



Occurrence of a tylosaurine mosasaur (Mosasauridae; Russellosaurina) from the Turonian of Chihuahua State, Mexico

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Abstract

A new mosasaur specimen was discovered in the Ojinaga Formation (Turonian) in Chihuahua, Mexico. It is described here based on an incomplete, slightly deformed skull. Comparative analysis reveals features from the parafamily Russellosaurinae, especially the genus *Tylosaurus*. Some features as the “V” shaped skull, well developed rostral process, 12 to 13 dentary and maxillary teeth, shape of premaxilla-maxilla suture, and similar proportions of mandible and quadrate bone are characteristics of *Tylosaurus*, and are similar to *T. proriger* and *T. nepaeolicus*, but the absence of an infrastapedial process indicates it is most closely related to *T. kansasensis*.

Keywords: Mosasauridae, Chihuahua, Ojinaga Formation, *Tylosaurus*.

Resumen

Un nuevo espécimen de mosasaurio fue descubierto en la Formación Ojinaga (Turoniano), en el estado de Chihuahua, México; aquí se describe con base en un cráneo incompleto, ligeramente deformado. El análisis comparativo revela caracteres pertenecientes a la parafamilia Russellosaurina, en especial al género *Tylosaurus*. Algunos caracteres como el cráneo en forma de “V”, proceso rostral bien desarrollado, 12 a 13 dientes maxilares y dentarios, sutura premaxilar-maxilar y proporciones similares de la mandíbula y del hueso cuadrado, son características del género *Tylosaurus*, y son similares a *T. proriger* y *T. nepaeolicus*, pero la ausencia de un proceso infrastapedial indica que está más cercanamente relacionado a *T. kansasensis*.

Palabras clave: Mosasauridae, Chihuahua, Formación Ojinaga, *Tylosaurus*.

1. Introduction

Mosasaurs were a group of marine lizards closely related to monitor lizards or snakes (McDowell and Bogert, 1954; De Braga and Carroll, 1993; Vidal and Hedges, 2004; Lee, 1997; Caldwell, 1999; Lee and Caldwell, 2000). They may have benefited from the extinction of ichthyosaurus and of invading shallow waters during Cenomanian time (Polcyn *et al.*, 1999), and during the Turonian and thereafter, evolved to become the apex predators of the ocean during the remainder of the Late Cretaceous (Russell, 1967; Bell, 1997a). Traditionally, Mosasauridae were thought to be a monophyletic group of hydropedal (paddle-like limbs) mosasaurs that descended from or were closely related to Aigialosauridae (plesiopedal, terrestrial limbs forms). However, the monophyly of Aigialosauridae was questioned by Bell (1997b) and with the discovery of *Dallasaurus turneri*, a plesiopedal mosasaurine mosasaur (Bell and Polcyn, 2005), the concept of Aigialosauridae lost significant support. Currently, the superfamily Mosasaurioidea includes Aigialosauridae, which only contains *Aigialosaurus* (Bell and Polcyn, 2005; Caldwell *et al.*, 1995) and it is the sister family to Mosasauridae; however, there are no derived characters that define Aigialosauridae, and retention for other than historical purposes is currently not justified. Mosasauridae includes four subfamilies: Halisaurinae, Mosasaurinae, Plioplatecarpinae and Tylosaurinae. The latter two are included in the clade Russellosaurina (Polcyn and Bell, 2005).

