

A NEW ANKYLOSAURID FROM THE UPPER CRETACEOUS KIRTLAND FORMATION, SAN JUAN BASIN, WITH COMMENTS ON THE DIVERSITY OF ANKYLOSAURIDS IN NEW MEXICO

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Abstract—A new, small ankylosaurid, *Ahshislepelta minor*, from the upper Campanian Kirtland Formation (Hunter Wash Member), San Juan Basin, New Mexico, consists of shoulder girdle and forelimb elements, vertebral fragments, and numerous osteoderms. *Ahshislepelta minor* differs from other ankylosaurids on the basis of a prominent dorsolateral overhang of the acromion and its osteoderm texture. It ranks as one of the most complete ankylosaur specimens known from New Mexico and adds to our understanding of ankylosaurid paleobiogeography, stratigraphy, and taxonomy.

INTRODUCTION

For over a century, the Upper Cretaceous terrestrial deposits of the San Juan Basin, New Mexico, have produced significant specimens of extinct vertebrates. Several type specimens of dinosaurs, representing tyrannosaurids, ornithomimids, dromaeosaurids, hadrosaurids, ankylosaurs (nodosaurids and ankylosaurids), pachycephalosaurids, and ceratopsids, have been discovered and named (Sullivan and Lucas, 2006). Among the most significant taxa are the iconic lambeosaurines *Parasaurolophus tubicen* Wiman, 1931 and *Parasaurolophus cyrtocristatus* Ostrom, 1961; the chasmosaurine *Pentaceratops sternbergi* Osborn, 1923; the titanosaurid *Alamosaurus sanjuanensis* Gilmore, 1922, the only sauropod from the Late Cretaceous of North America; and the unique, and rare, ankylosaurid *Nodocephalosaurus kirtlandensis* Sullivan, 1999.

Ankylosaur (Nodosauridae and Ankylosauridae) remains consist mostly of isolated osteoderms, vertebrae and some incomplete appendicular elements, and have been known for years from the Fruitland and Kirtland formations. Only in recent years has more diagnostic material been discovered and identified. A partial left scapula (USNM 8571) and several osteoderms (USNM 8610, 8611) were referred to “Scelidosauridae” by Gilmore (1919); the scapula was later identified as *Panoplosaurus* (Lehman, 1981). Ford (2000) named *Glyptodontopelta*, based on USNM 8610 and placed it in the new subfamily “Stegopeltinae” with *Aletopelta* and *Stegopelta*. Burns (2008), in a preliminary review of ankylosaur osteoderms, upheld the validity of *Glyptodontopelta*. He placed it in the Nodosauridae, thus making the “Stegopeltinae” equivocal due to the uncertain affinities of *Aletopelta* (Ford and Kirkland, 2001). *Edmontonia australis* Ford, 2000 was also synonymized with *Glyptodontopelta* (Burns, 2008).

Although the taxon *Euoplocephalus* (including cf. *Euoplocephalus*) is known from the Oldman, Dinosaur Park and Horseshoe Canyon formations of Alberta as well as from the Two Medicine Formation of Montana, its occurrence in the San Juan Basin has never been convincingly demonstrated (Sullivan and Lucas, 2006). *Nodocephalosaurus kirtlandensis* is known solely from the Kirtland Formation (De-na-zin Member) based on a partial skull and isolated postcranial osteoderms that were subsequently referred to it (Sullivan, 1999; Sullivan and Fowler, 2006).

The holotype (SMP VP-1930), and only known specimen, was found in the lower part of the Kirtland Formation (Hunter Wash Member) in the Ah-shi-sle-pah Wilderness Study Area along the south side of Ah-shi-sle-pah Wash (Fig. 1). The holotype specimen was discovered in

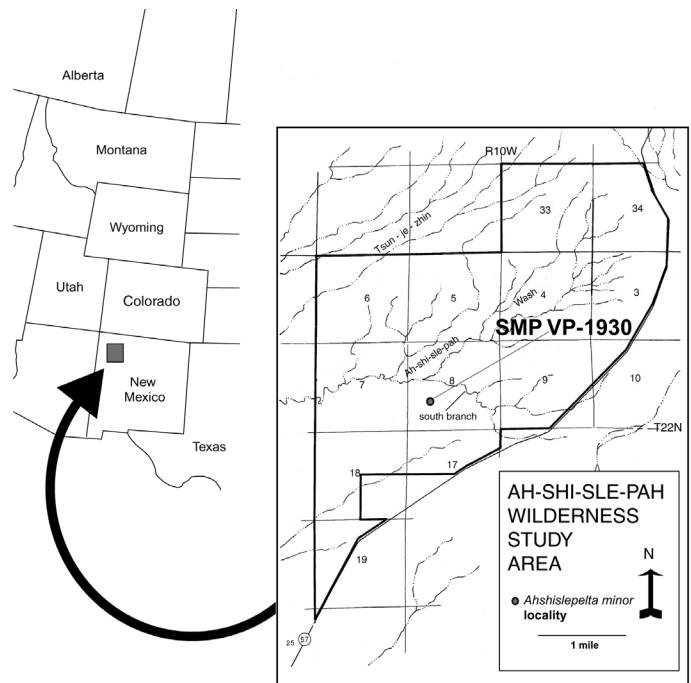


FIGURE 1. Map of Ah-shi-sle-pah WSA, showing the locality where *Ahshislepelta minor* was collected.

2005 and collected over consecutive field seasons (2005–2009). This new specimen, while incomplete, provides additional information regarding the diversity and distribution of ankylosaurids during the Late Cretaceous in New Mexico.

Institutional Abbreviations—AMNH = American Museum of Natural History, New York, New York; BMNH = British Museum of Natural History, London, England; CMN = Canadian Museum of Nature, Ottawa, Ontario; ROM = Royal Ontario Museum, Toronto, Ontario; SMP = State Museum of Pennsylvania, Harrisburg, Pennsylvania; TMP = Royal Tyrrell Museum of Palaeontology, Drumheller, Alberta; UALVP = University of Alberta Laboratory for Vertebrate Paleontology, Edmonton, Alberta; USNM = National Museum of Natural History, Smithsonian Institution, Washington, D.C.; and ZPAL = Institute of Paleobiology (Zakład Paleobiologii) of the Polish Academy of Sciences, Warsaw.

SYSTEMATIC PALEONTOLOGY

DINOSAURIA Owen, 1842
 ORNITHISCHIA Seeley, 1888
 ANKYLOSAURIA Osborn, 1923
 ANKYLOSAURIDAE Brown, 1908
 ANKYLOSAURINAE Brown, 1908
Ahshislepelta, n. gen.

