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## ISOLATED ARCHOSAURIAN TEETH FROM “LA BONITA” LOCALITY (LATE CRETACEOUS, SANTONIAN-CAMPANIAN), RÍO NEGRO PROVINCE, ARGENTINA.

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**Abstract.** The tetrapod assemblage of the Bajo de la Carpa Formation (Late Cretaceous; Santonian-

early Campanian) is dominated by archosaurs, represented by saurischians, such as alvarezsaurid, enantiornithine, and abelisauroid theropods (e.g. *Velocisaurus unicus* Bonaparte, 1991) and titanosaurs (e.g. *Bonitasaura salgadoi* Apesteguía, 2004), as well as crocodyliform remains which are the most abundant specimens (e.g. *Notosuchus terrestris* Woodward, 1896). Here we report new archosaur remains from the Bajo de la Carpa Formation at the 'La Bonita' locality, consisting of isolated shed teeth. Two of these specimens present a crown with a straight distal border and denticles with shape and density similar to that observed in abelisauroid theropods. A third tooth is more distally curved, without mesial denticles, and with a figure eight-shaped basal cross-section, resembling the dental features described for the basal tetanuran *Orkoraptor burkei* Novas, Ezcurra and Lecuona, 2008, but differing from this theropod due to the presence of parallel transversal wrinkles throughout the labial and lingual surfaces of the crown. A fourth specimen is considered as belonging to a neosuchian tooth, because it has a circular cross-section, lack of labiolingual compression, and a serrated carina. Although represented by isolated shed teeth, these findings allow increasing the knowledge of the Cretaceous fauna of the Bajo de la Carpa Formation.

**Key words:** Archosauria, teeth, Neosuchia, Abelisauridae, Bajo de la Carpa Formation.

**Resumen.** La fauna de tetrápodos de la Formación Bajo de la Carpa (Cretácico Tardío; Santoniano-Campaniano temprano) está dominada por arcosaurios, representados por saurisquios, como terópodos alvarezsáuridos, enantiornites y abelisauroides (e.g. *Velocisaurus unicus* Bonaparte, 1991) y titanosaurios (e.g. *Bonitasaura salgadoi* Apesteguía, 2004), así como también restos de cocodrilos los cuales representan los especímenes más abundantes (e.g. *Notosuchus terrestris* Woodward, 1896). Se reportan aquí nuevos restos de arcosaurios de la localidad 'La Bonita' de la Formación Bajo de la Carpa consistentes principalmente en dientes de despojo aislados. Dos de estos especímenes presentan coronas con un borde distal recto y una densidad y morfología de denticulos similares a aquellas observadas en dientes de abelisáuridos. Un tercer diente presenta una mayor curvatura distal, sin denticulos mesiales, y con una sección basal en forma de ocho, asemejándose a las características dentales presentes en el tetanuro basal *Orkoraptor burkei* Novas, Ezcurra y Lecuona, 2008, pero diferenciándose de este terópodo debido a la presencia de arrugas paralelas y transversales a lo largo de las superficies labial y lingual de la corona. El cuarto espécimen es considerado como perteneciente a un diente de neosuquio, debido a su sección basal circular, falta de compresión labiolingual, y por poseer carenas aserradas. Aunque representados por dientes de despojo aislados, estos hallazgos permiten incrementar el conocimiento de la fauna Cretácica de la Formación Bajo de la Carpa.

**Palabras Clave.** Archosauria, dientes, Neosuchia, Abelisauridae, Formación Bajo de la Carpa.

## INTRODUCTION

The Bajo de la Carpa Formation (Santonian, Late Cretaceous; Bonaparte, 1991; Hugo and Leanza, 1999, 2001) is well-known since the late XIX century because of the findings of the notosuchian crocodylomorph *Notosuchus terrestris* Woodward, 1896, and the large basal snake *Dinilysia patagonica* Woodward, 1901. Since then, several other tetrapod remains were recovered from this formation, but generally dinosaur findings were much less frequent. The dinosaur record for the Bajo de la Carpa Formation includes the holotype of the small abelisauroid *Velocisaurus unicus* Bonaparte, 1991, discovered in the north part of the Neuquén City, an indeterminate abelisaurid (Ezcurra and Méndez, 2009), the alvarezsaurids *Alvarezsaurus calvoi* (Bonaparte, 1991) and *Achillesaurus manazzoni* (Martinelli and Vera, 2007), the enantiornithine *Neuquenornis volans* (Chiappe and Calvo, 1994), the ornithuromorph *Patagopteryx deferrariisi* (Alvarenga and Bonaparte,

