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A new elasmosaurid plesiosaur from the lower Maastrichtian of North Canterbury, New Zealand

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ABSTRACT

A postcranial specimen from the lower Maastrichtian levels of the Conway Formation, Middle Waipara River, North Canterbury, New Zealand shows clear elasmosaurid affinities, based on the articular faces, with a ventral notch, of the centra of cervical vertebrae. The ilia have some distinctive features such as a gracile shaft divided into two parts by a posterior "knee", with the distal portion being longer than the proximal one, and the flattened distal end being slightly expanded and bearing an ovoid depression. These features differentiate this specimen from other elasmosaurids from the Weddellian Biogeographic Province, in which the ilia are known, but these are considered insufficient grounds on which to erect a new taxon. However, this specimen demonstrates a potentially greater elasmosaurid diversity in the lower Maastrichtian of the southern Hemisphere than previously appreciated. The gastrolith cluster associated with the bones has sedimentological features similar to those previously recorded in gastroliths of other elasmosaurids.

1. Introduction

PLESIOSAUR remains were first discovered on the banks of the Waipara River in North Canterbury, New Zealand in 1859 (Hood, 1870; Welles and Gregg, 1971). Since then, further specimens were discovered from time to time, with most of the material being lodged in the collections of Canterbury Museum in Christchurch or the Colonial and Dominion museums, predecessors of the Museum of New Zealand Te Papa Tongarewa, in Wellington. Welles and Gregg (1971) provided a review of most of the specimens known to that time. In the decades since, more material has come to light, especially in the Hawkes Bay region of the North Island (Wiffen and Moisley, 1986) and North Otago on the South Island (Cruickshank and Fordyce, 2002). However, the Waipara River area has also continued to yield partial skeletons, only some of which have been described (e.g. Hiller and Mannering, 2005).

The collections of Canterbury Museum, Christchurch, include several specimens that could not be readily placed in known taxa. These prompted Hiller and Mannering (2003), in a conference abstract, to ask the question about whether there were other plesiosaurs from the Upper Cretaceous of New Zealand, other than the previously described species. One of these specimens, CM Zfr 159, a partial postcranial skeleton, possesses distinctive features that deserve a detailed study.

The specimen that is the focus of this contribution was discovered by Mr John Lester in April 1982 and recovered with the assistance of a party from Canterbury Museum and the University of Canterbury. It was collected in seven blocks from a broken calcareous concretion and lodged in the collections of Canterbury Museum, Christchurch. Originally placed tentatively as a juvenile pliosauroid, according to the museum catalogue, it has not previously been fully described nor its characters properly assessed, although the bones were dated as early Maastrichtian by Wilson et al. (2005) using associated dinoflagellate cysts.

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2. Geological setting

Exposures of the Conway Formation along the margins of the Waipara River, immediately downstream of the Doctors Gorge (Fig. 1), are well known for their marine reptile remains. Indeed, it was here that plesiosaur bones were first discovered in New Zealand in 1859 (Welles and Gregg, 1971). In this area, the Conway Formation is a soft, easily eroded, massive dark grey siltstone or silty sandstone. It lacks primary sedimentary structures, probably as a result of pervasive bioturbation. The unit is characterised by large calcareous concretions, some of which contain reptile bones, although not all reptile remains were recovered from concretions.

The Conway Formation contains few macrofossils other than the reptile remains although, in some places where the siltstone has not been completely decalcified, a few species of molluscs have been found. Non-calcareous remains, such as phosphatic-shelled brachiopods, sharks' teeth, teleost bones and scales, and plant material, are present but uncommon (Hiller and Mannering, 2005). Among the microfossils, foraminiferans are generally rare and poorly preserved, but rich dinoflagellate assemblages are present and these have formed the basis of a refined biostratigraphy (Roncaglia et al., 1999).

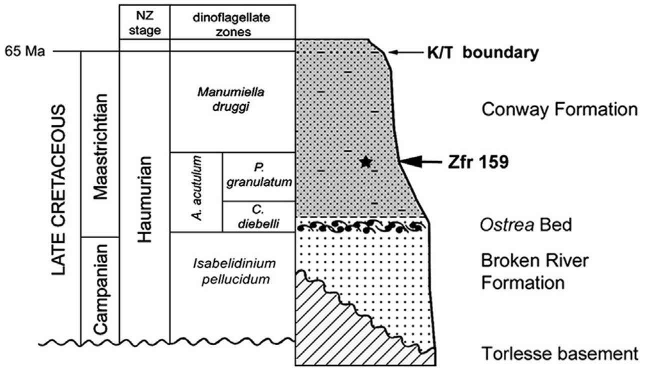

Fig. 2. Simplified stratigraphic column of the Upper Cretaceous sequence exposed along the mid-Waipara River, indicating (black star) the level from which the specimen material was derived.

3. Methods

The specimen was prepared at Canterbury Museum by Al Mannering between 1997 and 2001, primarily using mechanical techniques. All bones were removed from the matrix and fragmented bones repaired whenever possible. In particular, the ribs and gastralia were recovered in short sections and required extensive reconstruction using reversible acetone-based adhesive.

Linear measurements were taken using a vernier calliper that allows a precision of 0.1 mm. The indices calculated are those proposed by Welles (1952), taking into consideration the ratios between height (H) and length (L) ($100^{*}H/L$), breadth (B) and length ($100^{*}B/L$), and breadth and height ($100^{*}B/H$) of vertebral centra. Breadth and height were measured on the posterior articular faces. The vertebral length index [$\mathrm{VLI} = L/(0.5^{*}(H + B))$] of Brown (1981) was also used. The categories of ontogenetic development proposed by Brown (1981), based on the degree of neurocentral fusion along the cervical vertebrae (neural closure), were considered in assigning "adult" and "juvenile" conditions.

To describe the gastroliths, the parameters employed were those frequently considered in previous analyses of plesiosaur stomach stones (e.g. Darby and Ojakangas, 1980; Cicimurri and Everhart, 2001; O'Gorman et al., 2012, 2013). The long (a), intermediate (b) and short (c) axes of each gastrolith were measured and used to calculate the Maximum Projection Sphericity Index [$\psi = (c^2/b^{*}a)^{1/3}$] and the Oblate–Prolate Index [$\mathrm{OP} = (10/(c/a))^{*}((a - b)/(a - c) - 0.5)$] (Dobkins and Folk, 1970). The total mass and volume of the pebbles were not measured because only a fraction of the pebbles could be freed from the matrix without breakage.

Institutional abbreviations: CM = Canterbury Museum, Christchurch, New Zealand; DM = Museum of New Zealand Te Papa Tongarewa, Wellington, New Zealand; KHM = Kaikoura Historical Museum, Kaikoura, New Zealand.

