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RESEARCH/REVIEW ARTICLE

The oldest elasmosaurs (Sauropterygia, Plesiosauria) from Antarctica, Santa Marta Formation (upper Coniacian? Santonian–upper Campanian) and Snow Hill Island Formation (upper Campanian–lower Maastrichtian), James Ross Island

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Keywords

Elasmosauridae; Antarctica; Late Cretaceous.

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Abstract

Elasmosaurs are recorded for the first time in the Lachman Crags Member (Beta Member) of the Santa Marta Formation (lower Campanian) and in the Herbert Sound Member of the Snow Hill Island Formation (upper Campanian). These are the first elasmosaurids from James Ross Island, Antarctic Peninsula. These records greatly improve our knowledge of the taxonomic diversity of plesiosaurs of the Santa Marta Formation and Herbert Sound Member of the Snow Hill Island Formation, and extend the lower limit of the record of Elasmosauridae in Antarctica to the lower Campanian, making this the oldest record of an Antarctic elasmosaur.

Plesiosaurs are a clade of reptiles adapted to the marine environment. Their record extends from the Upper Triassic to the Upper Cretaceous and their geographical distribution is cosmopolitan, having been recorded in all continents, including Antarctica (Welles 1952, 1962; Persson 1963; del Valle et al. 1977; Brown 1981; Carpenter 1996, 1999; Bardet et al. 1999; Fostowicz-Frelik & Gazdicki 2001; O’Keefe 2001, 2004; Kear 2003; Ketchum & Benson 2010; Vincent et al. 2011).

The stratigraphic range of the Elasmosauridae, one of the best represented plesiosaur groups, is under debate because it depends largely on which genera are considered as belonging to this family (Ketchum & Benson 2010). According to different authors, their stratigraphic range could be Toarcian–Maastrichtian (Brown 1993), Valanginian–Maastrichtian (O’Keefe 2001) or Aptian–Maastrichtian (Ketchum & Benson 2010). However, all authors agree that Elasmosauridae became cosmopolitan during Late Cretaceous times. In the present article, the Elasmosauridae family is understood in a general way in the sense used by Ketchum & Benson (2010).

Elasmosaurs are characterized by the development of a cervical region with (1) a high number of cervical vertebrae (reaching 72 in *Elasmosaurus platyrus*); (2) an

elongated vertebral centra; (3) vertebral centra with lateral ridges; and (4) dumbbell-shaped articular faces in Late Cretaceous genera, for example, *Hydrotherosaurus alexandrae*, *Morenosaurus stocky* and *Terminonator ponteixensis* (Welles 1943, 1962; Brown 1981, 1993; Bardet et al. 1999; Carpenter 1999; Gasparini & Salgado 2000; O’Keefe 2001, 2004; Sato 2003). The combination of these characters allows the identification at family level, even when the material consists only of cervical vertebrae. Note that only (3) is considered a synapomorphy of Elasmosauridae *sensu* Ketchum & Benson (2010; see Wiffen & Molesley 1986; Werner & Bardet 1996; Gasparini & Salgado 2000; O’Gorman et al. 2011).

Antarctic plesiosaurs were recorded for the first time in the 1970s (del Valle et al. 1977). Mostly elasmosaurids, they were discovered in James Ross Basin. However, elasmosaurs have never been recorded in Campanian levels in Antarctica (Table 1). During fieldwork organized by the Instituto Antártico Argentino and undertaken in the summer of 1986, Dr. E. Olivero collected two juvenile plesiosaurs referable to Elasmosauridae in the Herbert Sound Member of the Snow Hill Island Formation of James Ross Island (Figs. 1, 2). Currently housed at the Museo de La Plata (with identification numbers preceded

Table 1 Plesiosaur records from Antarctica. The stratigraphy follows Olivero et al. (2008).

Assignment	Locality	Stratigraphy	Age	Reference
<i>Aristonectes parvidens</i> (Mortueneria)	Marambio Island (Seymour)	López de Bertodano Fm. ("molluscan units")	late Maastrichtian	Chatterjee & Small 1989
<i>Aristonectes</i> sp.	Vega Island (Cape Lamb)	López de Bertodano Fm. (Sandwich Bluff Member)	late Maastrichtian	O'Gorman et al. 2010
<i>Aristonectes</i> cf. <i>parvidens</i>	Vicecomodoro Marambio Island (Seymour)	López de Bertodano Fm. ("molluscan units")	late Maastrichtian	O'Gorman, Olivero et al. 2012
<i>Mauisaurus</i> sp.	Vega Island (Cape Lamb)	Snow Hill Island Fm. (Cape Lamb Member)	late Campanian–early Maastrichtian	Martin et al. 2007
Elasmosauridae indet.	Marambio Island (Seymour)	López de Bertodano Fm. ("molluscan units")	late Maastrichtian	Chatterjee & Small 1989
Elasmosauridae indet.	Marambio Island (Seymour)	López de Bertodano Fm. ("molluscan units")	late Maastrichtian	Martin & Crame 2006
Elasmosauridae indet.	Marambio Island (Seymour)	López de Bertodano Fm. ("Rotularia units")	late Maastrichtian	Gasparini et al. 1984
Elasmosauridae indet.	Marambio Island (Seymour)	López de Bertodano Fm. ("Rotularia units")	late Maastrichtian	Chatterjee & Small 1989
Elasmosauridae indet.	Marambio Island (Seymour)	López de Bertodano Fm. ("Rotularia units")	late Maastrichtian	Fostowicz-Frelic & Gazdzicki 2001
Elasmosauridae indet.	James Ross Island (Santa Marta Cove)	Snow Hill Island Fm. (Herbert Sound Member)	late Campanian	this article
Elasmosauridae indet.	James Ross Island (Monolithic Lake)	Santa Marta Fm. (Beta Member) (upper part of the Lachman Crag Member)	early Campanian	this article
Elasmosauridae indet.	Vega Island (Cape Lamb)	Snow Hill Island Fm. (Cape Lamb Member)	late Campanian–early Maastrichtian	O'Gorman et al. 2008
Elasmosauridae indet.	Vega Island (Cape Lamb)	Snow Hill Island Fm. (Cape Lamb Member)	late Campanian–early Maastrichtian	O'Gorman, Gasparini et al. 2012
Cf. <i>Elasmosauridae</i>	Marambio Island (Seymour)	López de Bertodano Fm. ("molluscan units")	late Maastrichtian	Martin & Crame 2006
Polycotylidae indet.	James Ross Island	Santa Marta Fm. (Alpha Member) (lower part of the Lachman Crag Member)	late Coniacian? Santonian–early Campanian	D'Angelo et al. 2008
Plesiosauroidea indet.	Vega Island (Cape Lamb)	Snow Hill Island Fm. (Cape Lamb Member)	late Campanian–early Maastrichtian	del Valle et al. 1977
Plesiosauroidea indet.	James Ross Island (The Naze)	Snow Hill Island Fm. (Cape Lamb Member)	late Campanian–early Maastrichtian	del Valle et al. 1977
Plesiosauria indet.	James Ross Island (The Naze)	Snow Hill Island Fm. (Cape Lamb Member)	early Maastrichtian	Martin & Crame 2006
Plesiosauria indet.	Marambio Island (Seymour)	López de Bertodano Fm. ("molluscan units")	late Maastrichtian	Martin & Crame 2006
Plesiosauria indet.	James Ross Island (Brandy Bay)	Santa Marta Fm. (Alpha Member) (Lachman Crag Member)	late Coniacian? Santonian–early Campanian	Kellner et al. 2011