1992), and the titanosaur sauropod *Bonitasaura salgadoi* Apesteguía, 2004, collected at the locality of “La Bonita”. In the latter locality is represented the boundary between the Bajo de la Carpa Formation and the overlain Anacleto Formation (Early Campanian; Leanza, 1999; Dingus et al., 2000; Hugo and Leanza, 2001).

In the present communication we report the findings of new archosaur remains from this locality that consist of isolated shed teeth. Although fragmentary, these findings contribute to increase the knowledge of the Cretaceous faunal assemblage of the Bajo de La Carpa Formation.

## MATERIAL AND METHODS

The specimens described here are four isolated and well-preserved archosaur shed teeth (Table 1). Three of them belong to theropod dinosaurs: specimens MPCA 247 (Figure 2), MPCA 249 (Figure 3), and

	MPCA 246	MPCA 247	MPCA 249	MPCA 251
CH	18,63	<b>21,69</b>	<b>15,53</b>	<b>20,79</b>
CBL	9,89	14,53	9,07	<b>10,52</b>
CBW	8,62	7,8	4,94	<b>5,68</b>
AL	<b>17,94</b>	24,88	<b>13,83</b>	<b>13,07</b>
CBR	0,872	0,537	0,545	0,540
CHR	1,884	1,493	1,712	1,976
MAVG (dent./mm)	5	0	3,5	2,25
DAVG (dent./mm)	4	3,5	3,25	2,5

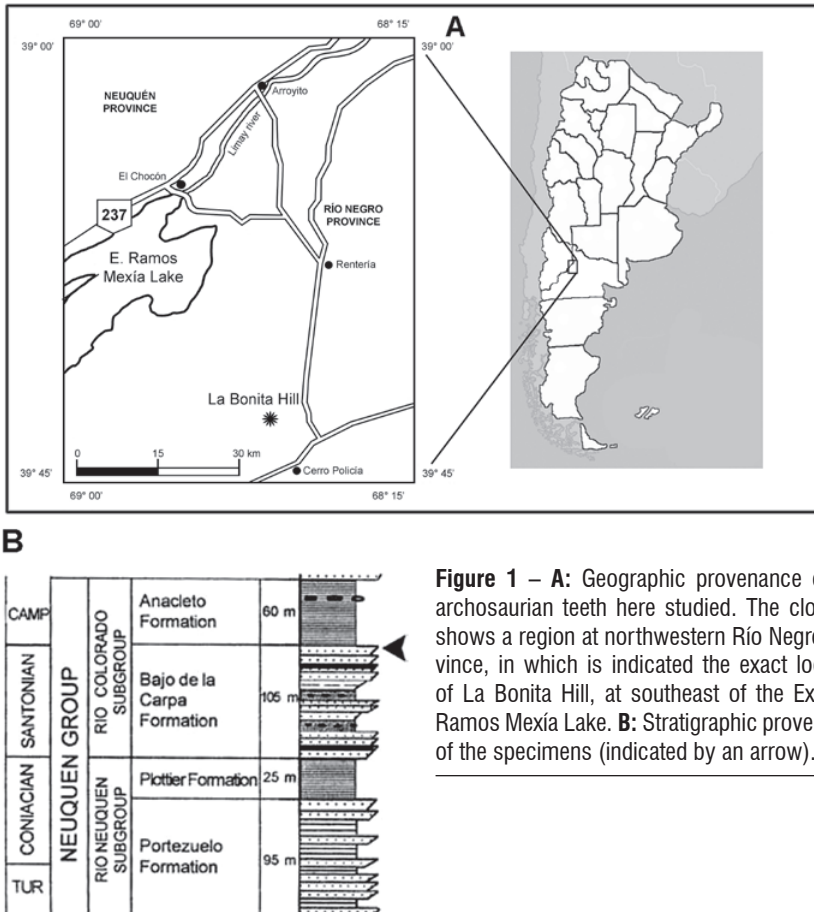
**Table 1** - Measurements and index of the four teeth from ‘La Bonita’. Those values in ‘black’ are estimated, because absent portions of the crowns have not allowed to take correct measures. All values are in millimeter.