Type species - *Ahshislepelta minor*, type and only species.

Distribution - Late Cretaceous (late Campanian), New Mexico.

Etymology - The generic name is derived from the locality of the holotype, Ah-shi-sle-pah Wash (formerly Meyers Creek), San Juan Basin, New Mexico.

Diagnosis - As for species.

Ahshislepelta minor, n. sp.

Figs. 2-8

Holotype - SMP VP-1930, closely associated incomplete postcranial skeleton including partial left girdle and forelimb (scapulocoracoid, humerus, and proximal portion of the radius), right partial scapulocoracoid, numerous vertebral fragments (likely cervical and/or

dorsal), complete and fragmentary thoracic osteoderms, and other unidentifiable postcranial fragments.

Type Locality - SW ¼ of Sec. 8, T22N, R10W (precise UTM coordinates on file at the SMP and are available to professional researchers), Ah-shi-sle-pah Wash, San Juan County, New Mexico.

Horizon/Stratum, Provenance and Age - Kirtland Formation (Hunter Wash Member), San Juan Basin, New Mexico; Late Campanian, Late Cretaceous.

Etymology - The species name “minor” is in reference to its small adult size relative to other North American ankylosaurids of similar age.

Diagnosis - Apomorphies of taxon: dorsolateral overhang of scapular acromion process to 25% of the dorsoventral width of the scapula. Differs from other ankylosaurids (with the exception of *Euoplocephalus sensu stricto*) in its superficial osteodermal surface texture, characterized by uniformly distributed pitted rugosity, and sparse distribution of reticular neurovascular grooves with neurovascular foramina extending perpendicularly to obliquely into the bone.

DESCRIPTION

The holotype specimen of *Ahshislepelta minor*, SMP VP-1930 (Figs. 2–8), consists of associated anterior postcranial elements and osteoderms. The left forelimb is more than 50% complete, preserving the

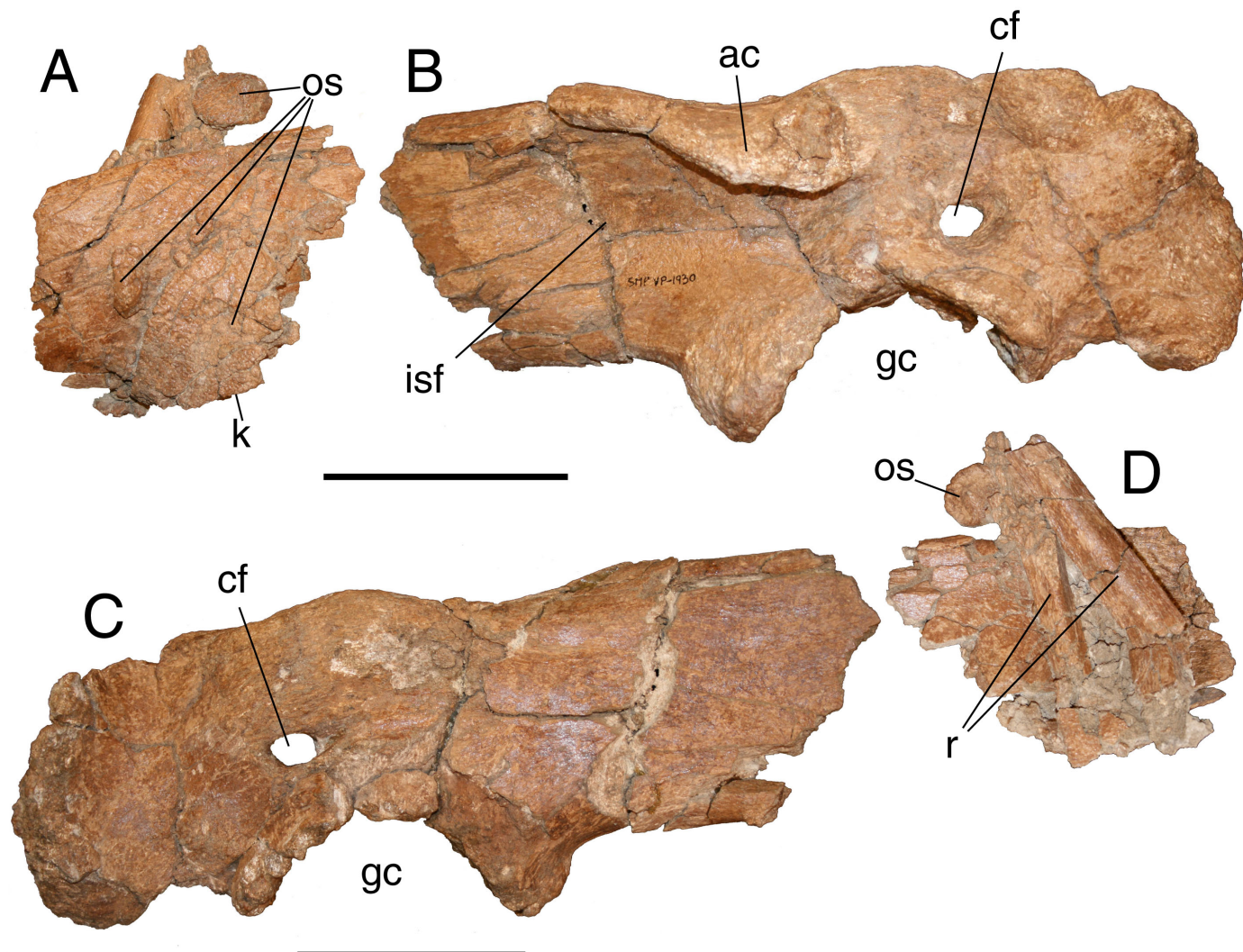


FIGURE 2. *Ahshislepelta minor*, n. gen., n. sp. (SMP VP-1930, holotype). Right scapulocoracoid: **A**, distal and **B**, proximal sections in lateral view; **C**, proximal and **D**, distal sections in medial view. Dorsal is up. Abbreviations: **ac**, acromion; **cf**, coracoid foramen; **gc**, glenoid cavity; **isf**, infraspinous fossa; **k**, keel (on osteoderm); **os**, osteoderm; **r**, rib. Scale bar = 10 cm.