4. Systematic paleontology

Subclass SAUROPTERYGIA Owen, 1860

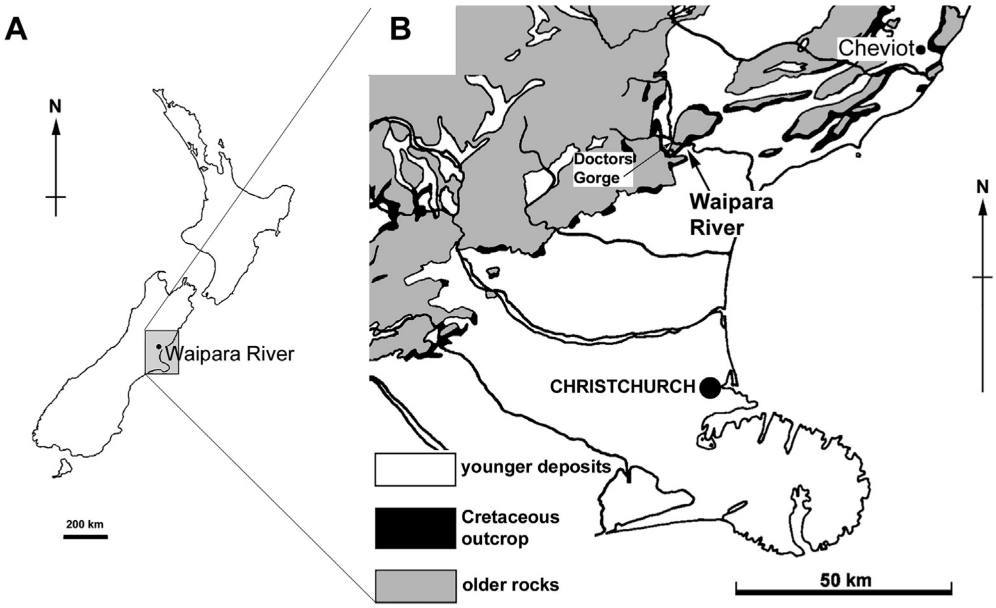

Fig. 1. Locality maps. **A**, map of New Zealand showing the location of the North Canterbury region (shaded square). **B**, simplified geological sketch map of part of North Canterbury showing the Cretaceous outcrop and the location of the Waipara River section.

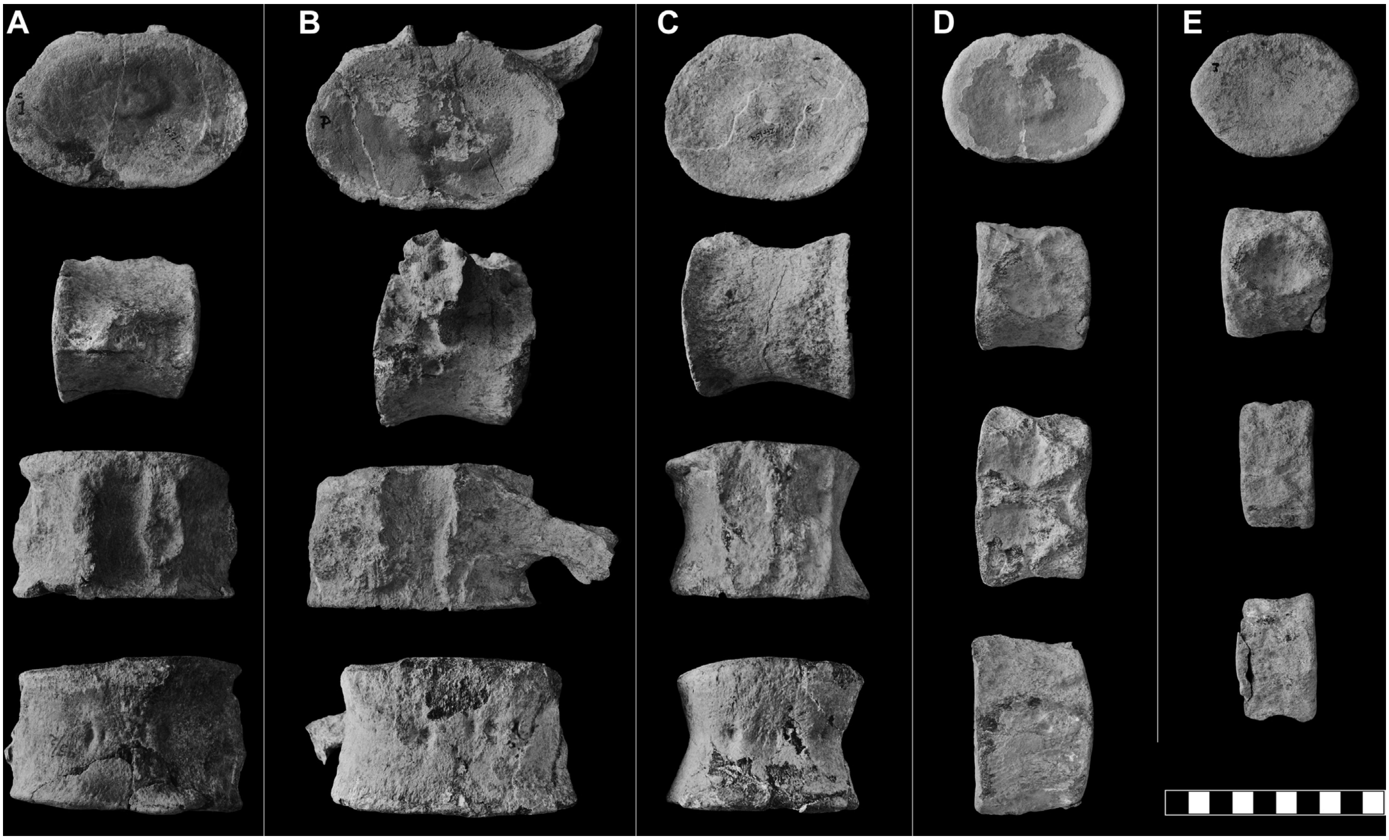

Fig. 3. Examples of vertebral centra. **A**, posterior cervical 1 seen in, from top to bottom, posterior, left lateral, dorsal and ventral views. **B**, pectoral in posterior, right lateral, dorsal and ventral views. **C**, mid-dorsal 1 in posterior and left lateral views; mid-dorsal 2 in dorsal and ventral views. **D**, sacral in anterior, left lateral, dorsal and ventral views. **E**, caudal 3 in anterior, left lateral, dorsal and ventral views. Scale bar in centimetres.

Order PLESIOSAURIA de Blainville, 1835
Superfamily PLESIOSAUROIDEA Welles, 1943
Family ELASMOSAURIDAE Cope, 1869
Genus and species indeterminate

Material

CM Zfr 159 (1994.19.1) a partial skeleton comprising more than 115 bones, including 15 vertebrae, several detached neural spines, both right and left ilia, a propodial interpreted to be a femur, about 40 other paddle bones and numerous fragments of ribs and gastralia. Associated with the bones are more than 300 gastroliths, ranging from a few mm to about 140 mm in maximum dimensions.

Locality and stratigraphic unit

The specimen, CM Zfr 159, was recovered from the middle levels of the Conway Formation (Upper Cretaceous; early Maastrichtian), Middle Waipara River, North Canterbury, New Zealand (Fig. 2); (New Zealand Fossil Record File Number M34/f461). Dinoflagellate cysts associated with the skeletal remains allowed Wilson et al. (2005) to place the specimen in the *Alterbidinium acutulum* Zone (*Palaeocystodinium granulatum* Subzone) of the biostratigraphic scheme of Roncaglia et al. (1999).