MPCA 251 (Figure 4). MPCA 249 and 251 are very similar to each other, while MPCA 247 presents a distinctive morphology. The remaining specimen, MPCA 246 (Figure 5), is markedly different and possibly does not belong to a theropod dinosaur but a crocodyliform. All dental features were observed through naked eye and employing binocular and scanning electron microscopy techniques. Measurements were taken with a digital calliper. In the analysis of the quantitative characters of the theropod teeth we considered the measurements proposed by Smith *et al.* (2005), i.e., crown height (CH), basal width (CBW), mesial-distal basal length

(CBL), apical length (AL), crown angle (CA), crown height ratio (CHR), crown basal ratio (CBR), and denticle density for the mesial and distal carinae (MAVG and DAVG, respectively). These measurements were used also to characterize MPCA 246. The orientation terminology for the tooth crowns follows that proposed by Smith and Dodson (2003).

**LOCALITY AND HORIZON**

The locality corresponds to “La Bonita” hill fossil quarry, approximately 10 km from Cerro Policía village, at northwest-



**Figure 1 – A:** Geographic provenance of the archosaurian teeth here studied. The close-up shows a region at northwestern Río Negro Province, in which is indicated the exact location of La Bonita Hill, at southeast of the Exequiel Ramos Mexia Lake. **B:** Stratigraphic provenance of the specimens (indicated by an arrow).

ern Río Negro Province, Patagonia, Argentina (Figure 1). All remains were found in sandstones deposited in a fluvial environment (Hugo and Leanza, 1999). Such sedimentites belong to the uppermost layers of the Bajo de la Carpa Formation (Santonian; Bonaparte, 1991; Hugo and Leanza, 1999, 2001) (Figure 1).

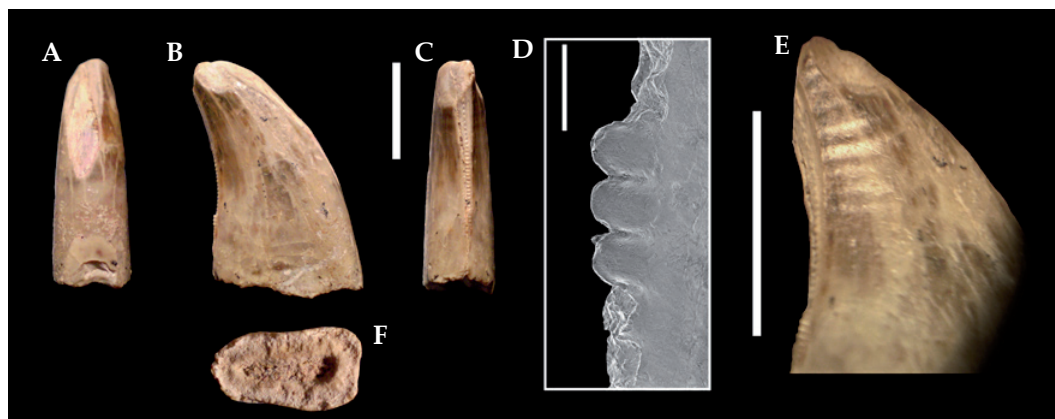
## DESCRIPTION

In addition to the saurischian dinosaurs already registered from this locality, new remains belonging to previously unrecorded taxa were collected. These remains consist of three theropod shed teeth, one of them considered a possible non-coelurosaurian tetanuran, while the remaining two are considered as abelisaurid teeth.

