# BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

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Volume 40, 1994

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# North America's First Pre-Cretaceous Ankylosaur (Dinosauria) from the Upper Jurassic Morrison Formation of Western Colorado

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## ABSTRACT

The first occurrence of a North American Upper Jurassic ankylosaur is described. It is herein named *Mymoorapelta maysi* n. gen. n. sp. and is represented by scattered elements thought to pertain to a single individual, including the holotype ilium, four dorsal vertebrae, seven caudal vertebrae, several ribs, ulna, metacarpal, phalanx, pedal ungual, and numerous elements of the armor from throughout the body. The *Mymoorapelta* is apparently most closely related to *Polacanthus* as it also has grooved cervical spines, asymmetric hollow-based triangular caudal plates, and a sacral shield of fused armor. The taxon differs from *Polacanthus* and all other described ankylosaurs in being less derived in many aspects of its postcranial skeleton.

## INTRODUCTION

The type and referred specimens were recovered from the Mygatt-Moore Quarry, which is located in western Colorado near the Utah-Colorado border (fig. 1A). The quarry site was discovered in March 1981 by Peter and Marilyn Mygatt and John D. and Vanetta Moore while on an excursion in the high desert of western Colorado (Mygatt 1991). They reported the presence of numerous dinosaur bones at the site to Lance Erikson, then paleontologist at the Museum of Western Colorado (MWC), and excavations under a Bureau of Land Management (BLM) permit began in 1982. Finds at that time included the remains of *Apatosaurus, Camarasaurus,* and *Allosaurus.* In 1985, a cooperative management agreement for the area was entered into by the BLM and MWC—the first agreement of its kind for the management of paleontological resources on public land. This area, referred to as the Rabbit Valley Research Natural Area, includes the Mygatt-Moore Quarry and an interpretive trail referred to as the Trail through Time (Armstrong and others 1987). Excavations at the quarry resumed in the late 1980s with crews headed by the MWC's paleontologist, Harley Armstrong, and the Dinamation International Society's (DIS) paleontologist, James Kirkland, resulting in the recognition of additional taxa, together with a better understanding of the depositional history of the quarry with further excavations ongoing.

Stratigraphically the Mygatt-Moore Quarry (fig. 1B) is located near the middle of the Brushy Basin Member of the Morrison Formation (Armstrong and McReynolds 1987, Kirkland and Armstrong 1992). The base of the quarry is defined by a 0–30 cm thick, discontinuous pebble bed of calcareous soil nodules with abundant broken and abraded dinosaur bone indicating an interval of erosion on a floodplain surface (fig. 2). Large, lenticular carbonate concretions occur intermittently along this surface. The basal unit is overlain by a 173-cm-thick mudstone unit that contains abundant disseminated plant detritus. The majority of the bones in the quarry are concentrated at the base of this mudstone unit. Bones range from highly broken and abraded to pristine from disarticulated associated skeletons. Breakage of the upper surfaces and the association of broken pieces of the same bones suggest trampling of many of the bones in place by other dinosaurs (Behrensmeyer and others 1986). These include the remains of several *Apatosaurus* represented by large and small individuals, one or more individuals of *Camarasaurus,* parts of *Barosaurus, Diplodocus, Allosaurus,* and *Ceratosaurus,* a few fragments of a small unidentified theropod, and the polacanthid nodosaur described herein. Small vertebrate remains are rare at the locality but include disarticulated semionotid fish remains and a sphenodontid jaw fragment, cf. *Opisthias.* Common theropod teeth and tooth marks on some of the bones suggest that predation and/or scavenging occurred at the site. Unusual and rare
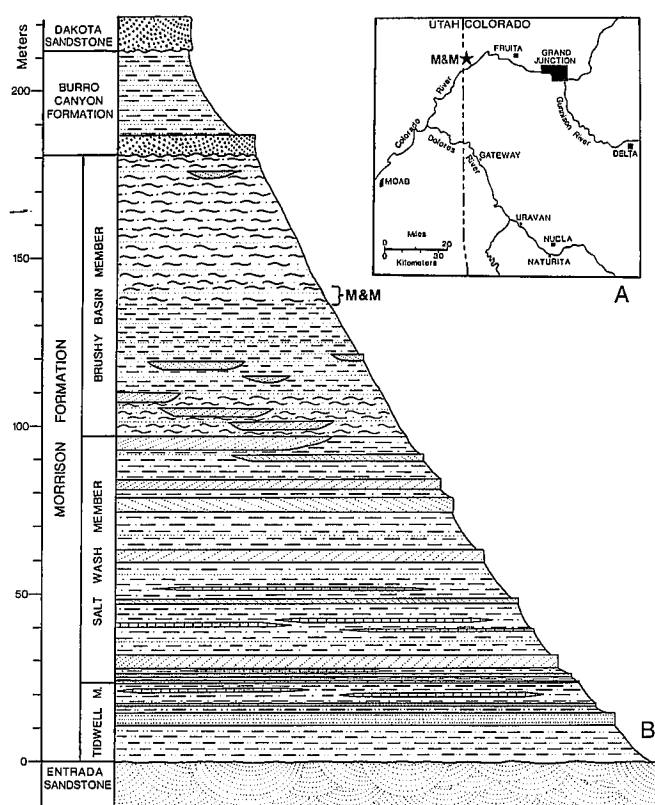
FIGURE 1.—*Locality and stratigraphy. (A) Locality of Mygatt-Moore Quarry. (B) Generalized stratigraphic section for the Grand Valley region showing the stratigraphic position of* Mymoorapelta maysi *at the Mygatt-Moore Quarry, western Colorado. M&M = Mygatt-Moore Quarry.*



FIGURE 2.—*Mygatt-Moore Quarry profile showing distribution of fossil material.*

vertebrate remains preserved in the quarry include a small fragment of dinosaur skin and a small, broken dinosaur egg. The latter is being studied by Karl Hirsch.

Plant fossils are abundant but poorly preserved. Woody materials include *Xenoxylon, Hermanophyton,* and perhaps tree fern. Carbonaceous compressional plant materials include numerous *Equisetum* rhizomes with bulbils, very rare fern frond fragments, uncommon *Brachyphyllum* leaf scales, and possibly rare cycad seeds and frond fragments. The majority of the plant detritus is composed of short, unidentifiable shreds of plant material that may represent dinosaur dung that was churned into the mud-stone by dinoturbation as first suggested by Robert Bakker (personal communication 1993). The presence of some intact dinosaur dung supports this interpretation (Karen Chin personal communication 1992). Although highly speculative, it is also possible that some of the smaller abraded bone fragments passed through the digestive track of a dinosaur prior to deposition in the mudstone.

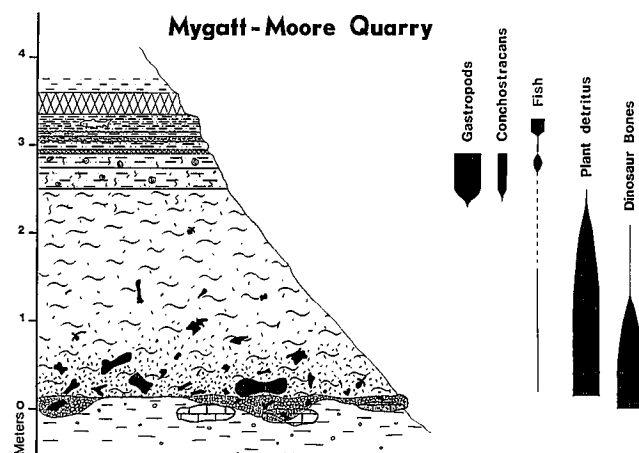The abundance of bone and plant debris decreases up section through the mudstone unit. Above the mudstone

preserving the bone, 89 cm of root-mottled, silty shale grades upward into 37 cm of rippled siltstone. The siltstone is interbedded by two thin volcanic ashes. The siltstone contains the snails *Viviparus reesidei* and *Amplovalvata scabrida* (Yen 1952), the conchostracan *Cyzicus* (*Lioestheria*) cf. *tendagurensis* (Janensch 1933, Tasch 1987), and charophytes. These strata are capped by a hard, purplish, siltstone 21 cm thick that preserves very rare articulated fish, including a paleoniscid (cf. *Coccolepis*) and unidentified semionotids. A 26-cm-thick volcanic ash caps the sequence (fig. 2). This complete sequence of strata can be traced laterally in outcrop for over 200 m, making this one of the largest individual dinosaur sites in the region.