by "MLP"), these specimens are important because they are the first records of plesiosaurs in the Herbert Sound Member. More recently, during fieldwork in 2011, organized by the Instituto Antártico Argentino and with the participation of scientists from the MLP, the Universidad Nacional del Comahue and the Museo Municipal Carmen Funes in Plaza Huinul, Elasmosauridae remains were collected from the Lachman Crag Member of the Santa Marta Formation. The aim of this article is to describe the material collected in 1986 and in 2011, discuss their elasmosaurid affinity and highlight the

implications of these records for our knowledge of Antarctic plesiosaurs.

Geological setting

The Marambio Group, which crops out mostly in the James Ross Archipelago, was deposited during the upper Coniacian–Danian interval (Macellari 1988; Ineson 1989; McArthur et al. 2000; Crame et al. 2004) or Santonian–Danian (Olivero & Medina 2000). This article follows the stratigraphy proposed by Olivero et al. (2008) in which

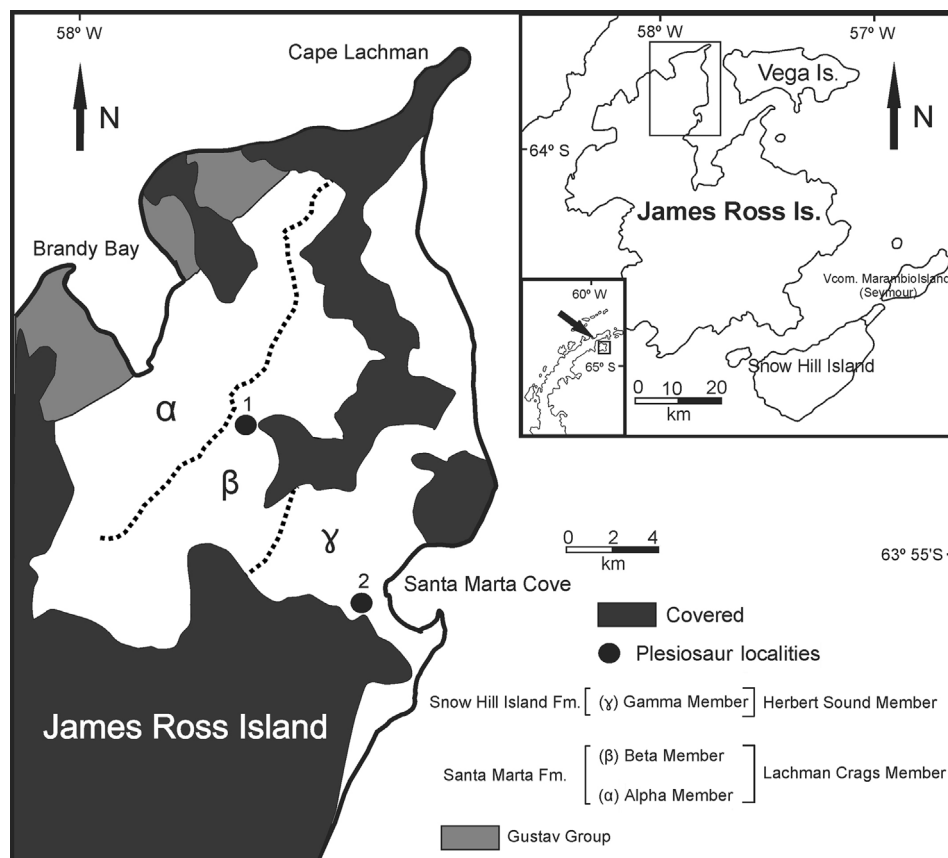


Fig. 1 Map of north-west James Ross Island, where the Snow Hill Island and Santa Marta formations crops out. The black dot numbered 1 is the location where the plesiosaur specimen MLP 11-II-20-4 was discovered; 2 is where specimens MLP 86-X-28-3 and MLP 86-X-28-(2-6) were found. (Illustration modified from Olivero 1992; McArthur et al. 2000; Olivero et al. 2008.)

the Marambio Group is divided into the Santa Marta, Snow Hill Island, Haslum Crag and López de Bertodano formations, and the Herbert Sound Member is considered to be the lower part of the Snow Hill Island Formation. The Santa Marta Formation, which roughly corresponds to the Lachman Crag Member proposed by Crame et al. (1991) (Figs. 1, 2), is divided into the Alpha and Beta members (Olivero et al. 1986; Olivero et al. 2008). The Alpha member is characterized by the abundance of tuffaceous sandstones and mudstones, whereas the Beta member includes interbedded conglomerates and carbonatic bioclastic layers (Olivero 1992). The Herbert Sound Member, now included in the Snow Hill Island Formation (Olivero et al. 2008), is composed of quartz sandstone and mudstone and a mudstone-dominated upper section (Olivero 1992).

The Santa Marta Formation (Alpha and Beta members) was deposited in a mid-to-outer shelf environment and the Herbert Sound Member of the Snow Hill Island Formation was deposited in a shallow marine environment (Crame et al. 1991; Olivero et al. 2008). The Santa

Marta Formation represents (Alpha and Beta members) the late Coniacian–early Campanian interval (McArthur et al. 2000). Olivero & Medina (2000) interpreted that the Santonian–Campanian boundary is located in the lower to middle levels of the Alpha Member and the lower Campanian–upper Campanian boundary in the upper levels of the Beta Member (Olivero 1992; Olivero et al. 2008) and, therefore, the Herbert Sound Member is late Campanian in age (Olivero & Medina 2000).