### MPCA 247 (Figure 2):

This specimen corresponds to a theropod tooth crown, labiolingually compressed, and distally curved. The crown is almost fully preserved, lacking its basal-most region, a small portion of the apical tip of the crown, and the apical half of its mesial border (Figure 2, A,B). Wear facets are preserved close to the apex, on both sides of the crown (Figure 2, B,C,E), and possibly in the crushed apical half of the mesial border. The enamel is good preserved over most of crown surface. The crown is slightly curved distally at its basal half, but the curvature increases sharply in the apical half (Figure 2, B). Both sides of the crown are convex, particularly close to the mesial border; but one of them is a slightly more convex, therefore the latter is considered as the labial side. Each side shows at the basal half a shallow median depression with an approximately triangular form. The lingual

depression is better defined, and flanked by shallow ridges. The crown surface presents wrinkles, best defined close to the distal border (Figure 2, E), but extending over the surface of the labial side until the mesial border, like the bands described by Brusatte *et al.* (2007), Canale *et al.* (2009), and Ezcurra (2009) in other theropod teeth. The mesial border is rounded and lacking carina and denticles, at least at its basal half (Figure 2, A). On the other hand, the presence of carina or denticles on the apical half of the mesial border is not possible to discern due to the longitudinal rupture observed in this area. By contrast, the distal border has a well-defined carina with denticles along its entire extension (Figure 2, C). This carina is slightly displaced to the lingual side and is broken along most of its extension. Because of that, only some denticles close to the apex are preserved, which are chisel-like in form, with parallel borders, and rounded apex (Figure 2, D). Most available denticles only preserve the dentine inner core, without the enamel cover layer. No blood grooves are observed associated with any denticle. The basal cross-section of the crown is figure-eight shaped (Figure 2, F), due to the presence of the median depressions on both sides of the crown, similar to that observed in some coelurosaurian teeth (e.g. Currie *et al.*, 1990; Sankey *et al.*, 2002; Gianechini *et al.*, 2010). In particular, MPCA 247 closely resembles the teeth of the neovenatorid tetanuran *Orkoraptor burkei* (Novas *et al.*, 2008), especially after the absence of a mesial carina, the abrupt curvature of the apical portion of the crown, the presence of wear facets, the distal denticle density, and the figure-eight shaped basal section. However, MPCA 247 differs from *Orkoraptor* in the presence of wrinkles, which are extended from the mesial to the distal border, throughout the labial and lingual sur-



**Figure 2** - MPCA 247. **A:** mesial view. See the absence of a serrated carina and the broken zone at the apical half. **B:** lingual view. **C:** distal view. Note the presence of denticles and the displacement of the carina to the lingual side. In A, B, and C, notes the presence of wear facets (wf), close to the apex of the crown. **D:** SEM micrograph showing the distal denticles in detail. **E:** detail of the wrinkles, on the lingual side. **F:** basal view. See the figure-eight shaped basal section. Scales: 1 cm in A, B, C, E, and F; 500  $\mu\text{m}$  in D.

faces of the crown, as parallel, transversal, and upward concave bands. These traits are more similar to those observed in the teeth of other groups of theropods, such as spinosauroids (e.g., *Torvosaurus*), allosauroids (e.g., *Allosaurus* and *Fukuiraptor*), and tyrannosauroids (e.g., *Daspletosaurus*, *Albertosaurus*, *Tyrannosaurus*) (Azuma and Currie, 2000; Holtz, 2004; Brusatte et al., 2007). On the other hand, in carcharodontosaurid and abelisaurid theropods are present very characteristic wrinkles with a much sharper and most pronounced relief located close to the mesial and distal carinae, as those observed in *Carcharodontosaurus*, *Mapusaurus*, and *Skorpiovenator* (Sereno et al., 1996; Coria and Currie, 2006; Brusatte et al., 2007; Canale et al., 2009; Ezcurra, 2009).