The Mygatt-Moore Quarry is interpreted as an attritional accumulation of abundant dinosaur remains at a permanent water hole. This is based on the abundance of carbonaceous plant material together with the presence of freshwater snails (ex. Yen 1952) and fish. In a semiarid seasonal environment such as that suggested for the Morrison by Dodson and others (1980), a water-hole environment would be the site of significant biological activity. Three main causes of death are probably responsible for the dinosaur remains recorded at the site: (1) the animals were killed coming down to the water hole to drink, (2) the animals died of thirst and/or starvation at the water hole during prolonged drought, and (3) the animals became trapped in the mud along the margin of the water hole when seeking water during dry periods when the water hole was small. Many of the bones at the site have evidence of scavenging and/or subsequent trampling; thus the specific cause of death of any particular animal cannot be determined at present. The ankylosaur described herein is a good example of the taphonomy of individual

dinosaurs at the Mygatt-Moore Quarry. The bones are scattered over 20 square meters of the approximately 150 square meters of the quarry excavated to date, and range vertically through 1.5 m of mudstone. It is presumed that all the ankylosaur specimens are from one individual as there is no duplication of elements and the material is consistent in size and degree of ossification to represent one adult individual. There are extensive tooth marks present on the posterior dorsal vertebrae, the ilium, and one caudal plate. The ribs are often preserved in short isolated lengths. Although it is obvious the animal was fed upon, it can not be determined if the animal was killed by a predator or simply scavenged. A small (less than 10 cm in diameter) dinosaur egg of unique ornithischian-style microstructure (Karl Hirsch personal communication 1993) was found in association with the ankylosaur. As there is no other ornithischian dinosaur known from the quarry and, other than possibly the small theropod, none of the associated saurischian dinosaurs was small enough to have laid an egg so small, we suspect that egg may have been aborted on the death of the ankylosaur. Although speculative, if the egg belongs to the ankylosaur, it suggests that the death of the animal may have been sudden, perhaps by the animal being trapped in the mud and then killed or at least scavenged.

Jurassic ankylosaurs are rare and poorly known, being limited to the newly discovered ankylosaurid *Tianchiasaurus* from China (Dong 1993) and several very fragmentary nodosaurids from Europe (Galton 1980a–c, 1983a–b). The new Jurassic ankylosaur described herein is the first ankylosaur to be described from the Jurassic of North America. Although disarticulated, together with *Tianchiasaurus* it is one of the most complete Jurassic ankylosaurids described to date. In addition, it is the smallest adult, quadrupedal dinosaur yet identified in the Morrison Formation.

## SYSTEMATIC PALEONTOLOGY

*Repository.* All described elements are in the collections of the Museum of Western Colorado (MWC), Grand Junction, Colorado.

Suborder Ankylosauria
Family ? Nodosauridae
*Mymoorapelta* n.g.

*Diagnosis.* Centra of dorsal vertebrae cylindrical, less compressed laterally than *Sauropelta, Edmontonia, Dracopelta, Polacanthus,* and perhaps *Tianchiasaurus;* anterior dorsal vertebrae with triangular pit between prezygapophyses; transverse processes not steeply angled up as in other ankylosaurs; prezygapophyses of proximal caudal vertebrae small, anteroposteriorly elongate, widely separated, and divergent, unlike joined and parallel condition in *Polacanthus;* rib triangular in cross section, rather than T- or L-shaped as in other ankylosaurs; olecranon process broad and massive, not lateromedially compressed as in some ankylosaurs; preacetabular process of ilium curves lateroventrally and is not horizontal as in all other ankylosaurs; preacetabular process extends twice the distance below ilium as pubic peduncle; ilium preacetabular process not divergent from midline; acetabulum partially closed; as in stegosaurs the antitrochanter is absent; cervical dermal spine with groove extending from base to tip in contrast to *Polacanthus marshi,* where it extends only about three-quarters from base to tip; proximally tall triangular caudal plates with base proportionally shorter relative to height than in other taxa with spinelike caudal plates (details below).

*Etymology.* Name honors Peter and Marilyn Mygatt and John D. and Vanetta Moore, who discovered the Mygatt-Moore Quarry; *pelta*—Greek for shield. Shield of Mygatt-Moore.

### *Mymoorapelta maysi* n. sp.

*Diagnosis.* As for the genus.

*Etymology.* Species named for Chris Mays, president of Dinamation International Corporation and founder of the Dinamation International Society (a nonprofit organization to promote paleontology), who with DIS funded this research.

*Holotype.* MWC 1815, complete left ilium with numerous grooves interpreted as tooth marks over dorsal surface.

*Hypodigm.* All material from type locality associated with the holotype ilium and apparently pertaining to one individual; four dorsal vertebrae, MWC 1800–1803; seven caudal vertebrae, MWC 1804–1808, 1839a,b; several ribs, MWC 1809–1813, 1840; a right ulna, MWC 1814; a metacarpal, MWC 1816; a phalange, MWC 1817; a probable pedal ungual, MWC 939; one large triangular cervical spine, MWC 1818; six caudal dermal plates, MWC 1819–1824; one small solid, triangular dermal spine, MWC 1825; five circular to oval dorsal scutes, MWC 1826–1830; one dorsal scute wider than long, MWC 1831; two rectangular dorsal scutes, MWC 1832–1833; one massive dorsal scute, MWC 1834, three large asymmetric dorsal scutes, MWC 1835–1837; one large sacral shield fragment, MWC 1838.

*Type locality.* MWC Loc. 1.05.86, Mygatt-Moore Quarry, middle Brushy Basin Member, Morrison Formation, Mesa

*Table 1. Measurements (given in mm) of vertebrae and ribs. H, height of rib external to diapophysis; HAFC, height of anterior face of centrum; HNC, height of neural canal; HPFC, height of posterior face of centrum; LC, length of centrum; MH, maximum height of entire vertebra; ML, maximum length of rib; MW, maximum width of entire vertebra; MWC, minimum width of centrum; W, width of rib external to diapophysis; WAFC, width of anterior face of centrum; WNC, width of neural canal; WPFC width of posterior face of centrum; > = slightly greater than; () = approximately.*

DORSAL VERTEBRAE

| | LC | WAFC | HAFC | WPFC | HPFC | MWC | MW | MH | HNC | WNC |
|---|---|---|---|---|---|---|---|---|---|---|
| MWC 1800 ANT DOR (D-1?) | 43.5 | 51.2 | | 49.0 | 35.4 | 36.1 | 136.4 | >103 | 16.6 | 16.9 |
| MWC 1801 MID-DOR | 52.0 | 42.4 | 43.0 | 37.4 | 44.3 | 31.7 | | | 15.2 | 15.8 |
| MWC 1802 MID-DOR | 55.0 | >42 | 48.4 | 43.0 | >45 | 32.6 | | | 15.5 | 15.8 |
| MWC 1803 POS DOR | 59.6 | >34 | >46 | >37 | 46.5 | 29.9 | | | 25.4 | 13.8 |

CAUDAL VERTEBRAE

| | LC | WAFC | HAFC | WPFC | HPFC | MWC | MW | MH | HNC | WNC |
|---|---|---|---|---|---|---|---|---|---|---|
| MWC 1804 Caudosacral (C-1) | 51.2 | >54 | 54.0 | >54 | >49 | | | | 14.0 | 13.0 |
| MWC 1805 Caudal (C-2) | 44.3 | 59.1 | 48.2 | 59.8 | 49.5 | | 233.2 | 120.9 | 12.6 | 13.0 |
| MWC 1806 Caudal (C-2) | 42.7 | 57.2 | 45.2 | 57.4 | 48.7 | | 227.0 | 122.0 | 11.9 | 12.4 |
| MWC 1807 Ant Midcaudal | 47.1 | 44.9 | 40.3 | 46.2 | 42.5 | | 123.2 | 94.8 | 8.1 | 7.6 |
| MWC 1808 Pos Midcaudal | 50.6 | | (33.5) | | | | | | | |
| MWC 1839a and b 2 Partly Fused Pos Caudals w/ Chevrons | | | | | | | | | | |
| MWC 1839a Ant Pos Caudal | 46.3 | 34.3 | 28.4 | 32.5 | 28.6 | | 34.3 | 38.0 | 4.3 | 5.0 |
| MWC 1839b Pos Ant Caudal | 45.6 | 31.6 | 28.6 | 31.5 | 22.0 | | 32.9 | 35.5 | 3.8 | 4.1 |
| MWC 1839a & b Chevrons | approximately 40 mm long | | | | | | | | | |

RIBS

| | H | W | ML |
|---|---|---|---|
| MWC 1809 | 18.2 | 23.3 | >450 |
| MWC 1810 | 23.6 | 18.9 | |
| MWC 1811 | 20.0 | 21.1 | >450 |
| MWC 1812a | 18.5 | 20.0 | |
| MWC 1812b | 21.0 | 19.3 | |
| MWC 1840 | 15.1 | 2.77 | |

County, Colorado. Exact locality data on file at the Museum of Western Colorado, Grand Junction, and Dinamation International Society, Fruita, Colorado.

*Description.* Measurements of all described specimens are provided in tables 1–3.

## DORSAL VERTEBRAE

A single anterior dorsal vertebra (D-1?) is known (fig. 3A–D). The vertebra is slightly distorted due to crushing. The anterior face of the centrum is damaged and the top of the neural spine is missing. The damaged centrum face precludes determining if the centrum is heart-shaped as in *Edmontonia.* The posterior face of the centrum is oval. There is no trace of a notochordal prominence on either articular face. The centrum is elongated, more so than the anterior dorsal vertebrae of *Edmontonia rugosidens* (Gilmore 1930), given a maximum posterior height to length ratio of 123 for *Mymoorapelta* vs. 65 for *Edmontonia.* There is a distinct triangular fossa at the top of the neural arch, between the prezygapophyses. On each side of the triangular fossa is a small pit, located medially in a laterally elongated fossa. Each of these fossa is separated from the triangular fossa by a nearly vertical ridge. The neural canal is circular and not dorsally tall as in the anterior dorsal vertebrae of *Edmontonia* (Gilmore 1930). The transverse processes are not inclined steeply upward, but have a dihedral angle of about 20° as opposed to 30°–50° in *Polacanthus foxi* (Blows 1987, Hulke 1881), 35° in *Edmontonia rugosidens* (Gilmore 1930), 35° in *Nodosaurus* (Lull 1921), 45° in *Silvisaurus* (Eaton 1960), and 50° in *Sauropelta* (Ostrom 1970). The postzygapophyses extend only slightly beyond the centrum. The neural spine is a laterally compressed blade; the tip is missing and it is not known if it was laterally swollen as in other ankylosaurs.

