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NOTE ON A NEW LOCALITY WITH PTEROSAURS (ARCHOSAURIA: PTERODACTYLOIDEA) FROM THE ATACAMA REGION, NORTHERN CHILE

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ABSTRACT

A new locality with fossils of pterosaurs from Cerros Bravos, northeast of Copiapó, Atacama Region is reported, in outcrops of Quebrada Monardes Formation, a geological unit assigned to the Lower Cretaceous. Among the discovered remains are two incomplete first wing phalanges (one of them tridimensionally preserved), which have been assigned to pterodactyloids. This finding adds a second locality with pterosaur bones from Quebrada Monardes Formation. Future investigations of the pterosaurs of this locality will probably increase the knowledge about the diversity of these animals in the southwestern margin of Gondwana at the beginning of the Cretaceous period.

Key words: Pterosaurs, Quebrada Monardes Formation, Lower Cretaceous, Chile

RESUMEN

Nota sobre una nueva localidad con pterosaurios (Archosauria: Pterodactyloidea) de la región de Atacama, norte de Chile. Se da a conocer un nuevo sitio con fósiles de pterosaurios en la localidad de Cerros Bravos, al noreste de Copiapó, Región de Atacama, en afloramientos pertenecientes a la Formación Quebrada Monardes, unidad geológica asignada al Cretácico Inferior. Entre los restos descubiertos se encuentran dos falanges alares del dedo I incompletas (una de ellas preservada en tres dimensiones), las que fueron asignadas a pterodactyloideos. Este hallazgo añade un segundo sitio con huesos de pterosaurios en la Formación Quebrada Monardes. Futuras investigaciones de los pterosaurios de esta localidad probablemente incrementarán el conocimiento sobre la diversidad de estos animales en el margen suroeste de Gondwana a principios del periodo Cretácico.

Palabras clave: Pterosaurios, Formación Quebrada Monardes, Cretácico Inferior, Chile

Institutional abbreviations: SGO.PV. Área Paleontología, Museo Nacional de Historia Natural; MIC, Museo Interactivo de Ciencias, Universidad Nacional de San Luis, San Luis, Argentina.

INTRODUCTION

Pterosaurs (Reptilia: Pterosauria) were a group of flying archosaurs that coexisted with avian and non-avian dinosaurs, being abundant and diverse in Mesozoic ecosystems (Wellnhofer 1991). Pterosaur remains have been found in all continents, including Antarctica (Hammer and Hickerson, 1994), however, most known pterosaurs are represented by fragmentary remains preserved mostly in marine environments (Padian and Rayner 1993, Barrett *et al.* 2008, Butler *et al.* 2013, Upchurch *et al.* 2015). The more derived pterosaurs are part of a clade called Pterodactyloidea, which includes a large variety of short-tailed species, except for anurognathids (Döderlein 1929, Wang *et al.* 2002), with proportionally large heads and a tendency to lose their teeth, whose members lived from the Upper Jurassic to the Upper Cretaceous (Wellnhofer

1991, Kellner 2003, Unwin 2003, 2006). Earlier pterosaurs excluded from Pterodactyloidea are collectively called non-pterodactyloids, a term that groups species of relatively small size, head proportionally smaller than that of the pterodactyloids, and mostly a long tail, which lived between the Upper Triassic and the Lower Cretaceous (Wellnhofer 1991, Kellner 2003, Unwin 2003, 2006).

In Chile, pterosaurs findings are limited to fragmentary remains preserved in rocks of the Upper Jurassic and Early Cretaceous of the Antofagasta Region (Martill *et al.* 2000, Alarcón *et al.* 2015), and the Lower Cretaceous of the Atacama Region (Bell and Suárez 1989, Bell and Padian 1995, Rubilar *et al.* 2002, Martill *et al.* 2006, Soto-Acuña *et al.* 2015, Alarcón-Muñoz *et al.* 2016, 2017, Alarcón-Muñoz 2018).