Bivalves, ammonites (Olivero & Medina 2000), chondrichthyes, teleosts (Kriwet et al. 2006), turtles (de La Fuente et al. 2010) and plesiosaurs (D’Angelo et al. 2008; Kellner et al. 2011) have been recorded in the Santa Marta Formation. In the Herbert Sound Member of the Snow Hill Island Formation, bivalves, ammonites (Olivero & Medina 2000), chondrichthyes and teleosts (Kriwet et al. 2006) have also been recorded, as well as mosasaurs (Novas et al. 2002; Martin & Fernandez 2007; Fernandez & Gasparini 2012) and dinosaurs (Gasparini et al. 1987; Gasparini et al. 1996; Salgado & Gasparini 2006).

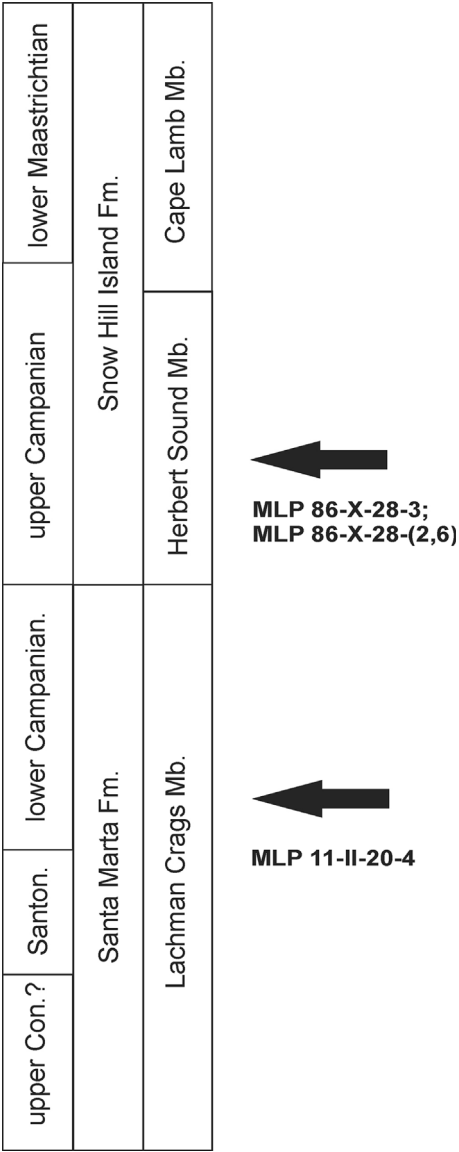


Fig. 2 Schematic stratigraphic column showing the levels where the elasmosaur materials were collected (modified from McArthur et al. 2000; Olivero et al. 2008).

Material and methods

Fossils were prepared using Micro Jack and ME 9100 model jackhammers (Paleotool; Brigham City, UT, USA). The linear measurements were taken using an electronic caliper accurate to 0.01 mm. The vertebral indices used are those proposed by Welles (1952), which take into account the centrum length (L), the ratio between height (H) and length of the centrum ($100 \times H/L$), and the ratio between breadth (B) and length of the centrum ($100 \times B/L$). In addition, the ratio between the breadth and height ($100 \times B/H$) was considered. In this work, both breadth

and height were measured on the posterior articular face of the centrum. The vertebral length index ($VLI = L/[0.5 \times (H + B)]$) (Brown 1981) was also used. 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 employed to distinguish between “adult” and “juvenile” conditions.

Systematic paleontology

1. Sauropterygia Owen 1860
2. Plesiosauria de Blainville 1835
3. Plesiosauroidea Welles 1943
4. Elasmosauridae Cope 1869
5. Gen. and spp. indet.

Materials

MLP 11-II-20-4, one cervical vertebra preserving a partial rib; MLP 86-X-28-3, two cervical vertebrae; MLP 86-X-28-(2-6), 10 posterior cervical vertebrae articulated with three pectoral vertebrae, part of two dorsal vertebrae, ribs and indeterminate fragments.

Locality and horizon

MLP 11-II-20-4, Monolithic Lake (S 63° 52' 38.4", W 57° 54' 36"), James Ross Island, James Ross Archipelago, Antarctica. Santa Marta Formation, lower part of Beta Member (middle levels of Lachman Crags Member), lower Campanian (McArthur et al. 2000; Olivero & Medina 2000) (Figs. 1, 2).

MLP 86-X-28-3 and MLP 86-X-28-(2-6), Santa Marta Cove, locality of QF stratigraphic section of Olivero (1992) (S 63° 55' 36.4", W 57° 51' 0.8"), James Ross Island, James Ross Archipelago, Snow Hill Island Formation, Herbert Sound Member, upper Campanian (McArthur et al. 2000; Olivero & Medina 2000) (Figs. 1, 2).

Description

MLP 11-II-20-4

The vertebral centrum is longer than it is high and broader than it is long (Table 2). The articular faces are slightly concave, but their exact shape cannot be determined because they are damaged (Fig. 3b). The lateral surface has a conspicuous lateral ridge (Fig. 3a). There are two slightly anteroposteriorly elongated foramina in the ventral surface of the vertebral centrum and, in all likelihood, there was at least another one, but this cannot be determined because the ventral surface is not

Table 2 Measurements of specimens MLP 11-II-20-4, MLP 86-X-28-3 and MLP 86-X-28-(2-6). Measurements of vertebral centra (in mm): length (L); height (H); breadth (B); height index (HI) $100 \times H/L$; breadth index (BI) $100 \times B/L$; breadth–height index (BHI) $100 \times B/H$; and vertebral length index (VLI) $L/(0.5 \times (H+B))$.