Description

Taphonomic aspects. A number of rough sketches made prior to preparation show that the skeletal elements were completely dissociated and scattered, more or less randomly, through the blocks of rock. Unfortunately, there is no information on how the blocks relate to one another or how they were oriented in their source stratum.

The bones are reasonably well preserved with very little evidence of pre-burial fragmentation or abrasion, suggesting a minimum of transport by current activity. However, several articulation surfaces, such as the capitulum of the femur and acetabular faces of the ilia have been noticeably degraded. Whether this is the result of chemical attack or bioerosion is difficult to determine, but it suggests that the bones were partially exposed for some time on the sea floor prior to burial. Similar damage observed in another elasmosaurid skeleton from the same area has been interpreted by Barnes and Hiller (2010) to result from the activity of bioerosive agents, such as echinoids, molluscs or worms (Glover et al., 2008).

Ontogenetic stage. The presence of fused neurocentral sutures in the cervical vertebrae is evident based on the remains of neural pedicels which are still attached to some of the cervical centra; cervical rib facets are visible in all centra; caudal centra also have visible lateral facets without fused ribs; finally, posterior dorsals as well as caudal vertebrae show both rib and neural facets without fusion. These features indicate that the studied specimen is a sub-adult individual.

Axial skeleton. There are three cervical vertebrae, one pectoral vertebra, six dorsal vertebrae, one sacral vertebra and four caudal vertebrae preserved. All these vertebrae are represented by their centra only. The assemblage of bones includes a number of detached neural spines, some with transverse processes, but none of these can be positively associated with any of the vertebral centra. Most of the neural spines are poorly preserved, having been

Table 1
Dimensions of vertebrae in mm.

Vertebra	Length	Height	Breadth	HI	BI	BHI	VLI
Post cerv 1	64.1	67.5	111.6	105.3	174.1	165.3	71.6
Post cerv 2	66.3	70.0	110.9	105.6	167.3	158.4	73.3
Post cerv 3	70.2	70.0	110.2	99.7	157.0	157.4	77.9
Pectoral	64.8	72.4	116.8	111.7	180.2	161.3	68.5
Dorsal 1	68.6	74.7	111.4	108.9	162.4	149.1	73.7
Dorsal 2	66.4	74.6	93.9	112.3	141.4	125.9	78.8
Dorsal 3	64.3	78.8	93.2	122.6	144.9	118.3	74.8
Dorsal 4	65.9	69.7	92.1	105.8	139.8	132.1	81.5
Dorsal 5	68.0	?	94.3	–	138.7	–	–
Dorsal 6	66.5	81.0	?	121.8	–	–	–
Sacral	64.8	65.2	94.9	100.6	146.5	145.6	80.9
Caudal 1	48.0	60.9	80.7	126.9	168.1	132.5	67.8
Caudal 2	47.7	58.9	80.6	123.5	169.0	136.8	68.4
Caudal 3	42.4	56.2	78.9	132.5	186.1	140.4	62.8
Caudal 4	41.2	55.7	69.1	135.2	167.7	124.1	66.0

exposed to the same bone-destroying mechanisms that affected the femur and ilia.

The cervical centra (Fig. 3A) are broader than long and as long as high (Table 1). The articular faces are flat to very gently concave with transversely elliptical outlines, although the anterior face of each displays a slight ventral notch giving a dumbbell shape to the articular face. None of the three has a lateral crest, a feature typical of the anterior and middle parts of the cervical region of elasmosaurids, suggesting they belong to the posterior portion of the neck. The pedicellar facets are narrowly separated and occupy about two-thirds of the length of the centrum. The ventral surface is marked by two pairs of foramina with a small pair inside a larger pair on each side of the midline (Fig. 3A). The rib facets are roughly ovoid in shape, extending from just anterior of mid-length almost to the posterior margin of each centrum when observed in lateral view. The rib facets have a prominent anterior lip and are angled downwards (ventrally) posteriorly.

The preserved pectoral and dorsal vertebrae are higher than long and broader than high. They have almost flat elliptical articular faces. In the pectoral centrum these are transversely ovoid but in the dorsals they become subcircular. There are three to five ventral foramina. The pectoral centrum (Fig. 3B) has the short right transverse process preserved but the left one is missing. The dorsal centra (Fig. 3C) are spool shaped and the pedicellar facets extend the entire length of each. Two incomplete detached neural spines with diapophyses clearly belong to the dorsal series. The transverse processes (Fig. 4) are robust, dorsoventrally compressed and with a distinctive groove along the ventral surface just below the sharp anterior edge, extending the width of the process (Fig. 4A). They terminate in an ovoid, cranio-caudally extended rib facet.

The breadth of the sacral vertebra, probably the posteriormost, (Fig. 3D) is much greater than both length and height, which are almost equal. The rib facet is dorsoventrally enlarged, extending over the neural arch suture. The pedicellar facets are broad and almost as long as the centrum, triangular in outline being posteriorly narrower.

The caudal vertebrae (Fig. 3E) have transversely ovoid, concave articular faces. Prominent rib facets occupy approximately 50% of the centrum length. Triangular hemapophyses are preserved to varying degrees on both the anteroventral and posteroventral margins of the centra. Each centrum has a single large foramen on the ventral midline. Pedicellar facets extend for about three-quarters of the centrum length from the anterior margin. These are anteriorly broader and have a triangular outline in dorsal view. One of the detached neural spines can be identified as belonging to the caudal series.

Ribs and gastralia. More than thirty typically single-headed individual ribs have been identified from the numerous fragments recovered from the matrix, including elements from the cervical, dorsal and caudal regions. The longest rib recovered (Fig. 5A), one of the 10 dorsals, has a preserved length of 520 mm and tapers from a maximum diameter of 48.6 mm at the proximal end to 16.5 mm at the distal end. Along its length the rib changes its cross-section profile from flattened elliptical proximally to almost circular distally. However, in the mid-section of the rib, longitudinal anterior and posterior grooves produce a cross-section profile with a figure-eight (binocular or bilobed) outline. The flattened elliptical proximal cross-section is consistent with the dorsoventrally compressed transverse process of the dorsal vertebrae, suggesting that the ribs where oriented ventroposteriorly on each side of the axial skeleton.

Three short rectangular ribs, lacking any anterior–posterior expansion of the distal end, can be positively identified as caudal ribs (Fig. 5B–D), ranging from 45–60 mm in length. These are parallel-sided with gently curved terminations and would have been angled caudally from their associated vertebrae. Two sacral ribs have been identified (Fig. 5E–F), 100 mm and 85 mm long respectively. Another three ribs are taken to be pectorals (Fig. 5G–H); they have a similar shape to the dorsals but are much thinner. A further four ribs probably belong to the posterior cervical series; these range in length from 95 mm to 120 mm. The remaining ribs are difficult to place with certainty because of their state of preservation.

