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First occurrence of Mosasauridae (Squamata) in the Maastrichtian (latest Cretaceous) of Alicante (Valencia Community, Eastern Spain)

Primer hallazgo de Mosasauridae (Squamata) en el Maastrichtiense (Cretacico final) de Alicante (Comunidad de Valencia, Levante Español)

N. Bardet[1], J.F. Baeza Carratalá[2], V. Díez Díaz[3], Á. Carbonell[4], Manuel García Ávila[5], V. Giner[4]

ABSTRACT

Although the mosasaurid genus *Prognathodon* is known worldwide during the latest Cretaceous (Campanian-Maastrichtian), we report here its first occurrence in the Eastern area of the Iberian Peninsula. It was previously known from coeval levels of the Basque Country. The specimen from Castalla (Alicante) corresponds to a pterygoid tooth. Though it cannot be precisely determined at the specific level, the tooth belongs to a *Prognathodon* species with 'slender' teeth such as *P. compressidens, P. sectorius* and *P. mosasauroides*, all known in the Campanian-Maastrichtian of Europe, or *P. kianda* from the Maastrichtian of Angola.

Keywords: Mosasauridae, *Prognathodon*, latest Cretaceous, Betic Cordillera, Spain.

RESUMEN

Aunque el genero de mosasaurio *Prognathodon* esta conocido mundialmente durante el Cretácico final (Campaniense-Maastrichtiense), damos a conocer su primera occurencia en el Levante Español. Previamente ya se conocía en niveles contemporáneos del País Vasco. El especimen de Castalla corresponde a un diente del pterigoides. Aunque no se puede identificar a nivel especifico, el diente pertenece a una especie de *Prognathodon* con dientes 'delgados' como *P. compressidens, P. sectorius* y *P. mosasauroides*, del Campaniense-Maastrichtiense de Europa, ó *P. kianda* del Maastrichtiense de Angola.

Palabras claves: Mosasauridae, *Prognathodon*, Cretácico final, Cordillera Bética, España.

Introduction

Mosasaurid remains are extremely scarce in the latest Cretaceous (Campanian-Maastrichtian) of the Iberian Peninsula and are exclusively known in two areas: the Lusitanian Basin and the Basque-Cantabrian Region (see Bardet *et al*., 2008).

In Portugal, only few isolated remains consisting of teeth and vertebrae were described by Sauvage (1897-1898). More recently, a few mosasaurid vertebrae have been mentioned (Antunes & Broin, 1988).

In the northern Iberian Peninsula, mosasaurid specimens found in the Campanian-Maastrichtian of the Basque-Cantabrian Basin have been described in

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recent years by Bardet *et al*. (1993, 1997a, 1999, 2006, 2012). The material, which also mainly consists of isolated teeth and vertebrae, represents however the most diverse mosasaurid assemblage found to date in the Iberian Peninsula (Bardet *et al*., 2008). Here, the genera *Mosasaurus*, *Prognathodon*, *Platecarpus* and *Tylosaurus* have been recognised.

Prognathodon has been reported as follows : 1) *Prognathodon* sp. in the Upper Campanian Vitoria Formation of Castillo-Lasarte, Álava (Bardet *et al*., 1997a) ; 2) *Prognathodon solvayi* Dollo, 1889 and *Prognathodon* sp. in the Upper Maastrichtian of an unnamed unit (lateral equivalent of the Torme Formation) of Albaina, Condado de Treviño (Bardet *et al*., 1999); 3) *Prognathodon* cf. *sectorius* in the Upper Campanian Vitoria Formation of Olazti (Olazagutia), Navarre (Bardet *et al*., 2012).

Here we report on the discovery of new mosasaurid specimen, an isolated tooth, from the Late Cretaceous of near Alicante, Valencia Community.

Institutional abbreviation—CVAI, Colección Vertebrados Asociación Isurus.

Geographical and geological setting

The studied specimen came from Sierra de La Argueña (Alicante, SE Spain), a calcareous terrain characterized by a predominance of marine hemipelagic sedimentation during the Late Cretaceous (Fig. 1B). The level where the specimen has been found is located in the Foia Redona locality, an old quarry for the extraction of marls.