The oldest occurrence of derived mosasaurs is in the lower Turonian of Morocco, represented by the russellosaurian *Tethysaurus nopcsai* (Bardet *et al.*, 2003; Polcyn and Bell, 2005). In Texas, *Russellosaurus coheni* and *Dallasaurus turneri* are found in the lower middle Turonian (Bell, 1995; 1997b; Bell and Polcyn, 2005). Other forms are *Yaguarasaurus colombianus* from the Turonian of Colombia (Páramo, 1994; 2000), and *Angolasaurus bocagei* and *Tylosaurus iembeensis* (formerly *Mosasaurus iembeensis*) from Angola (Antunes, 1964). Recently, a relative derived premaxilla of a mosasaur purportedly similar to *Russellosaurus* was discovered in the Cenomanian of Russia (Grigor'ev *et al.*, 2009); however, this occurrence is suspect given its highly evolved nature compared with other contemporaneous forms. A few mosasaur specimens have been discovered in Mexico. The first record was *Amphokepubis johnsoni*, consisting of a partial skeleton from the San Felipe Fm. (Santonian), east of Monterrey (Mehl, 1930); other findings, mainly in the Vallecillo (Nuevo León) area, includes an aigialosaurid (basal mosasaur), which preserves the post-cranial skeleton (Buchy *et al.*, 2005; Buchy, 2007). Campanian-Maastrichtian material is limited to a fragmentary jaw (UANL-FCT-R6) and a skull (UANL-FCT-R4), the cranial anatomy of which was described by Buchy *et al.* (2007) and is the best preserved cranial remains in Mexico described so far.

This paper reports a tylosaurine mosasaur found in

the San Antonio El Bravo area, Ojinaga municipality, in the central-eastern portion of Chihuahua state (Figure 1). It was collected in the middle member of the Ojinaga Formation, during Late Cretaceous coal shale exploration by the Dirección de Evaluación de Minerales Energéticos del Servicio Geológico Mexicano.

2. Geologic Setting

The Ojinaga Formation was originally defined as sedimentary rocks deposited on the Aurora Formation by Burrows (1910); Vivar (1925) named this unit as the Ojinaga Group, and the thin, stratified shales on the base was named as the Ojinaga Formation. Wolleben (1966) subdivided the Ojinaga Group into Ojinaga, San Carlos and Picacho formations. The Ojinaga Formation correlates to the Indidura Formation of Coahuila (Petróleos Mexicanos, 1982; Castillo-Madrid, 1982), the Pen and Boquillas formations of the Big Bend region, Texas, the Agua Nueva Formation from northeastern Mexico, and the Eagle Ford (Castillo-Madrid *op cit.*; Mena-Escobar, 1994) and Austin formations of western Texas in the lower and upper member, respectively (Mena-Escobar *op cit.*; Wolleben, 1966). Petróleos Mexicanos (1983) described the Ojinaga Fm. as fissile shale and thin beds of dark gray, clayey mudstone, and yellow colored, medium-grained, calcareous sandstone. According to the section measured by the Servicio Geológico Mexicano (SGM), at the site of the discovery of the specimen (Figure 1), the Ojinaga Fm. thickness is approximately 714 m (Wolleben, 1965) and consists of a series of interbedded, dark gray shales, marls and thin mudstone with *Inoceramus* sp. and layers with ferrous concretions. The depositional environments of the Ojinaga Formation were: an open shelf (Petróleos Mexicanos, 1983; McBride and Caffey, 1979; Cantú-Chapa, 1993); a deep, neritic environment with abundant terrigenous input, and deep, closed, restricted ocean water circulation and reducing conditions in marginal lagoons (Mena-Escobar, 1994). The lack of ammonite fossils makes it difficult to establish a reliable stratigraphic control, but other studies of the Ojinaga Fm. indicate that its age ranges from Cenomanian to Maastrichtian (Castillo-Madrid, 1982), Cenomanian to Santonian (Cabrera *et al.*, 1984), late Cenomanian to early Coniacian (Monreal, 1987), and late Cenomanian to Turonian (Cantú-Chapa, 1993).

The paleogeography of the Chihuahua trough is related to the Western Interior Seaway during the Turonian. At that time, a change of the sediment type took place: from shallow water carbonates to marine clastic deposits, all related to the last stages of the Sevier orogeny (Muehlberger, 1992; Haenggi, 2002). Units such as the Ojinaga Formation and the correlatable Indidura Formation (Petróleos Mexicanos, 1982) were deposited in neritic environments of variable depth, depending on former paleogeographic elements upon which sedimentation took place: the Indidura Formation