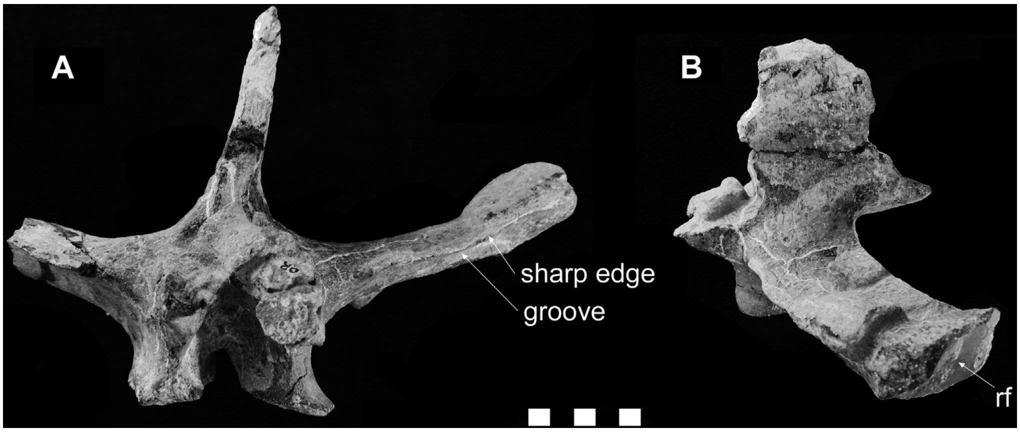

Fig. 4. Detached dorsal neural arch with neural spine and transverse processes in **A**, anterior and **B**, oblique dorsoanterior views. **rf** = rib facet. Scale bar in centimetres.

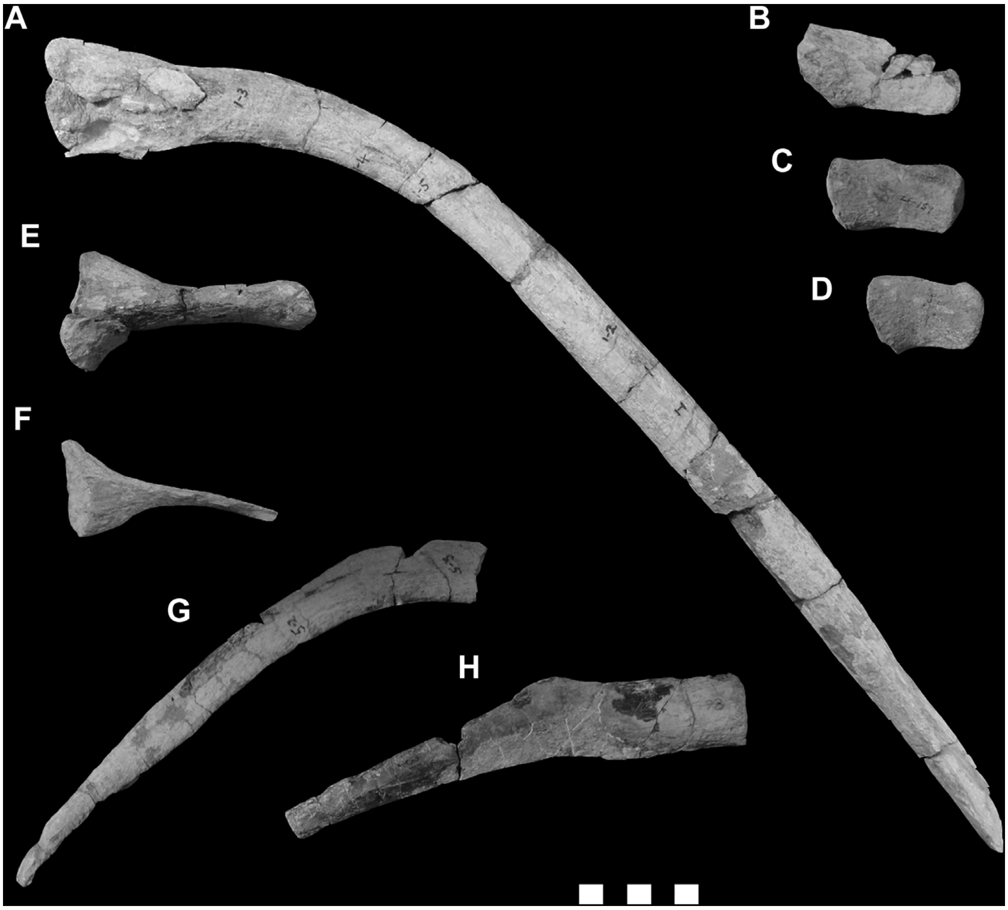

Fig. 5. Ribs from CM Zfr 159. **A**, longest preserved dorsal rib; **B**–**D**, caudal ribs with proximal ends to the left; **E**–**F**, sacral ribs; **G**–**H**, pectoral ribs. In none of the ribs is it possible to positively determine whether they come from the right or left side.

The remains of about 15 gastralia have been recovered but they have been too severely disrupted to allow a meaningful reconstruction. At least two, with lengths over 600 mm, are slightly curved central section belly ribs that gently taper towards each termination. Most of the remainder appear to be more strongly curved lateral belly ribs. These elements bear a strong groove along most of their length, over one of the two axial surfaces (cranial or caudal is difficult to identify).

Pelvic bones. Only the ilia are preserved from the pelvic girdle (Fig. 6A–C). They have maximum preserved lengths of 225 mm and 213 mm; there has been some loss of bone at both proximal and distal ends. Each ilium is very gently curved, with a subtly developed “knee” separating the cylindrical dorsal shaft from the thicker and shorter ventral portion, with an angle of approximately 155^o between them. The dorsal end has a flattened, rounded termination and bears an ovoid depression on one surface, presumably related to the articulation with the sacral ribs (Fig. 6A–B). The ventral end is less cylindrical, being slightly flattened laterally. Loss of bone precludes detailed description of the morphology of this portion of each ilium. A gently convex acetabular facet subtends an angle of about 135^o with the facet for the ischium, although in neither ilium is this well preserved.

Appendicular skeleton. A single propodial (Fig. 7) is preserved among the bones; the association with pelvic rather than pectoral elements along with its relatively slender outline and the angle between the epipodial facets suggest it is the left femur, although loss of bone from the distal end renders this interpretation equivocal. However, comparison with the femur of an Antarctic specimen (MLP 93-I-5-1), which preserves both fore and hind limb propodials, supports the identification. The bone is 309 mm long, 150 mm wide at its widest point and 70 mm wide at the narrowest point. The distal end is gently curved, with facets for tibia and fibula clearly differentiated. The dorsal surface is quite flat and fairly smooth; the ventral surface is convex in cross-section and immediately distal of the narrowest point, a raised callosity marks the site of attachment of the retractor muscle. The articular surface is oval in outline with the ventral side more convex than the dorsal. At the proximal end, loss of bone and deep pitting makes determination of the morphology difficult. The capitulum appears to be relatively small, narrower than the shaft of the femur, with a rounded triangular outline and flat upper surface. The trochanter appears wider than the capitulum, with a flat elliptical surface. It is not clearly separated from the capitulum.