MLP 11-II-20-4	L	H	B	HI	BI	BHI	VLI
Cervical	104	80	118	77	113	148	1.05
MLP 86-X-28-3							
Cervical	40	38	56	95	140	147	0.85
Cervical	42	40	–	–	–	–	–
MLP 86-X-28-(2-6)							
Cervical	45	46	62	102	138	135	0.83
Cervical	45	44	63	98	140	143	0.84
Cervical	46	45	65	98	141	144	0.84
Cervical	45	44	65	98	144	148	0.83
Cervical	44	48	66	109	150	138	0.77
Cervical	46	45	67	98	146	149	0.82
Cervical	46	48	68	104	148	142	0.79
Cervical	47	48	66	102	140	138	0.82
Cervical	45	44	67	98	149	152	0.81
Cervical	46	49	69	107	150	141	0.78
Pectoral	47	49	79	104	168	161	0.73
Pectoral	–	–	–	–	–	–	–
Pectoral	–	–	–	–	–	–	–

completely preserved and at least half of the ventral surface is lost. The left cervical rib is dorsoventrally compressed and it occupies a large part of the ventrolateral margin of the vertebral body. The suture of the rib with the vertebral centrum is closed (Fig. 3a). Because of the complete closure of the neurocentral suture, the individual is considered an adult.

MLP 86-X-28-3

The vertebral centra are slightly longer than high and broader than long (Table 2). The articular faces are slightly dumbbell-shaped (Fig. 3d). One vertebral centrum has lateral ridges (Fig. 3c). The parapophyses are formed by a ventrolateral depression (Fig. 3c). On the ventral surface, there are two elongated ventral foramina separated by a blunt keel (Fig. 3e). The neurocentral suture of this specimen is open, so it is a juvenile *sensu* Brown (1981).

MLP 86-X-28-(2-6)

This specimen includes 10 cervical and 3 pectoral vertebrae, which were originally articulated (Fig. 3e). In addition, there are two dorsal vertebrae not articulated with the sequence. However, since all the material was collected together, they probably belong to the same individual. All of the vertebral centra are as long as high and both measurements are exceeded by breadth

(Table 2). The VLI of the cervical vertebrae decreases cranio-caudally in the vertebral sequence (Table 2; Fig. 4). The articular faces are flat and suboval (Fig. 3i). The lateral surfaces of the centra are anteroposteriorly slightly concave. The parapophyses are suboval and cranio-caudally elongated in the most anterior cervical vertebrae. From the sixth pre-pectoral vertebra, the parapophyses drift dorsally towards the lateral surface and are more dorsoventrally elongated (Fig. 3f). Ventrally, there are two foramina separated by a blunt keel in the most anterior vertebrae (Fig. 3h), but in the first and third pre-pectoral vertebrae (the ventral surface of the second pre-pectoral vertebra is damaged) there are one or two extra smaller foramina in addition to the two main ones (Fig. 3g). The neural spines in the most anterior cervical vertebrae are anteroposteriorly expanded and posteriorly displaced with respect to the centrum. The pectoral region consists of three vertebrae in which the passage of the rib facet from the vertebral centrum to the neural arch can be observed (Fig. 3f). The dorsal region is represented only by two fragments of vertebral centra. This specimen is considered a juvenile because the neurocentral suture is open in all vertebrae.

Discussion

In the MLP 11-II-20-4 vertebra, the neurocentral suture is closed and not visible (Fig. 3a, b), so it is considered to be an adult individual. Because MLP 86-X-28-3 and MLP 86-X-28-(2-6) show open neurocentral sutures, they are considered juveniles. Therefore, among the described specimens, there are individuals of different ontogenetic stages.

The specimen MLP 11-II-20-4 possesses a vertebral centrum longer than it is high and lateral ridges and is therefore referred to Elasmosauridae. Because the articular surfaces are badly damaged, it cannot be determined whether the articular faces were originally dumbbell-shaped. However, the elongation of the vertebral centrum and the lateral ridge is a combination of characters that has not been reported in any other families of Upper Cretaceous plesiosaurs and is exclusive to Elasmosauridae (Werner & Bardet 1996; Gasparini & Salgado 2000).

The MLP 86-X-28-3 vertebrae have slightly elongated centra, dumbbell-shaped articular faces and lateral ridges. This exclusive combination of characters allows us to refer MLP 86-X-28-3 to Elasmosauridae also.

The vertebral centra of MLP 86-X-28-(2-6) are as long as high and do not have dumbbell-shaped articular faces or lateral ridges. The absence of elongation of the vertebral centra, lateral ridge and dumbbell-shaped articular faces in MLP 86-X-28-(2-6) may be due to the

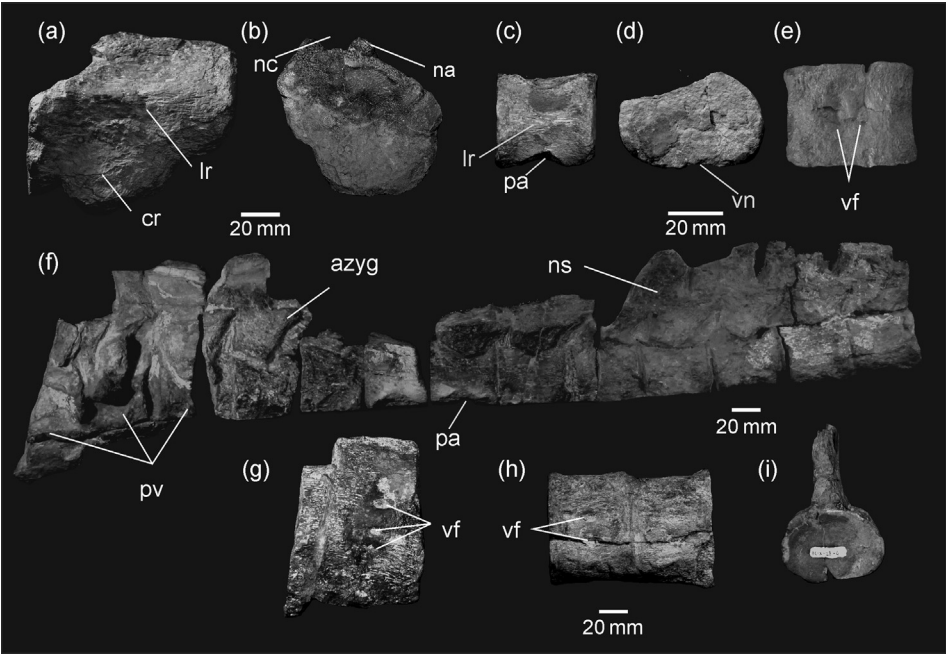


Fig. 3 Elasmosauridae indet. Material from Santa Marta Formation (Beta Member) and Snow Hill Island Formation (Herbert Sound Member). (a–b) MLP 11-II-20-4 cervical vertebra in (a) left lateral and (b) anterior views. (c–d) MLP 86-X-28-3 cervical vertebra in (c) left lateral and (d) anterior views. (e–h) MLP 86-X-28-(2-6) cervical-pectoral series in (e) right view; (f), first pre-pectoral in ventral view; (g), 10th and 9th pre-pectoral vertebrae in ventral view and (h) 9th pre-pectoral vertebra in anterior view. All scale bars are 20 mm. Anatomical features are abbreviated as follows: anterior zygapophyses—azyg; cervical rib—cr; lateral ridge—lr; neural arch—na; neural channel—nc; neural spine—ns; parapophyses—pa; pectoral vertebrae—pv; ventral foramina—vf; ventral notch—vn.

