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PALEONTOLOGICAL NOTE

First record of Elasmosaurid Plesiosaurs (Sauropterygia: Plesiosauria) in upper levels of the Dorotea Formation, Late Cretaceous (Maastrichtian), Puerto Natales, Chilean Patagonia

Rodrigo A. Otero[1], Mario E. Suárez[2], Jacobus P. Le Roux[3]

[1] *Laboratorio de Zoología de Vertebrados, Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile. Las Palmeras 3425, Santiago, Chile.*
paracrioceras@gmail.com
[2] *Museo Paleontológico de Caldera. Av. Wheelwright 001, Caldera, Chile.*
museopaleontocaldera@gmail.com
[3] *Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Casilla 13518, Correo 21, Santiago, Chile.*
jroux@cec.uchile.cl

ABSTRACT. New remains of plesiosaurs (Diapsida; Sauropterygia) found in a transported block correlated with upper levels of the Dorotea Formation, Late Cretaceous (Maastrichtian) are described herein. They were collected on the southern slopes of Sierra Dorotea located northeast of Puerto Natales (51°41'20,4"S, 72°26'07,4"W), Magallanes Region, Chile. This is the first discovery of the family Elasmosauridae in high latitudes of South America, complementing the previously known paleodistribution of this group in the eastern Pacific Ocean and the Antarctic during the latest Cretaceous.

Keywords: Plesiosaurs, Elasmosauridae, Maastrichtian, Dorotea Formation, Magallanes, Chile.

RESUMEN. Primer Registro de Plesiosaurios Elasmosáuridos (Sauropterygia: Plesiosauria) en estratos superiores de la Formación Dorotea, Cretácico Tardío (Maastrichtiano), Puerto Natales, Patagonia Chilena. Se describen nuevos restos de plesiosaurios (Diapsida; Sauropterygia) incluidos en un bloque rodado correlacionado con estratos superiores de la Formación Dorotea (Cretácico Tardío, Maastrichtiano), recolectados en la parte sur de la sierra homónima, ubicada al noreste de Puerto Natales (51°41'20,4"S, 72°26'07,4"W), Región de Magallanes, Chile. Se reconoce por primera vez la presencia de la familia Elasmosauridae en altas latitudes de Sudamérica, complementando así la paleodistribución previamente conocida de este grupo en el margen oriental del Océano Pacífico y de la Antártica durante la última parte del Cretácico Tardío.

Palabras claves: Plesiosaurios, Elasmosauridae, Maastrichtiano, Formación Dorotea, Magallanes, Chile.

1. Introduction

Plesiosaurs (Diapsida: Sauropterygia) are Mesozoic reptiles adapted to the marine environment, with limbs modified as paddles and hydrodynamic bodies with elongated necks. Since the XIX century, previous occurrences of plesiosaurs in Chile have been widely reported in the scientific literature (Gay, 1848; Philippi, 1887; Steinmann *et al.*, 1895; Wetzel, 1930; Colbert, 1949; Casamiquela, 1969; Gasparini, 1979). Recent studies on this group in this country and Argentina (Suárez, 2000; Gasparini and Salgado, 2000; Suárez and Fritis, 2002; Gasparini *et al.*, 2003a) indicate that most of the regional material belongs to plesiosaurs of the Elasmosauridae family, the latter being the best represented group of marine reptiles in the Late Cretaceous of southern South America and Antarctica (Gasparini *et al*., 2003b).

Previous finds of elasmosaurid plesiosaurs in the uppermost Cretaceous of central Chile, came from the type localities of the Quiriquina Formation near Concepción (Gay, 1848; Steinmann *et al.*, 1895; Wetzel, 1930; Gasparini, 1979), and from the localities of Loanco in the Maule Region, Topocalma in the O'Higgins Region, and Algarrobo in the Valparaíso Region (Suárez *et al*., 2003). Only one genus was recognized (Suárez and Fritis, 2002), *Aristonectes* Cabrera, previously recovered in Argentina (Cabrera, 1941). Other reports from Chilean Patagonia include unfigured material from the Magallanes Region (Gasparini, 1979). These are until now the southernmost records of plesiosaurs in South America.