Some 35 other paddle bones (Fig. 8), with additional fragments, are assumed to have come from the same left hind limb. These include the fibula, fibulare, intermedium, tibiale, distal tarsals I, II+III and IV, metatarsals I - V, 23 complete phalanges and fragments of at least five more.

Gastroliths

The assemblage of pebbles recovered from among the bones comprises approximately 50% siliceous lithologies (vein quartz, chert and flint) and 50% greywacke and fine sandstone. The

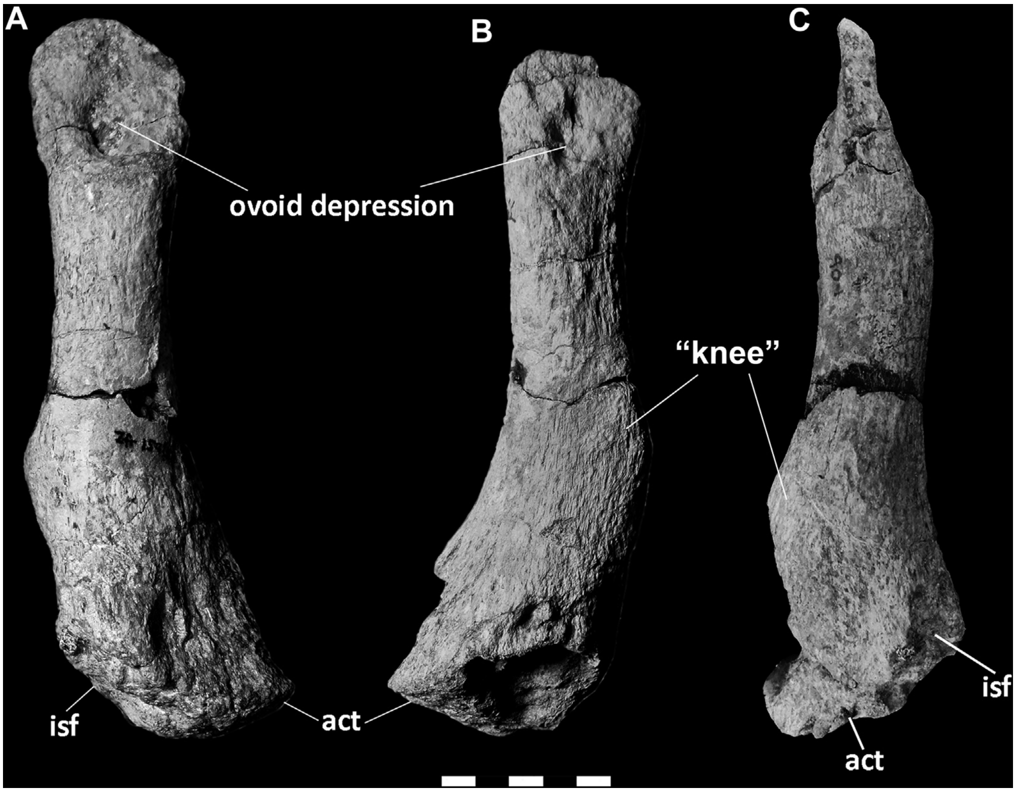

Fig. 6. Ilia. **A**, right ilium and **B**, left ilium in lateral (internal) view; **C**, right ilium in dorsal view. **isf** = ischial facet; **act** = acetabular facet. Scale bar in centimetres.

siliceous pebbles are generally smaller than the arenaceous clasts that make up the majority of the flattish (discoid and bladed) pebbles. Analysis of the shape of the pebbles is made difficult because many are still embedded in matrix and removing them often leads to breakage, thus compromising any measurements that are made. Of the more than 300 pebbles recovered, only 92 have been measured for analysis but these are regarded as being representative of the entire assemblage. The measured pebbles (Fig. 9) have a mean Maximum Projection Sphericity Index of 0.65 (standard deviation = 0.13) and a mean OP Index value of 0.06 (standard deviation = 5.45). According to Krumbein's (1941) classification, 35.9% are oblate (discoidal), 29.3% are equant (spheroidal), 14.1% are prolate (cylindrical) and 20.7% are bladed (Fig. 10). All are well rounded.

5. Discussion

The presence of cervical vertebrae with a ventral notch in the articular faces indicates clear affinities with the Elasmosauridae. However, the taxonomic placement of CM Zfr 159 has been far from clear. In line with the Canterbury Museum catalogue entry for the specimen, Hiller and Mannering (2003) considered the possibility that the bones could belong to a polycotylid, on the basis of the relatively slender femur. Certainly this appears more slender than that of the genus *Mauisaurus* Hector, 1874, of which the lectotype, designated by Welles (1962), was recovered from upper Campanian levels of the Conway Formation near Cheviot, North Canterbury (Fig. 1). In that taxon, the maximum width of the femur is about two-thirds of the length but in CM Zfr 159 the maximum width of the femur is just less than half of the length. It also differs from the femur of *Kaiwhekea katiki* Cruickshank and Fordyce, 2002 from the early Maastrichtian of New Zealand, which has a prominent hemispherical articular head (J.P.O. pers. obs. 2013) and a large, diagonal trochanter similar to that of *M. haasti*. Although an indeterminate amount of bone has been eroded from the distal posterior margin of the femur of CM Zfr 159, it is unlikely that the missing bone would be sufficient to bring the proportions up to match those of the *Mauisaurus* specimens, or the femoral proportions of the holotype of *K. katiki*. However, it is probable that the original, undamaged, morphology of the femur resembles that of specimen MLP 93-I-5-1 (Fig. 11), an elasmosaur from Vega Island, Antarctica (O'Gorman et al., 2008), as well as that of the propodial of a third indeterminate elasmosaur from the Maastrichtian of southernmost Chile (Otero et al., 2013). In addition, the capitulum of the femur, although eroded, does not appear to have been as hemispherical as that of *Mauisaurus*.

The presence of more than 300 gastroliths among the bones was, at one stage, taken to support the specimen's elasmosaurid affinities, as polycotylids usually only have a few stones (about a dozen or so) associated with their skeletal remains (M. Everhart pers. comm. 2003). However, more recently, Schmeisser and Gillette (2009) described an occurrence of 298 gastroliths in a polycotylid. This shows that the presence or absence of gastroliths, or their number, should not be used in making taxonomic determinations.

Comparing CM Zfr 159 with contemporary elasmosaur specimens from New Zealand and elsewhere is made difficult by the general dearth of bones present. The proportions of the preserved vertebral centra compare closely with those of typical long-necked elasmosaurs such as CM Zfr 115, a sub-adult, and CM Zfr 103, a juvenile, which have been placed in *Mauisaurus* by Hiller et al. (2005). It is certainly set apart from aristonectine elasmosaurs, in which the vertebrae are relatively much shorter, especially the posterior cervicals. Specimen CM Zfr 104 (O'Gorman et al., 2014b in press) is one such aristonectine, which preserves a similar suite of vertebrae to CM Zfr 159, and displays markedly different proportions of the cervical centra (Fig. 12).