ontogenetic stage and their position in the cervical region. This interpretation receives support from the posterior part of the cervical series of some elasmosaurids, which lacks certain characteristics, such as the centrum elongation, the lateral ridge and the dumbbell-shaped articular faces, although these characteristics are present in the

anterior and middle cervical vertebrae (for example, in *Mauisaurus haasti*, *Morenosaurus stocki*; Welles 1943, 1952, 1962; Hiller et al. 2005). Therefore, the absence of typical characters of the Elasmosauridae in MLP 86-X-28-(2-6) does not necessarily exclude this specimen from this group because the sequence of MLP 86-X-28-(2-6)

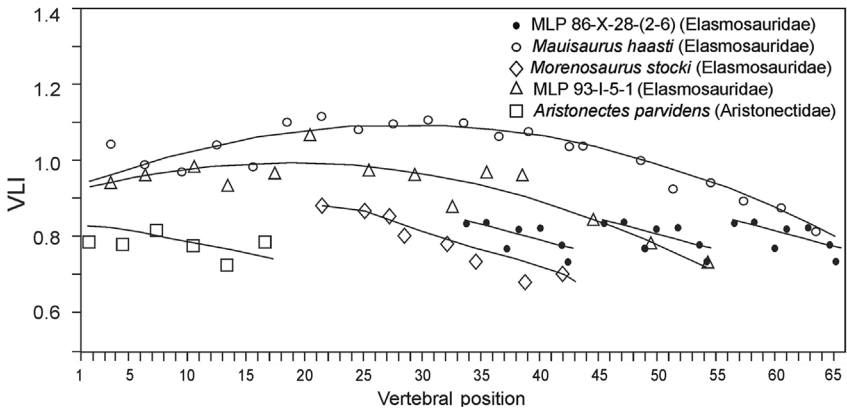


Fig. 4 Plot of vertebral length indices (VLI) of cervical vertebrae of three generalized elasmosaurids and *Aristonectes parvidens* compared with MLP 86-X-28-(2-6), an Elasmosauridae indet. specimen at the Museo de La Plata in La Plata, Argentina. The *Mauisaurus haasti* specimen is CM Zfr 115, at the Canterbury Museum, Christchurch, New Zealand. The *Morenosaurus stocki* is CIT 2802, at the California Institute of Technology, CA, USA. The second Elasmosauridae indet. specimen, MLP 93-I-5-1, is also at the Museo de La Plata, as is the *A. parvidens* specimen (MLP 40-XI-14-6). The data are drawn from Welles (1943) and O’Keefe & Hiller (2006) as well as the author’s own data.

corresponds to the 10 first pre-pectoral vertebrae (the last 10 cervical vertebrae). Moreover, the limited elongation of MLP 86-X-28-(2-6) may be due to its juvenile condition (Welles 1952, 1962; O’Keefe & Hiller 2006). Another element to take into account is that the genus *Aristonectes* has been recorded in the James Ross Basin, López de Bertodano Formation, upper Maastrichtian (Chatterjee & Small 1989; Gasparini et al. 2003; O’Gorman et al. 2010). The phylogenetic relationships of *Aristonectes parvidens* have been debated recently and it has been located within the Elasmosauridae (Ketchum & Benson 2010) or Aristonectidae (O’Keefe & Street 2009). Although the revision of the phylogenetic relationships of *Aristonectes* is not the aim of this article, it is still necessary to determine whether the material described here could be referred to *A. parvidens*. The anterior cervical vertebrae of *A. parvidens* (Cabrera 1941) are dumbbell-shaped (middle and posterior cervical vertebrae are not known) and their centra are only moderately elongated with ventral foramina separated by a ventral keel (Gasparini et al. 2003). Figure 4 shows a plot of the VLI of the cervical vertebrae of four Upper Cretaceous plesiosauroid adults, including the holotype of *Aristonectes parvidens* (Cabrera 1941), and three elasmosaur species: *M. haasti* (Hector 1874); Campanian–Maastrichtian of New Zealand and Chile (Hiller et al. 2005; Otero et al. 2010); *M. stocki* (Welles 1943); Maastrichtian of California (Welles 1962); and MLP 93-I-5-1, an Elasmosauridae represented by a complete postcranial skeleton currently under study by the author from the Cape Lamb Member of the Snow Hill Island Formation (lower Maastrichtian levels). Figure 4 shows that in *M. haasti*, *M. stocki* and MLP 93-I-5-1 the last 10 cervical vertebrae have VLI values similar to those of the cervical vertebrae of MLP 86-X-28-(2-6). This similarity is not surprising since ontological changes in the VLI are less marked in the posterior cervical vertebrae than in the anterior vertebrae (O’Keefe & Hiller 2006). In contrast, in *A. parvidens* the VLI decreases in the first 19 anterior cervical vertebrae (Fig. 4). Assuming that the cervical region of *A. parvidens* has a structure similar to that observed in other plesiosauroids (maximum VLI in the middle and anterior cervical vertebrae, and a marked decrease at the posterior cervical region; Brown 1981; O’Keefe & Hiller 2006), the VLI of the posterior cervical vertebrae of *A. parvidens* would be substantially less than 0.8 and therefore it would be considerably less elongated than MLP 86-X-28-(2-6). Furthermore, MLP 86-X-28-(2-6) is a juvenile and its vertebral centra may have not yet reached their maximum elongation and, therefore, maximum VLI values at the time of death. Consequently, the vertebrae of MLP 86-X-28-(2-6) cannot be referred to as *A. parvidens*.