This paper presents new material of Plesiosauria from the Late Cretaceous of Patagonia. It constitutes the first confirmed report of elasmosaurid plesiosaurs in the Maastrichtian of Magallanes, complementing previous records from central Chile with an early Maastrichtian age (Stinnesbeck, 1986). In addition, it represents the first reliable evidence of the Elasmosauridae family in an intermediate region between central Chile and Antarctica, confirming the presence of the group along the eastern margin of the Pacific Ocean during the Late Cretaceous.

Other Cretaceous elasmosaurid plesiosaurs have been reported from the Cenomanian-Turonian of Australia (Kear, 2003) and Venezuela (Colbert, 1949). They are also present in the Santonian of Japan (Sato *et al*., 2006) and Canada (Nicholls and Meckert, 2002). The Maastrichtian records include New Zealand (Cruickshank and Fordyce, 2002), Japan (Ogawa and Nakaya, 1998), California (Welles, 1943), Chile (Suárez and Fritis, 2002), Argentina (Cabrera, 1941; Gasparini and Goñi, 1985) and Antarctica (Gasparini *et al*., 1984; Gasparini and Goñi, 1985; Chaterjee and Small, 1989), confirming that these reptiles had a worldwide distribution and a marked abundance in the Pacific at the end of the Cretaceous.

The material is hosted at the National Museum of Natural History (Museo Nacional de Historia Natural) of Santiago under the acronym SGO.PV. The few preserved bone fragments only allow them to be identified to family level. In addition, the considerable hardness of the rock constituting the host block hampers preparation of the remains, and due to the lack of more diagnostic characters, such preparation would not necessarily facilitate further identification.

2. Source of material

The Elasmosauridae material for this study was recovered in January 2007 during a field campaign of the Paleobotany Group of the Antarctic Ring Bicentenary Project (Proyecto Bicentenario Anillo Antártico, PBCT-ARTG-04), directed by Dr. Teresa Torres. The remains were found by the first author on the southern slopes of Sierra Dorotea (51°41'20.4"S, 72°26'07.4"W), approximately 2 kilometers NE of Puerto Natales, Magallanes Region, Chile (Fig. 1), within a transported block of calcareous sandstone found at an elevation of 243 m a.s.l. The block has approximate dimensions of 80x50x40 cm, and a weight of about 350 kg. The nearest outcrop of calcareous sandstone is in an inaccessible cliff higher up on the slopes of Sierra Dorotea. Field observations allow us to interpret the stratigraphic provenance of the block to be a horizon with calcareous lenses and concretionary nodules at an estimated elevation of 300 m a.s.l., located about 50 m below the top of the cliff. This lithologic unit is correlated with the upper levels of the Dorotea Formation (Katz, 1963).

3. Geologic setting

The stratigraphic sequence of the study area is composed, from bottom to top, of the following units (Fig. 2):

