207 – CNRS, MNHN, UPMC, Muséum National d'Histoire Naturelle, Sorbonne Universités, 57 rue Cuvier, CP38, F-75005, Paris, France
[b] UMR 7179 – CNRS/Muséum National d'Histoire Naturelle, Département Adaptations du Vivant, 57 rue Cuvier, CP55, F-75005, Paris, France

ARTICLE INFO

Article history:
Received 16 May 2017
Received in revised form
5 September 2017
Accepted in revised form 26 September 2017
Available online 28 September 2017

Keywords:
Cranial anatomy
Microtomography
Elasmosaurid
Polycotylid
Goulmima
Morocco

ABSTRACT

Two new plesiosaurian specimens coming from lower Turonian deposits of Goulmima in Morocco are described. The three-dimensional digital reconstructions of both specimens provide details about their skull roof, mandible and atlas-axis complex. In addition, computed tomography allows to reconstruct their braincase, which is a part of the skull poorly known among plesiosaurians due to either poor preservation and/or insufficient preparation, but that offers a large number of characters used in phylogenetical analyses. After descriptions and comparisons, the two specimens D1-8213 and MNHN F-GOU14 are assigned to *Libonectes morgani* and to an undetermined Polycotylidae, respectively. The presence of the North American taxon *Libonectes morgani* in the deposits of Goulmima confirms a trans-Atlantic faunal connectivity at that time and that Elasmosauridae were able to exploit the open marine environment for dispersion. Polycotylids have already been described from Goulmima; however, the typical preservation of these specimens in nodules prevented their preparation and the access to their internal anatomy. Here, the use of X-ray computed tomography shows the strong interest to use such a technique and provide new anatomical details.

1. Introduction

Plesiosaurians are extinct predatory marine reptiles that represent one of the longest-ranging groups of Mesozoic marine reptiles, extending stratigraphically from the Upper Triassic to the uppermost Cretaceous (Vincent et al., 2011; Benson et al., 2012). During the Late Cretaceous, they achieved a worldwide distribution, including high-latitude seas surrounding Antarctica (e.g., Gasparini et al., 2003; Vandermark et al., 2006; Novas et al., 2015; Sachs et al., 2015). Compared to in other continents, the fossil record of plesiosaurians is scarce in Africa where only seven valid taxa are known (see Vincent et al., 2011, 2013; Allemand et al., 2017).

The Turonian deposits (Upper Cretaceous) of the Goulmima area, in the Southern slope of the High Atlas (see Fig. 1A), have yielded a diverse marine fauna including ammonites, chondrichthyans (Underwood et al., 2009), bony fishes (Cavin, 1995, 1997, 1999, 2001; Cavin et al., 2001, 2010) and large marine reptiles, such as a turtle, the basal mosasauroid *Tethysaurus nopcsai* Bardet et al., 2003a (Bardet et al., 2003a, 2008) and three major families of Cretaceous plesiosaurians (Angst and Bardet, 2015). The Elasmosauridae are represented by *Libonectes morgani* (Carpenter, 1997), the Polycotylidae by *Thililua longicollis* Bardet, Pereda Suberbiola and Jalil, 2003b and *Manemergus anguirostris* Buchy, Métayer and Frey, 2005, and the Pliosauridae by *Brachauchenius lucasi* Williston, 1903 (Bardet et al., 2003b; Buchy, 2005; Buchy et al., 2005; Angst and Bardet, 2015; Sachs and Kear, 2017; Allemand et al., 2017). The taphonomical preservation in Goulmima is particular in that fossils are contained in one or several ovoid calcareous nodules (Cavin et al., 2010), in which the siliceous material prevents complete preparation of the specimens and fossilized bones in the nodules are often completely dissolved, making their extraction from the host rock and their study difficult or impossible. This preservation can often prevent a complete access to the fossil anatomy and the use of computed microtomography represents a suitable solution to circumvent these technical issues.

The present study examines two new plesiosaurian specimens (D1-8213 and MNHN F-GOU14) from the area of Goulmima in

* Corresponding author. Centre de Recherches sur la Paléobiodiversité et les Paléoenvironnements, CR2P – UMR 7207 – CNRS, MNHN, UPMC, Muséum National d'Histoire Naturelle, Sorbonne Universités, 57 rue Cuvier, CP38, F-75005, Paris, France.
E-mail address: remi.allemand@edu.mnhn.fr (R. Allemand).