The morphology of MLP 86-X-28-(2-6) does not correspond to the morphology observed in Polycotylidae, in which the vertebral centra are not elongated and the articular surfaces are subcircular and strongly depressed (Williston 1908; Storrs 1999; Sato & Storrs 2000; Salgado et al. 2007). Therefore, the specimen MLP 86-X-28-(2-6) can be reasonable assigned to Elasmosauridae.

On the basis of our present knowledge, the morphology of isolated cervical vertebrae cannot be used for taxonomic assignment below the family level in Elasmosauridae (O’Keefe & Hiller 2006). Hence, a generic determination of the described material is currently impossible.

Previous records of plesiosaurs in the Santa Marta Formation come from the Alpha Member (lower levels of the Lachman Crag Member) and include materials referred to Polycotylidae (MACN 19.781, Museo Nacional de Ciencias Naturales “Bernardino Rivadavia”, Buenos Aires; D’Angelo et al. 2008) and Plesiosauria indet (MN 7163-V at The Museu Nacional de la Universidade Federal de Rio de Janeiro; Kellner et al. 2011). The vertebrae reported by Kellner et al. (2011) differ from the specimen MLP 11-II-20-4 (described in this article) in that the vertebral centrum of specimen MLP 11-II-20-4 is subequal in length and height and its articular faces are flat and dumbbell-shaped or elliptical, whereas the vertebrae described by Kellner et al. (2011) (MN 7163-V) show the vertebral centrum to be higher than long (the length of the vertebral centrum is inferred because the vertebrae are poorly preserved, although each vertebra has preserved its anterior or posterior half), with strongly concave circular articular faces. The presence of short cervical vertebrae together with strongly concave articular faces that are subcircular in shape is a combination characteristic of Polycotylidae (Williston 1908; Storrs 1999; Sato & Storrs 2000; Salgado et al. 2007). Therefore, specimen MN 7163-V may be referred to as Polycotylidae in accordance with the possibility stated by Kellner et al. (2011), making this specimen the second record of Polycotylidae in the Santa Marta Formation (D’Angelo et al. 2008).

These new records of Elasmosauridae increase our knowledge of the Plesiosauria diversity in the Santa Marta Formation. The Elasmosauridae are now recorded in three of the four formations of the Marambio Group: Santa Marta (upper Coniacian? Santonian–lower Campanian), Snow Hill Island (upper Campanian–lower Maastrichtian) and López de Bertodano (upper Maastrichtian). In contrast, the Polycotylidae are only recorded in the Santa Marta Formation (D’Angelo et al. 2008) (Table 1). Extending the record of Elasmosauridae from Antarctica to the lower Campanian, the new material

described in this article constitutes the oldest record of this group in Antarctica.

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References

- Bardet N., Godefroit P. & Sciau J. 1999. A new elasmosaurid plesiosaur from the Lower Jurassic of southern France. *Palaeontology* 42, 927–952.
- Brown D.S. 1981. The English Upper Jurassic Plesiosauroidea (Reptilia) and a review of the phylogeny and classification of the Plesiosauroidea. *Bulletin of British Museum of Natural History, Geology Series* 35, 253–347.
- Brown D.S. 1993. A taxonomic reappraisal of the families Elasmosauridae and Cryptoclididae (Reptilia: Plesiosauroidea). *Revue de Paléobiologie Volume Spécial* 7, 9–16.
- Cabrera A. 1941. Un plesiosaurio nuevo del Cretáceo del Chubut. (A new plesiosaur from the Cretaceous of Chubut.) *Revista del Museo de La Plata* 2, 113–130.
- Carpenter K. 1996. A review of short-necked plesiosaurs from the Cretaceous of the Western Interior, North America. *Neues Jahrbuch für Geologie und Paläontologie* 201, 259–287.
- Carpenter K. 1999. Revision of North American elasmosaurs from the Cretaceous of the Western Interior. *Paludicola* 2, 148–173.
- Chatterjee S. & Small B.J. 1989. New plesiosaur from the Upper Cretaceous of Antarctica. *Special Publications of the Geological Society* 47, 197–215.
- Cope E.D. 1869. *Synopsis of the extinct Batrachia and Reptilia of North America. Part I. Transactions of the American Philosophical Society* 14. Philadelphia: American Philosophical Society.
- Crame J.A., Francis J.E., Cantrill D.J. & Pirrie D. 2004. Maastrichtian stratigraphy of Antarctica. *Cretaceous Research* 25, 411–423.
- Crame J.A., Pirrie D., Riding J.B. & Thomson M.R.A. 1991. Campanian–Maastrichtian (Cretaceous) stratigraphy of the James Ross Island area, Antarctica. *Journal of the Geological Society of London* 148, 1125–1140.
- D'Angelo J.S., Novas F.E., Lirio J.M. & Isasi M.P. 2008. Primer registro de Polycotylidae (Sauropterygia, Plesiosauria) del Cretácico Superior de Antártida. (First record of Polycotylidae [Sauropterygia, Plesiosauria] from the Upper Cretaceous of Antarctica.) In: *Resúmenes del Tercer Congreso Latinoamericano de Paleontología de Vertebrados. (Abstracts of the Third Latin-American Congress of Vertebrate Palaeontology.)* P. 72. Neuquén, Argentina: Committee of the Third Latin-American Congress of Vertebrate Palaeontology.
- de Blainville H.D. 1835. Description de quelques espèces de reptiles de la Californie, précédée de l'analyse d'un système general d'Erpetologie et d'Amphibiologie. (Description of some species of reptiles of California, preceded by the analysis of a general system of herpetology and amphibiology.) *Nouvelles Annales du Muséum (National) d'Histoire Naturelle, Paris* 4, 233–296.
- de La Fuente M., Novas F.E., Isasi M.P., Lirio J.M. & Nuñez H.J. 2010. First Cretaceous turtle from Antarctica. *Journal of Vertebrate Paleontology* 30, 1275–1278.
- del Valle R.A., Medina F. & Gasparini Z. 1977. Nota preliminar sobre el hallazgo de reptiles fósiles marinos del suborden Plesiosauria en las islas James Ross y Vega, Antártida. (Preliminary note on the discovery of fossil marine reptiles from the suborder Plesiosauria from James Ross and Vega islands, Antarctica.) *Contribución del Instituto Antártico Argentino* 212, 1–13.
- Fernandez M. & Gasparini Z. 2012. Campanian and Maastrichtian mosasaurs from Antarctic Peninsula and Patagonia, Argentina. *Bulletin de la Société Géologique de France* 183, 93–102.
- Postowicz-Frelik L. & Gazdziki A. 2001. Anatomy and histology of plesiosaur bones from the Late Cretaceous of Seymour Island, Antarctic Peninsula. *Palaeontologia Polonica* 60, 7–32.
- Gasparini Z., Bardet N., Martin J.E. & Fernández M. 2003. The elasmosaurid plesiosaur *Aristonectes parvidens* Cabrera from the latest Cretaceous of South America and Antarctica. *Journal of Vertebrate Paleontology* 23, 104–115.
- Gasparini Z., del Valle R. & Goñi R. 1984. Un elasmosaurido (Reptilia, Plesiosauria) del Cretácico Superior de la Antártida. (An elasmosaurid [Reptilia, Plesiosauria] from the Upper Cretaceous of Antarctica.) *Contribuciones del Instituto Antártico Argentino* 305, 1–24.
- Gasparini Z., Olivero E., Scasso R. & Rinaldi C. 1987. Un anquilosaurio (Reptilia, Ornithischia) Campaniano en el continente antártico. (A Campanian ankylosaur [Reptilia, Ornithischia] from Antarctica.) In: *Anais do X Congresso Brasileiro de Paleontologia, Rio de Janeiro. (Proceedings of the*