**MPCA 249** (Figure 3) and **MPCA 251** (Figure 4):

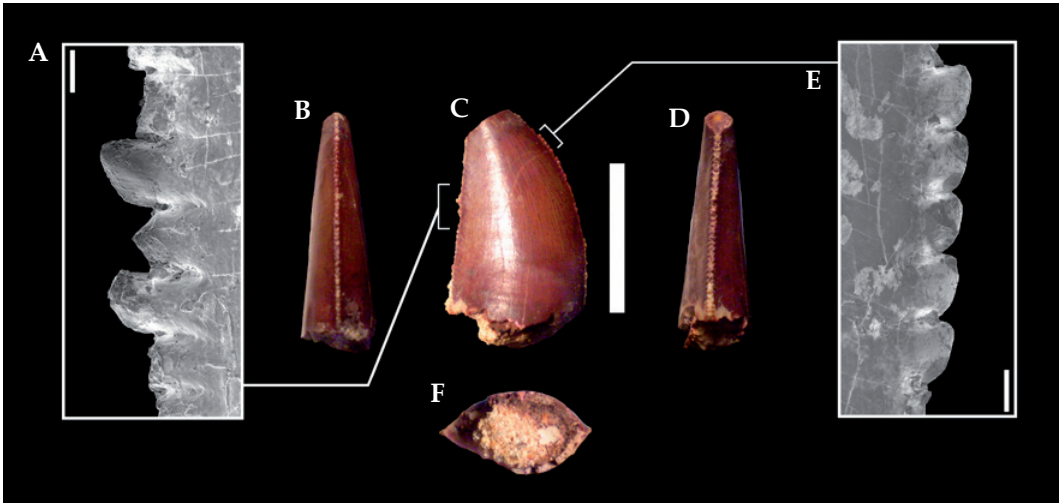
Both specimens are similar to each other, both labio-lingually compressed and slightly curved in distal direction, but MPCA 251 is more asymmetrical. The crown base

and apex of MPCA 249 are absent, and the crown sides are similarly convex, so is very symmetrical (Figure 3, B,C,D,F). The enamel is well-preserved on the entire surface of the crown. The mesial border is anteriorly convex, but the distal border is straight and without evidence of curvature (Figure 3, C). The latter condition is also present in MPCA 251 (Figure 4, C,E), character which is probably synapomorphic for Abelisauridae (e.g., Fanti and Therrien, 2007; Smith, 2007). In MPCA 249 both crown sides have thin transversal shallow wrinkles, like those observed in MPCA 247, which are curved and concave towards the apex of the crown. Both mesial and distal borders have serrated carinae along their entire extension, without displacement towards any direction. Due to the symmetry of both sides of the crown and the lack of displacement of carinae is not possible to assess which side is the lingual and which the labial in MPCA 249 (Figure 3, B,D,F). By contrast, MPCA 251 is very asymmetrical with one side more convex, especially

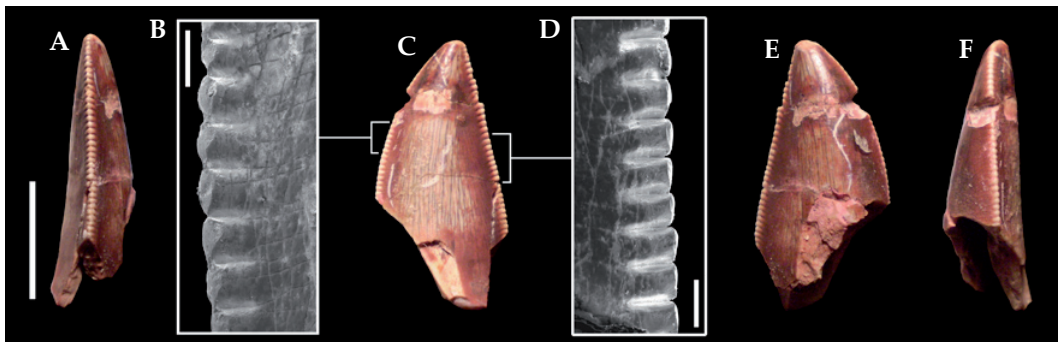


close to the mesial border (Figure 4, A,F), therefore can be considered as premaxillary, anterior maxillary or anterior dentary tooth. In MPCA 251 both mesial and distal carina have denticles in their entire extension and are displaced to the less convex side of the crown, which is considered the lingual side (Figure 4, A,F). This tooth also has shallow bands on both crown surfaces,

but less marked and inconspicuous. The denticles in both specimens are chisel-like, although the mesial ones are smaller and shorter. In MPCA 251 the distal denticles are rectangular, whereas the mesial are squarer, with planning tips in both mesial and distal denticles (Figure 4, B,D). By contrast, the mesial denticles in MPCA 249 turned to be hook-shaped and shorter to-



**Figure 3** – MPCA 249. **A** and **E**: SEM micrographs of the distal and mesial denticles, respectively. Note the hook-shaped mesial denticles close to the apex. **B**: mesial view, showing the serrated carina. **C**: side view of the crown. **D**: distal view, showing the serrated carina. **F**: basal view, showing the symmetrical oval section. Scales: 1 cm in B, C, D, and F; 200  $\mu$ m in A and E.