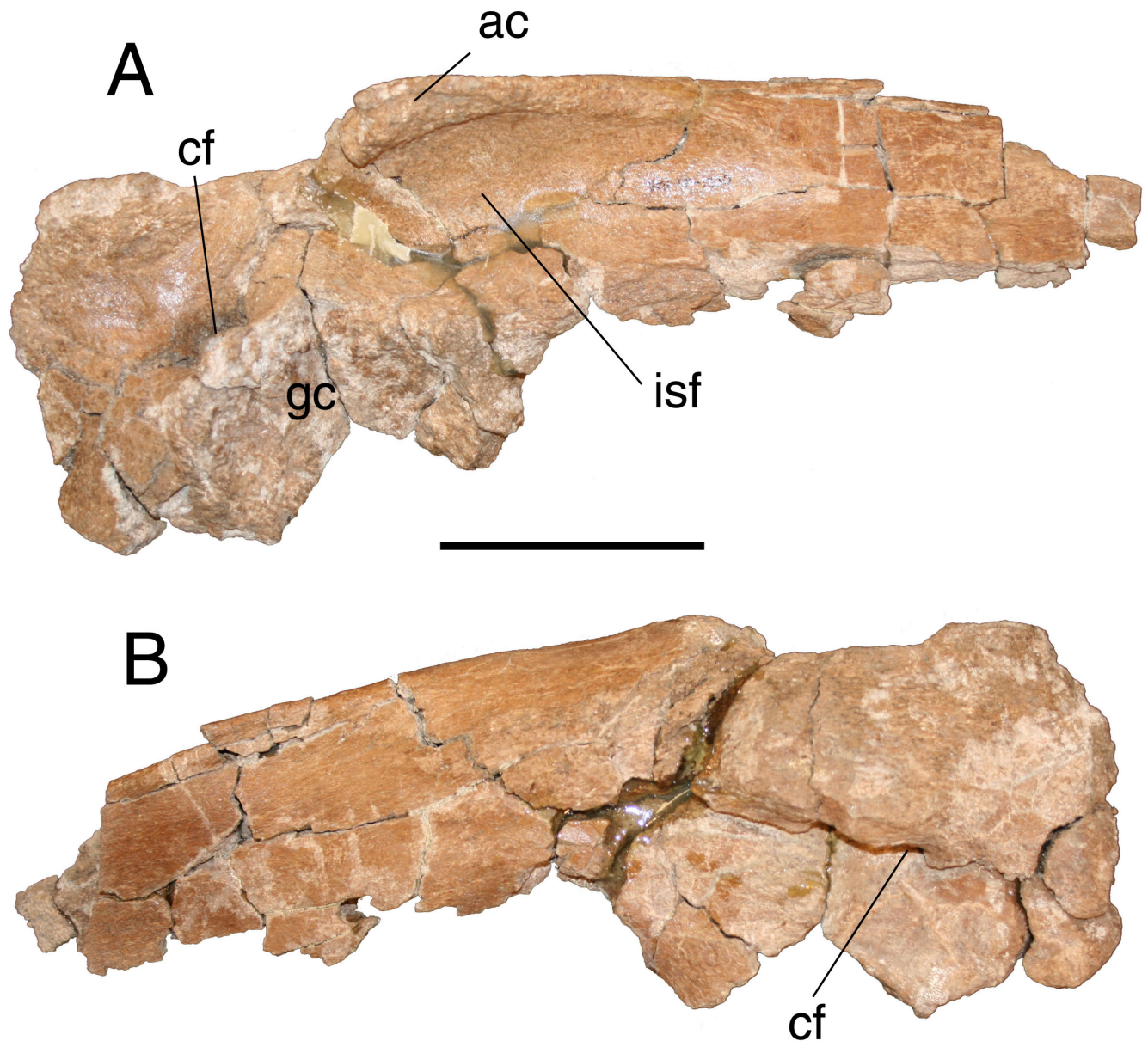


FIGURE 3. *Ahshislepelta minor*, n. gen., n. sp. (SMP VP-1930, holotype). Incomplete left scapulocoracoid. **A**, lateral and **B**, medial views. Due to taphonomic shearing, the articular surface of the glenoid cavity is visible in **A**. The coracoid foramen is not visible due to its oblique anteroposterior orientation. Dorsal is up. Abbreviations same as in Fig. 2. Scale bar = 10 cm.

partial scapulocoracoid, humerus, and proximal portion of the radius. The right forelimb consists only of a partial scapulocoracoid. In addition, there are numerous vertebral fragments (likely cervical and/or dorsal), complete and fragmentary thoracic osteoderms, and other unidentifiable postcranial fragments.

Scapulocoracoid - The right scapulocoracoid (Fig. 2) is well preserved along the anterior margin of the coracoid to a point just posterior to the acromion, where it is broken. The most distal portion (Fig. 2A, D) of the scapula has three osteoderms on the lateral side and is associated with fragments of two ribs (mostly visible on the medial side). The left scapulocoracoid (Fig. 3) is preserved approximately as far posteriorly as the right scapulocoracoid; however, the ventral margin of the scapula is missing and the entire element has been distorted (postmortem) by shear. The following composite description is based on both right and left scapulocoracoids.

The coracoid is fused completely with the scapula, leaving no indication of a sutural contact between them. It has a blunt, rugose process along the anterodorsal margin for the attachment of the *M. biceps brachii* and/or *M. coracobrachialis*. Roughly square, the coracoid is 14 cm dorsoventrally and 16 cm anteroposteriorly. The coracoid foramen (= coracoid fenestra) is anterodorsal to the glenoid cavity, anteroposteriorly elongate, and 2 cm² in area.

The glenoid cavity is open, extends 11 cm anteroposteriorly, and forms an arc such that the scapular margin projects posteroventrally at an 80° angle relative to the coracoid margin. The scapula is not dorsoventrally narrow relative to the coracoid and does not exhibit a prominent scapular neck (as in nodosaurids).