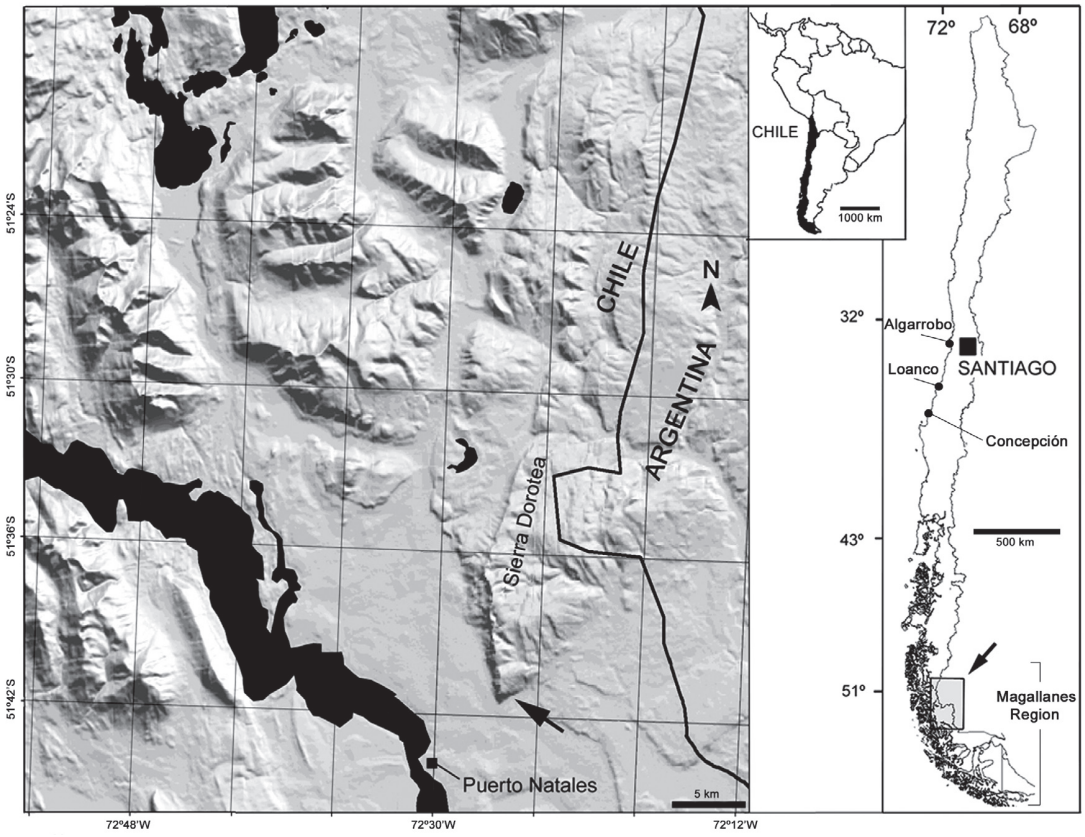

FIG. 1. ArcView based map of Puerto Natales-Seno Última Esperanza area, Magallanes, southernmost Chile. The black arrow indicates the location of Sierra Dorotea, about 2 km NE of Puerto Natales, where the material for this study was collected. The other Chilean localities with reports of elasmosaurid plesiosaurs are indicated on the map on the right.

Cerro Toro Formation (Cecioni, 1957). Shales, conglomerates and sandstones assigned to the Santonian-Campanian, based on ammonoids and bivalves (Hoffstetter *et al*., 1957) and constrained by U-Pb dating on detrital zircons from the underlying Punta Barrosa Formation (Fildani *et al*., 2003).
Tres Pasos Formation (Katz, 1963). Turbidites and sandstones with conglomerate lenses, assigned to the Campanian-early Maastrichtian based on ammonoids and bivalves (Katz, 1963).
Dorotea Formation (Katz, 1963). Sandstones with frequent conglomerate lenses, concretionary levels and claystones. Includes calcareous sandstones with abundant marine invertebrate and fragmentary vertebrate fossils (this study).
Río Turbio Formation (Feruglio, 1938, *sensu lato*; amended by Hünicken, 1955). Mainly marine sedimentary rocks of middle Eocene-late Eocene age based on stratigraphic correlation and microfossils (Malumián and Caramés, 1997).

In the present study, the collected material of elasmosaurid plesiosaurs from the upper levels of the Dorotea Formation (Katz, 1963) was associated with a specimen of *Gunnarites* sp. (study in progress at the Sección de Paleontología y Estratigrafía, Servicio Nacional de Geología y Minería, SERNAGEOMIN, Chile), and a specimen of '*Pterotrigonia*' *cazadoriana* (Wilckens) (identified by E. Pérez d'A., personal communication, 2008). Additionally, transported material was collected and identified as monocotiledons (T. Torres, personal communication, 2007). The genus *Gunnarites*, according to Macellari (1985), is typical of the middle to late Campanian of Seymour Island, Antarctica, but in his opinion it could extend into the Maastrichtian in Patagonia based on the record

