Protoceratopsian? ulnae from Australia

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Introduction

In 1994 we illustrated and briefly described an ulna, NMV P186385, and noted its remarkable similarity to a specimen of the Canadian Maastrichtian protoceratopsian [= non-ceratopsid Neoceratopsia][1] *Leptoceratops gracilis* Brown 1914 (Rich & Vickers-Rich 1994). At the time, work by our volunteers and us on the Early Aptian coastal outcrops of the Wonthaggi Formation of the Strezelecki Group where the specimen was found, was just getting underway. This area is about 100 km south-east of Melbourne, Australia. We hoped then that further effort would yield additional material that might be conspecific with the ulna then being reported. After nine years, no such specimens have been recognised amongst the material subsequently collected from that area.

However, about 300 km to the west, an ulna, NMV P186399, has been recovered from the Early Albian Eumeralla Formation of the Otway Group at Dinosaur Cove East that appears to resemble that of protoceratopsians as well. It is quite distinctive from both *Leptoceratops gracilis* and the older specimen from the Wonthaggi Formation in being noticeably more slender as well as smaller.

In 1994 there were no reports of Early Cretaceous neoceratopsians except for the holotype and only known specimen of *Kulceratops kulensis* Nessov et al. 1986, an incomplete dentary from the Albian Khodzhakul' Formation of Uzbekistan. This made the allocation of the first Australian ulna to the protoceratopsians doubly suspect: being Aptian, it was too old and on a continent where there was no previous neoceratopsian record. Since then there have been two reports of Chinese Early Cretaceous neoceratopsians: *Archaeoceratops oshimai* Dong and Azuma 1997, based on a partial protoceratopsian skeleton described from the Early Cretaceous Xinminbao Group of Gansu Province and *Liaoceratops yanzigouensis* Xu et al. 1998, based on two partial skulls from the probable Early Cretaceous (Middle Barremian) Yixian Formation of Liaoning Province (Swisher et al. 1999). In addition, in North America there are now a number of reports of Middle to Late Aptian or Albian records of Neoceratopsia in the Early Cretaceous (summarised in Chinnery et al. 1998).

ABBREVIATIONS

NMC, Canadian Museum of Nature, Ottawa
NMV P, Museum Victoria, Melbourne, Australia, Palaeontological collections

SYSTEMATIC PALAEONTOLOGY

Neoceratopsia Sereno 1986

The mediolaterally flattened nature of the two Australian ulna suggest their placement in the Neoceratopsia. The shafts of thyreophoran ulnae are also mediolaterally flattened both in the middle and at their ventral end but differ from Neoceratopsia in that they are much broader mediolaterally across the dorsal end.

Serendipaceratops genus novo

Type species. *Serendipaceratops arthurcclarkei* sp. nov.

Etymology. *Serendip*, (1) a fortuitous chance event as in the discovery of the holotype of the species *S. arthurcclarkei* at a site that yielded only half a dozen individual fossil bones and bone fragments on a continent where the Neoceratopsia were previously unknown, (2) from Sarandib, the name given to Sri Lanka, the home of Sir Arthur C Clarke, by Muslim traders (Clarke 1979). *Keratos*, horn in Greek.

Diagnosis. Distinguished from the ulna of *Leptoceratops* by the following features. Coronoid process: extends further forward, anterior edge forms a greater angle with the axis of the shaft, in anterior view narrower and the medial and lateral sides are parallel rather than V-shaped. Lateral tubercule: much more robust and mediolaterally inflated. In ventral view, the anterolateral surface of the distal end of the ulna is much more inflated. Viewed posteriorly, the shaft of the ulna is more recurved near the ventral end. Distinguished from all the other protoceratopsians whose ulnae have been described, including *Leptoceratops,* by the shorter dorsoventral length of the bone relative to its anteroposterior depth.

Serendipaceratops arthurcclarkei species novo

Holotype. NMV P186385, a left ulna, missing the region dorsal to the midpoint of the semilunar notch (Figs 2, 4).

Etymology. Named in honour of Sir Arthur C Clarke, who inspired both of us in our youth with his writings and who in his youth was lured into science by dinosaurs.

Diagnosis. That of the genus until additional species are described.