This area belongs to the External Zones of the Betic Cordillera, which, during the Mesozoic, formed the south Iberian Paleomargin (Vera, 1988), in an area that previous authors have set in the easternmost Internal Prebetic Domain (Azéma *et al*., 1979; García Hernández *et al*., 1980; De Ruig, 1992, Martin-Chivelet, 1992, Chacón, 2002; Chacón & Martín-Chivelet, 2003, among others) (Fig. 1A), and included into the recently individualized Prebetic zone of the Aspe-Jijona-Alicante Sector (Arias *et al*., 2004).

The stratigraphy of this Prebetic zone during the Cretaceous has been studied in detail by many authors (e.g.: Vera *et al*., 1982, Martínez del Olmo *et al*., 1982, Martin-Chivelet, 1992, Chacón, 2002; Chacón & Martín-Chivelet, 2001, 2003, 2005). Recent studies by Chacón & Martín-Chivelet (2005) divided the stratigraphical sequence of this region in different lithostratigraphical formations. Among them, in the

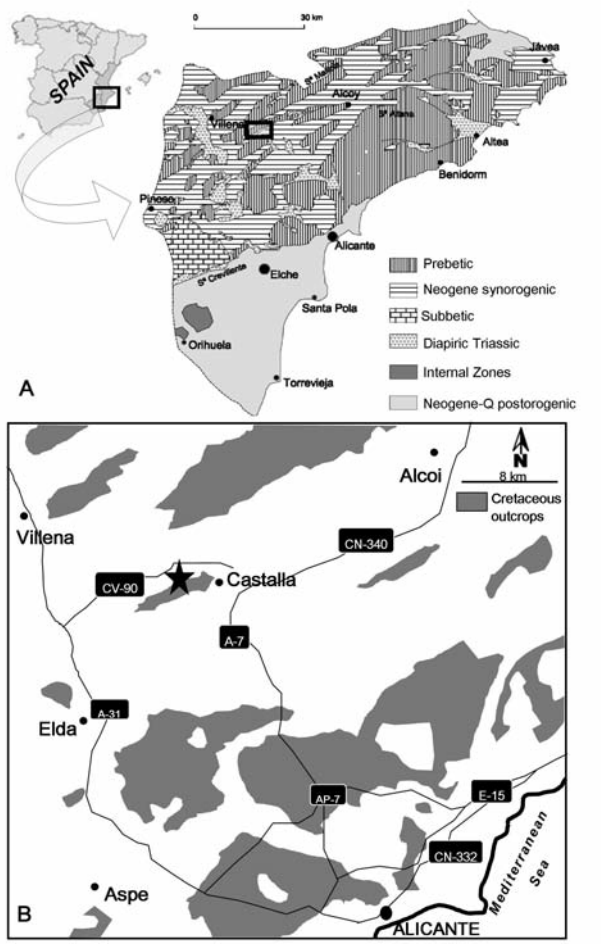

Figure 1—A. Geological sketch showing the studied area within the context of the Betic Cordillera in Alicante Province (modified after Estévez *et al*., 2004). B. Situation map and stratigraphical setting of Foia Redona section into Cretaceous outcrops in the northern Alicante province.

Sierra de La Argueña, very homogeneous facies are observed; however some successive levels referred to the Maastrichtian could be characterized.

The level that has yielded the mosasaur tooth consists of marly sediments that can be assigned to the Raspay Formation (Martin-Chivelet, 1994), widely outcropping in this eastern part of the Cordillera according to Chacón & Martín-Chivelet (2005), and which is assigned to the upper Maastrichtian. In the studied stratigraphical section, it corresponds to the predominantly marly member deposited into the basin after the middle Maastrichtian discontinuity that implies a change from the underlying carbonate succession to marly hemipelagic sedimentation (Martín-Chivelet *et al*., 2002; Chacón, 2002; Chacón