**Figure 4** - MPCA 251. **A**: mesial view. See the serrated carina. **C**: lingual view. **E**: labial view. **F**: distal view. See the serrated carina. **B** and **D**: SEM micrographs of the mesial and distal denticles, respectively. See the difference in the morphology between the denticles of both carinae. Scales: 1 cm in A, C, E, and F; 500  $\mu$ m in B and D.

wards the crown apex (Figure 3, E). Blood grooves are present in both specimens and are inclined towards the crown base.

Saurischian dinosaurs are not the only archosaurs found at this locality. Additionally, an isolated crocodylomorph tooth was recovered at the same quarry where *Bonitasaura salgadoi* was exhumed.

#### MPCA 246 (Figure 5):

This specimen corresponds to a well-preserved isolated tooth of uncertain position. The crown is conical in shape; it has a low height and tapers abruptly from the base to the apex. Both crown sides are convex, but one of them presents a more pronounced convexity and therefore is considered as the labial side of the crown (Figure 5, A). The entire crown is strongly curved towards the lingual side, while is slightly distally curved (Figure 5, A,B). The base is sub-circular in cross-section, in contrast with the transverse compression seen in baurusuchid crocodylomorphs (Riff and Kellner, 2001). The enamel is very well-preserved and it exhibits fine developed longitudinal grooves extending from the basal portion of the crown up to the apex, which are more conspicuous in the lingual side (Figure 5, B). Both mesial and distal borders have very well-developed carinae with denticles, displaced to the lingual side (Figure 5, A,B,C). However the denticles are poorly defined, conforming a pseudoziphodont pattern (sensu Prasad and Broin, 2002), and only few morphological features of them can be observed, appearing to be chisel-like (Figure 5, C). This condition clearly differs from that of baurusuchids, in which the denticles are clearly defined and separated by deep grooves (Riff and Kellner, 2001). MPCA 246 shows a unique combination of features seen in only two terrestrial tetrapod clades: Crocodylomor-

pha and Spinosauridae theropods. In fact, the above described tooth shows a conical crown with striated enamel, presence of denticulated carinae, and subcircular cross section. However, MPCA 246 resembles crocodylians and differs from Spinosauridae, with the exception of *Spinosaurus* Stromer, 1915, in the following traits: 1) subcircular cross-section (in most spinosaurids the cross-section of the teeth is elliptical or oval in contour; Buffetaut and Ingavat, 1986; Buffetaut et al., 2008), 2) smooth enamel surface (contrasting with the strong ornamentation composed by ridges and grooves seen in known spinosaurids; Martill and Hutt, 1996), and 3) presence of pseudoziphodont carinae, with non-individualized denticles (differing from the condition in all known theropods, including spinosaurids, in which the denticles are much smaller, and are well defined and separated by deep notches; Martill and Hutt, 1996; Ruiz-Omeñaca et



Figure 5 - MPCA 246. A: mesial view, showing the serrated carina. B: lingual view. Note the striated surface of the crown. C: SEM micrograph of the denticles. Scales: 1 cm in A and B; 200  $\mu$ m in C.



al., 1998; Buffetaut et al., 2008). Moreover, MPCA 246 differs from all known spinosaurid theropods, including *Spinosaurus* in having a concave lingual face and a convex labial face, whereas in theropods the crown is mesially convex and distally concave (Buffetaut et al., 2008). The position within crocodylians of MPCA 246 is still uncertain. However, the presence of two derived features: 1) circular cross-section and 2) pseudoziphodont serrated carinae indicate its affiliation with neosuchian mesoeucrocodylians (Prasad and Broin, 2002).