Type locality. 'The Arch' on the shore platform near the village of Kilcunda, Victoria, Australia, (38° 32' 54" S, 145°27' 29" E, [Universal Transverse Mercator 55]).

Stratigraphic Unit and Age. Wonthaggi Formation of the Strzelecki Group, Early Aptian (Wagstaff & McEwen 1989).

Comparisons. Sternberg (1951) listed four ulnae of *Leptoceratops gracilis*. Through the good offices of Dr Dale Russell, a cast of one of them, NMC 8889, was provided to us (Figs 1, 3, 5). All the comparisons that follow between NMV P186385 and NMC 8889 are based on that cast.

The general resemblance of the two specimens is quite remarkable. However, they do differ in the following respects. The coronoid process of NMV P186385 projects further anteriorly than that of NMC 8889 (Figs 2A-A', 3A-A', 4A-A', 5A-A'). This, together with the lesser distance from the ventral margin of the semilunar notch to the most distal point on NMV P186385 (measurement b in Figure 1 and in the Table of Measurements), combines to give the impression that the bone is shorter and stockier than NMC 8889. Specifically, the ratio of the distance from the anterior edge of the coronoid process to the posterior edge of the bone (measurement c in Figure 1 and in the Table of Measurements) divided by the distance from the anterior edge of the semilunar notch to the distal edge of the bone (measurement b in Figure 1 and in the Table of Measurements) is 20 % greater in the Australian specimen (0.43) than in the Canadian one (0.36). [Dr Brenda Chinnery pers. comm., June 2003, has measured ratios of 0.39 and 0.47 in two American Museum of Natural History specimens referred to *Leptoceratops gracilis*. She further notes that of three *Protoceratops andrewsi* ulnae she measured, one had a ratio nearly as great as the Australian ulna, 0.40.] The ventral edge of the coronoid process forms a noticeably greater angle with the long axis of the bone on the Australian specimen (Figs 2A-A', 3A-A', 4A-A', 5A-A'). The lateral tubercle posterior to the semilunar notch that extends ventrally from that point is much broader both anteroposteriorly and mediolaterally in the Australian specimen (Figs 2C-C', 3C-C', 4A-A', 5A-A'). A prominent groove parallel and posterior to the lateral tubercle is present on the Australian specimen and absent on the Canadian one (Figs 4A-A', 5A-A'). This groove does not appear to be an artifact of crushing. The situation is reversed in the ventral area of the lateral aspect of the shaft where the Canadian specimen has a broad groove extending dorsoventrally and the Australian one does not (Figs 4A-A', 5A-A'). Again, this groove does not appear to be an artifact of crushing. Despite the ventral end of the Australian specimen being somewhat abraded, there is an anterolateral inflated area that is absent on the unabraded Canadian ulna (Figs 4A-A', C-C', 5A-A', C-C'). In posterior view, while the shaft of *Leptoceratops gracilis* is almost straight, that of *Serendipaceratops arthurcclarkei* is noticeably concave medially (Figs 2B-B', 3B-B'). Developed on the medial side of the shaft of both specimens is a broad groove extending dorsoventrally (Figs 2A-A', 3A-A'). These grooves do not appear to be an artifact of crushing.

Protoceratopsian, genus and species indet.

Material. NMV P186399, left ulna with dorsal and ventral edges either abraded or not fully ossified, the latter interpretation suggesting a juvenile.

Locality. Dinosaur Cove East, Dinosaur Cove, Victoria, Australia (38° 46' 53±1" S, 143° 24' 14±1" E).

Stratigraphic Unit and Age. Eumeralla Formation, Otway Group, Late Aptian-Early Albian (Wagstaff & McEwen 1989).