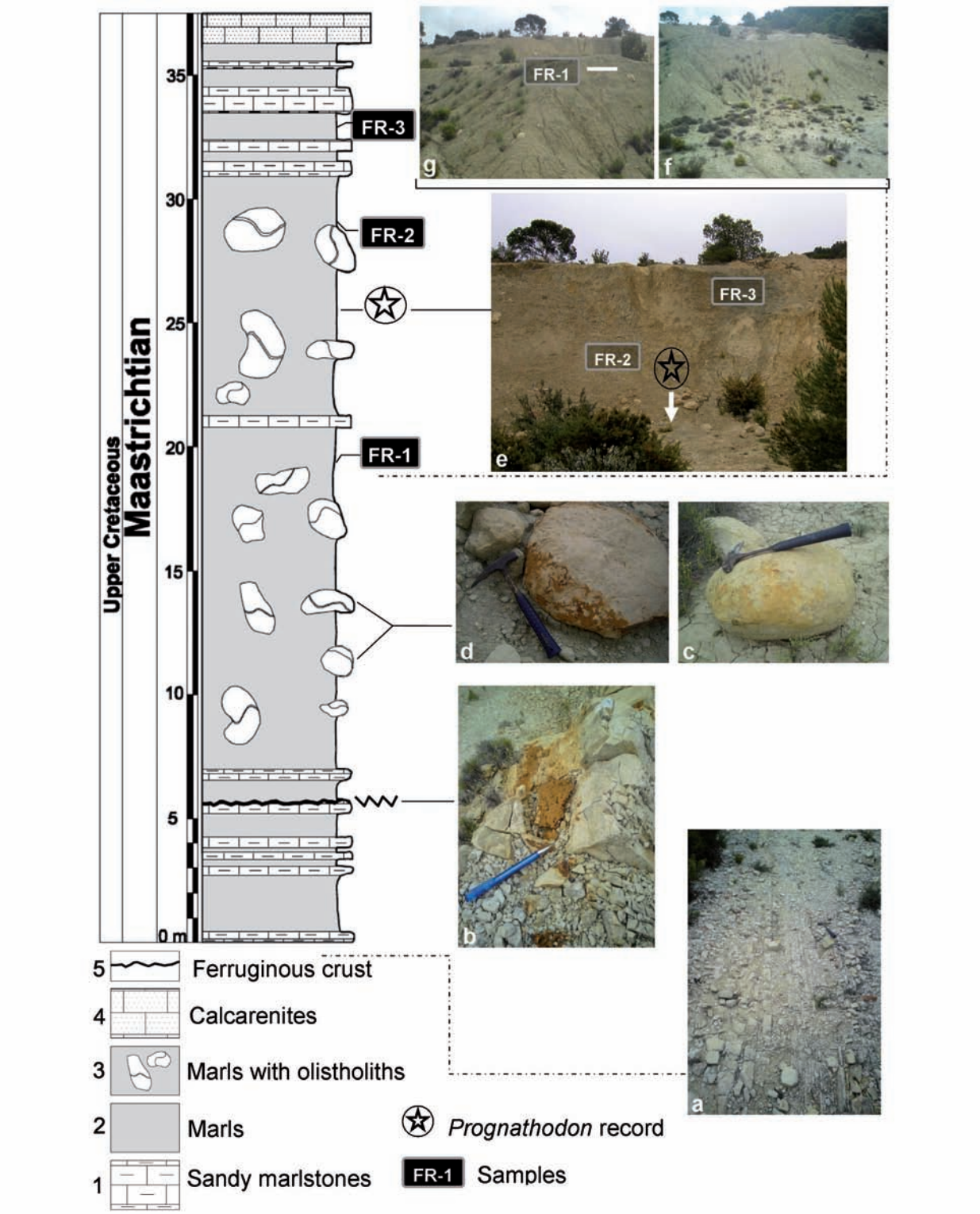

Figure 2—Foia Redona lithostratigraphical section. a. pre-Middle Maastrichtian carbonates succession in La Argueña Sierra; b. Outcrop detail showing the ferruginous crusted surface. c, d. Detailed view of olistholiths. e. Marls strata with *Prognathodon* remains. f, g. Outcrop perspective of the Raspay Fm. in Foia Redona site, showing the chaotic appearance because of the olistholiths and extractive activities.

& Martín-Chivelet, 2003, 2005). The paleoenvironmental conditions of these sediments have been interpreted as an open-marine environment with significant terrigenous content, located between the outer shelf and the upper bathyal zone (Chacón & Martín-Chivelet, 2005).

Stratigraphical data

In the stratigraphic section of Foia Redona where the outcrop occurs (Fig. 2) marly levels are mainly represented from the Raspay Formation (Martín-Chivelet, 1994), overlying the mostly carbonated succession (corresponding to the Aspe or Carche Formation, according to the Prebetic zone in which they crop out; Chacón & Martín-Chivelet, 2005).