The acromion is a rugose, ridge-like structure along the dorsal margin of the scapula opposite the glenoid cavity. The acromion attains its anteriormost extension posteroventral to the most anterior extent of

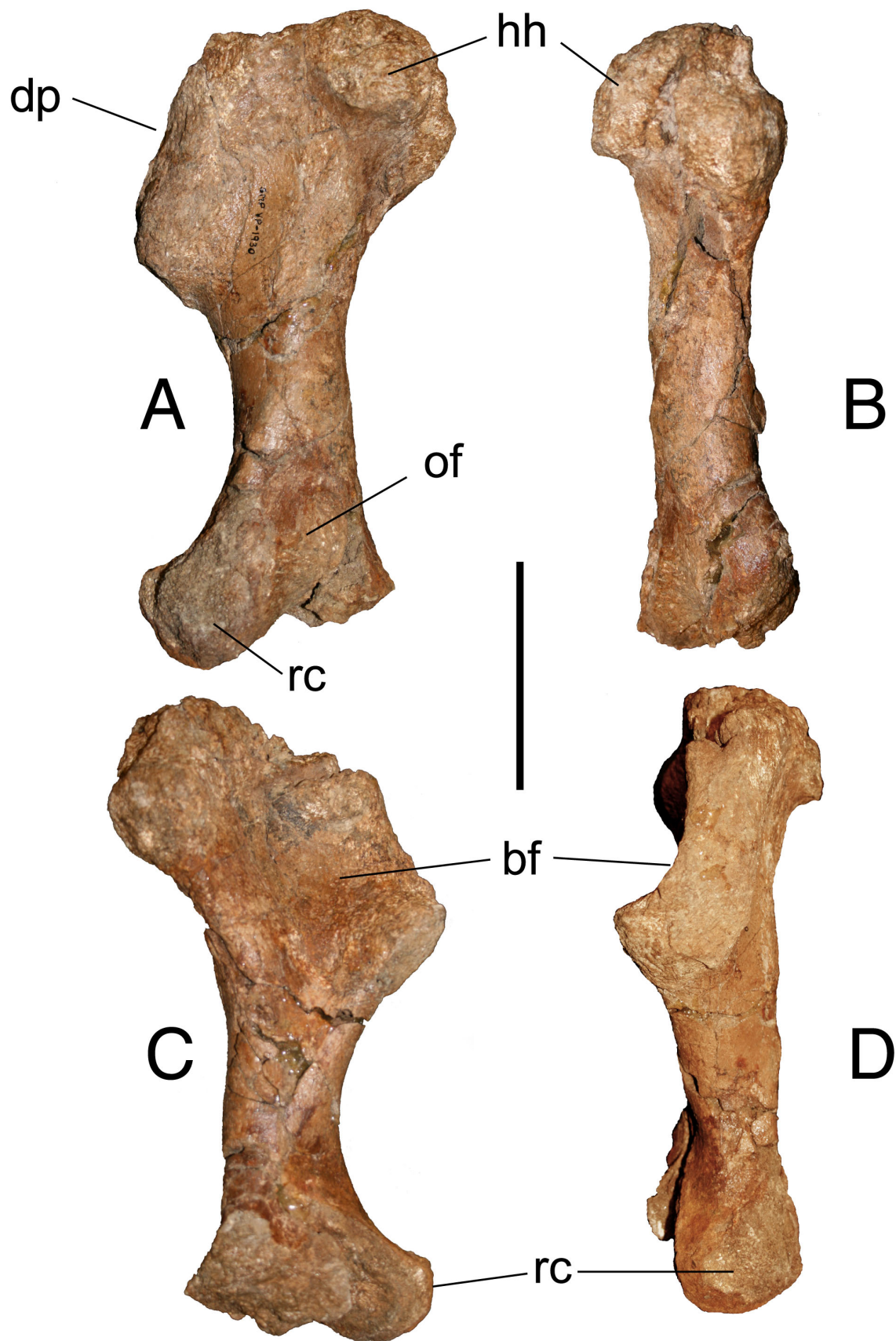


FIGURE 4. *Ahshislepelta minor*, n. gen., n. sp. (SMP VP-1930, holotype). Left humerus. **A**, posterior; **B**, lateral; **C**, anterior; and **D**, medial views. Proximal end is up. Abbreviations: **bf**, bicipital fossa; **dp**, deltopectoral crest; **hh**, humeral head; **of**, olecranon fossa; **rc**, radial condyle. Scale bar = 10 cm.