The three more posterior dorsal vertebrae were apparently damaged by something feeding on the back of the animal. The transverse processes and neural spines are missing, and the zygapophyses are damaged. Two of the dorsal vertebrae are believed to be mid-dorsal because the neural canals are circular like the anterior dorsal (fig. 3E–J). The third dorsal vertebra is believed to be a posterior dorsal because the neural canal is larger in cross section than the other vertebrae. It is also taller than wide (fig. 3K–M). The centrum of the posterior dorsal is more elongated than the mid-dorsal centra (table 1); *Edmontonia* (Gilmore 1930) also shows a progressive elongation of the centra posteriorly. Ventrally, the mid-dorsal vertebral centra are rounded ventrally, whereas the posterior centrum is weakly keeled. The prezygapophyses extend slightly over the anterior face of the centrum. Unlike *Polacanthus* (Blows 1987), the left and right postzygapophyses of the middle dorsal vertebrae do not contact each other along

*Table 2. Measurements (given in mm) of appendicular skeleton. DW, distal width; MAXL, maximum length; MINL, minimum length; PH, proximal height; PW, proximal width; PTW, proximal total width.*

MWC 1814
ULNA

| MAXL | PW | PTW | DW |
|------|------|------|------|
| 197.1 | 65.0 | 81.7 | 41.0 |

MWC 1815
ILIUM

| MAXL | W |
|------|------|
| 495.0 | 150.0 |

MWC 1816
METACARPAL

| MAXL | PW | DW |
|------|------|------|
| 46.9 | 32.8 | 27.2 |

MWC 1817
PHALANGE

| MAXL | MINL | W | H |
|------|------|------|------|
| 13.9 | 9.5 | 21.9 | 19.0 |

MWC 939
UNGUAL

| L | PW | PH |
|------|------|------|
| (34) | 23.6 | 20.1 |

the midline but are separated by a wide groove. The postzygapophyses extend posteriorly over the posterior face of the centrum by at least half their length. One of the vertebra preserves a partial neural spine that is a laterally compressed blade. The neural arch of the posteriormost dorsal vertebra is taller and is anteriorly inclined. Consequently, the prezygapophyses extends well forward of the anterior centrum face, whereas the postzygapophyses do not extend beyond the posterior face.

## CAUDAL VERTEBRAE

There are seven caudal vertebrae present. The first caudal, or caudosacral, is represented only by a damaged centrum (fig. 4A–C). The centrum faces converge ventrally, giving the bone a wedge shape in lateral view. The articular faces of caudal vertebrae two and three are offset so that the posterior face is lower than the anterior face. These centra are also wedge-shaped, although not as

*Table 3. Measurements (in mm) of armor. H, height of scute from base to top of crest; L, length of scute along line of crest; LB, length of base of spine; MAXL, maximum length of spine from tip to anterior end of base; MW maximum width of spine at right angles to L; SH, height of spine at right angle to base; W, width of scute at right angle to length; WB, maximum width of base of spine. ( ) = measurement is estimated.*

## ARMOR—SPINES

|  | MAXL | SH | MW | LB | WB |
|---|---|---|---|---|---|
| MWC 1818 L Tri Spine | 284 | 164 | 117.2 | 129.7 | 55.6 |
| MWC 1819 Plate | 243 | 189 | 121.3 | 153.8 | 35.6 |
| MWC 1820 Plate | 239 | 125 | 116.1 | 158.2 | 37.8 |
| MWC 1821 Plate | (240) | (135) | (130) | (175) | (38) |
| MWC 1822 Plate | 217 | 164 | 106.3 | 138.9 | 50.6 |
| MWC 1823 Plate | (193) | 167 | 107.8 | 124.0 | 36.9 |
| MWC 1824 Plate | 212 | 118.1 | 119.1 | 194 | 51.5 |
| MWC 1825 S Tri Spine | 86.1 | 86.1 | 56.5 | 50.6 | 32.4 |

## ARMOR—SCUTES

|  | L | W | H |
|---|---|---|---|
| MWC 1826  Cir Scute | 53.7 | 58.8 | 17.5 |
| MWC 1827  Cir Scute | 43.9 | 47.9 | (16) |
| MWC 1828  Cir Scute | 40.7 | 39.8 | 19.3 |
| MWC 1829  Cir Scute | 64.1 | 47.8 | 16.4 |
| MWC 1830  Cir Scute | 59.6 |  | 18.9 |
| MWC 1831  Wide Scute | 43.1 | 69.8 | 22.5 |
| MWC 1832  Rect Scute | 73.1 | 46.2 | 23.3 |
| MWC 1833  Rect Scute | >70 | 42.7 |  |
| MWC 1834  Massive Scute | 74.5 | 70.7 | 36.8 |
| MWC 1835  L Asym Scute | 98.7 | 75.9 | 32.8 |
| MWC 1836  L Asym Scute | 94.6 | 77.3 | 27.6 |
| MWC 1837  L Asym Scute | >100 | (61) | (28) |
| MWC 1838  Sacral Shield Fragment |  |  |  |
| Large Scute | 59.5 | 51.2 | 16.4 |
| Small Scutes | 8.5–28 mm in diameter | | |

strongly as the first caudal vertebra (fig. 4D–F). A notochordal prominence is present on the posterior face of the caudal centra. There is a weak keel on the ventral surface of centra one to three. The caudal ribs are long, extend laterally, and curve ventrally; their contacts with the centra are dorsoventrally narrow, like that of *Polacanthus foxi*

(Blows 1987), and not massive as in *Sauropelta* (Ostrom 1970) and *Edmontonia* (Gilmore 1930). The ends of these ribs are damaged, but one of them is somewhat swollen. The neural canal is circular. The articular faces of the prezygapophyses are small and elongated. Viewed dorsally, the prezygapophyses are widely separated and angle

away from each other at about 60°. The long axes of the prezygapophyses in *Polacanthus foxi* (Blows 1987) are almost parallel to the centra axis. The pre- and postzygapophyses extend about half their length over the face of the centra. The neural spines are short and posteriorly inclined as in *Edmontonia rugosidens* (Gilmore 1930). The tops of the neural spines are swollen and are circular in dorsal view; the spine is square-shaped in *Polacanthus foxi*. The posterior chevron facets are more prominent than the anterior ones on caudal three. The posterior face of the centrum is heart-shaped because of the chevron facets. These facets also make the vertebra about as deep as wide; the faces on the centra on caudal vertebra two and the anterior face of three are wider than tall.

An anterior midcaudal is complete, except for a missing left prezygapophyses (fig. 4G–I). The small elongate, right prezygapophyses angles about 40° laterally from the midline. A small notochordal prominence is present on the circular anterior face. The posterior face is heart-shaped. The centrum is more elongate than in *Edmontonia*. The caudal rib extends laterally; its tip is slightly swollen. The neural spine is tall and thin laterally with its tip swollen laterally to form an anteroposteriorly elongated oval shape. A pair of low ridges connects the anterior and posterior chevron facets as in caudal three.

A posterior midcaudal vertebra is represented by half of a centrum that is split vertically along its length (fig. 4J). There is a short caudal rib that protrudes laterally.

Finally, there is a pair of complete posterior caudal vertebrae with chevrons that were held together by a fused chevron (MWC 1839, not figured). The centra are elongate and somewhat depressed with heart-shaped anterior and posterior faces. The ventral sides of each caudal centra are depressed with a low central keel that bifurcates anteriorly and posteriorly to meet the chevrons. Laterally the sides of each caudal centra are pinched to form lateral keels that are slightly wider at the middle of the centra at the position of the caudal ribs on more anterior caudal vertebrae. The neural arch is low with no hint of a neural spine. The long axes of the prezygapophyses are nearly parallel and extend anteriorly out over the preceding vertebra for about one-quarter of the length of the centra. The postzygapophyses are fused together and extend caudally out over the succeeding vertebrae for a similar distance.

The chevrons are strongly fused to the lower posterior margin of the centra. Below the haemal canal the chevrons are elongate and extend parallel to the elongate vertebral centra. They extend further anteriorly than posteriorly, forming a nearly continuous skid below the haemal canal. Overall the posterior portion of the tail looks closest to that of *Hylaeosaurus* (Owen 1858, pl. 10, fig. 2) in that it does not appear to taper as rapidly as that of *Sauropelta* (Coombs 1978).

## RIBS

Despite most ribs being incomplete, at least eight are represented in *Mymoorapelta*. Although dinosaur ribs show variation in cross section depending on placement along the rib cage, those associated with *Mymoorapelta* differ from any known in an ankylosaur. The ribs at the bend external to the diapophyses are consistently not as strongly T- or L-shaped in cross section as they are in other ankylosaurs. The costal grooves on the medial side of the rib are more strongly developed in *Polacanthus foxi* than in *Mymoorapelta* (fig. 5). Consequently the ribs of *Mymoorapelta* are more triangular in cross section and less T-shaped than the ribs of *Polacanthus*.