Comparisons. Sternberg (1951) noted that the ulna, together with the humerus and radius of *Leptoceratops gracilis* was, '. . . relatively heavier and shorter than in *Protoceratops* . . .' Given the available published information about the ulnae of protoceratopsians, this is still the sole basis for allocating isolated ulna (but note the cautionary remark above of June 2003 by Dr Brenda Chinnery regarding the proportions of the ulna of one specimen of *Protoceratops andrewsi*.). The ulna has been illustrated for the following protoceratopsians: *Protoceratops andrewsi* Granger and Gregory 1923 [illustrated in Brown and Schlaikjer (1940), Figs 28a-b], *Breviceratops kozlowskii* Kurzanov 1990 [illustrated as *?Protoceratops kozlowskii* in Maryańska and Osmólska (1975, Plate 40, Fig. 1a)], *Graciliceratops mongoliensis* Sereno (2000) [illustrated as *Microceratops gobiensis* in Maryańska and Osmólska (1975, Plate 38, Fig. 3)], and *Leptoceratops gracilis* Brown 1914 [illustrated in Rich and Vickers-Rich (1994), Fig. 18 B-B']. The ulna of *Udanoceratops tschizhovi* Kurzanov 1992 is known but not yet described (Dr Brenda Chinnery, pers. comm. April 2003). The Dinosaur Cove ulna, as far as it can be compared, is more like that of *P. andrewsi* than the single illustrated ulnae of *B. kozlowskii* and *G. mongoliensis*. *B. kozlowskii* does not appear to have the coronoid process developed as a prominence projecting away from the shaft of the ulna as is the case in *P. andrewsi* and *G. mongoliensis* as well as NMV P186399. As illustrated by Maryańska and Osmólska (1975), the ulna of *Graciliceratops mongoliensis* appears to be slightly shorter than NMV P186399 and has a more prominent coronoid process together with a much more slender midshaft. The juvenile specimen of the ulna of *P. andrewsi* illustrated by Brown and Schlaikjer (1940, Fig. 28a) is about the same length as NMV P186399 but differs in having a more prominent coronoid process and possibly a more distinct lateral tubercle. Brown and Schlaikjer (1940) noted that in *P. andrewsi,* the ends of the ulna in adults were more flared than in juveniles. If NMV P186397 represents a less mature individual than the juvenile illustrated by Brown and Schlaikjer (1940, Fig. 28a), the differences between the two may be ontogenetic.

DISCUSSION AND CONCLUSIONS

There are now two ulnae from the Early Cretaceous of Australia that can be tentatively referred to the Neoceratopsia. The ulnae of *Leptoceratops gracilis* and the holotype of *Serendipasceratops arthurcclarkei* stand apart from those of other protoceratopsians to the extent that information about the latter is available in the published record. The two species more closely resemble ulnae of the much larger ceratopsids in that the shaft of the bone is markedly broader anteroposteriorly relative to its length. The strongest evidence that the holotype ulna of *S. arthurcclarkei* is a neoceratopsian is its similarity to ceratopsids in this regard, an autapomorphic character of ceratopsids + *L. gracilis* + *S. arthurcclarkei*. The Dinosaur Cove ulna, although reminiscent of that of the protoceratopsid *Protoceratops andrewsi,* is not as distinct from the condition of the ulna of all other tetrapods, as is the case of the holotype of *S. arthurcclarkei.*

The group with ulnae most similar to those of the neoceratopsians are the thyreophorans. However, the thyreophoran ulnae are consistently much broader mediolaterally across the dorsal end. Compare the anterior view of the ulna of the thyreophoran *Stegosaurus sulcatus* (Fig. 7A) with the corresponding anterior views of *Serendipaceratops arthurcclarkei* (Fig. 4B-B') and *Leptoceratops gracilis* (Fig. 5B-B'). Typical of ankylosaurs generally, the expanded condition of the dorsal end of the ulna in the nodosaurid *Sauropelta edwardsi* is even more extreme than is the case in *S. sulcatus* (Fig. 7D). It is difficult to imagine how a thyreophoran ulna could be mediolaterally crushed so as to resemble that of a neoceratopsian in this regard. Presumably any such crushing would result in the dorsal end of a crushed thyreophoran ulna to still be noticeably broader mediolaterally than the midshaft or distal end unless the degree of crushing varied significantly along the shaft, a seemingly unlikely phenomenon that should be detectable by examination of the surface features of such a fossil.

Because of its foreshortened nature, when initially discovered, the holotype of *Serendipaceratops arthurcclarkei* was thought to possibly be that of a theropod. However, upon examining a number of theropod ulnae, it was soon realised that the ventral end was rod-like rather than tabular as in the case of *Leptoceratops gracilis* and the ceratopsids (Fig. 8).