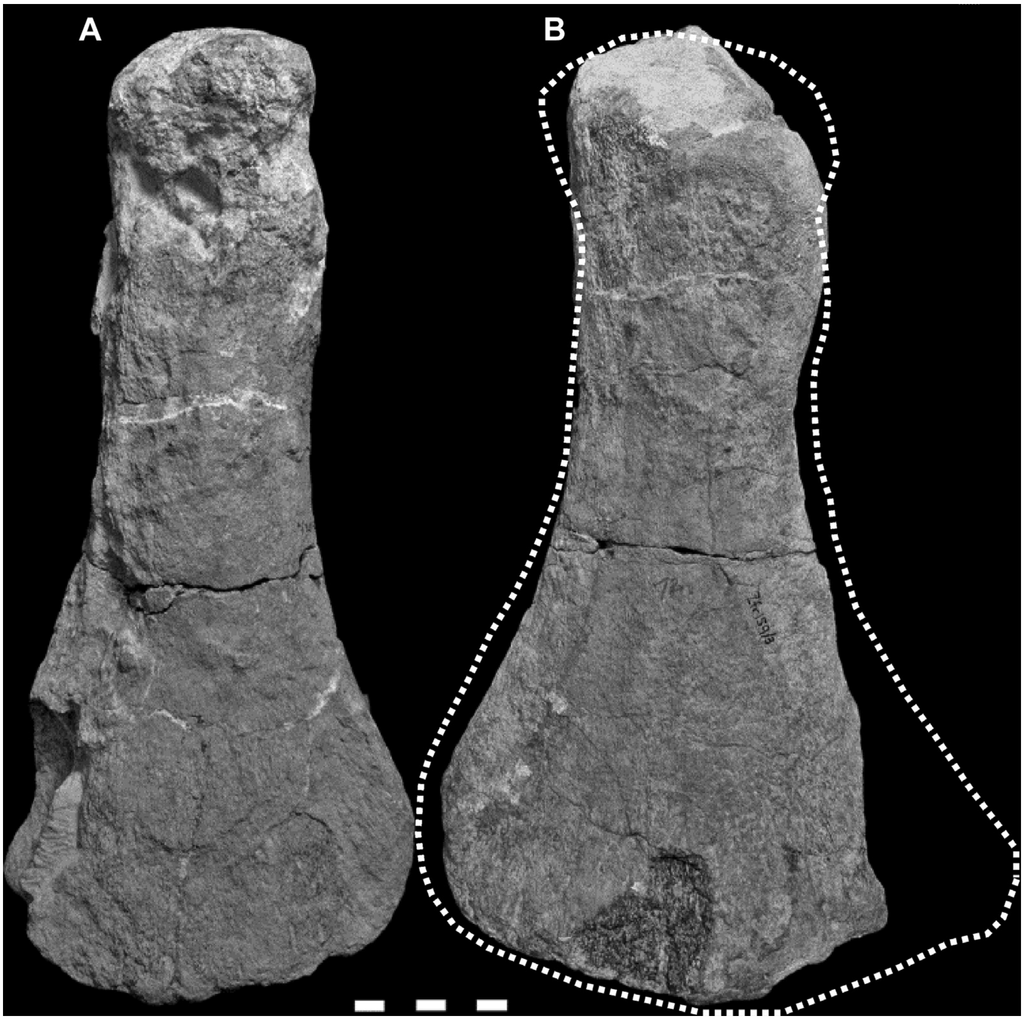

Fig. 7. Femur in **A**, ventral and **B**, dorsal views with suggested restored outline. Scale bar in centimetres.

Fig. 8. Fibula, tarsals and distal paddle bones. Scale bar in centimetres.

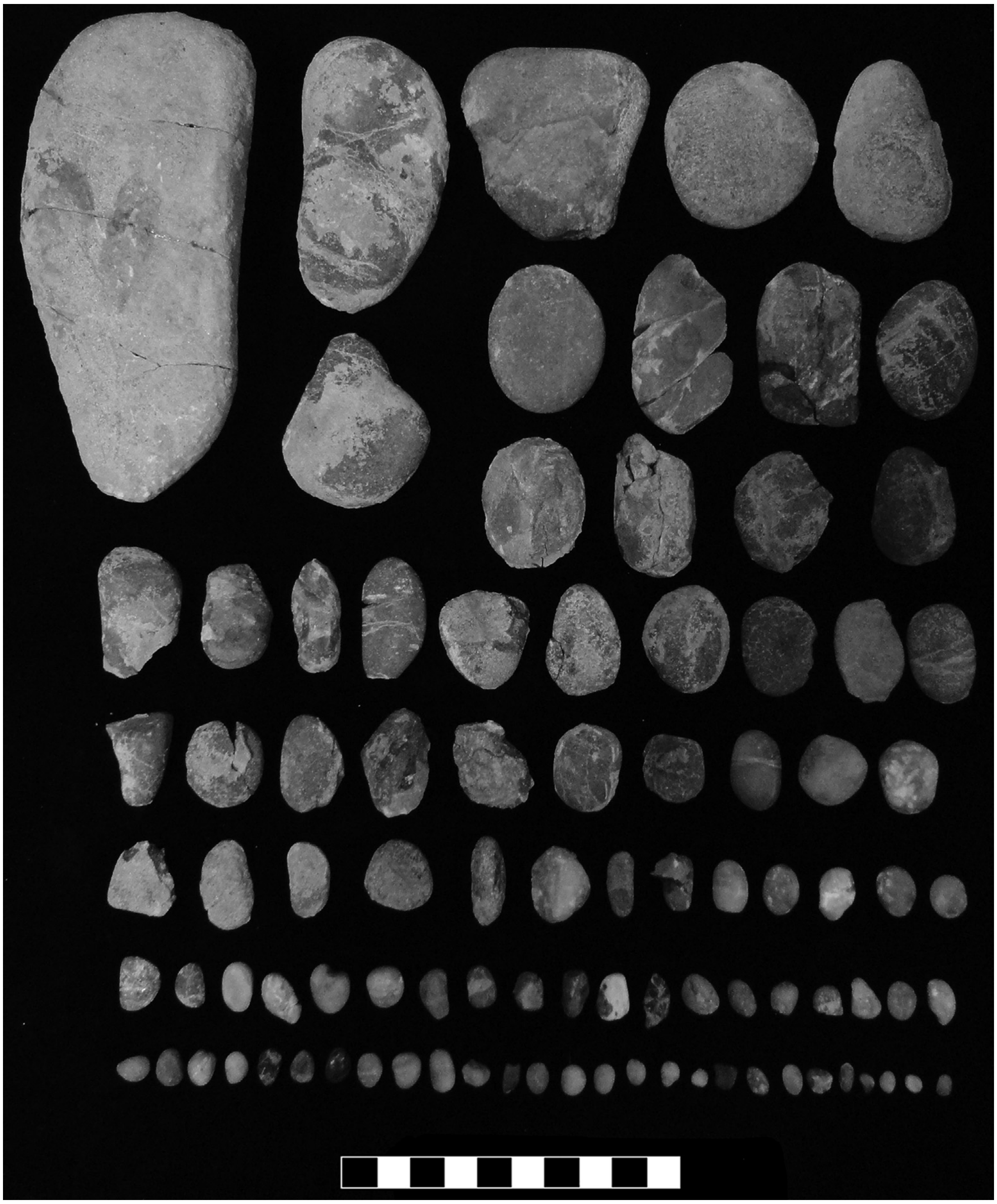

Fig. 9. Gastroliths freed from the matrix and from which reasonably accurate measurements could be made for analysis. Scale bar in centimetres.