During a field work made in 2013, in the context of a course of Geology of the Universidad de Chile, the students Edwin González and Hermann Rivas found several remains of pterosaurs in rocks of the Lower Cretaceous Quebrada Monardes Formation, which crops out in the sector of Cerros Bravos, northeast of Copiapó. Previously, fossils of pterosaurs have been recognized in rocks of the same formation in Cerro La Isla, a locality situated approximately 63 km south of this new locality (Bell and Suárez 1989, Bell and Padian 1995, Rubilar *et al.* 2003, Martill *et al.* 2006, Soto-Acuña *et al.* 2015, Alarcón-Muñoz *et al.* 2016, 2017, Alarcón-Muñoz 2018).

The fossils from Cerros Bravos correspond to bones of several individuals preserved three-dimensionally, as well as their impressions, preserved in reddish-brown slabs that were part of the layer of approximately one meter thick. All the elements are disarticulated, although some present association. These characteristics indicate that this new locality presents a high potential for future research, mainly related to the taxonomic determination of the pterosaurs, the origin of fossil accumulation, and their relationship with the pterosaurs of Cerro La Isla.

In this note, a new locality with pterosaurs of Quebrada Monardes Formation is announced. Two first wing phalanges are described, whose morphology in conjunction with the age of the Quebrada Monardes Formation suggests that these bones belong to pterodactyloids.

LOCALITY AND GEOLOGICAL SETTING

The new locality with fossil bones of pterosaurs is located approximately 120 km northwest of Copiapó, in the sector of Cerros Bravos (Fig. 1). According to the geological cartography exposed by Cornejo *et al.* (1998), the finding occurred in Quebrada Monardes Formation. This formation was defined by Mercado (1982), and it crops out at the Precordillera of Copiapó, in the Atacama Region, northern Chile (Hillebrandt 1973, Covacevich 1985). These deposits extend for approximately 200 km from north to south between 26°-28°S and 69°-70° W (Bell and Suárez 1989). The Quebrada Monardes Formation are constituted by a succession of red clastic rocks of continental and eolian origin, mainly red arcotic sandstones, pebbled sandstones, conglomerates, siltstones, evaporites and shales (Bell and Suárez 1985, Bell 1991, Bell and Suárez 1993). The sediments of Quebrada Monardes Formation were probably deposited during the Lower Cretaceous, since Upper Jurassic rocks underlie it, such as the marine limestones of the Pedernales Formation, which is probably Tithonian-Valanginian in age (Mpodozis *et al.* 2012) and is overlaid by Upper Cretaceous-Paleocene sedimentary and volcanic rocks of the Quebrada Seca Formation (Chong 1976, Muzzio 1980, Mercado 1982, Naranjo and Puig 1984, Covacevich 1985, Cornejo *et al.* 1998). A recent detrital zircon U-Pb age of $144,8 \pm 1,8$ My was obtained from the Pulido river, giving to Quebrada Monardes Formation a Berriasian age for the maximum deposition (Martínez *et al.* 2015). On the other hand, Iriarte *et al.* (1999) assigned an age close to 72 My for the base of the Quebrada Seca