On a continent in which the Mesozoic tetrapod record is as poorly known as that of Australia, another interpretation of these fossils must be considered. Could one or both of these ulnae represent the first record of a major group of tetrapods endemic to the continent which have previously not been recognized? While this possibility cannot be dismissed out of hand, the remarkable similarity of the holotype of *Serendipaceratops arthurcclarkei* to an ulna of *Leptoceratops gracilis* and those of the ceratopsids makes the degree of coincidence that must be invoked for such an hypothesis to be valid seem highly improbable.

On the basis of Cretaceous palaeogeography, one would expect the dinosaur fauna of Australia to show a greater resemblance to South America than to Asia. At that time, a broader ocean than at present separated Australia from Asia. Australia then lay adjacent to East Antarctica and that land mass was close to where it is now. East Antarctica, in turn, was loosely connected to South America across the West Antarctic Archipelago (Smith et al. 1994). While for these reasons one would expect that the affinities of Australia's Early Cretaceous dinosaurs should be with those of South America, surprisingly they are actually closer to those of Asia. South America entirely lacks a group common to Asia and Australia (ornithomimosaurs, Rich & Vickers-Rich 1994) and has a record of two groups other than neoceratopsians only long after appearing earlier in both Asia and Australia (ankylosaurs, Molnar 1996, and oviraptorosaurs, Currie et al 1996, Early Cretaceous in Australia and Asia, Latest Cretaceous in South America). Thus, there is nothing in the pattern of what little is known about the palaeobiogeographic affinities of the Australian dinosaur assemblage to militate against neoceratopsians having been present on that continent during the Early Cretaceous, for there was apparently a connection of some sort at that time between there and Asia.

ACKNOWLEDGEMENTS

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LIMERICK

A limerick provided by Sir Arthur C Clarke on the occasion of the naming of his dinosaur.

There once was an *Artclarkasaurus,*
That lived when the earth was all porous,
But it fainted with shame,
When it heard of its name,
And departed long ages before us.

NOTE

1. Sereno (2000) recognises two families within the Neoceratopsia: Protoceratopsidae and Ceratopsidae. Species are allocated to those two families on the basis of shared derived characters. Not all the species within the Neoceratopsia can be allocated to one of these two families. Those species outside the two families but within the Neoceratopsia lack shared derived characters of either family. All of these unallocated species have been regarded as protoceratopsians at one time or another; e.g. Dong & Azuma (1997). For the purposes of this paper, the term 'protoceratopsian' is used here to refer to non-ceratopsid Neoceratopsia and 'protoceratopsid', to the Protoceratopsidae *sensu* Sereno (2000).

Table of Measurements (in mm)

	NMV P 186385	NMV P 186399	NMC 8889 (cast)
a. Maximum length	----	118	196.3
b. Distance from the anterodistal corner of the bone to the anterodistal corner of the semilunar notch	139.9	>96	149.9
c. Distance from the posterior edge of the bone to most anterior point on the coronoid process	60.5	>28	53.9
d. Minimum anteroposterior depth of the ulna shaft distal to the coronoid process	25.2	14.2	27.2
e. Maximum anteroposterior depth of the ulna shaft at the distal end of the bone	36.5	>21	35.6