The base of the section is alternating greenish marls and yellowish marly/silty limestones, with abundant Fe-oxides and a typical conchoidal fracture. The levels are frequently well-bedded, with decimetric to metric-thick bedding. This bottom interval ends with a marly limestone level overlain by an encrusted ferruginous surface, with abundant bioturbation and a rich, well-preserved macrofauna in which is predominantly corals, bivalves and limonitized nucleus of gastropods and ammonoids. This surface presumably coincides with the middle Maastrichtian discontinuity that marks the transition to marly facies in the basin (Chacón & Martín-Chivelet, 2003, 2005, among others).

Overlying this level, there is a thick set of grey and greenish marly beds evolving upwards to darker marls; the underlying ferruginous surface is often found reworked in the basal tract of this levels.

The entire marly tract has a chaotic appearance. The apparent homogeneity is disrupted by the presence of numerous olistholiths. In the studied area reworking due to old mining activities must also be taken into account.

The olisthons consist of beige marly limestones, with wackstone-packstone texture; they are rounded and decimetric to metric in diameter and include small echinoderms (*Salenia* sp.), agglutinated benthic macroforaminifera, and bryozoans. This association is also found in the marls embedding the olistholiths, which also include *Isocrania* sp., *Magas* sp., bivalves, serpulids and small selachian teeth.

The first marly tract with olistholiths is followed by a second level of similar lithology, but lighter in colour, in which the studied tooth has been found, associated with a rich fauna of echinoderms in which *Echinocorys* sp. and *Cyclaster* sp. dominate.

In these marls, interbedded greenish to yellow marly levels are present and are about 50 cm thick. The marly sediments become darker upwards, and in their upper part, the marly limestones levels are well-bedded and acquire boudinaged morphology, and lighter shades.

The Foia Redona section finishes with a level of beige marls on which lays a metric-thick distinctive strata which lithology corresponds to yellow calcarenites with basal parallel lamination.

In addition to the data arising from the recorded macrofauna, the age of the deposits has been contrasted with the several sampling (samples FR-1 to 3 in Fig. 2) that have yielded a rich microfauna of foraminifera. Samples were taken from immediately above and below the level in which the mosasaur tooth was found. Both samples preserve a similar fauna. The underlying assemblage is dominated by Heterohelicids, Contusotruncanids, the notable occurrence of *Planoglobulina acervulinoides* and occasional ostracods. The overlying assemblage includes numerous Heterohelicids, several Globotruncanid species, *Rugoglobigerina* cf. *hexacamerata*, occasional *Racemiguembelina fructicosa, Globigerinelloides* sp. and few ostracods. The younger recorded assemblage includes almost the same microfauna but with an increase in the presence of *R. fructicosa*. In all samples the benthic foraminifera are lesser extent.

By comparing these data with the zonation proposed by Premoli-Silva and Sliter (2002) and the precise biostratigraphical data of Chacón (2002), and Chacón and Martín-Chivelet (2003, 2005) for the Raspay Formation, the assemblages found in the Foia Redona section can be assigned to the Late (but not latest) Maastrichtian, presumably to the upper part of the *Gansserina gansseri* Zone but not reaching the uppermost part of the Maastrichtian as the index fossil of this interval *Abathomphalus mayaroensis* having not been recorded.

Systematic palaeontology

Squamata Oppel, 1811

Mosasauridae Gervais, 1853

Prognathodon Dollo, 1889

Prognathodon sp.

Material: CVAI 00141, an isolated pterygoid tooth crown (Fig. 3).