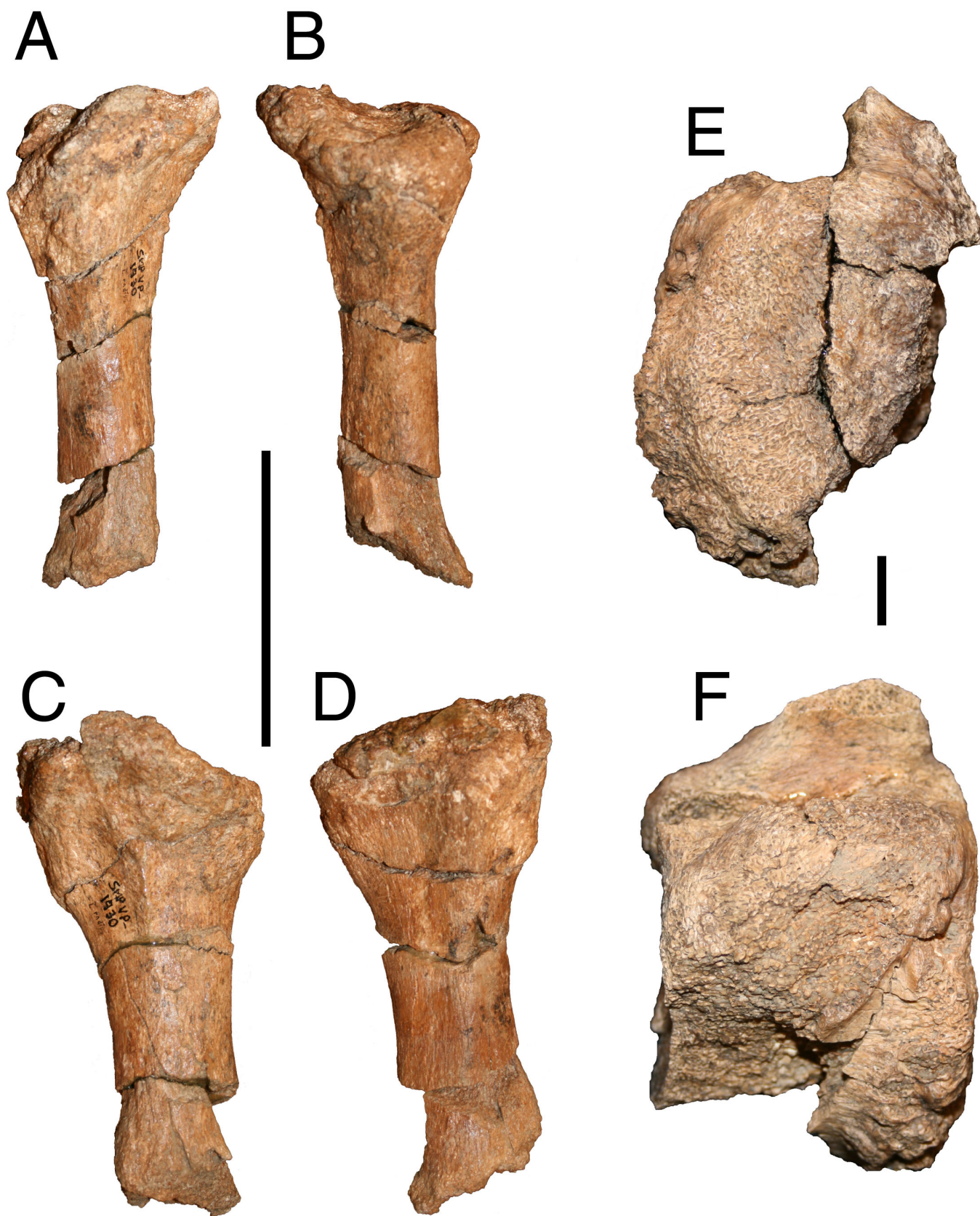


FIGURE 5. *Ahshislepelta minor*, n. gen., n. sp. (SMP VP-1930, holotype). Proximal end of left radius. **A**, anterior view; **B**, medial view; **C**, posterior view; and **D**, lateral view. Proximal is up. Vertebra. **E**, anterior axial view; **F**, left lateral view. Scale bars = 10 cm.

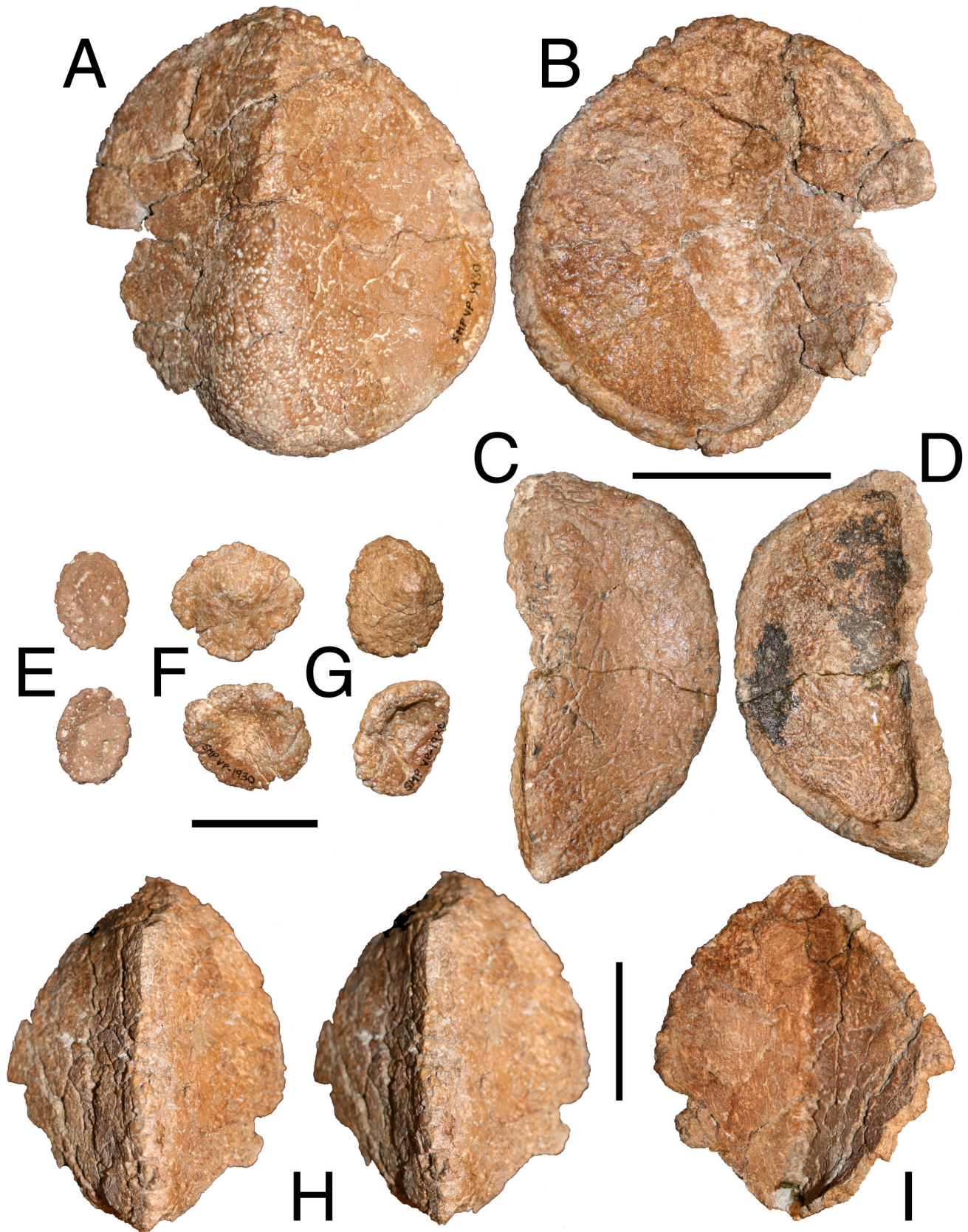


FIGURE 6. *Ahshislepelta minor*, n. gen., n. sp. (SMP VP-1930, holotype). Osteoderm morphology. Circular osteoderm with an offset apex. **A**, dorsal and **B**, ventral view. Lateral or distal keeled osteoderm. **C**, dorsal; and **D**, ventral view. Small osteoderms. **E-G**, dorsal views (top row); ventral views (bottom row). Median keeled osteoderm. **H**, dorsal (stereo) and **I**, ventral views. Anterior is up for osteoderms **A-D** and **H-I**. Scale bars = 5 cm.



FIGURE 7. Close-up of superficial osteodermal surface texture of *Ahshislepelta minor* from a median keeled osteoderm (Fig. 6H-I).

the glenoid cavity. The prominent lateral overhang of the acromion is not preserved on the left scapula due to taphonomic shearing. This feature is not a taphonomic artifact on the right scapulocoracoid. Although it is cracked, its junction with the scapular blade is visible, well-preserved, and confirms its natural ventrolateral projection. Ventral to the acromion, the borders of the infraspinous fossa are prominent, creating a 63 cm² area for the attachment of the *M. infraspinus*. The acromion attenuates along the posterior edge of the infraspinous fossa.