- Tenth Brazilian Palaeontological Congress.*) Pp. 131–141. Rio de Janeiro: Committee of the Tenth Brazilian Palaeontological Congress.
- Gasparini Z., Pereda-Suberbiola X. & Molnar R.E. 1996. New data on the ankylosaurian dinosaur from the Late Cretaceous of the Antarctica Peninsula. *Memoirs of the Queensland Museum* 39, 583–594.
- Gasparini Z. & Salgado L. 2000. Elasmosauridos (Plesiosauria) del Cretácico Tardío del norte de Patagonia. (Elasmosaurids [Plesiosauria] from the Upper Cretaceous of northern Patagonia.) *Revista Española de Paleontología* 15, 13–21.
- Hector J. 1874. On the fossil reptiles of New Zealand. *Transactions of the New Zealand Institute* 6, 333–358.
- Hiller N., Mannerling A.A., Jones C.M. & Cruickshank A.R. 2005. The nature of *Mauisaurus haasti* Hector 1874 (Reptilia: Plesiosauria). *Journal of Vertebrate Paleontology* 25, 588–601.
- Ineson J.R. 1989. Coarse-grained submarine fan and slope apron deposits in a Cretaceous back-arc basin, Antarctica. *Sedimentology* 36, 793–819.
- Kear B.P. 2003. Cretaceous marine reptiles of Australia: a review of taxonomy and distribution. *Cretaceous Research* 24, 277–303.
- Kellner A.W.A., Rodrigues Simões T., Riff D., Grillo O., Romano P., de Paula H., Ramos R., Carvalho M., Sayão J., Oliveira G. & Rodrigues T. 2011. The oldest plesiosaur (Reptilia, Sauropterygia) from Antarctica. *Polar Research* 30, article no. 7265, doi: 10.3402/polar.v30i0.7265.
- Ketchum H.F. & Benson R.J.B. 2010. Global interrelationships of Plesiosauria (Reptilia, Sauropterygia) and the pivotal role of taxon sampling in determining the outcome of phylogenetic analyses. *Biological Reviews* 85, 361–392.
- Kriwet K., Lirio J.M., Nuñez H.J., Puceat E. & Lécuyer C. 2006. Late Cretaceous Antarctic fish diversity. In J.E. Francis et al. (eds.): *Cretaceous–Tertiary high-latitude palaeoenvironments: James Ross Basin, Antarctica*. Pp. 83–100. London: Geological Society of London.
- Macellari C.E. 1988. Stratigraphy, sedimentology, and paleoecology of Upper Cretaceous Paleocene shelf-deltaic sediments of Seymour Island (Antarctic Peninsula). In R.M. Feldmann & M.O. Woodburne (eds.): *Geology and paleontology of Seymour Island, Antarctic Peninsula*. Pp. 25–53. Boulder, CO: Geological Society of America.
- Martin J.E. & Crame J.A. 2006. Palaeobiological significance of high-latitude Late Cretaceous vertebrate fossils from the James Ross Basin, Antarctica. In J.E. Francis et al. (eds.): *Cretaceous–Tertiary high-latitude palaeoenvironments: James Ross Basin, Antarctica*. Pp. 109–124. London: Geological Society of London.
- Martin J.E. & Fernández M. 2007. The synonymy of the Late Cretaceous mosasaur (Squamata) genus *Lakumasaurus* from Antarctica with *Taniwhasaurus* from New Zealand and its bearing upon faunal similarity within the Weddellian Province. *Geological Journal* 42, 203–211.
- Martin J.E., Sawyer J.F., Reguero M. & Case J.A. 2007. Occurrence of a young elasmosaurid plesiosaur skeleton from the Late Cretaceous (Maastrichtian) of Antarctica. *USGS OF-2007-1047, Short Research Paper 066*, doi: 10.3133/of2007-1047.srp066.
- McArthur J.M., Crame J.A. & Thirlwall J.E. 2000. Definition of Late Cretaceous stage boundaries in Antarctica using strontium isotope stratigraphy. *Journal of Geology* 108, 623–640.
- Novas F.E., Fernández M., Gasparini Z.B., Lirio J.M., Nunez H.J. & Puerta P. 2002. *Lakumasaurus antarcticus*, n. gen. et sp., a new mosasaur (Reptilia, Squamata) from the Upper Cretaceous of Antarctica. *Ameghiniana* 39, 245–249.
- O’Gorman J.P., Concheyro A., Olivero E., Reguero M., Moly J.J., Marenssi S. & Gasparini Z. 2008. An elasmosaurid (Plesiosaur, Plesiosauroidea) from the Upper Cretaceous, Vega Island, Antarctica. In: *Resúmenes del Tercer Congreso Latinoamericano de Paleontología de Vertebrados. (Abstracts of the Third Latin-American Congress of Vertebrate Palaeontology.)* P. 181. Neuquén, Argentina: Committee of the Third Latin-American Congress of Vertebrate Palaeontology.
- O’Gorman J.P., Gasparini Z. & Reguero M. 2010. *Aristonectes parvidens* Cabrera (Sauropterygia, Plesiosauria) from Cape Lamb, Vega Island (Upper Cretaceous), Antarctica. Paper presented at the Fourth Scientific Committee on Antarctic Research Open Science Conference. 3–6 August, Buenos Aires, Argentina.
- O’Gorman J.P., Gasparini Z. & Salgado L. 2012. Postcranial morphology of *Aristonectes* (Plesiosauria, Elasmosauridae) from the Upper Cretaceous of Patagonia and Antarctica. *Antarctic Science*, doi: 10.1017/S0954102012000673
- O’Gorman J.P., Olivero E.B. & Cabrera D.A. 2012. Gastroliths associated with a juvenile elasmosaur (Plesiosauria, Elasmosauridae) from the Snow Hill Island Formation (upper Campanian–lower Maastrichtian), Vega Island, Antarctica. *Alcheringa*, doi: 10.1080/03115518.2012.688673.
- O’Gorman J.P., Salgado L. & Gasparini Z. 2011. Plesiosauros de la Formación Allen (Campaniano–Maastrichtiano) en el área del Salitral de Santa Rosa. Provincia de Río Negro, Argentina. (Plesiosaurs from the Allen Formation in the Salitral de Santa Rosa zone, Río Negro Province, Argentina.) *Ameghiniana* 48, 129–135.
- O’Keefe F.R. 2001. A cladistic analysis and taxonomic revision of the Plesiosauria (Reptilia: Sauropterygia). *Acta Zoologica Fennica* 213, 1–63.
- O’Keefe F.R. 2004. Preliminary description and phylogenetic position of a new genus and species of plesiosaur (Reptilia: Sauropterygia) from the Toarcian of Holzmaden, Germany. *Journal of Paleontology* 78, 973–988.
- O’Keefe F.R. & Hiller N. 2006. Morphologic and ontogenetic patterns in elasmosaur neck length, with comments on the taxonomic utility of neck length variables. *Paludicola* 5, 206–229.
- O’Keefe F.R. & Street H.P. 2009. Osteology of the cryptocleidoid plesiosaur *Tatenectes laramiensis*, with comments on the taxonomical status of the Cimoliasauridae. *Journal of Vertebrate Paleontology* 29, 48–57.
- Olivero E. 1992. Asociaciones de amonites de la Formación Santa Marta (Cretácico Tardío), Isla James Ross. (Ammonite associations in the Santa Marta Formation [Late Cretaceous].) In C. Rinaldi (ed.): *Geología de la Isla*