One rib (MWC 1840) is shorter, not so strongly curved, and proportionally much wider than the other ribs. It is thought that this may represent one of the posterior ribs which attached to the ilia.

## ULNA

The only major limb element known in *Mymoorapelta* is a right ulna (fig. 6). The olecranon process is broad, massive, and its surface rugose. The coronoid process is about one-third of the way down the bone from the top of the olecranon process. This compares with about one-quarter for *Stegopelta* (Moodie 1911) and *Polacanthus foxi* (Hutt personal communication). The olecranon notch is shallow, as in *Nodosaurus* (Lull 1921) and *Panoplosaurus* (Lambe 1919). The ulnar shaft tapers distally and is narrowest just above the distal condyle in *Mymoorapelta*. In some nodosaurids, such as *Sauropelta* (Ostrom 1970) and *"Hierosaurus colei"* (Mehl 1936), the distal end is considerably more swollen in lateral view than in *Mymoorapelta*. In posterior view, the shaft of the ulna in *Mymoorapelta* is sigmoidal in shape, whereas it is straight in *Polacanthus foxi* (Hutt personal communications).

## ILIUM

The complete left ilium bears about 50 transversely directed grooves across the dorsal surface that are interpreted as tooth marks (fig. 7). The ilium appears more stegosaurian than ankylosaurian in form in that the preacetabular portion of the ilium curves lateroventrally. Unlike the condition in stegosaurs, however, *Mymoorapelta* lacks an antitrochanter, and there is partial closure of the acetabulum. The postacetabular segment of the ilium is horizontal, as is an equal segment in front of the acetabulum. The preacetabular process curves such that the anterolateral one-half is vertically oriented; it does not diverge away from the inner margin of the ilium as in stegosaurs and other ankylosaurids. It is possible that anteriorly the ilia diverged away from the midline of the

sacrum as a whole. The preacetabular blade extends almost twice the distance below the upper surface of the ilium as does the pubic peduncle. The medial and lateral margins of the ilium body are parallel. There appears to have been at least four sacral ribs attached to the medial side of the ilium. There are the impressions of two ribs and a portion of a third on the underside of the anterior portion of the iliac blade. Posterior to these, there is space for at least one or two additional presacral vertebrae that lacked ribs, perhaps indicating the presence of a typical ankylosaur synsacrum. The postacetabular segment of the ilium is short but lacks the posteriorly directed extension, or heel, that is present in stegosaurs (Gilmore 1914). Pubic peduncle is long, and the ischial process is very short.

## PHALANGES

The single metapodial is believed to be metacarpal III or IV because of its shortness relative to width as compared to *Edmontonia rugosidens* (Carpenter 1990) (fig. 8A, B). Also, the proximal end is somewhat rectangular and set oblique to the axial width of the distal condyles. A phalanx possibly from the pes is very short and wide, resembling those of other nodosaurids (fig. 8C, D). A distal phalanx or ungual (MWC 939, not illustrated), tentatively assigned to the pes, is longer than wide and rather pointed as compared to other ankylosaurs (ex. *Edmontonia*, Carpenter 1990).

## ARMOR

There are five major types of armor preserved: an elongated spine with a hollow base and a long groove up the side; a thin triangular plate with a narrow, asymmetric, hollow base; a small bladelike spine with a rounded, solid base; isolated, flat, keeled scutes; and scutes fused into a single sheet of armor.

The large spine is assumed to have extended laterally from the neck with the point curving posteriorly (fig. 9). It is triangular in cross section with a groove that extends along the posterior margin from the base to the tip. This groove is broad and becomes shallower near the tip. What is thought to be the dorsal side of the spine is almost flat, whereas the ventral side is slightly concave. The roughly

triangular base is hollow, with the rims extending out asymmetrically relative to each other. The rim on the concave side is deepest near the anterior edge of the base, whereas the rim is deepest more posteriorly on the flat side of the spine. A keel extends from the base to the tip along the anterior edge, forming the acute apex of the triangular cross section. On the anterior edge, just above the base, the keel arcs toward the convex ventral side of the spine. The flat side has very faint fluting about 1 cm apart and parallel to the posterior edge. The flutes become progressively less distinct toward the anterior edge. The hollow base has six nutrient foramina. There are two prongs of bone near the posterior end of the hollow base that may have been for a ligamentous attachment. Posterior to the prongs there is a deep pocket.

There are at least eight thin triangular plates, of which six are complete and two are fragmentary (fig. 10). As with the large spine, it is assumed that the point of the triangle recurved posteriorly. These plates are similar in appearance to those in *Polacanthus* (ex. Blows 1987, text fig. D–F) and are believed to be lateral caudal plates; as with *Polacanthus*, the tallest plates are assumed to be positioned more proximally on the tail. In dorsal profile the anterior edge of the plate is convex and is longer than the posterior concave edge. The result is that the tips of the plates overhang the posterior margin of the base. All of the plates are biconvex in cross section, although one side is more so than the other. The biconvexity of the spines results in sharp anterior and posterior margins. On the most convex side, there is faint fluting 1–1.5 cm apart approximately parallel to the posterior margin of the plate. The ornamented surface is assumed to be the dorsal side. The bases of the plates are hollow and the rims are asymmetrical, similar to those of the neck spine. In all but one plate, the most proximal point of the basal rim of the fluted side is more posterior than that of the rim of the other side; this gives the plate an asymmetrical appearance. As in the cervical spine, the caudal plates also have nutrient foramina along the midline of the deeply hollow base.

A single small, triangular plate is present (MWC 1825, not illustrated). It is thin, bladelike, and biconvex in cross section. The base is rugose and asymmetrical. There is a slightly constricted neck on one side separating the base from the plate. On the other side, the base is very rough and has a small spur that projects distally.

FIGURE 3.—*Dorsal vertebrae of* Mymoorapelta maysi. *Dorsal 1(?) MWC 1800 in anterior (A), right lateral (B), left lateral (C), and posterior (D) views. Anterior mid-dorsal MWC 1801 in anterior (E), right lateral (F), and posterior (G) views. Posterior mid-dorsal MWC 1802 in anterior (H), right lateral (I), and posterior (J) views. Posterior dorsal MWC 1803 in anterior (K), right lateral (L), and posterior (M) views. Heavy bar = 5 cm.*
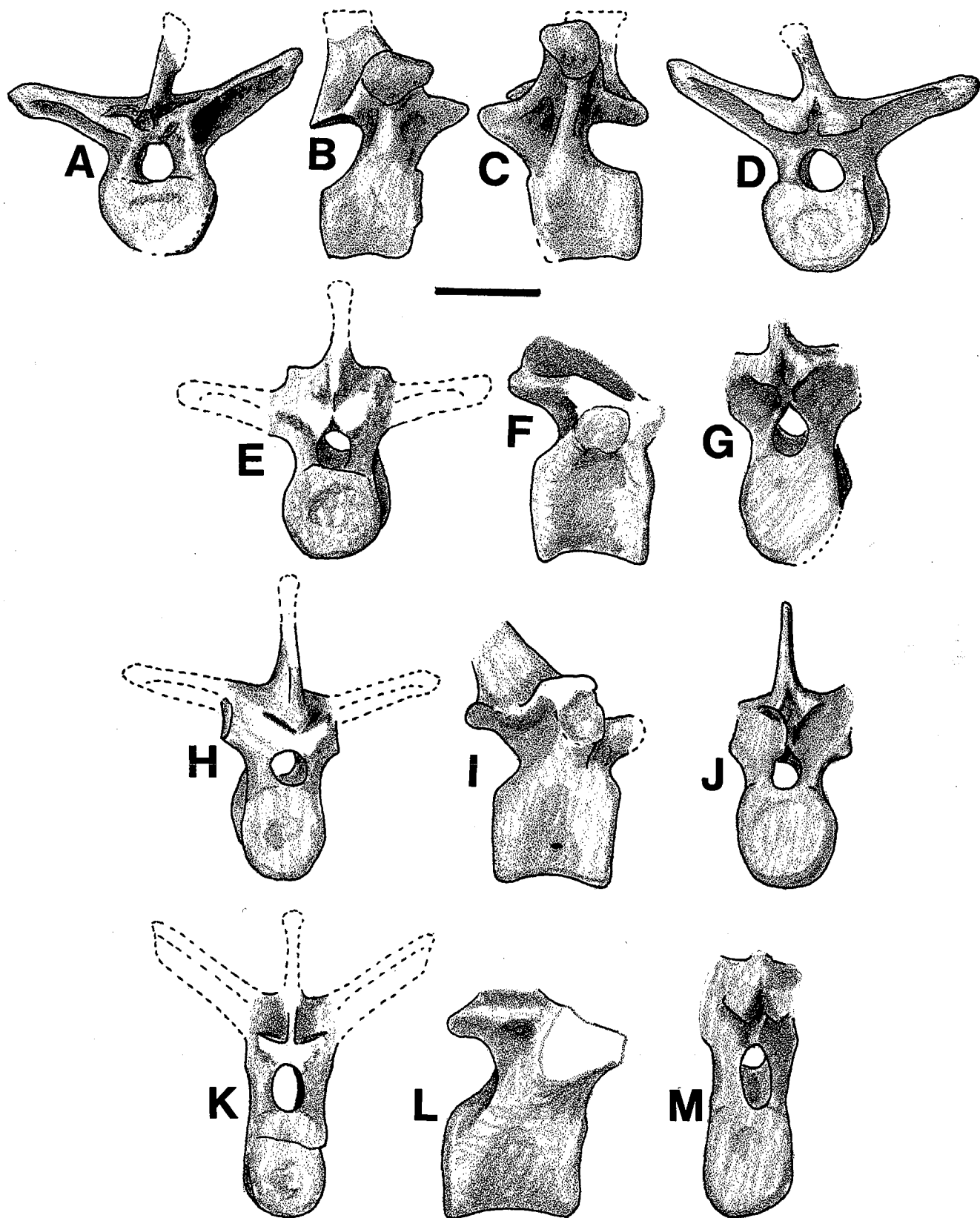
Twelve low, keeled flat scutes are known for *Mymoorapelta*. These resemble those present in many nodosaurs. Five of the scutes are circular to oval with a median keel that rises to a posterior peak (fig. 11A, B, F). The ventral surface of each scute is nearly flat, with a slight concave and convex undulation. One scute is wider than long, with a broad, slightly oblique medial keel extending in the short direction (fig. 11C). On the ventral surface there is a depression beneath the highest point of the keel. Two scutes are longer than wide and subrectangular in shape (fig. 11C, E). In these the keel extends diagonally lengthwise and rises to a blunt peak. It is also slightly excavated ventrally under the peak. Another scute is massive, broadly oval in dorsal view, and the broad blunt keel extends obliquely (fig. 11G). On the ventral surface there is a depression beneath the peak of the keel. The three largest flat scutes are oval, with the keel parallel and near one edge (fig. 11H, I). The opposite edge of the scute curves slightly upward. These scutes are also excavated ventrally beneath the keel.