Forelimb - The left humerus (Fig. 4A–D) is 31 cm long and massive, which is characteristic of taxa within the Ankylosauridae. The deltopectoral crest is well-developed and measures 15 cm across the widest portion of the humerus. In posterior view (Fig. 4A), the lateral margin of the deltopectoral crest forms a 23° angle with the long axis of the humerus. A broad, bicipital fossa on the anterior face of the humerus is bounded by the deltopectoral crest and humeral head. Distally, the hemispherical radial condyle is positioned on the anterior face of the humerus. The shallow olecranon fossa and trochlea are largely intact.

The proximal two thirds of the left radius (Fig. 5A–D) are preserved. The shaft and proximal articular surface are oval in proximal view. The proximal articular surface is concave. The articular surface is proportionally expanded to twice the diameter of the diaphysis (8 and 4 cm, respectively).

Vertebrae - Numerous vertebral fragments were recovered and they probably represent parts of the cervicals and/or dorsals, based on their association with elements of the pectoral girdles and forelimb. A few of the more complete vertebrae appear to have laterally compressed neural canals, suggesting that they were dorsoventrally tall dorsals. There are no open sutural facets for the neural arches preserved on any of the central fragments (Fig. 5E–F).

Osteoderms - Numerous osteoderms (Fig. 6) and osteoderm fragments were recovered. Most are from the thoracic region, although some may be from the pelvic region and forelimbs. One osteoderm and several

ossicles are preserved *in situ* superficial to the distal portion of the right scapula. These, along with another series of osteoderms preserved in their original association, display a rosette arrangement of small, interstitial ossicles surrounding the main body osteoderms. The largest osteoderm (Fig. 6H–I), inferred to be a median element from just posterior to the cervical region (due to its similar shape to median thoracic osteoderms of BMNH R5161), is 15 cm long, 12 cm wide and 10 cm high. The smallest complete ossicle has a minimum diameter of 1 cm. The osteoderms are either keeled or circular with off-center apices. Their superficial surface textures (Fig. 7) are smooth to uniformly pitted with a sparse reticular patterns of neurovascular grooves. Their deep surfaces are excavated such that overall osteoderm thicknesses are relatively low.

A petrographic section (Fig. 8) through one osteoderm shows that, histologically, the osteoderm is typical of the ankylosaurid condition (Scheyer and Sander, 2004; Burns, 2008; Hayashi et al., 2010). Distinct superficial and deep fibrolamellar cortices encircle a compact core characterized by randomly-oriented Haversian canals. This osteoderm is relatively thin (7.1 mm), and the superficial cortex is thinner (0.57 mm) than the deep cortex (1.6 mm).

DISCUSSION

A plot of relative skeletal element dimensions (Table 1; Fig. 9) provides a useful way for assessing the validity of possible taxonomic characters. *Ahshislepelta minor* consistently falls below the line of best fit for humeral widths versus length (Fig. 9A). The angle of the deltopectoral crest in *Ahshislepelta* (Fig. 9B) also falls within this range of variation, as does glenoid length (Fig. 9C). Quantification of lateral acromion overhang (Fig. 9D) confirms that this character is distinct among the taxa sampled within a 5% error interval (although the significance cannot be evaluated due to the small number of available specimens). Acromion overhang was measured as a percentage of dorsoventral scapular height (at the posteroventral terminus of the glenoid cavity). Most of the taxa evaluated with respect to acromial overhang (including *Ankylosaurus*, *Euoplocephalus*, *Pinacosaurus* (juvenile and adult), and *Saichania*) fall within the range of 8–21% (error included). *Ahshislepelta* has a more prominent acromion overhang of 25%.

Due to the fragmentary nature of the vertebrae in SMP VP-1930, neurocentral sutural fusion cannot be assessed for several elements. However, one partial vertebra demonstrates that the absence of a neural spine was due to taphonomic breakage rather than to lack of fusion. In addition, the complete fusion of the scapulacoracoids (and complete resorption of the scapulocoracoid sutures) indicates that the specimen is not a juvenile; rather, it is, at the very least, a subadult and may be fully mature adult. Evidence from small individuals, such as juvenile specimens of *Pinacosaurus grangeri* and a nodosaurid hatchling from the Paw Paw Formation of Texas (Jacobs et al., 1994), shows that these elements were not fused in the early stages of ontogeny. This new specimen falls within the same size range as adult specimens of other ankylosaurid taxa outside of North America based on measurements of the humerus and scapulacoracoids (Fig. 9). The scapulocoracoid of *Ahshislepelta* is larger than that of *Talarurus*; however, based on humeral size (geometric mean) alone, *Ahshislepelta* is smaller than *Talarurus* and *Pinacosaurus grangeri* (adult) but larger than *Pinacosaurus mephistocephalus* and juvenile specimens of *P. grangeri*.

Ahshislepelta occurs stratigraphically low compared to other known ankylosaurs from the San Juan Basin of New Mexico. Regardless of its stratigraphic position, it can be distinguished from these other taxa based on osteodermal characters. The nodosaurid *Glyptodontopelta* is diagnosed by a distinct osteodermal surface texture, characterized by a relatively smooth surface, with a dense pattern of reticular neurovascular grooves, and by neurovascular foramina that are oriented obliquely to the surface (Burns, 2008). The ankylosaurid *Nodocephalosaurus* also occurs in the Kirtland Formation, but it is from the younger De-na-zin Member. Each of its osteoderms is characterized by a uniformly distrib-