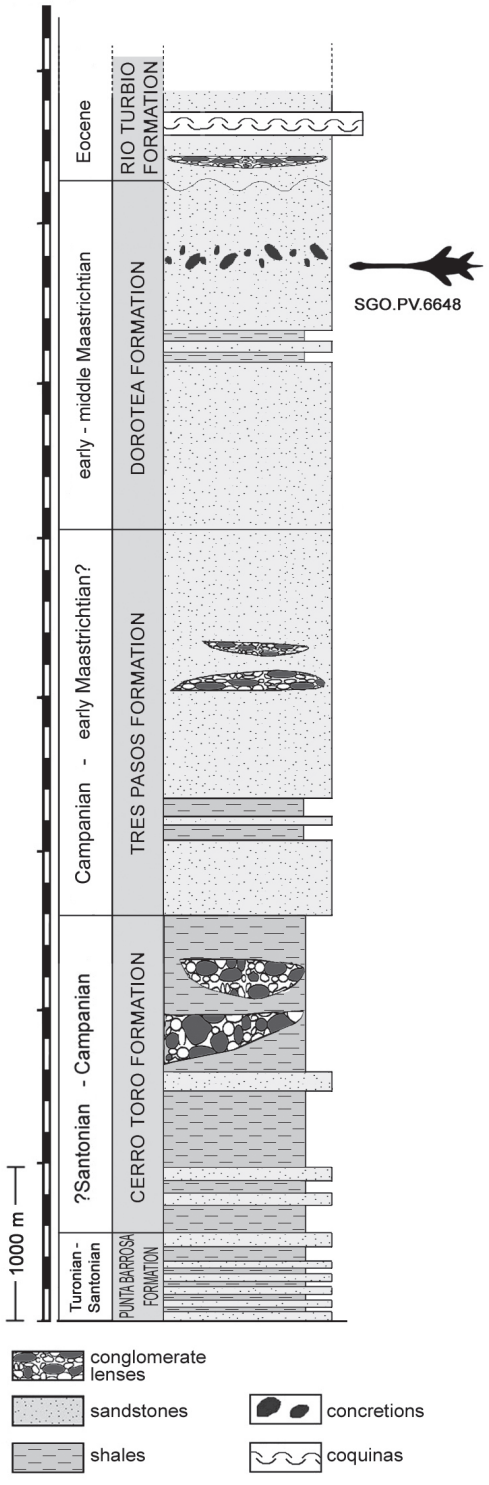

FIG. 2. General stratigraphic column of the units exposed near Puerto Natales, indicating the estimated stratigraphic position of the studied material. Thickness measures as given by Katz (1963).

of this genus above beds containing *Bolivinoides draco dorreeni* Finlay, considered as indicative of the late Maastrichtian (Martínez-Pardo, 1965). However, according to Pérez and Reyes (1978), '*P.*' *cazadoriana* could also indicate a late Campanian-Maastrichtian age.

The presence of the *Pachydiscus* aff. *gollevilensis* (d'Orbigny) ammonoid, previously mentioned by Cecioni (1955), could indicate a Maastrichtian age for the Dorotea Formation (Lahsen and Charrier, 1972), although Katz (1963) noted that, according to some previous authors, the top of the formation could reach the Paleogene. In addition, Hervé *et al*. (2004) obtained a maximum radiometric age of 67.4±1.5 Ma from detrital zircons contained in sandstones of the Dorotea Formation, collected at Sierra Dorotea from levels exposed near the base of the cliff (F. Hervé, personal communication, 2008). This restricts the maximum age of the horizon hosting plesiosaurs to the Maastrichtian.

4. Systematic description

Diapsida Osborn, 1903
Sauropterygia Owen, 1860
Infraorder Plesiosauria de Blainville, 1835
Family Elasmosauridae Cope, 1869

Elasmosauridae gen. et sp. indet.
(Fig. 3: A, B; Fig. 4: A, C)