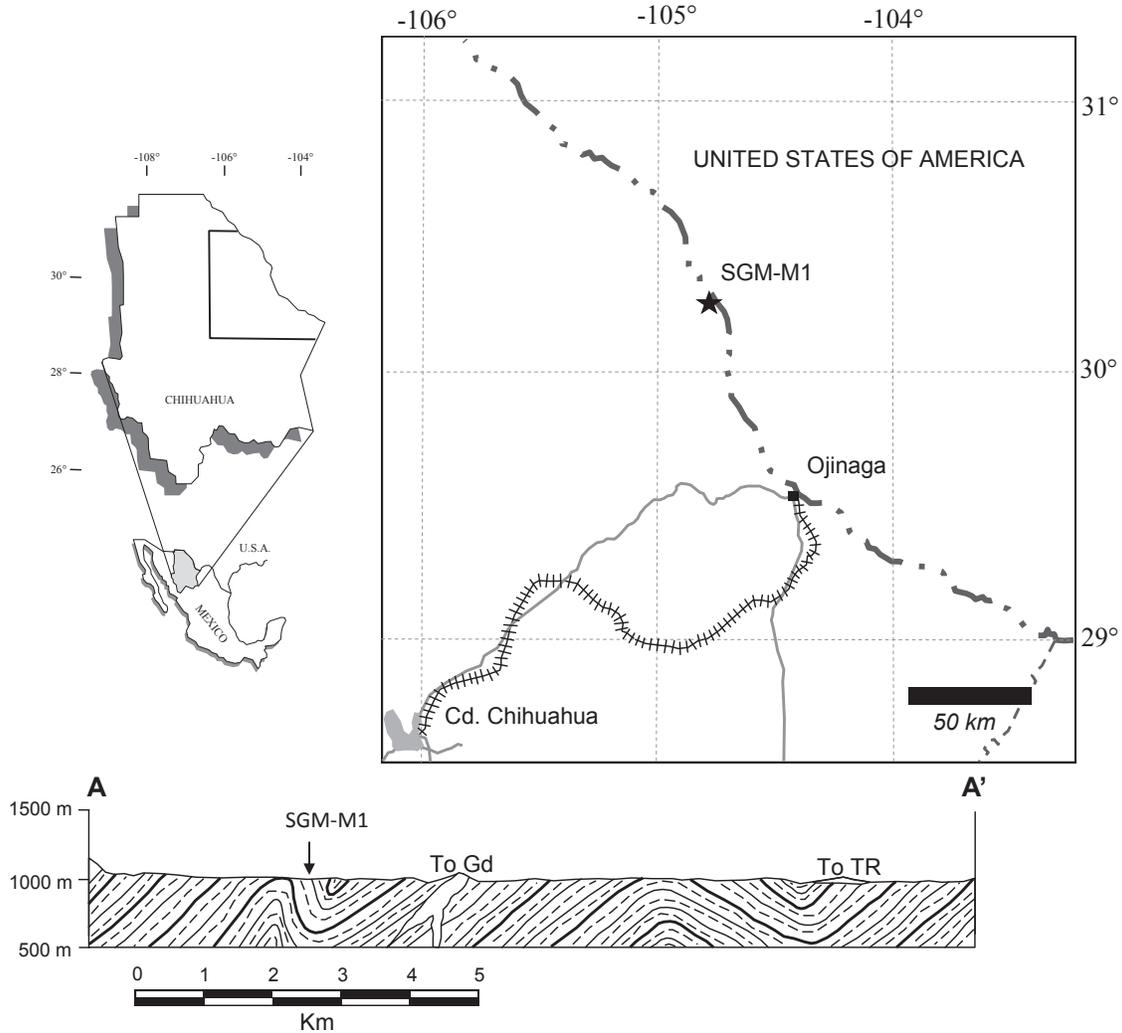


Figure 1. Location of mosasaur fossil SGM-M1, approximately 84 km northwest of Ojinaga, in the middle member of the Ojinaga Formation (Section A-A'). ToGd, granodiorite; ToTr, rhyolitic tuff.