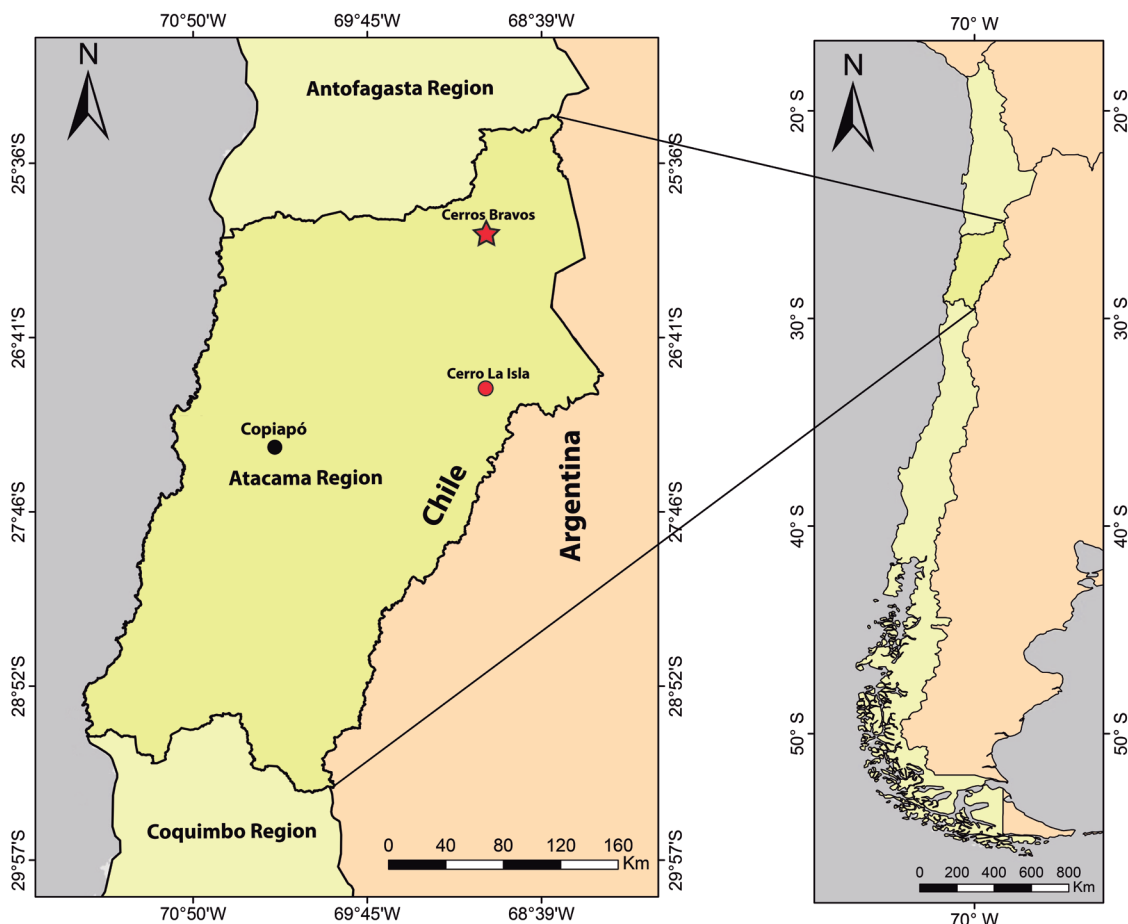


Figure 1. Map of the Atacama Region in which the location of Cerros Bravos is indicated (red star). It also includes the location of Cerro La Isla (red dot), which is the first locality where remains of pterosaurs were found in outcrops of the Quebrada Monardes Formation.

Formation. Additionally, Martínez *et al.* (2015) assign to the upper member of Quebrada Seca Formation an age range corresponding to the Maastrichtian-Danian, while Salazar and Coloma (2016) extend the age range of this formation to a Danian-Selandian. Thus, there is still a large margin of uncertainty about the age of the pterosaur bearing levels, however, can be constrained to Lower Cretaceous at maximum age.

MATERIALS AND METHODS

The studied fossils are housed in the Área de Paleontología of the Museo Nacional de Historia Natural (MNHN) of Santiago, Chile, under the acronym SGO.PV. In this work, a fragment of an incomplete wing phalanx I (SGO.PV.22811) and an incomplete impression of another wing phalanx I (SGO.PV.22812) are described. Additionally, there are several elements that are currently under preparation and study. The fossils were compared both with specimens published in specialized literature and directly with specimens of *Pterodaustro guinazui* housed in the “Repositorio de Fósiles, de la Facultad de Ciencias Físico, Matemáticas y Naturales” of the Universidad Nacional de San Luis, Argentina.