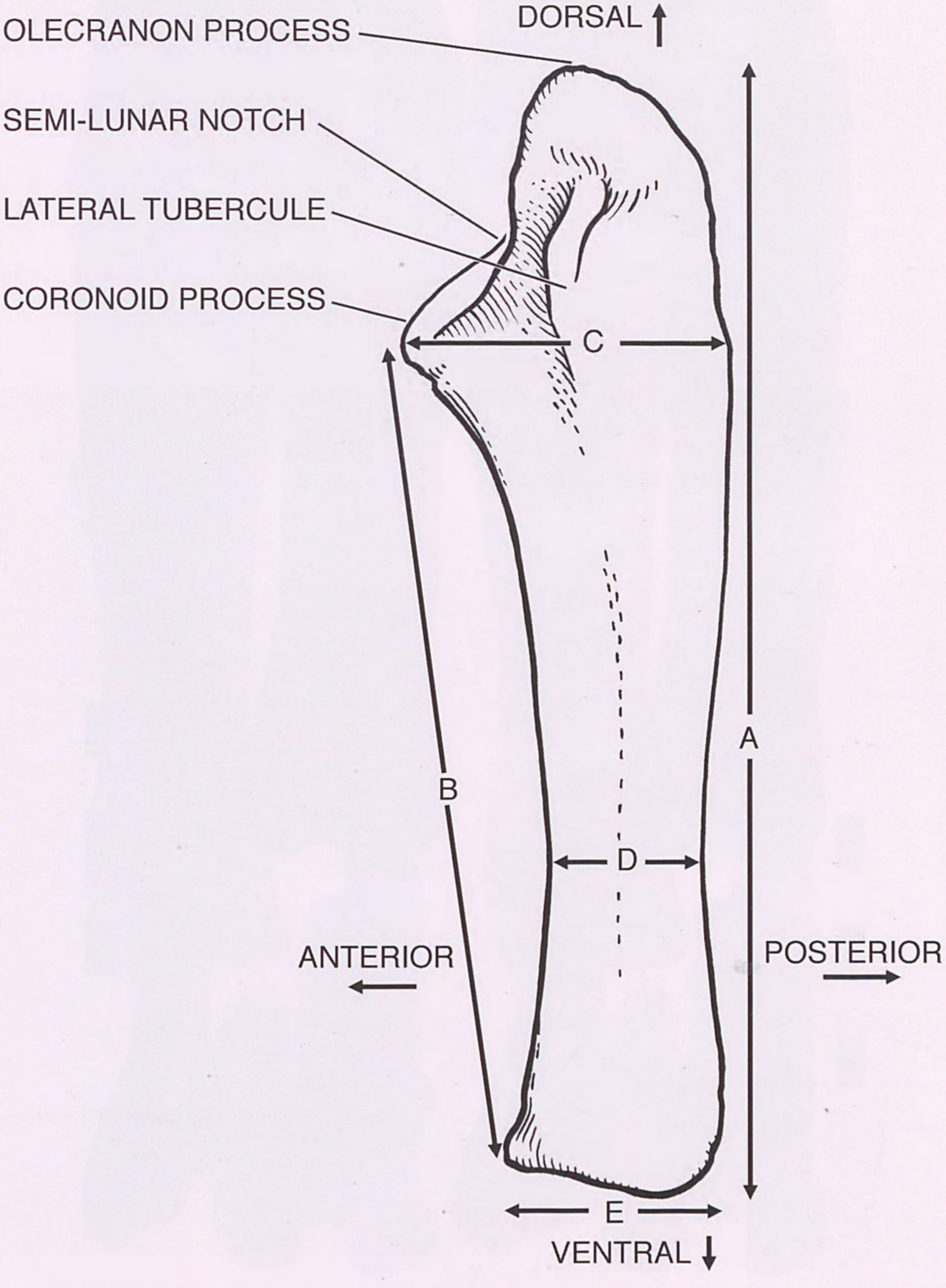

Figure 1. Ulna of *Leptoceratops gracilis,* NMC 8889. Lines associated with letters indicate how measurements were taken in the Table of Measurements. Diagram by Peter Trusler.

Figure 2. Left ulna of the holotype of *Serendipaceratops arthurcclarkei*, NMV P186385, from the Wonthaggi Formation of the Strzelecki Group of Aptian (late Early Cretaceous) age, 'The Arch', Victoria, Australia (38° 32' 54" S, 145° 27' 29" E, [Universal Transverse Mercator 55]). (A-A') Medial view, dorsal at the top. (B-B') Posterior view, dorsal at the top. (C-C') Dorsal view, anterior at the top. Photographs by Steven Morton.

Figure 3. Left ulna of *Leptoceratops gracilis,* NMC 8889, from the Scollard Formation, late Maastrichtian (latest Late Cretaceous), Alberta, Canada. (A-A') Medial view, dorsal at the top. (B-B') Posterior view, dorsal at the top. (C-C') Dorsal view, anterior at the top. Photographs by Steven Morton.

Figure 4. Left ulna of the holotype of *Serendipaceratops arthurcclarkei*, NMV P186385), from the Wonthaggi Formation of the Strzelecki Group of Aptian (late Early Cretaceous) age, 'The Arch', Victoria, Australia (38° 32' 54" S, 145° 27' 29" E, [Universal Transverse Mercator 55]). Lateral view, dorsal at the top. (B-B') Anterior view, dorsal at the top. (C-C') Ventral view, anterior at the top. Photographs by Steven Morton.