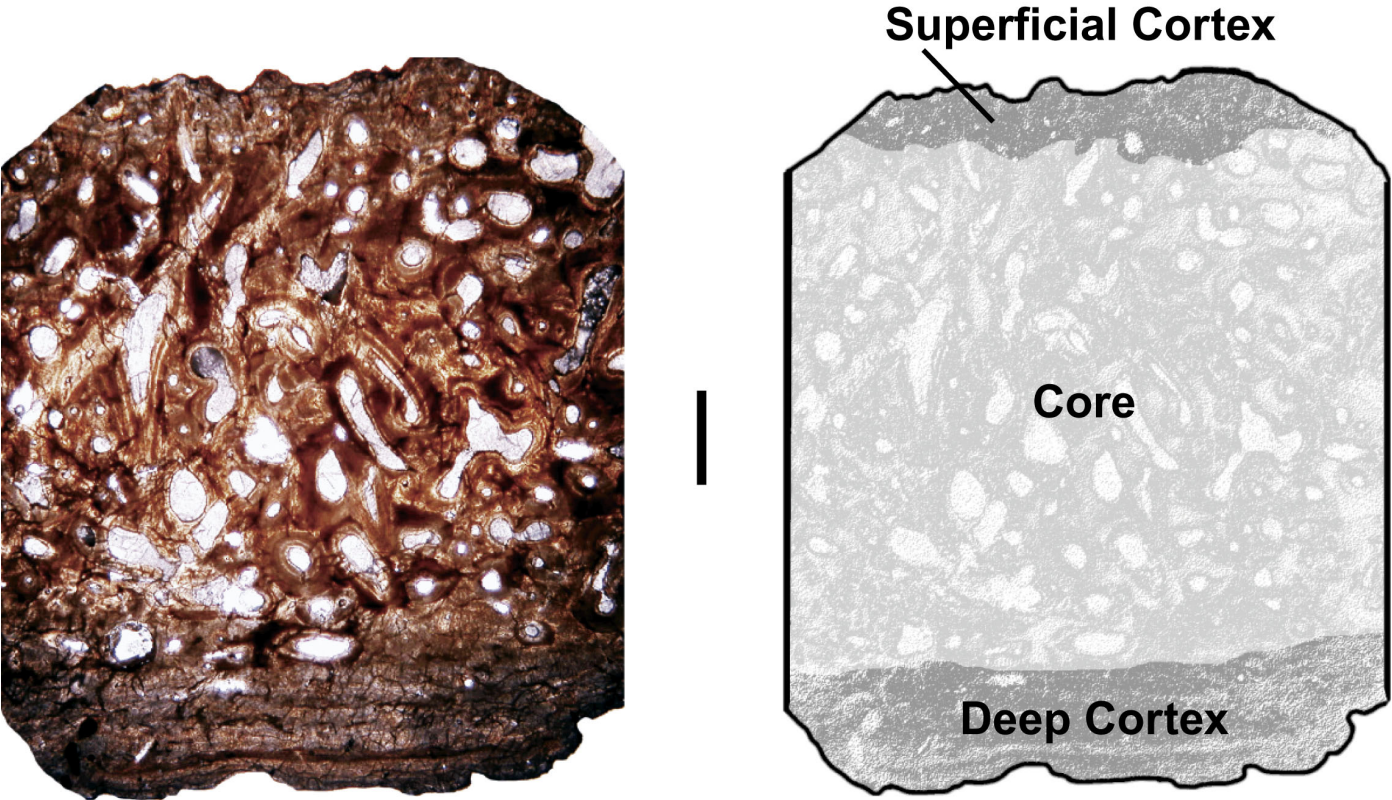


FIGURE 8. Transverse histological thin section through an osteoderm of *Ahshislepelta* and schematic sketch showing three distinct layers. Scale bar = 1 mm.

TABLE 1. Comparative postcranial measurements for Late Cretaceous ankylosaurids from North America and Asia. **Abbreviations:** AC, amount of lateral overhang of acromion measured as a percentage of dorsoventral scapular height at the posterior terminus of the glenoid cavity; **angDP**, angle of deltopectoral crest to the horizontal; **angGC**, angle formed by scapular and coracoid margins of the glenoid cavity; **distW**, mediolateral width of distal humeral epiphysis; **dorsW**, width across distal terminus of scapula; **LGC**, maximum anteroposterior length of glenoid cavity; **maxL**, maximum dorsoventral length; **midW**, midshaft width; **proxW**, mediolateral width of proximal epiphysis; **SC**, scapulocoracoid. All measurements in cm. Non-original measurements are from Maleev (1954), Coombs (1971), Maryańska (1977), Godefroit et al. (1999), Penkalski (2001), Carpenter (2004) and Arbour et al. (2009).

Species	Specimen #	maxL	dorsW	SC		AC	maxL	proxW	Humerus			Radius proxW
				LGC	angGC				midW	distW	angDP	
<i>A. magniventris</i>	AMNH 5214/5895	69.0	24.5	17.5	71.8	16%	53.9	29.0	10.4	26.0	89.8	-
<i>A. minor</i>	SMP VP-1930	51.5	-	11.4	65.0	25%	31.3	15.4	5.3	11.1	72.3	8.4
<i>D. actuosquameus</i>	ROM 784	-	-	-	-	-	-	-	-	-	-	8.8
<i>E. tutus</i>	AMNH 5404	67.3	20.6	16.9	-	-	39.9	22.6	8.2	19.2	87.9	-
	UALVP 31	-	18.2	-	-	-	-	-	-	-	-	-
	AMNH 5406	-	19.3	-	-	-	36.1	20.7	6.9	15.7	-	-
	AMNH 5424	-	-	-	51.1	18%	-	-	-	-	-	-
<i>P. grangeri</i>	ZPAL MgD-II/1	30.0	-	-	-	13%	16.0	7.5	3.1	6.5	64.9	3.9
	PIN 614	60.0	-	10.4	71.8	10%	30.0	13.6	5.4	13.3	85.5	3.2
	PIN 3144	-	-	-	-	-	14.3	6.3	2.6	5.1	72.1	-
<i>P. mephistocephalus</i>	IMM 96BM3/1	-	7.7	-	-	-	20.0	10.9	-	6.6	-	6.8
<i>S. chulsanensis</i>	GI SPS 100/151	58.0	15.7	-	-	13%	30.0	21.2	7.3	16.3	84.2	8.4
<i>T. plicatospineus</i>	PIN 557	60.0	15.0	10.5	-	-	30.0	13.5	5.3	13.7	-	7.7

uted, projecting rugosity, sparse distribution of reticular neurovascular grooves, and neurovascular foramina that extend normally to obliquely into the osteoderm. An osteoderm of *Ahshislepelta* is similar to that of *Nodocephalosaurus*, but has a pitted rugosity profile rather than the prominent, projecting rugosity. The superficial surface texture of *Ahshislepelta* is most similar to the smoother texture type of *Euoplocephalus* (*sensu* Arbour et al., 2009). Specimens AMNH 5406 and UALVP 31 possess this type of osteoderm textures and are unequivocally referable to *Euoplocephalus*. It is interesting to note the morphological similarities between *Ahshislepelta* and *Nodocephalosaurus*,

given the latter occurs higher in the section in the De-na-zin Member of the Kirtland Formation, a difference of about 1.5 Ma based on dating of the strata by Fassett and Steiner (1997). Despite similarities in osteoderm texture, there is a significant size difference between *Euoplocephalus* (AMNH 5406 and UALVP 31) and the smaller *Ahshislepelta*. The only juvenile specimen referred to *Euoplocephalus* (AMNH 5266) preserves only elements of the hind limbs and vertebrae (Coombs, 1986). The most posterior dorsals of AMNH 5266 are less than 3 cm in diameter, whereas the dorsal centra of SMP VP-1930 are around 5 cm. If the dorsals of SMP VP-1930 are from