A small fragment of sacral armor consists of a rosette formed by a large central scute surrounded by small co-ossified ossicles (fig. 12). The central scute is oval and has a blunt, slightly offset keel. Ventrally the scute is concave. The small ossicles are circular to oval in outline, and one has a transversely directed, low, blunt keel.

## DISCUSSION

Based on the features observed in the preserved material, it is difficult to fit *Mymoorapelta* into the generally accepted ankylosaur dichotomy of the Nodosauridae and Ankylosauridae (Coombs 1978, Coombs and Maryańska 1990, Sereno 1986). *Mymoorapelta* is tentatively placed in the Nodosauridae, as the taxon has a number of primitive features and the Nodosauridae include taxa that are considered to be the least derived among the Ankylosauria. The presence of solid dorsal scutes appears to be a primitive character of *Mymoorapelta* shared with the Nodosauridae, separating it from the Ankylosauridae, which have hollow dorsal scutes as a derived character state.

*Mymoorapelta maysi* is the oldest ankylosaur known from North America. Of described ankylosaurs, it shares several characters with *Polacanthus foxi* Hulke (1881, 1887). Shared characters include posteriorly grooved cervical spines, triangular caudal plates with asymmetrical hollow bases, and a co-ossified sacral shield. These similarities suggest a close relationship, possibly in a separate subfamily or family (Kirkland, in preparation). Recently, Blows (1987) suggested a synonymy of *Hoplitosaurus marshi* Lucas (1901, 1902) from the Lakota Formation of South Dakota with *Polacanthus* from the Wealden Formation on the Isle of Wight, England, as *P. marshi*.

This suggestion was accepted and expanded upon by Pereda-Suberbiola (1991). However, Coombs (1978, Coombs and Maryańska 1990, 1994 personal communication) regards the synonymy of *Hoplitosaurus* with *Polacanthus* as very tentative and poorly documented. Nevertheless, indications are that the Jurassic relatives of *Polacanthus* could have occurred on either or both sides of the Atlantic prior to the separation of North America and Europe.

A grooved cervical spine, similar to that of *Mymoorapelta*, is known for *Polacanthus marshi* (Gilmore 1914, pl. 29); and a similar grooved cervical spine, but with a ventral keel, may be present in *P. foxi* (Blows 1987, text fig. 7A, B; Delair 1982). No other ankylosaurs are known with armor of this morphology.

Triangular, platelike caudal armor with asymmetric hollow bases are known for *Polacanthus foxi*—a large ankylosaur from eastern Utah described as cf. *Hoplitosaurus* (Bodily 1969), another smaller related ankylosaur also from eastern Utah (Kirkland 1993a and 1993b, in preparation)—and perhaps *Struthiosaurus transylvanicus* (Nopsca 1929, pl. 4, figs. 1, 2). These plates are interpreted as caudal armor in *Polacanthus foxi* (Blows 1987, Hulke 1881, Nopsca 1905), which is further supported by the ankylosaur described by Bodily (1969) (see below). The taller proximal caudal plates of *Mymoorapelta* differ from those known in other taxa by the relative short length of the base as compared with the overall height of the plate.

The triangular caudal plates in *Mymoorapelta* and *Polacanthus* probably projected laterally, rather than dorsally as reconstructed by Nopsca (1905) for *Polacanthus foxi*, apparently based on reconstructions of *Stegosaurus*—the only adequately known armored dinosaur at that time. Nopsca's (1905) reconstruction of *Polacanthus foxi* was subsequently followed by Blows (1987). The lateral orientation hypothesis is supported by a large ankylosaur described as cf. *Hoplitosaurus* by Bodily (1969). Apparently the specimen consisted primarily of a tail, and the armor preserved with it included only massive keeled scutes and large caudal plates. Arranging this armor around the tail suggests that there was a pair of massive scutes lying along the dorsal surface of the tail with a triangular caudal plate projecting out laterally on each side (Kirkland, in preparation). This arrangement of caudal armor is substantiated by the caudal vertebrae, as the highly elongate caudal ribs and the low angle of the zygapophyses may be an adaption for swinging the tail from side to side. In this arrangement, with their keratinaceous covering, these bladelike plates would have been an effective defensive weapon as the tail was slashed from side to side.