Figure 5. Left ulna of *Leptoceratops gracilis,* NMC 8889, from the Scollard Formation, late Maastrichtian (latest Late Cretaceous), Alberta, Canada. (A-A') Lateral view, dorsal at the top. (B-B') Anterior view, dorsal at the top. (C-C') Ventral view, anterior at the top. Photographs by Steven Morton.

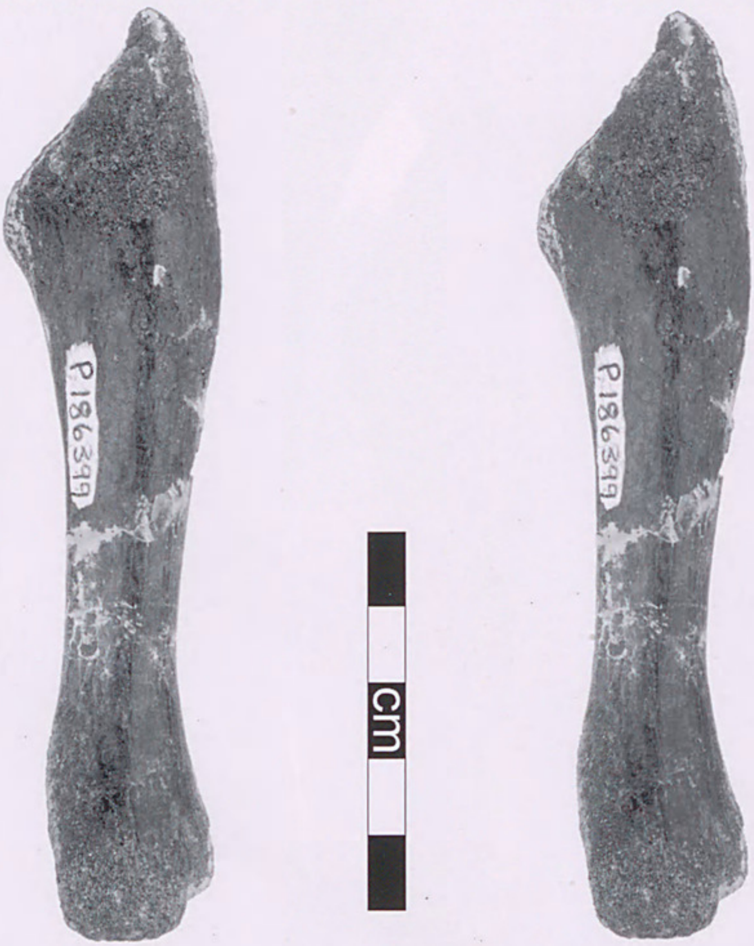

Figure 6. Lateral view, dorsal at the top, of left ulna of protoceratopsian, genus and species indet., NMV P186399, from the Eumeralla Formation, Otway Group of late Aptian-early Albian (late Early Cretaceous) age, Dinosaur Cove East, Dinosaur Cove, Victoria, Australia (38° 46' 53±1" S, 143° 24' 14±1" E). Photographs by Steven Morton.