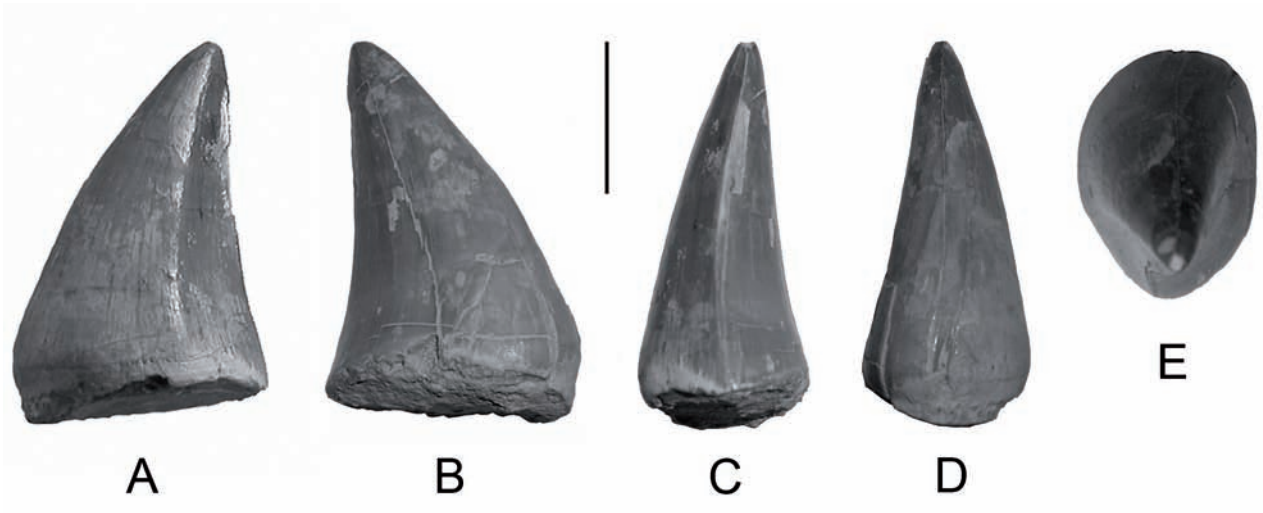

Figure 3—*Prognathodon* sp., CVAI 00141, pterygoid tooth crown; Raspay Formation; Late Maastrichtian (*Gansserina gansseri* Zone?); latest Cretaceous); Castalla (Alicante), Valencia Community, Eastern Spain. A, labial view; B, lingual view; C, anterior view; D, posterior view; E, apical view. Scale = 1 cm.

Geographical occurrence: Font de la Carrasca Quarry, East of Castalla, northwest of Alicante Province, Community of Valencia, Eastern Spain. UTM: 30S 6992204273190 (Fig. 1).

Stratigraphical occurrence: Raspay Formation; Late Maastrichtian, probably in the upper part of the *Gansserina gansseri* Zone (Fig. 2).

Description

The tooth preserves only the enamel crown which is 23.8 mm high, 16 mm long and 11.4 mm wide. In lateral view (Figs. 3A-B), the crown is a robust posteriorly recurved triangle, with a pointed apex, a convex anterior surface and a slightly concave posterior one. The crown is compressed labiolingually and the basal cross-section is teardrop shaped (Figs. 3C-E). The labial surface is slightly convex whereas the lingual one is almost flat (Figs. 3C-D). There is only a posterior marked carina slightly displaced laterally (Fig. 3C). It seems to be 'pinched' from the main shaft and bears minute serrations. The anterior surface is regularly curved without any carina. The enamel is completely smooth and has a shiny aspect.

Because of the lack of anterior carina, it could correspond either to an anterior marginal tooth or to a pterygoid one. Usually, the anterior marginal teeth have a slender appearance than the pterygoid teeth, as they are higher than long (height twice the length *versus* less than twice high than long—compared Fig. 3 to Fig. 5 of Schulp *et al*., 2008). The Castalla crown is thus considered here as a pterygoid tooth.

Comparisons and systematic attribution

Mosasaurid teeth (both marginal and pterygoid ones) are generally highly diagnostic at both generic and even specific level (Russell, 1967, Lindgren & Siverson, 2002) so that even isolated teeth can be identified taxonomically.

The absence of medial striae on the tooth excludes the Castalla tooth from the Russellosaurinae (Bell, 1997; Russellosaurina of Bell & Polcyn, 2005). Among Mosasaurinae, its relatively large size and robustness, as well as the occurrence of a completely smooth enamel, support its attribution to the Globidensini (sensu Bell, 1997; Bell & Polcyn, 2005) taxon *Prognathodon*, the only genus of this clade devoid of low blunt teeth, contrary to *Globidens* and *Carinodens* (Schulp *et al*., 2004).

The combination of the following characters, that are, a crown moderately posteromedially recurved, with subequal convex lingual and labial surfaces, a fairly well marked 'pinched' posterior carina, and a smooth shiny enamel, permits to refer the Castalla's mosasaurid to *Prognathodon* Dollo, 1889. This genus includes about ten species from the Campanian-Maastrichtian of many parts of the world, including Europe, North America, Africa, Middle-East and New Zealand (see Schulp *et al*., 2008).