## DISCUSSION AND CONCLUSIONS

The new remains here reported allow to expand the previously knowing archosaur record of the Bajo de La Carpa Formation. MPCA 247 presents some characters reminiscent to those observed in many tetanuran theropods, resembling especially the morphology of the teeth of *Orkoraptor*. Isolated teeth with similar features have been already found in Argentina, which were considered as dromaeosaurid teeth (e.g., Poblete and Calvo, 2003). However, the *in situ* dental pieces of the few dromaeosaurid taxa found in Argentina with cranial remains have strongly different features (Makovicky et al., 2005; Canale et al., 2007; Novas et al., 2008b; Gianechini et al., 2010). The latter plus the fact that neovenatorid and compsognathid teeth have this kind of dental morphology (i.e. a combination of a strongly distally curved crown and absence of mesial denticles) plays against an unambiguous assignment of these teeth to Dromaeosauridae, but an assignment to an indeterminate tetanuran seem to be more accurate (Novas et al., 2008a).

The characters observed in MPCA 249 and 251 are similar to those present in

abelisaurid teeth, considering principally the straight distal border of the crown, the degree of labiolingual compression, and the morphology of the denticles (chisel-like with rounded apex). The latter character allows extends tentatively the assignment of MPCA 249 and 251 to Abelisauridae. The presence of abelisaurids is already documented in the Early Cretaceous (e.g., Rauhut et al., 2003) and is well established in the Late Cretaceous in many Patagonian locations (e.g., Bonaparte, 1985; Bonaparte and Novas, 1985; Martínez et al., 1986; Coria and Salgado, 2000; Coria et al., 2002; Lamanna et al., 2002; Calvo et al., 2004; Canale et al., 2009). Additionally, Ezcurra and Méndez (2009) reported the presence of remains assigned to an indeterminate abelisaurid from the Bajo de la Carpa Formation. This latter record together with the possible occurrence of abelisaurid teeth in the same formation supports the presence of this group of theropods in this geological unit.

The crocodylomorph teeth exhibit some rough similarities with theropod teeth, especially with those of spinosaurids. The teeth of spinosaurids are conical in general morphology, with a sub-circular to circular cross-section and a longitudinally striated enamel (Kellner and Campos, 1996; Charig and Milner, 1997; Sereno et al., 1996, 1998; Sues et al., 2002), very similar to the striated surface observed in many mesoeucrocodylian teeth. Within Spinosauridae, there are different dental characters between its two clades: Baryonychinae and Spinosaurinae. The teeth of the Baryonychinae (i.e. *Baryonyx* and *Suchomimus*) present plesiomorphic features, including well-developed mesial and distal carinae with denticles (Charig and Milner, 1997; Sereno et al., 1998). On the other hand, the teeth of the Spinosaurinae do not have carinae, for example the teeth of *Angaturama limai*

and *Spinosaurus aegyptiacus* (Stromer, 1915; Kellner and Campos, 1996), or they have well-developed carinae but devoid of denticles, such as the teeth of *Irritator challengeri* (Sues *et al.*, 2002). Therefore, spinosaurine teeth are different from the teeth of 'La Bonita' in this aspect, because this latter has mesial and distal carinae with conspicuous denticles. The baryonychine teeth also present some distinctive characters from the mesoeucrocodylian tooth here presented. Baryonychinae teeth have fine denticles on the carinae, approximately from 5.5 to 7 denticles per millimeter (Charig and Milner, 1997; Sereno *et al.*, 1998; Smith *et al.*, 2005), a larger account with respect to the mesoeucrocodylian tooth. Another distinctive feature of the baryonychinae teeth is an enamel with a finely granular appearance, like those present in *Baryonyx* and *Suchomimus* (Charig and Milner, 1997; Sereno *et al.*, 1998). Conversely, in mesoeucrocodylian teeth and MPCA 246 the surface of the enamel is smooth and without this peculiar texture. Accordingly, if the determination is correct, the purported mesoeucrocodylian tooth MPCA 246 represents the first record of a neosuchian in the Bajo de la Carpía Formation. This small sample of archosaur remains, although represented by isolated shed teeth, shows that the archosaurian faunal assemblage of this locality is more diverse than previously known.

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