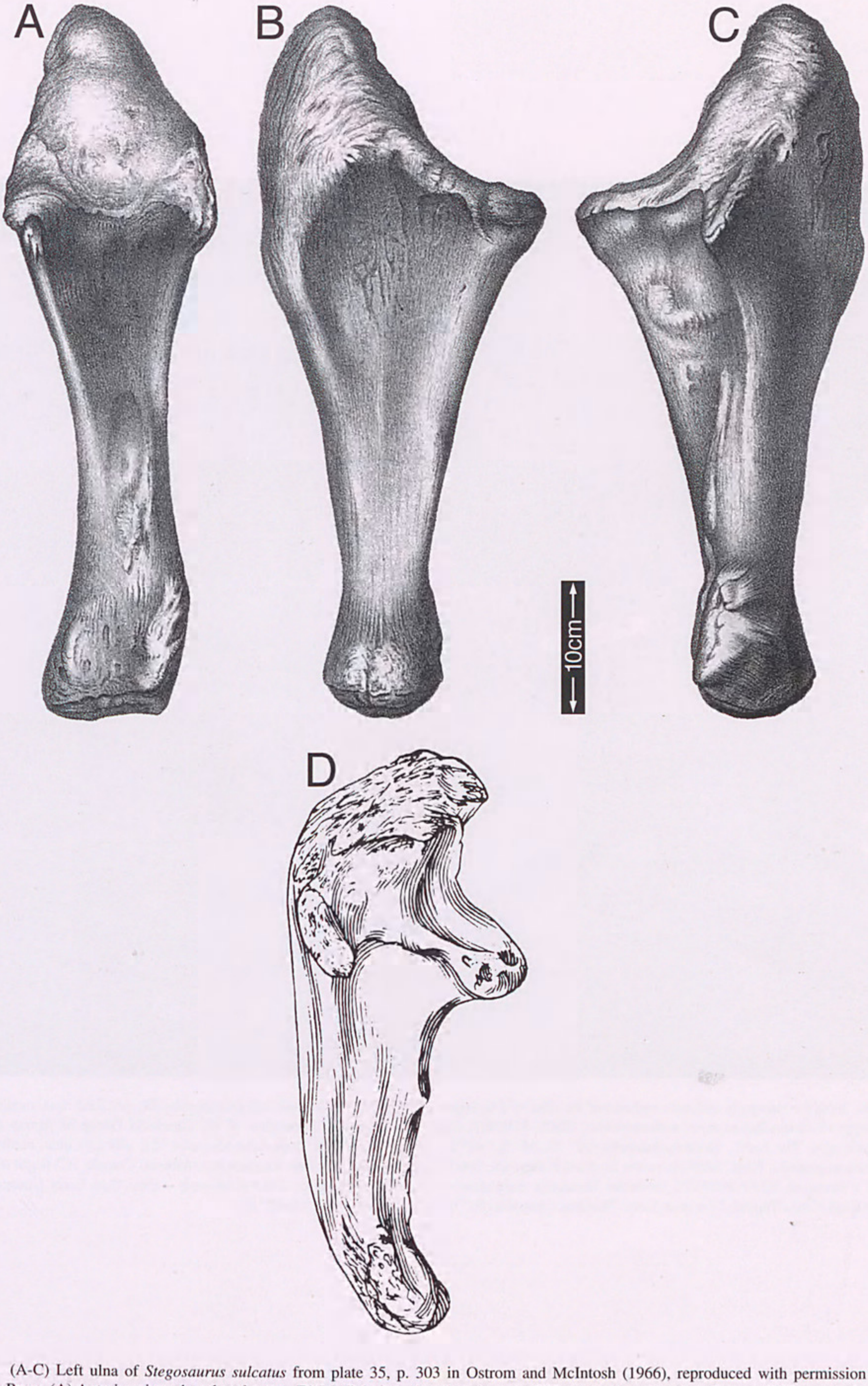

Figure 7. (A-C) Left ulna of *Stegosaurus sulcatus* from plate 35, p. 303 in Ostrom and McIntosh (1966), reproduced with permission of Yale University Press. (A) Anterior view, dorsal at the top. (B) Medial view, dorsal at the top. (C) Lateral view, dorsal at the top. (D) Lateral view, dorsal at the top, of right ulna of *Sauropelta edwardsi* from Figure 22.10 F in Coombs and Maryańska (1990), reproduced with permission of University of California Press.