The sacral shield in *Polacanthus foxi* and *Mymoorapelta* is composed of fused dermal armor. The individual ossicles began as separate centers of ossification, which grew
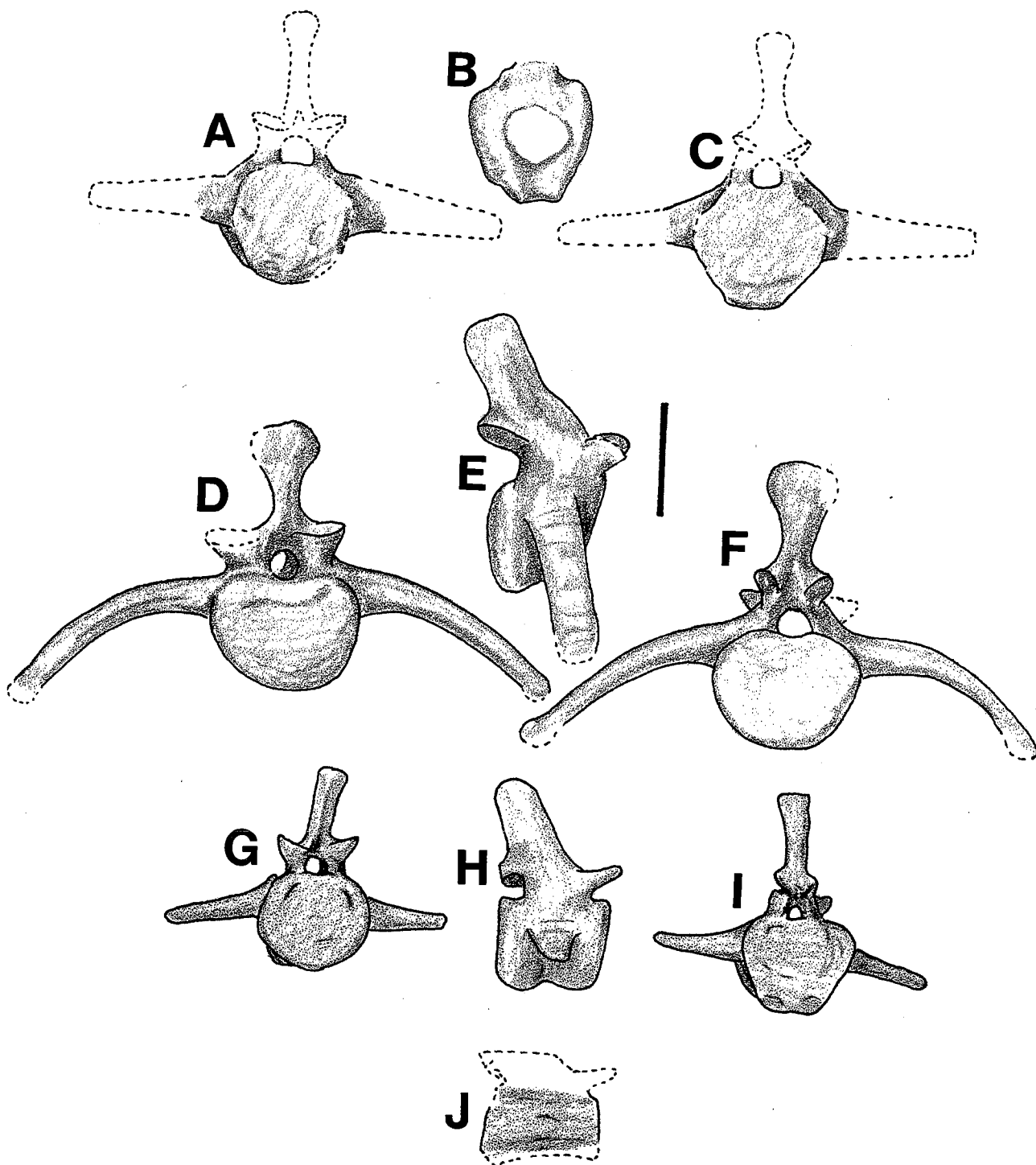
FIGURE 4.—*Caudal vertebrae of* Mymoorapelta maysi. *Sacral-caudal (caudal 1) MWC 1804 in anterior (A), right lateral (B), and posterior (C) views. Anterior caudal (caudal 3) MWC 1806 in anterior (D), right lateral (E), and posterior (F) views. Anterior midcaudal MWC 1807 in anterior (G), right lateral (H), and posterior (I) view. Posterior caudal MWC 1808 in right lateral (J) view. Heavy bar = 5 cm.*
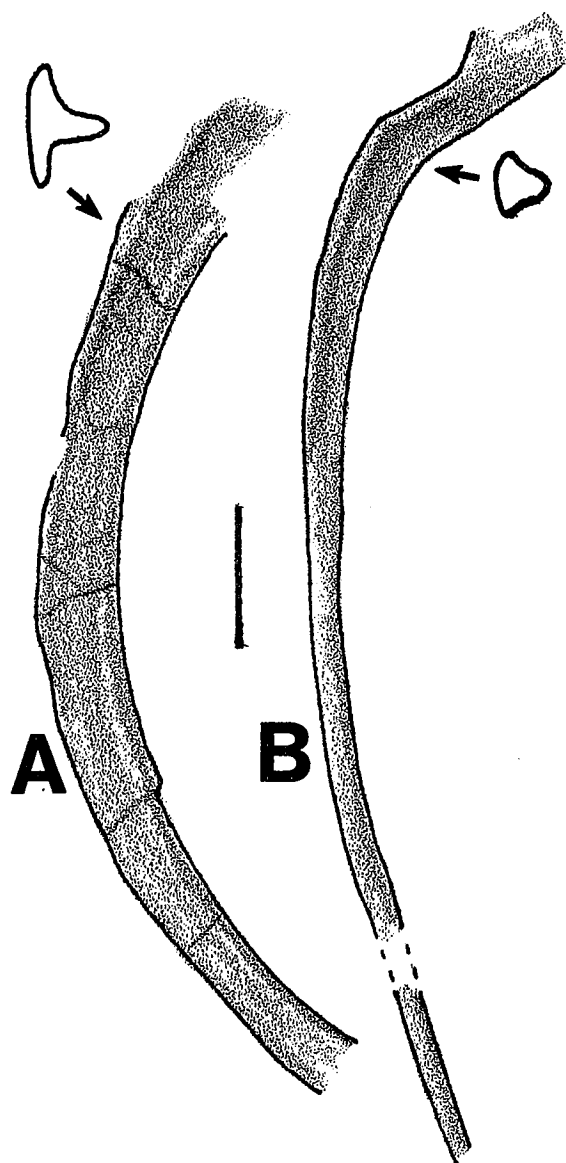
FIGURE 5.—*Comparison of ribs and rib cross sections of* Polacanthus foxi *BMNH 9293 (Blows 1987, text fig. 4, right side) (A) and* Mymoorapelta maysi *MWC 1810 (B). Heavy bar = 5 cm.*

together. Then, instead of simply suturing together, the ossicles fused together by a process of reabsorption and redeposition of bone on the basal surface of the shield. Thereafter the shield continued growth as a single, continuous sheet of dermal bone (Blows 1987, p. 573; Kirkland and others 1991). Based on direct comparison from casts of *Polacanthus foxi*, the individual elements of the sacral shield of *P. foxi* are smaller than those of *Mymoorapelta*, even though *P. foxi* is at least 25% bigger (Blows 1987, Hulke 1887). Triangular caudal plates and a co-ossified sacral shield are also present in a new genus of

ankylosaur from the Lower Cretaceous Cedar Mountain Formation of eastern Utah (Kirkland 1993a, 1993b, in preparation; Kirkland and others 1991). The larger elements of the sacral shield of the undescribed Utah ankylosaur have radial grooves around their margins, a feature not observed in *Mymoorapelta* or *Polacanthus*.

The ulna of *Mymoorapelta* differs from that of *Polacanthus foxi* in that the olecranon process is much more massive and the shaft is sigmoidal rather than straight. The ilium of *Mymoorapelta* is not as broad as that of *Polacanthus foxi*—or any other described ankylosaur for that matter— and no ankylosaur has as vertically oriented a preacetabular process (Coombs 1979, Coombs and Maryańska 1990).

*Mymoorapelta* differs from *Edmontonia rugosidens* (Gilmore 1930, Russell 1940), "*Hierosaurus*" *colei* (Mehl 1936), *Hylaeosaurus armatus* (Owen 1858), *Panoplosaurus mirus* (Lambe 1919, Sternberg 1921), *Nodosaurus textilis* (Lull 1921), *Sauropelta edwardsi* (Carpenter 1984, Ostrom 1970), and *Stegopelta landerensis* (Moodie 1911) in having posteriorly grooved cervical spines, a massive olecranon process, and a ventrolaterally curved preacetabular process of the ilium.

Compared with *Acanthopholis horridus* (Nopsca 1923, pl. 7, figs. 8–10; pl. 8, fig. 1), the dorsal vertebral centra are not as laterally constricted in *Mymoorapelta*. In addition, the groove on the ventral side of the caudal is not as deep in *Mymoorapelta* as compared with *A. horridus* (Nopsca 1923, pl. 7, fig. 11).

*Mymoorapelta* differs from *Struthiosaurus transilvanicus* in that the neural canal of the dorsal vertebrae are circular to oval rather than very tall (Nopsca 1929). The cervical dermal spine of *Mymoorapelta* is triangular in cross section and grooved along the posterior margin, whereas in *Struthiosaurus* the cervical plate is not triangular in cross section, nor does it have a posterior groove.

*Mymoorapelta* differs from the Lower Cretaceous Australian ankylosaur *Minmi* (Molnar 1980, 1991) in a number of important characters (Molnar personal communication). The caudal vertebrae of *Minmi* are more depressed, and the caudal ribs are short. The ilia of *Minmi* are much flatter, and the ulna is more gracile. There are also no elongate spines or plates in the armor of *Minmi*.

Among described Jurassic nodosaurs, there are no elements in common with *Sarcolestes* (Galton 1980c, 1983a,b) or *Priodontognathus* (Galton 1980b,c; 1983b), for which only lower jaws are known; or *Cryptodraco* (Galton 1980b, 1983b), for which only the femur is known. *Dracopelta* (Galton 1980a) from the Upper Jurassic of Portugal is represented by articulated vertebrae, ribs, and armor. None of the armor preserved compares with that known for *Mymoorapelta*. The dorsal vertebral centra are more laterally constricted in *Dracopelta*. An isolated prox-
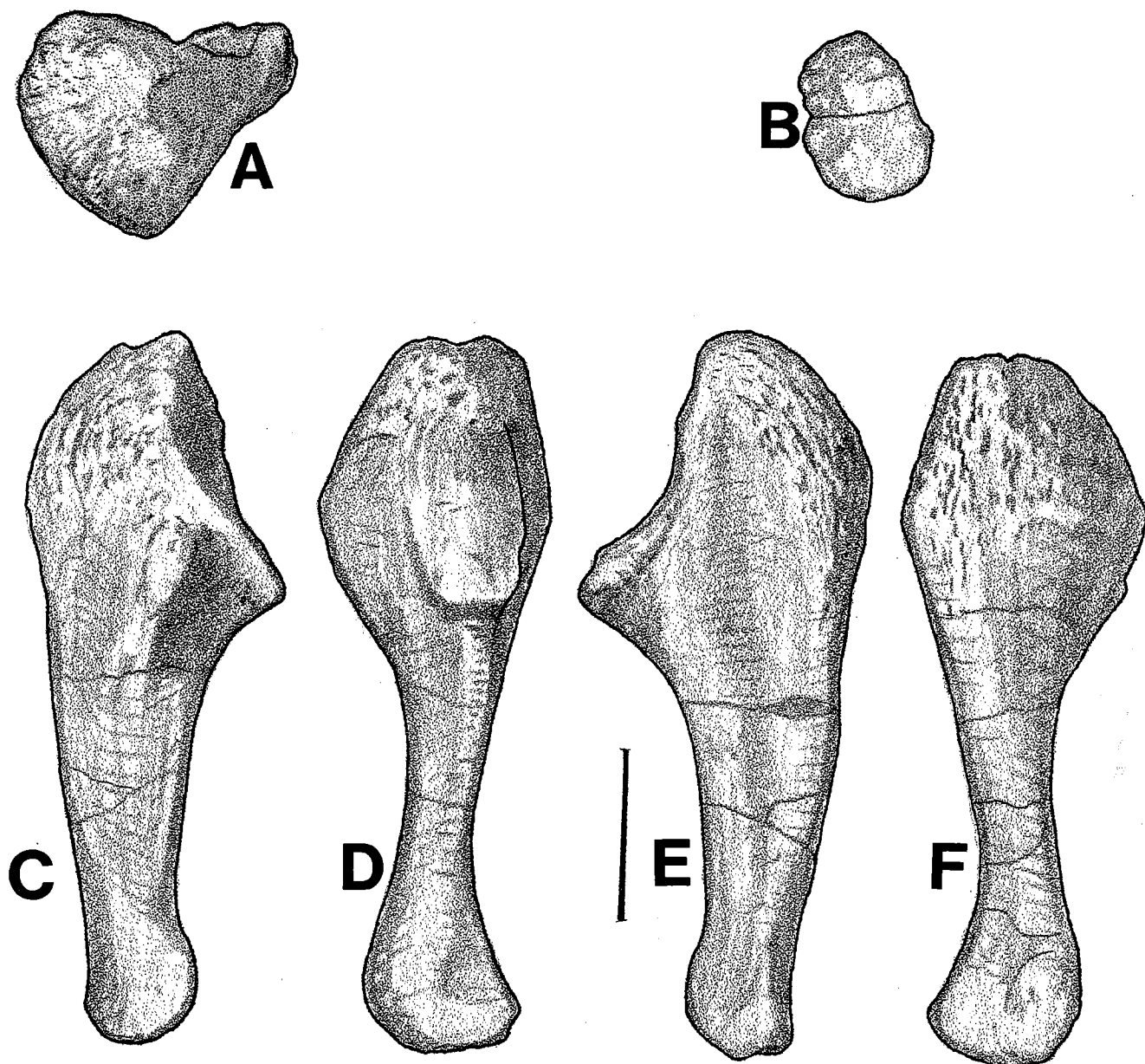
FIGURE 6.—*Right ulna MWC 1814 of* Mymoorapelta maysi *in proximal (A), distal (B), external lateral (C), anterior (D), medial (E), and posterior (F) views. Heavy bar = 5 cm.*