deposited on the Aldama and on the Coahuila platforms, and the Ojinaga Formation deposited on the eastern limit of the Chihuahua basin, at the very edge of El Diablo platform. Evidence of variable thicknesses from different zones are: Ojinaga área (Ojinaga Fm, 1395m), Rim Rock county (Ojinaga Fm, 714m), Camargo range (Ojinaga Fm, 144m), Pajaritos range (Indidura Fm, 165m), (Wolleben, 1965; Petróleos Mexicanos, 1982; Petróleos Mexicanos, 1983; Haenggi, 2002). According to Sageman and Arthur (1994), and Haenggi (2002), deposition of the Ojinaga Fm. in the area is coeval with a series of clastic wedges of the Western Interior Seaway. Geographically, is located on the southwestern margin and opening to the Western Interior Seaway (Figure 2), which at that time functions as an estuarine mouth with fresh water influx draining to the Tethys province and salted, deep water in opposite direction (Slingerland *et al.*, 1996).

3. Systematic Paleontology

Order Squamata Oppel, 1811
 Family Mosasauridae Gervais, 1853
 Parafamily Russellosaurina Polcyn and Bell, 2005
 Subfamily Tylosaurinae Willingston, 1897
 Genus *Tylosaurus*, Marsh, 1872

Material: Holotype (SGM-M1), Nearly complete skull, cranial vault crushed dorsolaterally and filled with clay, partially oxidized with pyrite. The rostrum includes premaxillae, maxillae and both dentarium, slightly deformed (Figures 3a-d). This fossil is housed at the Oficina Regional Chihuahua (ORC) of the Servicio Geológico Mexicano (SGM).

Horizon and Locality: Specimen collected in the middle member of the Ojinaga Formation, San Antonio El Bravo, approximately 84 km northwest of Ojinaga,