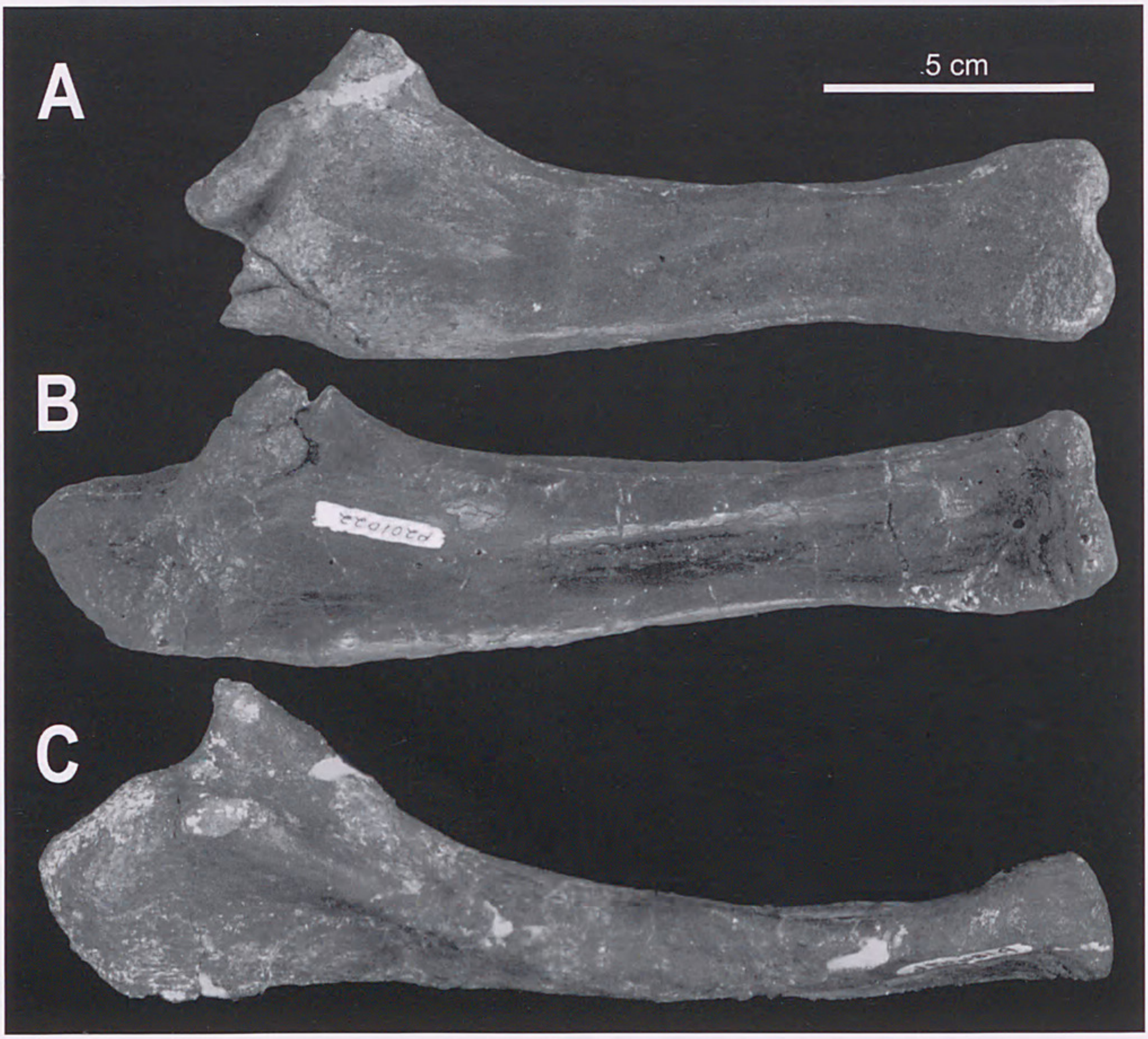

Figure 8. Note the strikingly different outlines of the ulna of a theropod (C) and an unquestioned neoceratopsian (B). (A) Left ulna, medial view, of the holotype of *Serendipaceratops arthurcclarkei*, NMV P186385, from the Wonthaggi Formation of the Strzelecki Group of Aptian (late Early Cretaceous) age, 'The Arch', Victoria, Australia (38° 32' 54" S, 145° 27' 29" E, [Universal Transverse Mercator 55]). (B) Left ulna, medial view, of *Leptoceratops gracilis*, NMC 8889, from the Scollard Formation, late Maastrichtian (latest Late Cretaceous), Alberta, Canada. (C) Right ulna, lateral view, of a theropod, NMV P186076, from the Eumeralla Formation of the Otway Group of late Aptian-early Albian (late Early Cretaceous) age, Slippery Rock Cross Tunnel, Dinosaur Cove, Victoria, Australia (36° 46' 53±1" S, 143° 24' 15±02" E).