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Identification of the first postcranial skeleton of *Aristonectes* Cabrera (Plesiosauroidea, Elasmosauridae) from the upper Maastrichtian of the south-eastern Pacific, based on a bivariate graphic analysis

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ABSTRACT

Cervical vertebrae of elasmosaurids (Sauropterygia, Plesiosauroidea) have proven to be informative even at family level. The present paper uses a previously developed methodology based on bivariate graphic analysis that evaluates the proportion indices of cervical vertebrae in elasmosaurids, which is applied to a well-preserved postcranial specimen of this group recovered from upper Maastrichtian beds of central Chile. The plotting of such indices groups the Chilean material with other specimens from the Late Cretaceous of Argentina and Antarctica, the latter referred to the genus *Aristonectes*. This result allows us to identify the first relatively complete individual of the genus based on non-cranial characters. The identification of the Chilean specimen as *Aristonectes* sp. provides important new data on the postcranial skeleton of the genus, that has remained poorly known until now.

1. Introduction

Plesiosaurs from the Upper Cretaceous of South America have been reported since the nineteenth century. However, despite abundant plesiosaur records, preservation of cranial materials is rare, and the systematic affinities of several specimens remain controversial or poorly known (Gasparini et al., 2003a; Otero et al., 2009; O'Gorman et al., 2011). Detailed descriptions of postcranial specimens carried out over the last few years have provided new information on this aspect. Otero et al. (2012) described an almost complete juvenile postcranial specimen from upper Maastrichtian beds of central Chile, which is especially relevant because it is one of the better preserved Upper Cretaceous plesiosaurs recovered in the south-eastern Pacific region. These authors concluded that SGO.PV.260 shares relevant features with *Aristonectes* but also with the specimen referred to *Tuarangisaurus*? *cabazai* by Gasparini et al. (2003b), from the upper Maastrichtian of the Río Negro Province, Argentina. Due to this complex combination of postcranial characters, and the juvenile condition of the specimen, Otero et al. (2012) prudently avoided referring this material to any known genera. O'Gorman et al. (in press) described a juvenile postcranial specimen from the Upper Cretaceous of Seymour (=Marambio) Island, Antarctica and referred it to *Aristonectes* cf. *parvidens*. This identification was based on an analysis of cervical vertebrae proportions of several juvenile elasmosaurids. This new result highlights the possibility of testing the likely affinities of SGO.PV.260. In this paper, we provide a new analysis that supports the hypothesis of the *Aristonectes* affinities of specimen SGO.PV.260. We also discuss the consequences of this analysis in understanding the unique combination of postcranial features found in SGO.PV.260.

2. Materials and methods

2.1. Material

The specimen analysed here was recovered from Las Tablas Bay, on the northern part of Quiriquina Island, central Chile (Fig. 1). The fossil-bearing beds are part of the Quiriquina Formation (Biró-Bagóczky, 1982), presently constrained to the upper Maastrichtian based on biostratigraphic correlations (mainly ammonoids) (Salazar et al., 2010; Stinnesbeck et al., in press).

2.2. Methods

The indices utilized here are those proposed by Welles (1952), which take into account the centrum length (L), the ratio between

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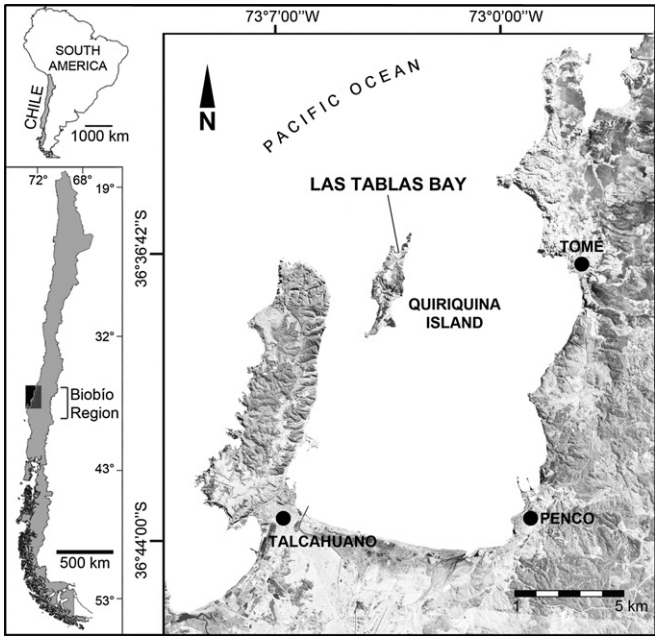