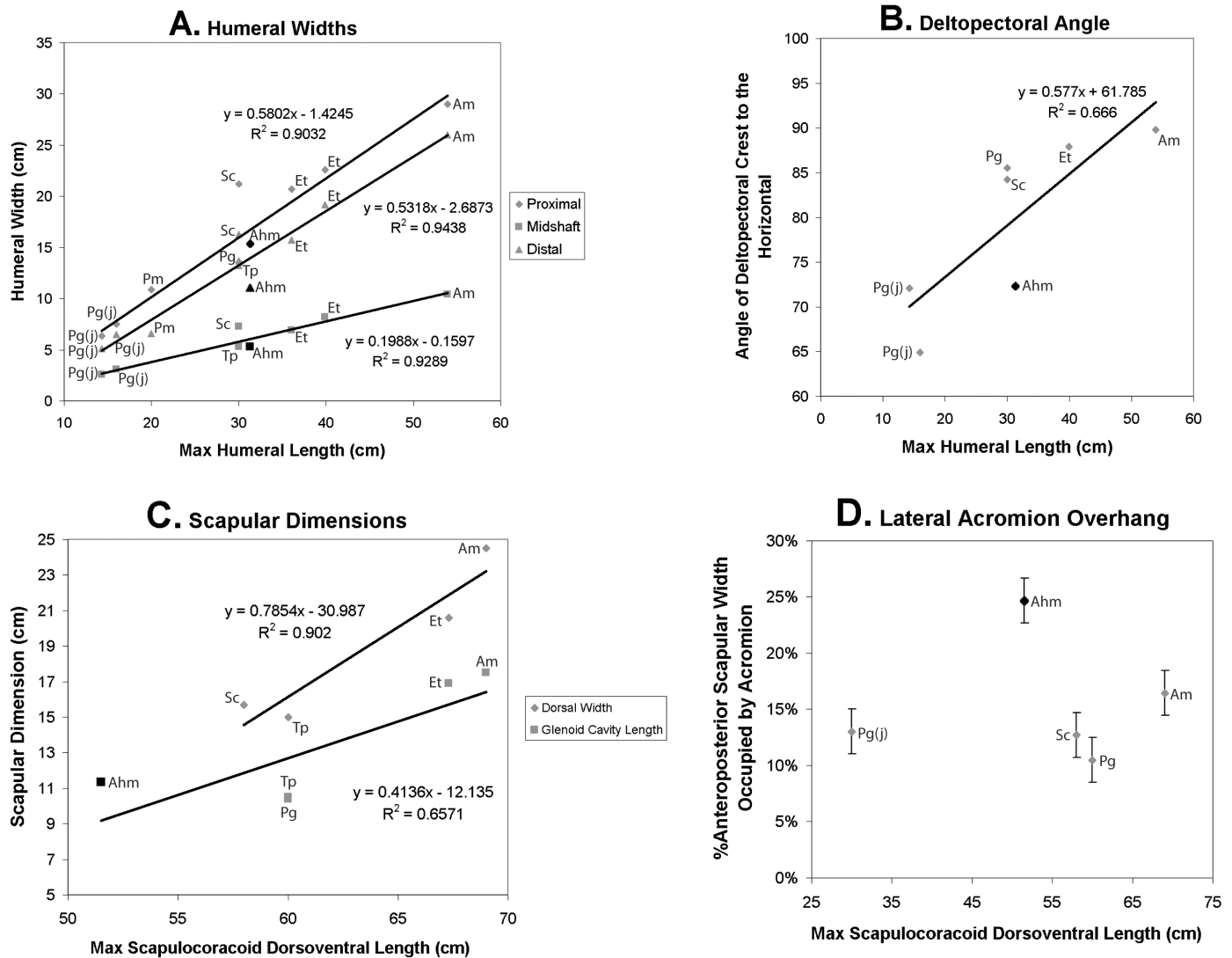


FIGURE 9. Differential forelimb and shoulder girdle measurements across derived ankylosaurids. Symbols for *Ahshislepelta* are in black. Taxonomic abbreviations are from Table 1. **A**, humeral widths versus length: values for *Ahshislepelta* consistently fall below the line of best fit. **B**, deltopectoral angle versus humeral length. **C**, dorsal scapular width (anteroposterior) and glenoid cavity length versus scapulocoracoid length (dorsoventral). **D**, lateral acromion overhang measured as a percentage of scapular width (anteroposterior) at the posterior terminus of the glenoid cavity (5% error bars are shown): *Ahshislepelta* is significantly different at 25%.

the anterior part of the dinosaur, then it is likely a bigger animal than AMNH 5266. This would also correspond to the ontogenetically delayed mineralization of osteoderms, which were not preserved in AMNH 5266. Even relatively complete juvenile ankylosaur specimens lack mature post-cervical osteoderms (Burns et al., 2011) and it is likely that the development of dermal elements was delayed with respect to the endoskeleton (Hayashi et al., 2009).

It is unlikely that SMP VP-1930 is a juvenile referable to *Euoplocephalus*, because evidence shows that it has a coossified scapulocoracoid, dorsal vertebrae, and fully mineralized osteoderms. Moreover, the histology demonstrates that the osteoderms are indeed fully developed, exhibiting mature remodelled Haversian cores characteristic of derived adult ankylosaurids (Scheyer and Sander, 2004; Burns, 2008; Hayashi et al., 2010).

CONCLUSIONS

Ahshislepelta minor (holotype SMP VP-1930) is a new genus and species of ankylosaurid that differs from the other North American Late Cretaceous ankylosaurids (*Ankylosaurus magniventris*, *Euoplocephalus tutus*, *Nodocephalosaurus kirtlandensis* and *Dyoplosaurus*

acutosquameus) based on a prominent overhang of the acromion process (~25%) and distinctive osteodermal sculpturing. It is interpreted as being a small sub-adult/adult ankylosaurid based on fusion of the scapulocoracoids, centra and neural arches of the vertebrae, and the remodelled Haversian osteoderm cores characteristic of mature individuals. The taxon is presently restricted to the lower Kirtland Formation (Hunter Wash Member), San Juan Basin, New Mexico.

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