Material: SGO.PV.6648: Seven vertebral centra, neural arches and at least six ribs, all poorly preserved. The remains are contained in a block of 80x50x40 cm, consisting of very hard, fine-grained, grey, calcareous sandstone (brown to reddish on weathered surfaces). The bone fragments are incomplete and the absent portions could possibly be included in an unrecovered portion of the block. The distribution and orientation of the preserved elements inside the block are irregular, resulting in different parts of the bones being exposed.
Litostratigraphic unit: Dorotea Formation (Katz, 1963), upper levels.
Age: Late Cretaceous (Maastrichtian).
Associated fauna: *Gunnarites* sp.; '*Pterotrigonia*' *cazadoriana* (Wilckens).
Repository: Museo Nacional de Historia Natural, Santiago, Chile.
Description: The preserved vertebral centra are indicated from left to right in figure 3, labelled 'v1'

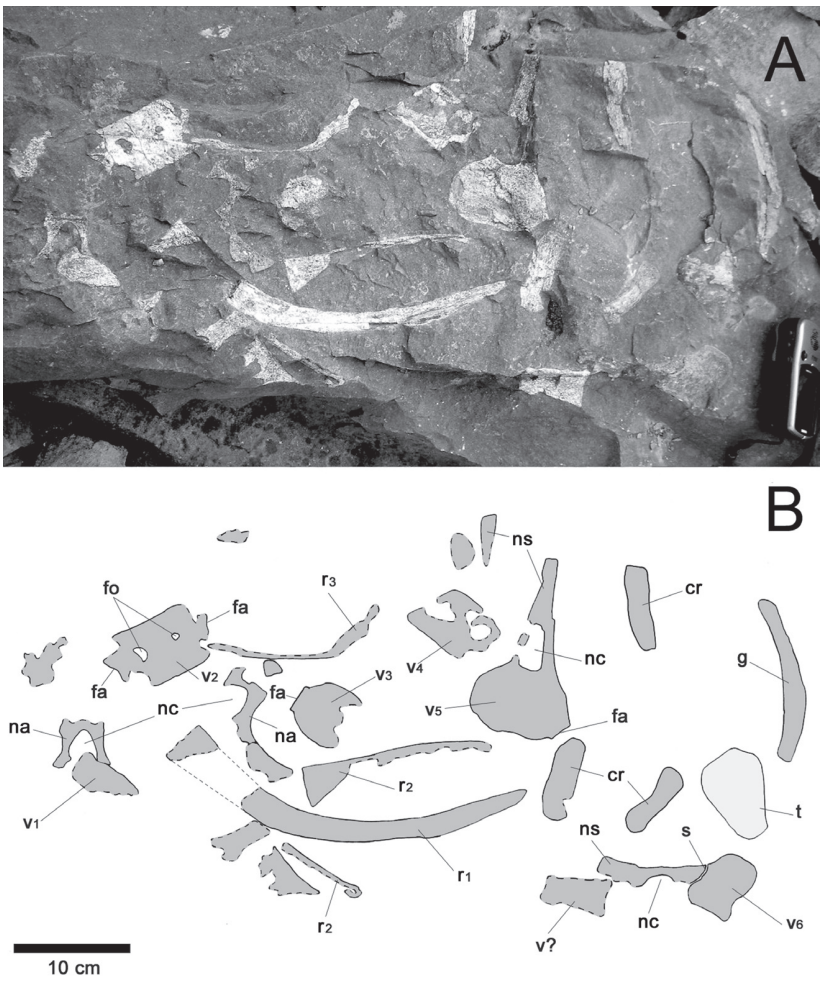

FIG. 3. **A.** SGO.PV.6648: Elasmosauridae gen. et sp. indet. Maastrichtian, Dorotea Formation; **B.** Anatomical description of the remains; **fo:** foraminae; **fa:** rib facets; **na:** neural arch; **v*:** vertebral centra (numbered from 1 to 6); **v?:** possible, incomplete vertebral centrum; **nc**: neural channel; **r*:** ribs (numbered from 1 to 3); **ns:** neural spine; **cr:** cervical ribs; **s.** suture; **g:** possible gastralia; **t:** associated trigonid.