Prognathodon exhibits a large tooth morphology variation interval. The Castalla specimen is clearly distinguishable from the strongly facetted teeth of the type species *P. solvayi* Dollo, 1889 from the Maastrichtian of Belgium (Lingham-Soliar & Nolf, 1989), as well as from species with large robust blunt teeth ornamented by a coarse thick 'anastomosed' enamel, that are, *P. currii* from the Maastrichtian of Negev and Morocco (Christiansen & Bonde, 2002; Bardet *et al*., 2005), *P. giganteus* from the Campanian-Maastrichtian of Europe, Syria and Morocco (Lingham-Soliar & Nolf, 1989; Bardet *et al*., 1997b; Bardet *et al*., 2000, 2010), *P. overtoni* (Williston, 1897) from the Campanian of South Dakota (Lingham-Soliar & Nolf, 1989; Schulp, 2006), *P. saturator* Dortangs *et al*., 2002 from the Maastrichtian of The Netherlands (Dortangs *et al*., 2002), *P. waiparaensis* Welles & Gregg, 1971 from the Maastrichtian of New Zealand, (Welles & Gregg, 1971), and a new, yet undescribed species from the Maastrichtian of Morocco (N.B., pers. obs.). Though the Castalla tooth resembles in general shape a tooth from the Maastrichtian of Normandy (Northwestern France) referred to as *Prognathodon* sp., this one is however distinctly more robust, bears an anterior carina (though slight) and a thick 'anastomosed' enamel (Buffetaut & Bardet, 2012).

As a whole, the Castalla tooth general appearance is more reminiscent of that of *Prognathodon* species possessing 'slender teeth', such as *P. compressidens* (Gaudry, 1892) from the Campanian of France (Schulp *et al*., 2008), *P. mosasauroides* (Gaudry, 1892) from the Maastrichtian of France (Schulp *et al*., 2008), *P. kianda* Schulp *et al*., 2008 from the Maastrichtian of Angola (Schulp *et al*., 2008), and *P. sectorius* (Cope, 1871) from the Maastrichtian of New-Jersey, The Netherlands and the Basque Country (Schulp *et al*., 2008, Bardet *et al*., 2012). As a whole, these species bear marginal teeth labiolingually compressed with completely smooth and shiny enamel. Those of *P. compressidens* are the smallest and are slender and notably posteriorly recurved. Those of *P. mosasauroides* are very large and compressed, acute, with a straight posterior surface. Those of *P. kianda* are the most slendest whereas those of *P. sectorius* are the most robust.

Unfortunately, pterygoid teeth are unknown in *P.* compressidens, *P. mosasauroides* and *P. sectorius*, so that comparisons are only possible with *P. kianda*. The morphology of the largest preserved pterygoid teeth of this species fits pretty well with that of the Castalla one (compare Fig. 2 to Fig. 5 of Schulp *et al*., 2008). However, as comparisons cannot be made with the three species above mentioned, we cannot confidently refer the Castalla tooth to this African species so that it appears safer to refer it only to *Prognathodon* sp.

Conclusion

The specimen from Castalla (Alicante) provides additional evidence of the potential richness of the Iberian Peninsula in mosasaurid remains, though they currently consist mainly on isolated teeth only. It also confirms once more that *Prognathodon* was a cosmopolitan predator during Campanian-Maastrichtian times. In Europe, several species of *Prognathodon* have been described, that are the Campanian *P. compressidens*, the Campanian-Maastrichtian *P. giganteus*, and the Maastrichtian *P. mosasauroides*, *P.* saturator, *P. sectorius* and *P. solvayi*. However, either the Castalla tooth does not fit in general morphology with some of them (*P. solvayi*, *P. giganteus*, *P. saturator*), or pterygoid teeth are unknown in other ones preventing direct comparison (*P. compressidens*, *P. mosasauroides*, *P. sectorius*). Only *P. kianda*, a species with 'slender' teeth from the Maastrichtian of Angola, is suitable for comparisons and shows possible affinities. However, due to the incompleteness of the data precluding for a specific assignment, the Castalla's specimen is here referred to *Prognathodon* sp. *Prognathodon* was previously known in the Iberian Peninsula by remains found in the Campanian-Maastrichtian of the Basque Country referred to *P. solvayi*, *P.* cf. *sectorius* and *Prognathodon* sp.

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