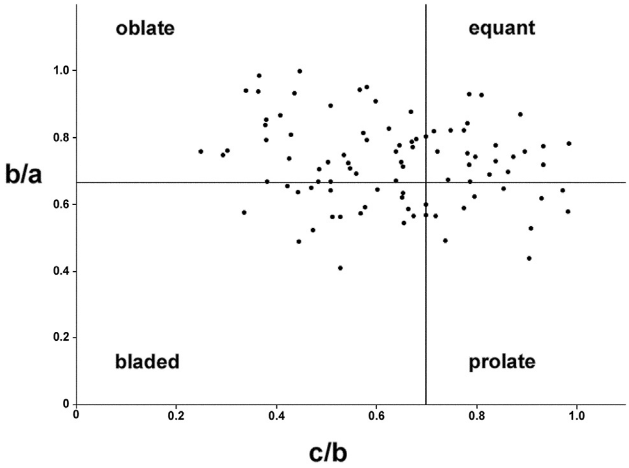

Fig. 10. Gastrolith shape distribution after Krumbein (1941).

Of the bones present, it seems that the ilia offer the best opportunities for making comparisons with other elasmosaurs. In most accounts of elasmosaur ilia, they are described as stocky curved or strongly arched rods (Welles, 1943; Welles and Bump, 1949) or as being wedged shaped, with a marked change in diameter between the proximal and distal ends (Riggs, 1939). In *Leurospondylus ultimus* Brown, 1913 (= Elasmosauridae indet.) the ilium is described as being “weakly arched” (Welles, 1943) and tapering “gradually from the lower to the upper end” (Brown, 1913) although its dorsal end is not compressed as in CM Zfr 159. Also, the ilia of *Futabasaurus suzukii* Sato, Hasegaua and Manabe, 2006 are described as ‘weakly curved’ with a curvature less marked than observed in CM Zfr 159.

Among the New Zealand forms, the ilia of *Tuarangisaurus* are unknown, so direct comparisons cannot be made, and of the *Mauisaurus* specimens only two have at least partial ilia preserved. In Hector’s (1874) original account of the lectotype of *M. haasti* (DM R 1529), he indicated that only a proximal fragment, approximately 150 mm long, was present of the ilium, which he mistakenly

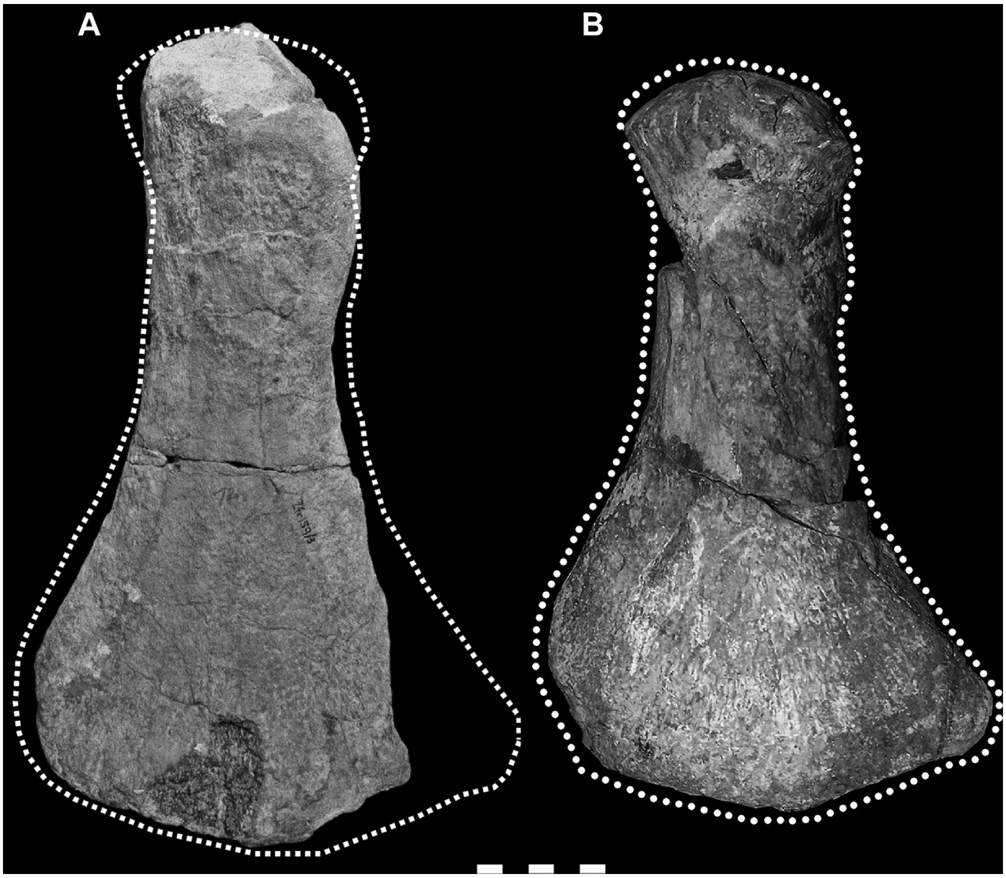

Fig. 11. A comparison of the femur of CM Zfr 159 **(A)** with that of MLP 93-I-5-1 from Vega Island **(B)**. Both are enclosed in the same suggested restored outline scaled to fit.

identified as a scapula. He described the bone as appearing to taper rapidly from about 100 mm in diameter at the articulation with the ischium to about 50 mm at the broken end. Hiller et al. (2005, fig. 20) illustrated the pelvic girdle of another large specimen (KHM N99-1079) placed in *Mauisaurus*, in which the ilium is shown to be sigmoidal in outline and tapering rapidly from the proximal end. Of the other material attributed to *Mauisaurus* by Hiller et al. (2005), it is unfortunate that in neither CM Zfr 103 nor CM Zfr 115, two of the more complete specimens, are the ilia preserved.

Wiffen and Moisley (1986) described and illustrated the ilium of an immature adult (CD 438) from the Mangahouga Stream, Hawkes Bay locality on the North Island. This bone has a very similar appearance to those mentioned above from *Mauisaurus* specimens. It is a robust, strongly curved rod, with a distinct knee, and it tapers markedly from proximal to distal ends. A second specimen from the same locality (CD 440) has a somewhat sigmoidal ilium that tapers markedly from ventral to dorsal ends.