to 'v6'. Neural arches are identified as 'na' and rib fragments as 'r', numbered from 1 to 3. 'v1' is a vertebral centrum with only part of its dorsal portion preserved. It is in contact with its respective neural arch ('na'). The centrum 'v2' is clearly exposed in ventral view and shows two subcentral foraminae ('fo'). The centrum is broader than it is long, with a marked expansion of the two articular, lateral facets located in the middle portion. Vertebral centrum 'v3' is exposed in anterior-posterior view, preserving only half of its body. Nevertheless, it is possible to observe one of the lateral facets. Alongside this bone is part of a neural arch ('na') that preserves part of a centrum. The fragmentary condition and the proximity of all these elements suggest that they belong to the same vertebra. 'v4' corresponds to a deteriorated vertebral centrum exposed in oblique view, showing a higher bone density near its exterior margin. The distal portion of the neural spine is partially preserved. Vertebral centrum 'v5' is exposed in cross-sectional view, with its respective neural spine still attached. This centrum has a dumb-bell shape and also preserves the lateral facets with one of their cervical ribs partially attached, in ventrolateral position. The neural spine is articulated and preserves the neural channel, which is elongated in a dorsal-ventral orientation.

The last vertebral centrum included in the block is 'v6', which is exposed in right-lateral view, somewhat oblique, with both the centrum and the neural spine showing. The suture between both elements and part of the neural channel can also be observed.

Concerning the lateral bone fragments, 'r1' corresponds to part of a rib that almost completely preserves the contour of its distal portion. The bone

is exposed as a longitudinal section. Its proximal end is partially preserved, but the intermediate segment between the proximal end and the rest of the rib is absent. Fragment 'r2' is exposed in the same way as 'r1' and is also broken in two recognizable parts that can be compared and correlated as part of the same bone. Rib 'r3' is poorly preserved with a much deteriorated perimeter. Nevertheless, a higher bone density can be observed along its exterior margin.

The respective lengths observed in 'r1', 'r2' and 'r3' seem to be all similar and indicate that these are indeed dorsal ribs of probable anterior position. The elements indicated as 'cr' are cervical ribs, one of which is associated with 'v5'. Fragment 'g' has an elongated shape and regular thickness, different from that observed in typical ribs that become narrower away from their attachment. Moreover, the thickness of 'g' is less than the maximum thickness observed in 'r1' and 'r2', which is why it is discarded that 'g' corresponds to a rib fragment and it is rather identified as a gastralium.

The rest of the bony elements are fragments with insufficient preservation or exposure for accurate identification. The material indicated as 'v?' could possibly be interpreted as a fragmentary vertebral centrum, based on the observed straight sections similar to articular faces, and also by a higher bone density near its exterior. This, added to its posterior position from 'v6', suggests that 'v?' could be a vertebral centrum.

5. Discussion and observations

Despite the fact that the studied material is in a poor state of preservation, it retains a group of characters that allow us to identify it as a plesiosaur of the Elasmosauridae family. The presence of ribs and a probable gastralium indicates thoraxic elements. In general, the bones could represent a part of the thorax and an incomplete vertebral sequence, with possible correlative centra ('v?'-v6').

The subcentral foraminae that are seen in centrum 'v2' in ventral view (Fig. 4A, B) correspond to a character present only in pistosaurids and all plesiosaurs (O'Keefe, 2001; Appendix I, character type No. 118). Another relevant postcraneal character is observed in the same centrum and also in cervical vertebra 'v6', where it can be seen that the articular faces are almost flat surfaces (platycelous). The possesion of this characteristic is considered as a synapomorphy of the clade Elasmosauridae (Bardet *et al*., 1999; Appendix I, postcranial characters, character No. 21). In vertebral centrum 'v6' the suture between the vertebra and its neural arch is observed. In mature individuals, the arches are strongly fused to the vertebral centrum and most of the sutures are erased (Gasparini *et al*., 2003b). The absence of a complete fusion between these bony elements in the studied material suggests a sub-adult condition for this individual (Brown, 1981).