Fig. 1. Map indicating the location of Las Tablas Bay, Quiriquina Island, Biobío Region, central Chile, where the studied material was collected.

height (H) and length of the centrum (100*H/L), and the ratio between breadth (B) and length of the centrum (100*B/L). In addition, the ratio between the breadth and height (100*B/H) was considered. In this study, both the breadth and height were measured on the posterior articular face. The vertebral length index [VLI = L/(0.5*(H + B))] follows the formula proposed by Brown (1981). The bivariate graphic used to refer SGO.PV.260 to *Aristonectes* is taken from O'Gorman et al. (in press). Furthermore, the categories of ontogenetic development proposed by Brown (1981) based on the fusion of the neural arch to the vertebral centrum (neural closure) were considered to differentiate the "adult" and "juvenile" conditions. The sources for measurements of each specimen are indicated in Table 1.

Institutional abbreviations.

ANSP, Academy of Natural Sciences of Philadelphia, Philadelphia, USA; AM, Australian Museum, Sydney, Australia; AMNH, American Museum Natural History, New York, USA; CMNH., Colorado Museum of Natural History, Boulder, USA; CIT, California Institute of Technology, California, USA; MLP, Museo de la Plata, Buenos Aires Province, Argentina; MML Pv, Museo Municipal de Lamarque, Río Negro, Argentina; MUC Pv, Museo de la Universidad del Comahue, Neuquén Province, Argentina; SGO.PV, Área Paleontología, Museo Nacional de Historia Natural, Santiago, Chile; UC. MUS. PAL, University of California Museum of Paleontology, Berkeley, California; TTU, Museum of Texas Tech University, Texas, USA.

Fig. 2. SGO.PV.260, *Aristonectes* sp., postcranial skeleton of sub-adult individual. Scale bar represents 50 cm. Modified from Otero et al. (2012).

3. Systematic paleontology

Sauropterygia Owen 1860
Plesiosauria de Blainville 1835
Plesiosauroidea Welles 1943
Elasmosauridae Cope 1869
Aristonectinae Otero, Soto-Acuña and Rubilar-Rogers, 2012
Aristonectes Cabrera 1941

Aristonectes sp.
(Fig. 2)

Material

SGO.PV.260, postcranial articulated skeleton lacking only the anterior-most portion of the neck and skull.

Locality and stratigraphic horizon

Las Tablas Bay, Quiriquina Island, Biobío Region, central Chile; zone of *Cardium* (*Bucardium*) *acuticostatum* (d'Orbigny), Quiriquina Formation (Biró-Bagóczky, 1982), upper Maastrichtian.

Table 1
Specimens utilized for measurements and bivariate graphic analysis.

Taxon	Repository	Locality	Lithostratigraphic unit and age	References
Aristonectes parvidens	TTU P 9219	Seymour Island, Antarctica	López de Bertodano Formation, upper Maastrichtian	Chatterjee and Small, 1989
"*Plesiosaurus chilensis*" type. (=*Aristonectes* cf. *parvidens*)	Unknown	Isla Quiriquina, Chile	Quiriquina Formation, upper Maastrichtian	Gay, 1848
Aphrosaurus furlongi	CIT 2832	California, USA	Moreno Formation, Maastrichtian	Welles, 1943
"*Leurospondylus ultimus*" (=Elasmosauridae indet.)	AMNH 5261	Alberta, Canada	Edmonton Formation, upper Campanian-lower Maastrichtian	Brown, 1913
(*Cimoliasaurus maccoyi*" (=Elasmosauridae indet.)	AM F9630-9928	White Cliffs, Australia	Wallumbilla Formation, Aptian	Persson, 1960; Kear, 2005
Elasmosauridae indet.	MLP 93-XII-20-1; MLP 99-XII-1-8 and MLP 86-X-28-(2-6)	Snow Hill Island, Antarctica	Snow Hill Island Formation, upper Campanian-lower Maastrichtian	O'Gorman et al., in press
Elasmosaurus platyurus	A.N.S.P. N° 10081	Kansas, United States	Pierre Shale Formation, Early Santonian	Cope, 1868 (first description); Welles, 1952 (measurements)
Hydrotherosaurus alexandrae	A.M.N.H. N° 1495	Fresno, United States	Moreno Formation, Maastrichtian	Welles, 1943
Thalassomedon haningtoni	C.M.N.H. N° 1588	Colorado, United States	Benton Formation, Turonian	Welles, 1943

Table 2
Measurements of cervical vertebrae of the specimen SGO.PV.260, including the indexes H, B, BH, and VLI, following Brown (1981) and Welles (1952).