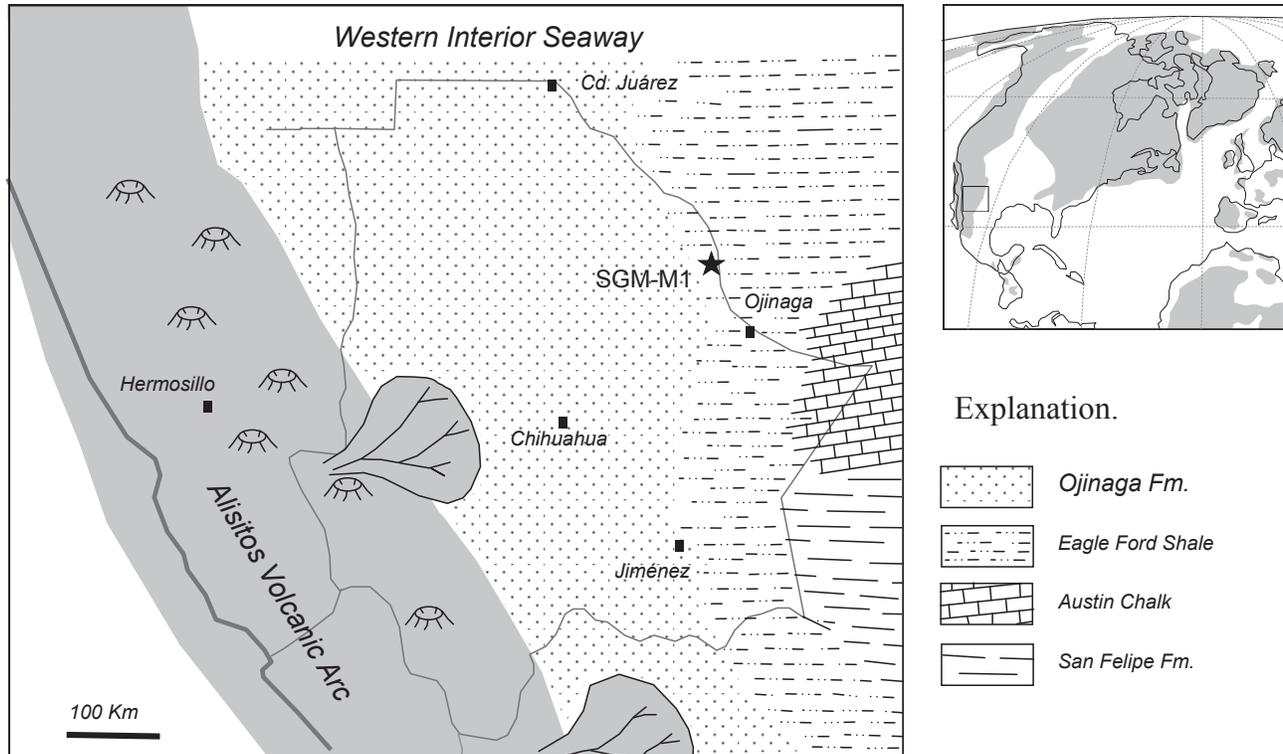


Figure 2. Paleogeography of Chihuahua and Ojinaga during Turonian time (Late Cretaceous). Modified from Mena-Escobar (1994) and Buchy *et al.* (2007).

Chihuahua (30°12'45" N, 104°46'17" E).

Description: Specimen SGM-M1 has an elongated conical, longirostrine skull with a length of 54.8 cm from the anterior end of rostral process to the posterior part of cranial cavity. In dorsal view, skull has an elongated "V" shape (Figure 3d). The skull width between orbits is 7.2 cm, stretching towards the rostrum. The rostrum comprises approximately 62 % of the skull length.

Premaxilla: Premaxilla possesses four dental positions, two each side; left teeth are broken on tip, more conical than maxillary teeth; internarial bar is broken 14 cm posterior of the teeth bearing portion and is triangular in cross-section (Figures 3d and 4d). The premental process extends 2 cm from the first premaxillary tooth, and in lateral view has a slightly conical shape, rounded and projected downward (Figures 4a-b), probably due to crushing. The premaxilla-maxilla projects backwards parallel to the rostrum beginning at about the 2nd or 3rd maxillary tooth position.

Maxilla: The left maxilla (Figures 3a and 4a) is long, slender and is fractured at approximately half its length. The suture with the premaxilla is blurred and slightly deformed. Contact with the prefrontal and frontal is broken and eroded; there are 11 teeth distributed in the pattern 1 X 3 4 5 6 X 8 9 X 11, where "X" represents a missing tooth position, likely in the process of replacement. The right maxilla (Figures 3b and 4b) is partially crushed by frontal and prefrontal and the contact between elements is irregular due to deformation; the dental replacement pattern is 1 X 3 4 X 6 7 X 9 10 X 12 13.

Frontal: Frontal is broad and shield-like (Figures 3d and 4d); there is no indication of midline ridge, but this may be due to erosion. In dorsal view, the lateral margins roughly form a rectangle, wider between orbits with no evidence of postero-lateral projections (*alae*) anterior to fronto-parietal suture, due to breakage. The anterior margin is damaged and the union between frontal and internarial bar is broken and eroded in the specimen.

Parietal: The visible portion of parietal is badly damaged (figures 3d and 4d), but the outline is recognizable, it has a slightly triangular shape anteriorly, but is broken at approximately 8 cm posterior to fronto-parietal suture. The parietal foramen apparently is located 2 cm posterior to suture and is diffuse mostly due to weathering.

Prefrontal: Left prefrontal (Figures 3a and 4a) is eroded and filled with a pyritized matrix. The right prefrontal (Figures 3b and 4b) is deformed and crushed dorsolaterally, with irregular edges, contact with jugal is blurred and is inferred in the interpretation.

Dentary: The right dentary (Figure 4b) has a total length of 34 cm, 13 teeth with the following dental formula: X X 3 4 5 X 7 8 9 10 11 X 13. The left dentary (Figure 4a) has 12 teeth and a dental formula of: X X 3 4 X X 7 8 9 10 11 12. Both prementary processes are broken 1 cm from the first dentary tooth. The dentaries (and anterior left maxilla) presents elongated foramina for the trigeminal nerves, obscured on the posterior portions of the jaws, probably due to preservation. The foramina are approximately half centimeter in length, aligned in a straight line on the central



Figure 3. Specimen SGM-M1: a) Left view, b) right view, c) ventral view, d) dorsal view; an. angular; ar. articular; c. coronoid; d. dentary; fr. frontal; j. jugal; mx. maxilla; n. internarial bar; par. parietal; pmx. premaxilla; pfr. Prefrontal; q. quadrate; sa. surangular; sp. splenial. Scale bar equals 10 cm.