Vertebral centrum 'v5' shows a dumb-bell shape in cross-section, very similar to those seen in other elasmosaurids such as *Morturneria seymourensis* (Chatterjee and Small, 1989) and *Aristonectes parvidens* Cabrera, 1941 (Fig. 4D, E, respectively), from Seymour Island, Antarctica. Both species are considered as synonyms (Gasparini *et al.*, 2003b). In Late Cretaceous elasmosaurids, the articular face presents this typical shape (dumb-bell), due to the development of a well-marked cavity in the ventral surface of the cervical centra. This feature is considered as a synapomorphy of Elasmosauridae (Bardet *et al*., 1999; Appendix I, Postcranial characters, character type No. 23).

To summarize, the presence of subcentral foraminae in the ventral part of vertebral centra allow us to include the studied material in the Plesiosauria. The flat surface of the articular faces seen in at least two vertebrae is coincident with those noted in the Elasmosauridae family. This identification is confirmed by the singular shape of the cervical centra, typical of Late Cretaceous elasmosaurid plesiosaurs.

6. Conclusions

The remains studied constitute the first report of plesiosaurs of the family Elasmosauridae in Magallanes, southernmost Chile. The relative age of the hosting levels of the material is assigned to the Maastrichtian based on fossil invertebrates with good chronostratigraphic resolution. Previous radiometric studies in rocks from lower levels of Sierra Dorotea (Hervé *et al*., 2004) indicate a maximum age of approximately 67 Ma for sandstones that crop out at the base of the cliff. This constrains the maximum age of the material to the Maastrichtian.

The occurrence of elasmosaurids, cephalopods and trigonids indicates an exclusively marine environment for the upper levels of the Dorotea Formation at the discovery site.

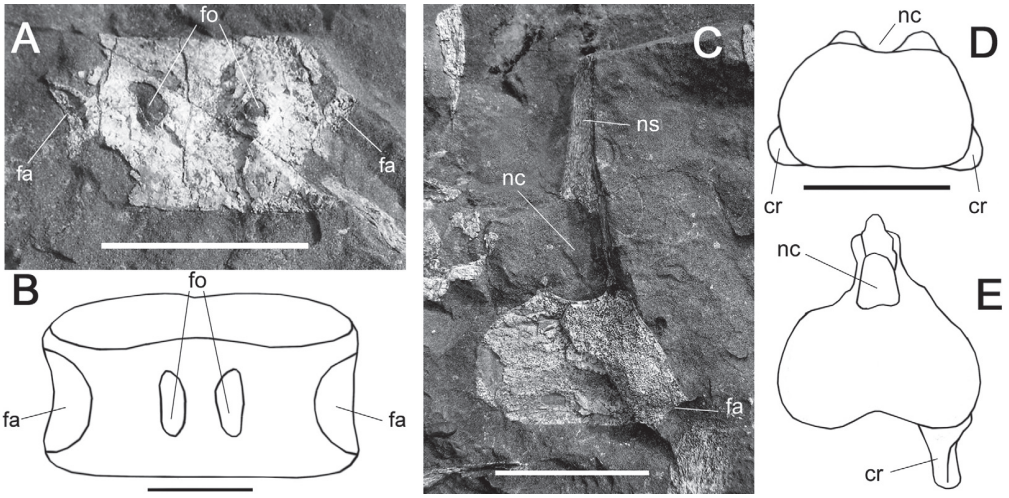

FIG. 4. Comparison of the material SGO.PV.6648 from Puerto Natales, with previous reports of Chilean material of Elasmosauridae indet. from Quiriquina Island. **A.** detail of the centrum 'v2' in SGO.PV.6648; **B.** outline of the cervical centrum figured by Oliver-Schneider (1921), originally referred to *Cimoliasaurus andium* Deecke; **C.** detail of the centrum 'v5' in SGO.PV.6648; **D.** cervical vertebral centrum of an elasmosaurid plesiosaur from Seymour Island, Antarctica, and **E.** *Aristonectes parvidens* Cabrera. Note the similarity of the synapomorphic characters in the compared materials. Scale = 5 cm. Abbreviations are the same as used in fi gure 3. B. Modified from Oliver-Schneider (1921). D. Modified from Chatterjee and Small (1989). E. Modified from Gasparini *et al*., 2003b.

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