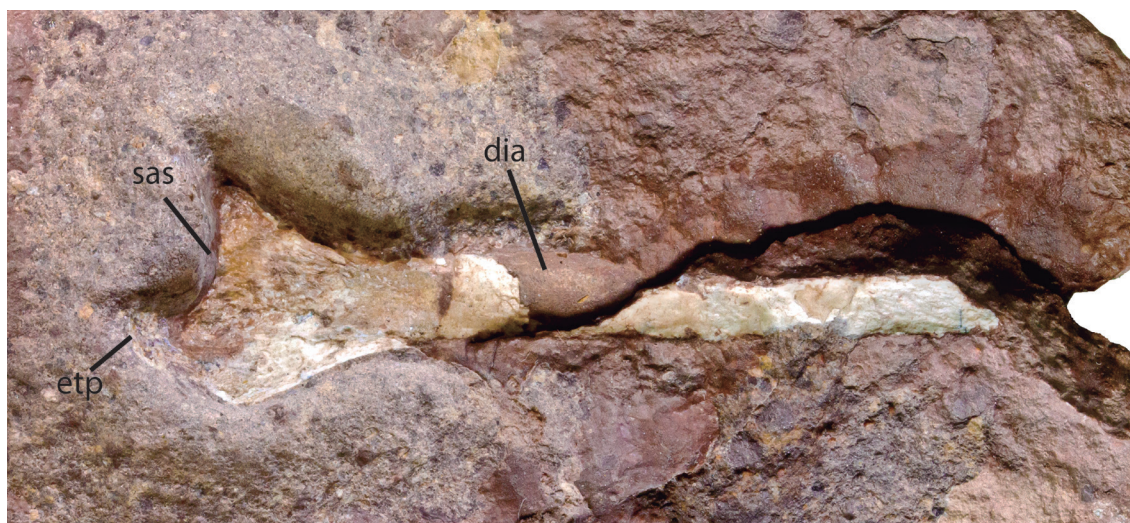


Figure 2. Pterodactyloidea indet., SGO.PV.23811. Proximal portion of an incomplete first wing phalanx. Abbreviations: dia= diaphysis, etp=extensor tendon process, sas= semilunar articular surface. Scale bar=1 cm.

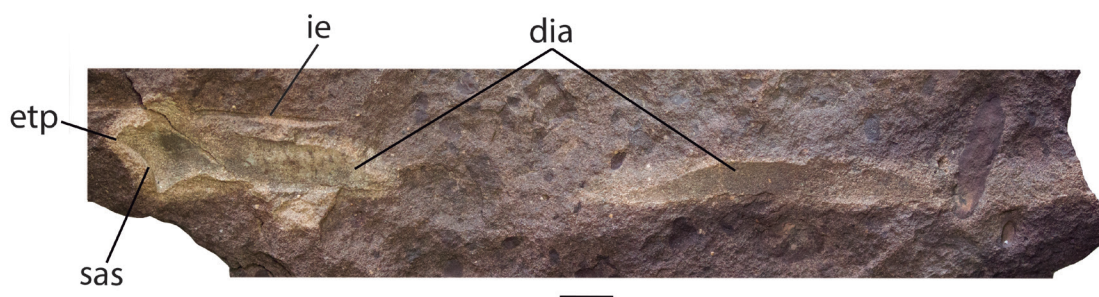


Figure 3. Pterodactyloidea indet., SGO.PV.22812. Impression of a first wing phalanx. Abbreviations: dia=diaphysis, etp=extensor tendon process, ie=indeterminate element, sas=semilunar articular surface. Scale bar=1 cm.

RESULTS

Systematic paleontology
Archosauria Cope, 1862
Pterosauria Kaup, 1834
Pterodactyloidea Plieninger, 1901

Pterodactyloidea indet.

Materials—Incomplete wing phalanx I (SGO.PV.22811) and the impression of an incomplete wing phalanx I (SGO.PV.22812).

Description—SGO.PV.22811 corresponds to the proximal end and part of the diaphysis of a wing phalanx I (wp1). Its preserved length is 5.5 cm and the maximum width of the proximal region is 1.6 cm. The proximal articular surface is broad and concave (Fig. 2). The extensor tendon process is preserved complete, although a little eroded at its most proximal end, and it is fused with the shaft of the wp1. This process shows a slight backward inclination in relation to the longitudinal axis of the element. There is no appreciable suture between the extensor tendon process and the rest of the element. This last feature suggests that the phalanx represents an osteologically mature stage and probably belonged to a sub-adult or adult individual, at the time of death (Bennett, 2001). Distally, the element narrows abruptly until it continues in the diaphysis, which is preserved as an impression and patina of bone. Its diameter is 0.6 cm.