Vertebra	L	H	B	HI	BI	BHI	VLI
22?	34.1	45.1	84	132.3	246.3	186.3	52.8
21	35.5	46.6	89	131.3	250.7	191	52.4
20	38						
19	41.6						
18	42.2						
17	44						
16	46.5						
15							
14	45						
13	45						
12	45.3						
11	45.7						
10	46	51.9	94.2	112.8	204.8	181.5	63
9	46.3						
8	44.8						
7	42.4		100.8		237.7		
6		55	101.6			184.7	
5	44.7	64	104.2	143.2	233.1	162.8	53.2
4	39.9	58.7	102.4	147.1	256.6	174.4	49.5
3	43.2	58	103.9	134.3	240.5	179.1	53.4
2	44						
1	45.5		106.8		234.7		

4. Discussion

Specimen SGO.PV.260 was described in detail by Otero et al. (2012) and a re-description is not necessary. The features that are used for referring this specimen to *Aristonectes* sp. are the special proportions of the cervical centra given by Otero et al. (2012). Because the indices values were not included in the first description of the specimen, in this opportunity the values are now indicated (Table 2) and included in the bivariate graphic analysis developed by O'Gorman et al. (in press).

4.1. Bivariate analysis

Using the same bivariated diagram developed by O'Gorman et al. (in press), the plot of measurements and indices of SGO.PV.260 can be referred to *Aristonectes* because it is grouped with the specimens previously referred to this genus (O'Gorman et al., in press; Gasparini et al., 2003a). Although the generic identity is well supported, the absence of cranial material and insufficient knowledge of postcranial morphology do not allow referring it with confidence to *A. parvidens*. Fig. 3A–C shows that the plots of the cervical vertebrae of SGO.PV.260 are located in each graph in the zone occupied by the *Aristonectes* cervicals and are separated from the plots of cervical centra of other juvenile elasmosaurids. Also, it shows that high B values are shared with previous specimens referred to *Aristonectes* (Chatterjee and Small, 1989; Gasparini et al., 2003a). This is related to the original estimated length of the specimen SGO.PV.260 at about 4.5 m (Otero et al., 2012). Although this comparison is focused on juvenile specimens because the condition of the SGO.PV.260, three individuals of adult elasmosaurids are also included in the analysis, belonging to the taxa *Elasmosaurus platyurus*, *Hydrotherosaurus alexandrae*, and *Thalassomedon haningtoni* (see Table 1 for sources of data). The bivariate graphic of their indices partially occupies a similar range with young individuals of this group, but most of the plotted points appeared as segregated from young elasmosaur individuals. The results obtained through the bivariate analysis are reliable for generic determination. Considering the incompleteness in the holotype of *Aristonectes parvidens* and the juvenile condition