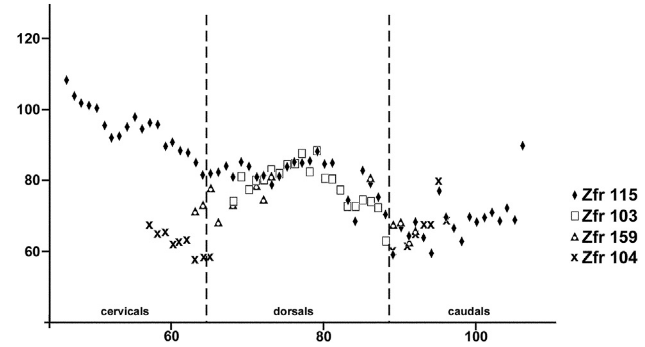

Fig. 12. A comparison of the Vertebral Length Indices (VLI) (Brown, 1981) of CM Zfr 159 with those of CM Zfr 115 (anterior cervicals omitted), a sub-adult, and CM Zfr 103, a juvenile, long-necked elasmosaurs attributed to *Mauisaurus* (Hiller et al., 2005) and CM Zfr 104, a juvenile aristonectine elasmosaur (O'Gorman et al., 2014b in press).

A further indeterminate elasmosaur (CM Zfr 145) from the Waipara River section, described by Hiller and Mannering (2005), has ilia that are robust curved rods with expanded ventral ends and parallel-sided, squared-off dorsal ends.

From available illustrations (Fig. 13), it seems that the ilia of CM Zfr 159 are quite different from any previously described. In particular, the ovoid depressions at the dorsal end seem to be unique. However, too little is known of the overall characteristics of this animal for the erection of a new taxon to accommodate it.

Other elasmosaurid ilia from the Weddellian Province include those of specimen MLP 93-I-5-1 from lower Maastrichtian strata on Vega Island, Antarctica (Fig. 14). These have a strongly bent shaft with a strong posterior knee and are less gracile than those of CM Zfr 159. They also lack an ovoid depression at the distal end. Nor do the ilia of CM Zfr 159 resemble the morphology described for those of MML PV 5, an indeterminate aristonectine from the upper Maastrichtian Jagüel Formation of Patagonia, because the latter has a long proximodistal facet (O'Gorman et al., 2014a, fig. 3) that is absent in CM Zfr 159.

Gastroliths

Dobkins and Folk (1970) plotted mean sphericity values against mean OP Index values to differentiate pebbles from fluvial and beach environments. The same parameters were used to analyse gastroliths

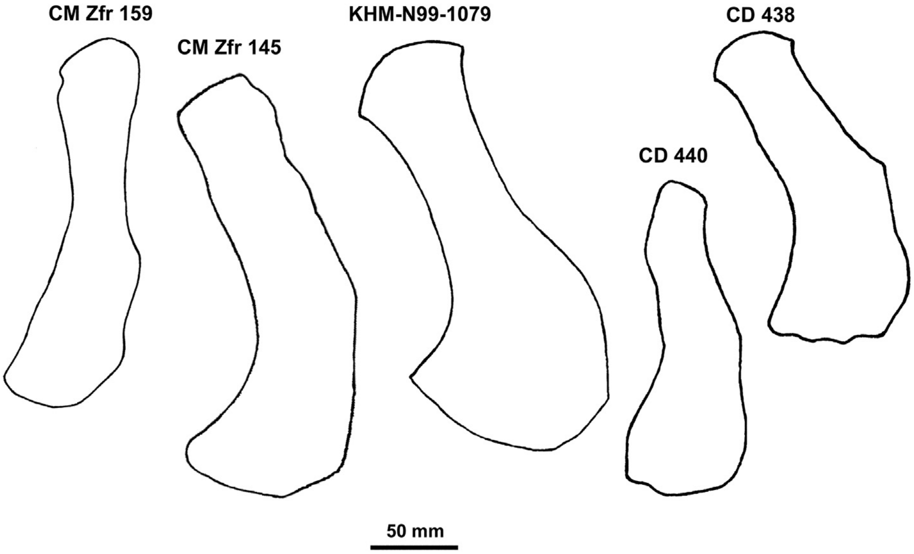

Fig. 13. Outline drawings of ilia from New Zealand elasmosaurs, presented in the same orientation and at the same scale.

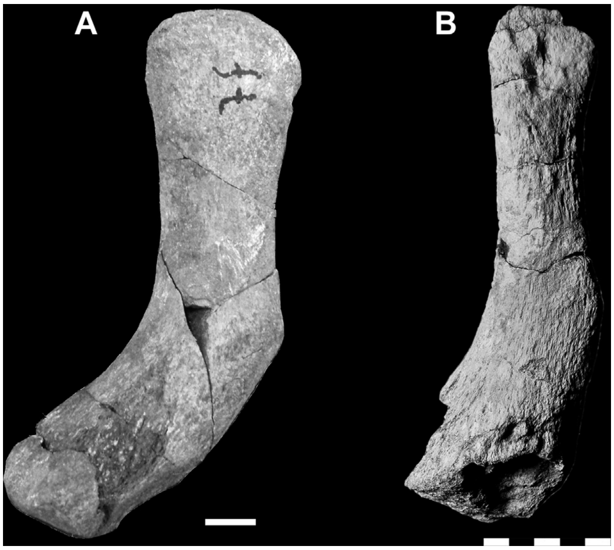

Fig. 14. Comparison of an ilium from MLP 93-I-5-1, Vega Island, Antarctica with one from CM Zfr 159. Scale bar in centimetres.

from non-aristonectine and aristonectine elasmosaurids from the Weddellian Province (Zinsmeister, 1979) and used to infer that several specimens had ingested pebbles from a fluvial or estuarine source (O'Gorman et al., 2012, 2013, 2014c in press). Schmeisser and Gillette (2009) found a similar result with pebbles associated with a Late Cretaceous polycotylid specimen in the United States. When these parameters are plotted for the gastroliths from CM Zfr 159, they also fall within the fluvial field. However, these results need to be treated with some caution; as pointed out by Hart (1991), even modern marine shoreface gravels can also have "fluvial" shapes, so we cannot say definitively that plesiosaurs always obtained their stomach stones from fluvial or estuarine sources.

6. Conclusions

Specimen CM Zfr 159 is interpreted to be a sub-adult on the basis that some neural arches are not fused to their vertebral centra (Brown, 1981). It can be confidently identified as an elasmosaurid, albeit indeterminate, based on the presence of the distinctive ventral notch on the articular faces of the cervical vertebrae.

The morphology of its ilia suggests that it differs from contemporary elasmosaurs, especially those from the Weddellian Biogeographic Province. However, the incompleteness of the skeleton and lack of skull material preclude determination to genus or species level. Nonetheless, this novel morphotype suggests a greater diversity among New Zealand elasmosaurs than previously appreciated.

The sedimentological analysis of the gastroliths, the first performed from a New Zealand elasmosaurid, shows features similar to those previously reported, mostly from other elasmosaurids, showing a pattern that appears to be widespread among Late Cretaceous plesiosaurs.

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