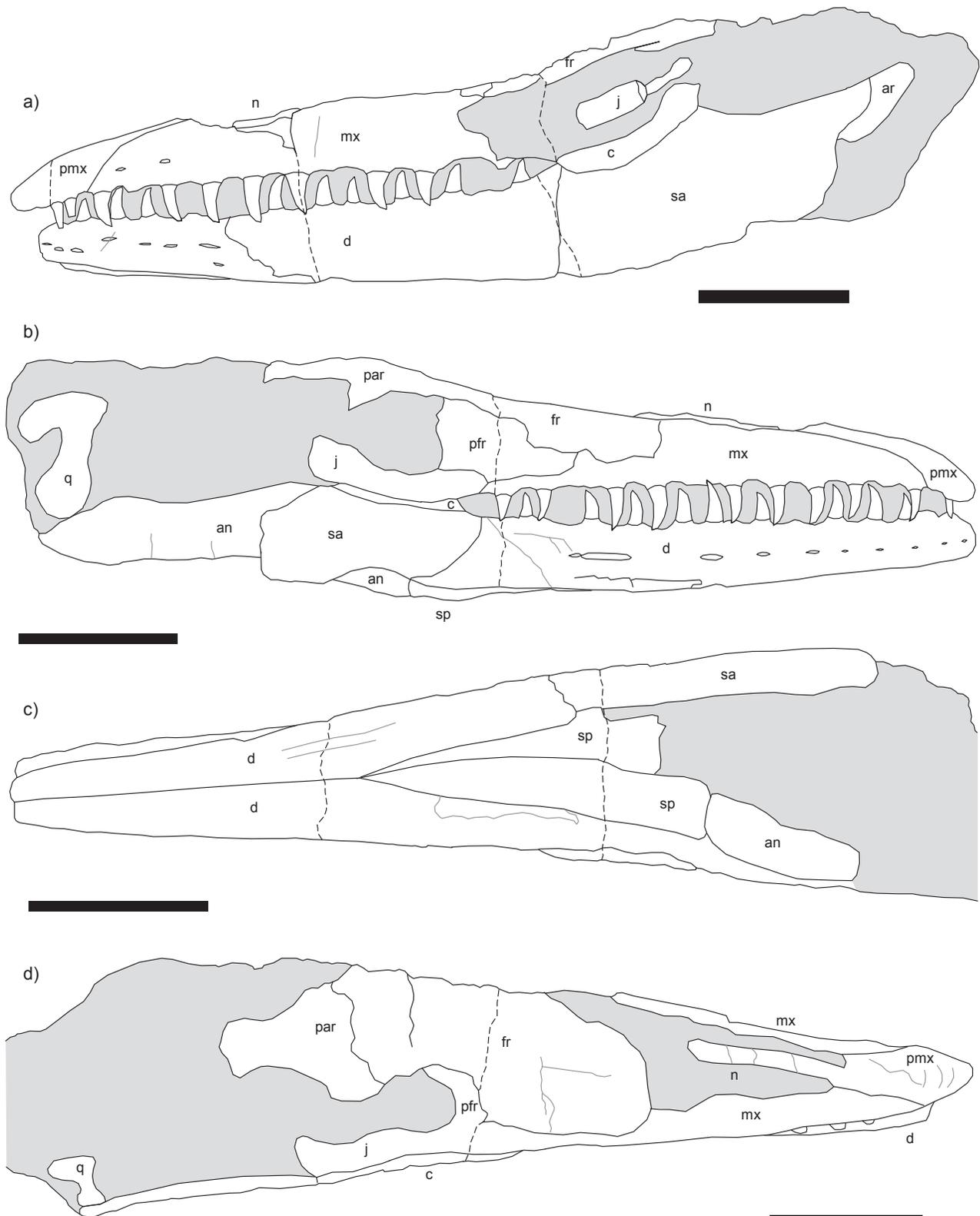


Figure 4. Interpretation of the specimen SGM-M1, a) Left view, b) right view, c) ventral view, d) dorsal view; an. angular; ar. articular; c. coronoid; d. dentary; fr. frontal; j. jugal; mx. maxilla; n. internarial bar; par. parietal; pmx. premaxilla; pfr. prefrontal; q. quadrate; sa. surangular; sp. splenial. Scale bar equals 10 cm.

portion, with the posterior foramen larger and slightly separated from the rest (Figure 4a). The marginal dentition is homodont with conical teeth slightly curved backwards at the middle and do not have any visible striae or carinae. Most crowns preserve the enamel intact.