https://doi.org/10.1016/j.cretres.2017.09.017
0195-6671/

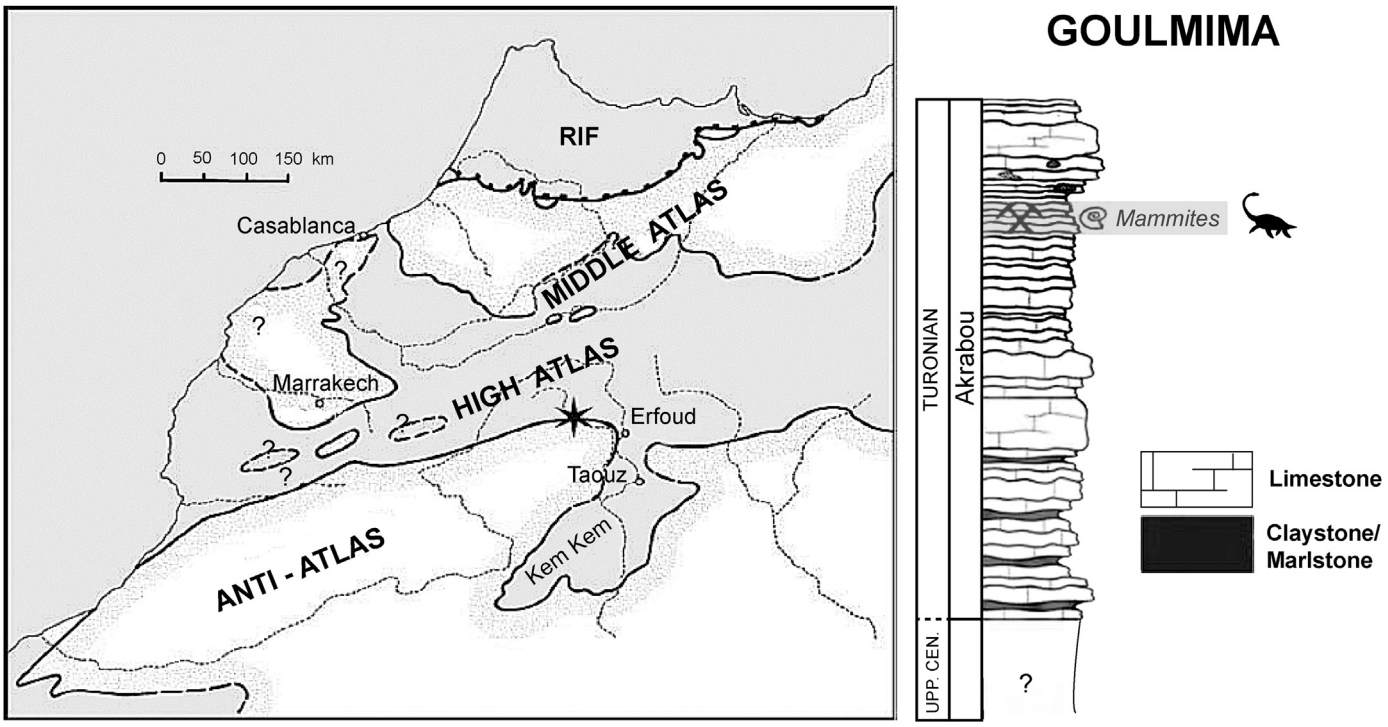

Fig. 1. Palaeogeographical location of the Goulmima area in southern Morocco and probable stratigraphic provenance of the plesiosaurian specimens D1-8213 and MNHN F-GOU14 (modified from Angst and Bardet, 2015).

Southern Morocco (Fig. 1). Although their exact location remains unknown, the calcareous matrix surrounding the specimens is nevertheless consistent with the vertebrate-bearing nodules known from the Unit T2a of the Akrabou Formation (Ettachfini and Andreu, 2004). These nodules are concentrated near the top of a Cenomanian-Turonian calcareous succession and considered as early Turonian in age based on the ammonite assemblage (mainly *Mammites*) (Cavin, 1995, 1997, 1999, 2001; Cavin et al., 2001, 2010; Bardet et al., 2003a,b; Ettachfini and Andreu, 2004; Buchy, 2005; Buchy et al., 2005; Kennedy et al., 2008; Allemand et al., 2017). Both specimens are preserved in incompletely prepared nodules and we used X-ray computed microtomography in order to reveal anatomical details that are not otherwise directly observable.

1.1. Institutional abbreviations

D, Musée de Rhinopolis, Gannat, France**; MNHN**, Muséum National d'Histoire Naturelle, Paris, France; **NHMUK**, Natural History Museum, London, UK; **ROM**, Royal Ontario Museum, Toronto, Ontario, Canada; **SGU**, Saratov State University, Saratov, Russia; **SMNK**, Staatliches Museum für Naturkunde Karlsruhe, Germany; **SMNS**, Staatliches Museum für Naturkunde, Stuttgart, Germany; **SMU SMP**, Shuler Museum of Paleontology, Southern Methodist University, Dallas, U. S. A.

2. Material and method

The two specimens, MNHN F-GOU14 and D1-8213 (Fig. 2), are respectively housed in the Muséum National d'Histoire Naturelle (Paris, France) and the Rhinopolis Museum (Gannat, France) collections. These two specimens are preserved in a nodule in two pieces that fit perfectly. The complete nodules enclosing MNHN F-GOU14 and D1-8213 measure 36, 12, 11 and 41, 15, 12 cm long, wide and high respectively. The specimens are incompletely prepared. In both cases, the anterior half of the nodule shows bones incompletely dissolved and/or exposed, surrounded by a light beige matrix (Fig. 2). The posterior half of the fossils is still embedded in the matrix and not observable.

The two specimens were scanned at the AST-RX platform of the MNHN (Paris) using a GEphoenix|Xray|v|tome|x L240 with a different voxel size, voltage and intensity for each piece (see Supplementary Data 1 for the parameters of the scans). A virtual three-dimensional reconstruction of each specimen was then performed at the Palaeontology Imaging Unit of the UMR 7207 CR2P CNRS/MNHN/UPMC using MIMICS (Materialise Interactive Medical Image Control System) Innovation Suite software (Materialise®, release 18). During segmentation work, bone elements appeared generally with darker grayscale values than the matrix due to the different X-ray absorption coefficients. However, no unique threshold value could accurately describe the boundary between the bone and the matrix. The reconstructions were thus realized from the multiple 2D cross-sectional slices edit tool of MIMICS and interpolation between selections on non-contiguous slices.

3. Systematic palaeontology

SAUROPTERYGIA Owen, 1860
Order PLESIOSAURIA de Blainville, 1835
Super Family PLESIOSAUROIDEA Welles, 1943 (sensu Ketchum and Benson, 2010)
Family ELASMOSAURIDAE Cope, 1869

Genus *LIBONECTES* Carpenter, 1997
Type species: *ELASMOSAURUS MORGANI* Welles, 1949