imal caudal vertebra from the uppermost Jurassic of Weymouth, England (Galton 1983b), differs from those of *Mymoorapelta* primarily in having more massive caudal ribs and a much more prominent posterior flange on the chevron facets. These differences suggest a greater diversity of Upper Jurassic ankylosaurs than is suggested by the paucity of skeletal remains.

*Mymoorapelta* differs from the newly described Middle Jurassic ankylosaurid from China (Dong 1993) in a number of characters. Although the genus is spelled

*Tianchisaurus* whenever referred to in Chinese, it is spelled *Tianchiasaurus* when it is referred to in English. As the paper is in English, preceded by a Chinese abstract, the authors have assumed that Dong intended the taxon to be spelled *Tianchiasaurus*.

The dorsal vertebrae of *Mymoorapelta* differ from those of *Tianchiasaurus* in having centra that are not as constricted, neural canals that are not depressed, and separate prezygopophyses. Dong's (1993, fig. 4) figure of a first caudal vertebra must actually be the anterior midcaudal
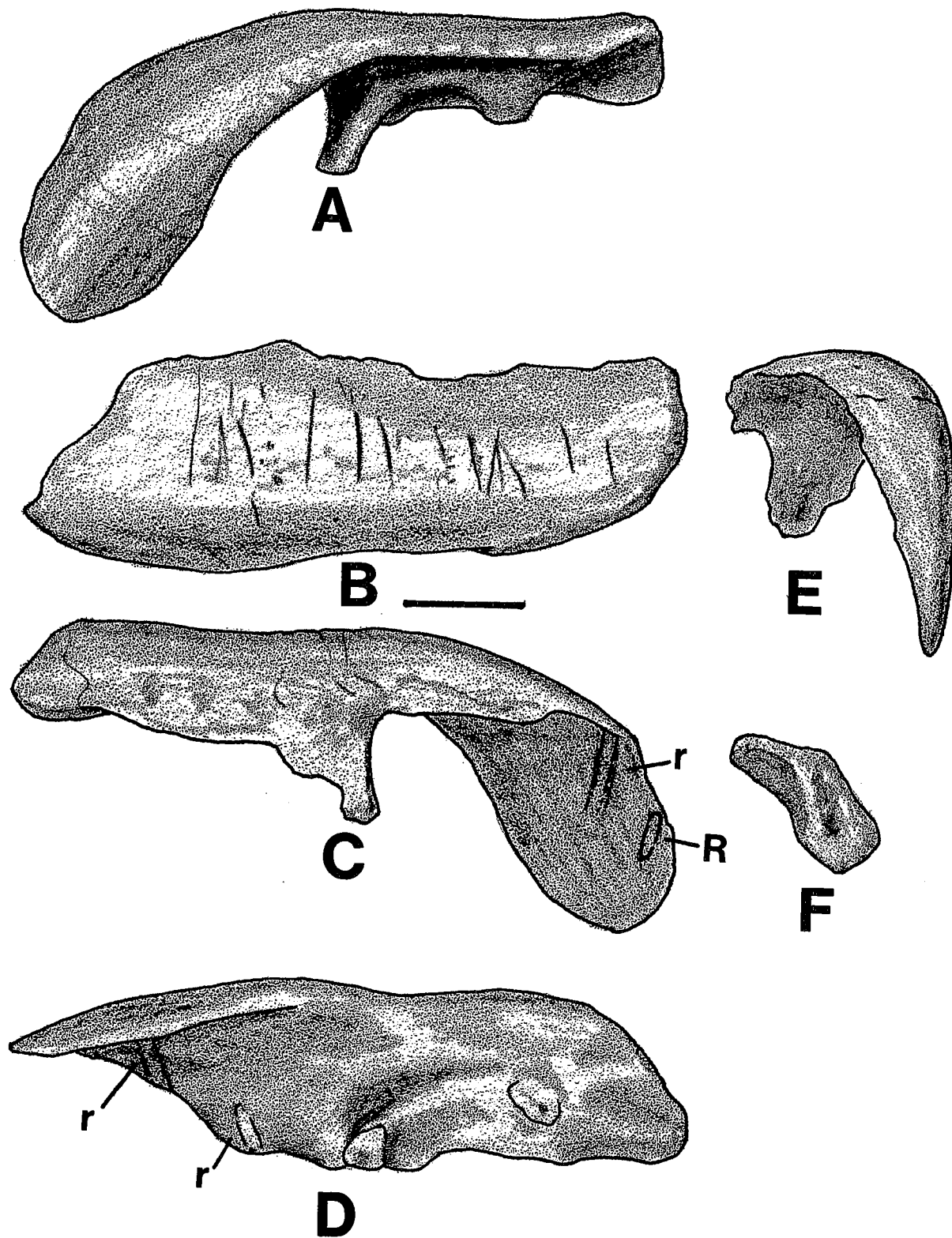
FIGURE 7.—*Left ilium MWC 1815 of* Mymoorapelta maysi *in lateral (A), dorsal (B), medial (C), and ventral views. r = scars of ribs, R = fragment of attached rib. Heavy bar = 10 cm.*

FIGURE 9.—*Cervical dermal spine MWC 1818 of* Mymoorapelta maysi *in dorsal (A), ventral (B), anterior (C), posterior (D), and medial (E) views. Heavy bar = 10 cm.*
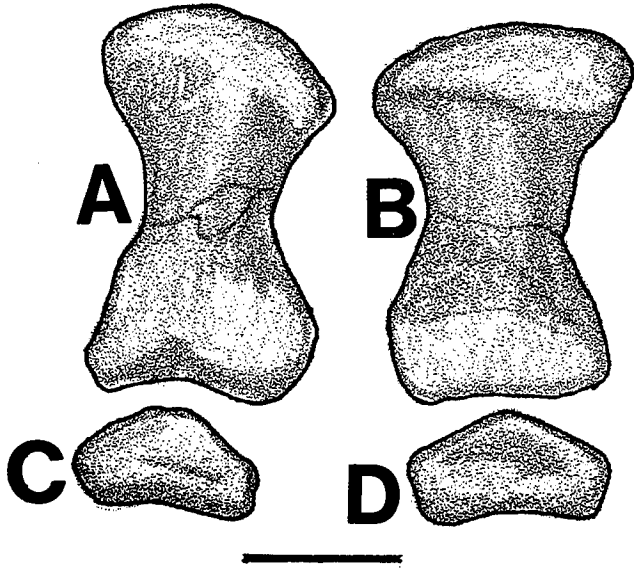


FIGURE 8.—*Metacarpal MWC 1816 (A, B) and phalanx MWC 1817 (C, D) of* Mymoorapelta maysi *in proximal (C) and ventral (D) views. Heavy bar = 2 cm.*

as it shows a posterior facet for the chevron as described for the midcaudal and not the proximal caudals. The proximal caudal vertebrae of *Mymoorapelta* have a posterior chevron facet that is not visible in *Tianchia-saurus*. In addition, the attachment of the caudal ribs with the centrum is much more massive in *Tianchiasaurus*. The ribs of *Tianchiasaurus* are described as distinctively T-shaped, unlike those of *Mymoorapelta*. A tail club is reported for *Tianchisaurus* and, although reported for *Polacanthus* (Blows 1987), a tail club is not known for *Mymoorapelta*.