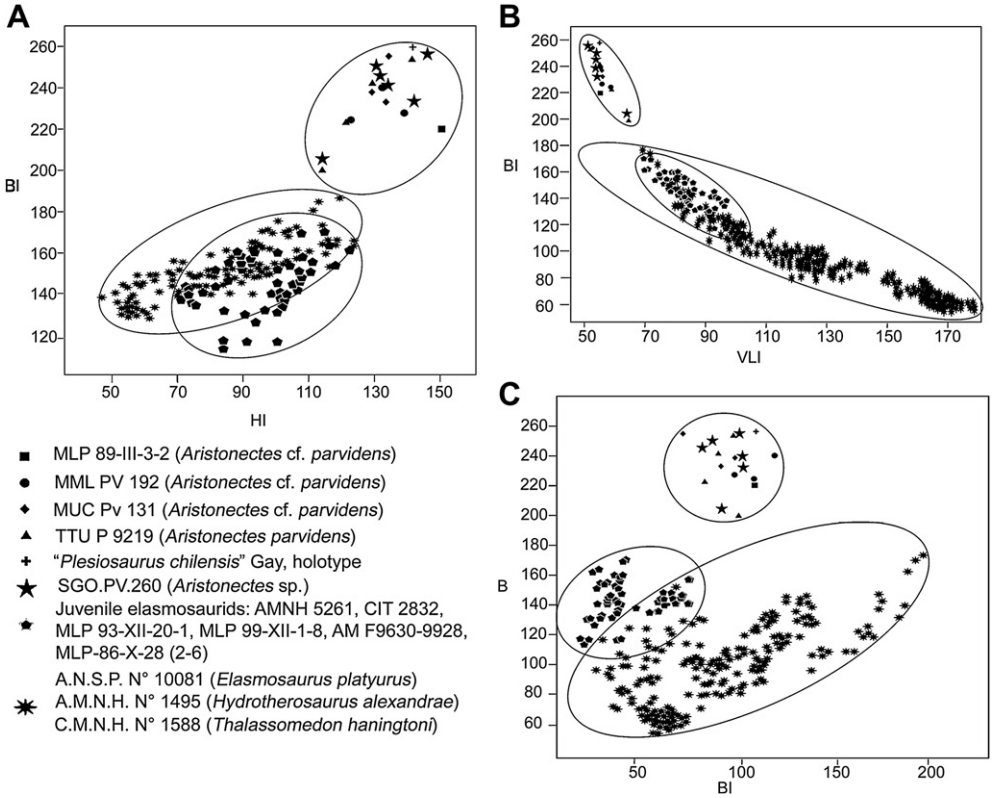

Fig. 3. Bivariate diagrams of cervical centrum values of juveniles of *Aristonectes* cf. *parvidens* and other elasmosaurs (modified from O'Gorman et al., in press). A, HI-BI, B, VLI-BI, and C, B-BI plots.

of the Chilean specimen, we recommend that SGO.PV.260 be assigned to *Aristonectes* under open nomenclature as a precaution, even in the actual monospecific status of the genus.

4.2. Comparison with other specimens referred to Aristonectes

Several elements are comparable between SGO.PV.260 and MLP 89-III-3-2 from the upper Maastrichtian of Seymour (=Marambio) Island, Antarctica, and described by O'Gorman et al. (in press). Especially the coracoids share the cordiform fenestra, mid-ventral process and a transversal ridge. Moreover, the specimens SGO.PV.260 and MLP 89-III-3-2 share distinctly massive neural arches, a feature also recorded for specimen MML Pv 5 referred to *Tuarangisaurus*? *cabazai* by Gasparini et al. (2003b), from the upper Maastrichtian of Salinas de Trapalcó, Argentina. Therefore, the reference of SGO.PV.260 to *Aristonectes* sp. is congruent with previous knowledge about the postcranial morphology of *Aristonectes* (O'Gorman et al., in press). However, due to the near-completeness of SGO.PV.260, the new result adds significant information about the postcranial morphology of *Aristonectes*.

The new results also confirm that the first described plesiosaur in South America, namely "*Plesiosaurus chilensis*" Gay, 1848, can be referred to *Aristonectes*, as pointed out by O'Gorman et al. (in press). Finally, the latter authors refer specimen MUC Pv 131 from the middle Campanian of nearby Lago Pellegrini, Neuquén, Argentina, to *Aristonectes* (Gasparini et al., 2001), that was previously referred by Gasparini et al. (2003a) to *Tuarangisaurus* sp. The similarities between the features of the cervical vertebrae now referred to *Aristonectes* and those previously referred to *Tuarangisaurus* explain why Otero et al. (2012) indicated that SGO.PV.260 shared significant features with specimen MML Pv 5, based on postcranial morphologic affinities. More studies of the postcranial morphology and particularly the revision of *Tuarangisaurus cabazai* are needed in order to clarify this complex situation.

5. Conclusions

The bivariate graphic analysis used here allows grouping specimen SGO.PV.260 from the upper Maastrichtian of central Chile within the genus *Aristonectes*. This result is consistent with previous observations about the close morphological affinities of the mentioned specimen with the incomplete postcranial materials of the holotype of *A. parvidens*. The method shows results that are reliable at genus level, while several slight differences between both specimens (which are difficult to explain by their respective ontogenetic stage), suggest precaution for assigning it more specifically to the species *A. parvidens.* The obtained results confirm the possibility of distinguishing young individuals of the genus *Aristonectes* among other elasmosaurids, which was previously possible only through cranial materials.

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