Splénial: In ventral view, the ventral portions of both splénials lie in articulation with the dentary (Figure 4c); right splénial overlaps with the left due to preservation (Figures 3c and 4c). The angular-splénial articulation is well defined and straight, but laterally inclines posteriorly (Figure 4b). In right side view it can be seen only in the posterior portion of the dentary. The left splénial is only visible on ventral view and is broken on its tip (Figure 4c).

Angular: The right splénial-angular articulation inclines posteriorly on lateral view, its posterior half is visible due to surangular missing a half of its length. Left angular is missing (Figures 3c and 4c).

Surangular: The left surangular is complete and robust with a total length of 21 cm (Figures 3 and 4), but the right is broken at approximately half its length, revealing what appears to be the articular. Judging from the left side, the surangular-articular suture slopes anteroventrally in a relatively tight radius, and then forms an irregular margin, but this irregular portion may be an artifact of preservation. The left coronoid contact with the surangular is gently curved (Figure 4a). Only a small portion of right coronoid contact is visible (Figure 4b) and is straight but this is due to poor preservation.

Coronoid: Left coronoid is complete, visible only its external contour (Figure 4a). Dorsal margin is concave with a well-developed posterior process, protruding 1.5 cm at a moderate angle. Right coronoid (Figure 4b) is compressed between surangular and prefrontal-jugal.

Jugal: The jugals are broken and the only visible part is a fragment of the horizontal bar located below the orbit (Figures 4a-b). As the “L” shaped vertex is not visible, it is not possible to define if posteroventral process on the jugal is well-developed. A small fragment of left jugal is embedded in matrix between coronoid and parietal (Figure 4b), with other bones missing.

Quadrate: The right quadrate is poorly preserved (Figures 3b and 4b); it is embedded in rock with a matrix filling the skull, although its outline is still visible. The infrastapedial process is short, rounded and poorly developed; the tympanic rim and suprastapedial processes are eroded.

4. Discussion and Conclusions

Coniacian through the Maastrichtian are reasonably well known; however, Turonian mosasaurs are scarce, which creates a gap in the knowledge of the evolutionary history of the group (Polcyn *et al.*, 2008). The relationships of the new specimen were analyzed by comparative paleontology. First, halisaurines and plioplatecarpines were excluded due

to the lack of a pronounced rostral process. *Clidastes* does possess a short rostrum, but is different in the details and more “V” shaped. Additionally, the shape of the frontal, the dental formula, and maxilla-premaxilla suture, excluded these taxa. Lack of a strongly buttressed coronoid process excludes all other derived mosasaurs.

The SGM-M1 specimen shares a number of features with *Tylosaurus*, such as the shield-like frontal, dental formula and elongate and rounded predental rostrum. The new material differs in proportion of the predental rostrum and appears to be shorter than either *T. proriger* or *T. nepaeolicus*. Additionally, the external nares begin at approximately the 4th maxillary tooth in *T. proriger* and *T. nepaeolicus*, but it is more anterior in our specimen. Absence of a developed infrastapedial process of the quadrate and the internarial bar, which is triangular in cross-section, places the specimen close to *T. kansasensis* (*sensu* Everhart, 2005a) but a significant difference is the absence of the central ridge on the frontal; however, this absence may be due to erosion and/or poor preservation. Thus, using anatomical features of SGM-M1 in comparison with other specimens, it could be determined that it belongs to the taxon *Tylosaurus* Marsh, 1872, with significant affinities with *Tylosaurus kansasensis* Everhart 2005b. Due to poor preservation and the possibility that the postcranial skeleton remains in the site, a more detailed search and a stratigraphic, micropaleontologic analysis, and a proper restoration of the specimen is needed.

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