SGO.PV.22812 corresponds to an incomplete impression of a wing phalanx I (Fig. 3). It stands out for being an element of relatively large dimensions, with a preserved length of 18.6 cm. The incomplete impression of the epiphysis shows great similarity with the proximal end of the wing phalanx I of other pterosaurs specimen, however, it does not allow to observe its features in detail. The impression shows a convex proximal articular surface, in anterior view. This is continued proximally to the beginning of what is interpreted as the extensor tendon process. Distally, the element narrows to give rise to the diaphysis, which apparently maintains its relatively constant diameter throughout the entire preserved portion (~1 cm). The portion that corresponds to the distal end has not been preserved.

DISCUSSION

The presence of the extensor tendon process in the proximal end of the first wing phalanx constitutes a synapomorphy of Pterosauria (Kellner, 1996). Additionally, authors such as Martill *et al.* (2006) and Ibiricu *et al.* (2012) propose that the convex articular surface of the first wing phalanx, called semilunar articulation, corresponds to an autapomorphy of Pterosauria. Both features are present in the materials studied here, which, together with their general morphology, makes it possible to refer them to this group of archosaurs.

The first wing phalanx one alone has few diagnostic features that facilitate its determination at more exclusive taxonomic levels. According to Kellner (2003), in the evolutionary history of pterosaurs there is a tendency to a proportional decrease in the length of the second and third wing phalanges with respect to the first one. However, since there are no complete wing fingers of adult individuals in the Cerros Bravos material, it is impossible to evaluate whether the proportions between these three phalanges are closer to that described in pterodactyloids or in non-pterodactyloids pterosaurs.

Martill *et al.* (2006) describe a fragment of a wing phalanx I from Cerro La Isla (SMNK-4015) although they do not discuss their taxonomic identity on the basis of their characters, limited to assuming its inclusion in the family Ctenochasmatidae because it was found in the same sedimentary horizon as the mandibular remains belonging to this family. SMNK-4015 differs from SGO.PV.22811 and SGO.PV.22812 in the morphology of the extensor tendon process. In SMNK-4015, this structure is more inclined towards anterior, with its proximal end more rounded and robust, and with a concave anterior surface. In addition, SMNK-4015 differs especially from SGO.PV.22811 in that the diaphysis is proportionally wider anteroposteriorly with respect to the anteroposterior length of the wider area of the proximal epiphysis, which gives the diaphysis of SMNK-4015 a comparatively more robust appearance. At the moment it is unknown if these differences have any taxonomic meaning.

The temporal distribution of pterodactyloids extends from the Late Jurassic to the Late Cretaceous (Upchurch *et al.* 2015), while the non-pterodactyloids appeared at the end of the Triassic and became

extinct at the beginning of the Cretaceous, when they were only represented by anurognathids which were restricted to the Lower Cretaceous of China (Unwin 2006, Lü *et al.* 2017).

Based on the Lower Cretaceous age that has been proposed for Quebrada Monardes Formation, the almost absence of non-pterodactyloid records in Cretaceous rocks and the relatively large size, both phalanges are preliminarily referred to Pterodactyloidea.

The fossils of pterosaurs of this new locality, although disarticulated and incomplete, are preserved three-dimensionally, which is rare in the fossil record of these animals, whose bones tend to be preserved in two dimensions (Unwin 2006). This factor has contributed to the relatively little knowledge we have about the osteology of the pterosaurs, and consequently on their phylogenetic relationships (Kellner 1996). The systematic collection, taphonomical studies, and the detailed study of specimens of pterosaurs from this and other sites of Quebrada Monardes Formation will possibly allow increasing knowledge about aspects such as osteology, phylogenetic relationships, paleobiogeography and even behavior.

CONCLUSIONS

We report the finding of pterosaur remains in Cerros Bravos, Atacama Region, Northern Chile. Two wing phalanges from this locality are described. Based on general features, both wing phalanges found in Cerros Bravos are referred to Pterodactyloidea. This finding allows us to recognize a new site of the Lower Cretaceous Quebrada Monardes Formation with presence of pterosaurs. Future studies will permit to expand the information on its taxonomy, taphonomy, biogeography and ethology of these pterosaurs. This finding suggests a wide distribution of pterodactyloid pterosaurs in southwestern margin of Gondwana during the Lower Cretaceous.

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