- James Ross. Pp. 47–76. Buenos Aires: Argentine Antarctic Institute.
- Olivero E.B. & Medina F.A. 2000. Patterns of Late Cretaceous ammonite biogeography in southern high latitudes: the family Kosmaticeratidae in Antarctica. *Cretaceous Research* 21, 269–279.
- Olivero E.B., Ponce J.J. & Martinioni D.R. 2008. Sedimentology and architecture of sharp-based tidal sandstones in the upper Marambio Group, Maastrichtian of Antarctica. *Sedimentary Geology* 210, 11–26.
- Olivero E.B., Scasso R.A. & Rinaldi C.A. 1986. Revision of the Marambio Group, James Ross Island, Antarctica. *Contribuciones del Instituto Antártico Argentino* 331, 1–28.
- Otero R.A., Soto-Acuña S. & Rubilar-Rogers D. 2010. Presence of the elasmosaurid plesiosaur *Mauisaurus* in the Maastrichtian (Late Cretaceous) of central Chile. *Acta Palaeontologica Polonica* 55, 361–364.
- Owen R. 1860. On the orders of fossil and recent Reptilia, and their distribution in time. *Reports of the British Association for the Advancement of Science* 29, 153–166.
- Persson P.O. 1963. A revision of the classification of the Plesiosauria with a synopsis of the stratigraphical and geographical distribution of the group. *Lunds Universitets Arsskrift* 59. Lund: Royal Physiographic Society in Lund.
- Salgado L. & Gasparini Z. 2006. Reappraisal of an ankylosaurian dinosaur from the Upper Cretaceous of James Ross Island (Antarctica). *Geodiversitas* 28, 119–135.
- Salgado L., Parras A. & Gasparini Z. 2007. Un plesiosaurio de cuello corto (Plesiosauroidea, Polycotylidae) del Cretácico superior del norte de Patagonia. (A short necked plesiosaur [Plesiosauroidea, Polycotylidae] from northern Patagonia.) *Ameghiniana* 44, 349–358.
- Sato T. 2003. *Terminonatator ponteixensis*, a new elasmosaur (Reptilia: Sauropterygia) from the Upper Cretaceous of Saskatchewan. *Journal of Vertebrate Paleontology* 23, 89–103.
- Sato T. & Storrs G.W. 2000. An early polycotylid plesiosaur (Reptilia: Sauropterygia) from the Cretaceous of Hokkaido, Japan. *Journal of Paleontology* 74, 907–914.
- Storrs G.W. 1999. An examination of Plesiosauria (Diapsida: Sauropterygia) from the Niobrara Chalk (Upper Cretaceous) of central North America. *The University of Kansas Paleontological Contributions* 11, 1–15.
- Vincent P., Bardet N., Pereda Suberbiola X., Bouya B., Amaghazaz M. & Meslouh S. 2011. *Zarafasaura oceanis*, a new elasmosaurid (Reptilia: Sauropterygia) from the Maastrichtian Phosphates of Morocco and the palaeobiogeography of latest Cretaceous plesiosaurs. *Gondwana Research* 19, 1062–1073.
- Welles S.P. 1943. Elasmosaurid plesiosaurs with description of new material from California and Colorado. *Memoirs of the University of California* 13, 125–254.
- Welles S.P. 1952. A review of the North American Cretaceous elasmosaurs. *University of California Publications in Geological Sciences* 29, 47–144.
- Welles S.P. 1962. A new species of elasmosaur from the Aptian of Colombia and a review of the Cretaceous plesiosaurs. Berkeley: University of California Press.
- Werner C. & Bardet N. 1996. A record of elasmosaurs (Reptilia, Plesiosauria) in the Maastrichtian of the Western Desert of Egypt. *Berliner geowissenschaftliche Abhandlungen* 18, 335–341.
- Wiffen J. & Molesley W.L. 1986. Late Cretaceous reptiles (Families Elasmosauridae and Pliosauridae) from the Mangahouanga Stream, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 29, 205–252.
- Williston S. 1908. North American plesiosaurs: *Trinacromerum*. *Journal of Geology* 16, 715–736.