The oldest ankylosaur or basal thyreophoran that *Mymoorapelta* can be compared with is *Scelidosaurus harrisonii* from the Lower Jurassic Lias of England (Owen 1862). *Mymoorapelta* differs in that the transverse processes of the dorsal vertebrae are proportionally longer, but not as robust. Furthermore, the neural canal in *Scelidosaurus* has an inverted teardrop shape, whereas in *Mymoorapelta* the canal is circular to oval. An ilium questionably referred to *Scelidosaurus* (Coombs, Weishampel, and Witmer 1990) has a partly closed acetabulum formed by a thin wall of the ilium as in *Mymoorapelta*. However, neither this ilium nor the one associated with the holotype has a ventrolaterally curved preacetabular process. In addition, as in *Mymoorapelta*, the postacetabular process is vertical rather than horizontal. The caudal armor of *Scelidosaurus* resembles that of *Mymoorapelta* in that the caudal armor is laterally compressed, elongated anterioposteriorly, and has a hollow base. However, the armor is much higher, forming triangular plates with asymmetrical
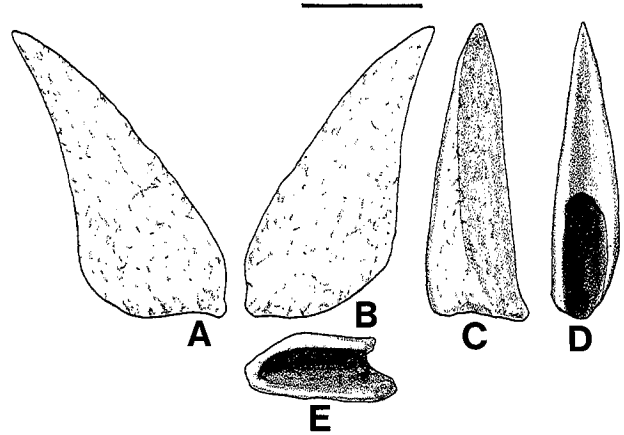
bases in *Mymoorapelta*, whereas the base of some plates are symmetrical in *Scelidosaurus* (Owen 1862, pl. 7, fig. 3). This difference is probably because the plates in *Scelidosaurus* come from the midline of the tail, rather than on each side.

The ulna and ilium of *Mymoorapelta* are similar in some features to those of primitive stegosaurs such as *Huayangosaurus* (Dong 1990; Dong and others 1982, 1983) and *Kentrosaurus* (Galton 1982; Hennig 1915, 1925), specifically in the massiveness of the ulna and the long lateroventral curve of the preacetabular portion of the ilium. The ulna of *Mymoorapelta*, however, is relatively more massive (fig. 6), and the ilium has no supra-acetabular flange, at least a partially closed acetabulum, and three ribs that are weakly attached to the underside of the preacetabular process (fig. 7).

The proportions of the ulna and ilium in *Mymoorapelta* suggest it had a stance reminiscent of that observed in stegosaurs with its high narrow hips and short powerful forelimbs. When the length of the ilium at 495 mm is compared to Carpenter's (1984) reconstruction of *Sauropelta*, an estimated total length of 2.7 m for *Mymoorapelta* is calculated. This compares with the 3-m estimated length of *Tianchisaurus* (Dong 1993) and the small size indicated from the bones for *Cryptodraco* (Galton 1980b, 1983b) and *Dracopelta* (Galton 1980a, 1983b) and suggests that all of the earliest ankylosaurs may have been relatively small. Because the fusion of the vertebral column is complete with no evidence of sutures, the Mygatt-Moore Quarry specimen of *Mymoorapelta* is recognized to be fully grown. Therefore, *Mymoorapelta* is the smallest quadrupedal dinosaur known from the Morrison Formation.
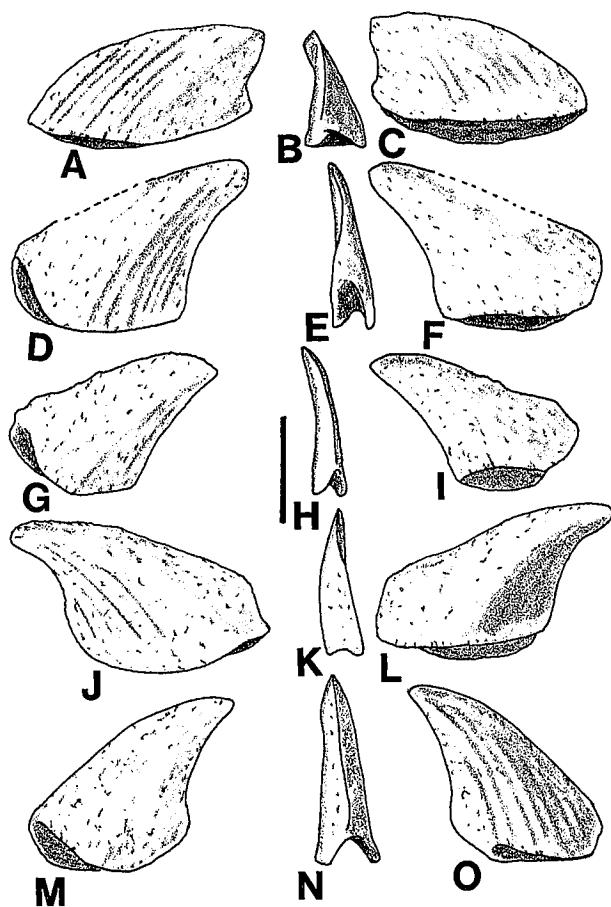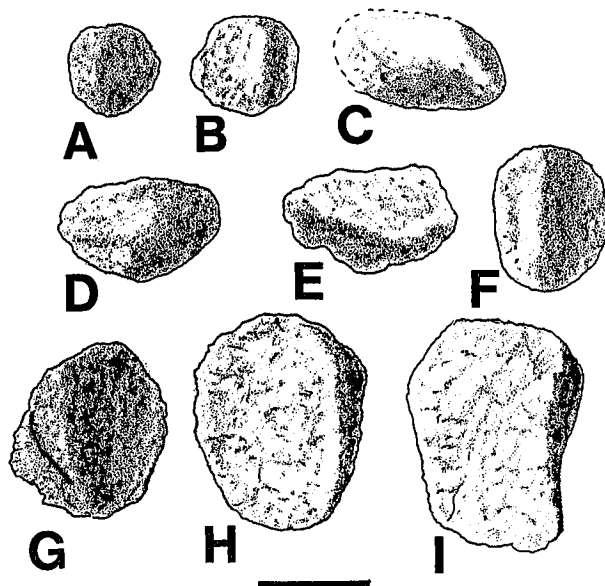
FIGURE 11.—*Examples of various scutes of* Mymoorapelta maysi *in dorsal views; see text for details. Circular scute MWC 1828 (A); circular scute MWC 1827 (B); rectangular scute MWC 1833 (C); wide scute MWC 1831 (D); rectangular scute MWC 1832 (E); circular scute MWC 1829 (F); massive scute MWC 1834 (G); large asymmetric scute MWC 1836 (H); and large asymmetrical scute MWC 1835 (I). Heavy bar = 5 cm.*

FIGURE 10.—*Caudal plates of* Mymoorapelta maysi. *Caudal plate MWC 1824 in dorsal (A), anterior (B), and ventral (C) views. Caudal plate MWC 1819 in dorsal (D), anterior (E), and ventral (F) views. Caudal plate MWC 1823 in dorsal (G), anterior (H), and ventral (I) views. Caudal plate MWC 1820 in dorsal (J), anterior (K), and ventral (L) views. Caudal plate MWC 1822 in dorsal (M), anterior (N), and ventral (O) views. Heavy bar = 10 cm.*
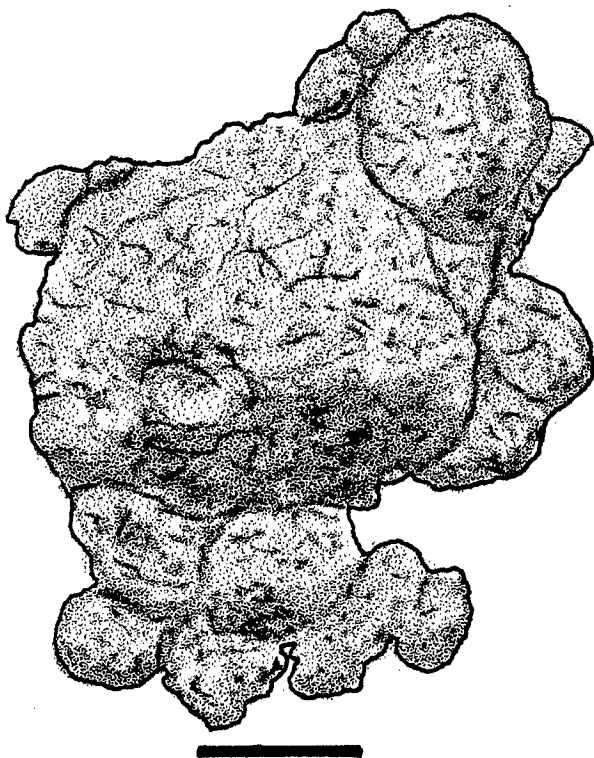
## ACKNOWLEDGMENTS

FIGURE 12.—*Fragment of pelvic armor (sacral shield) of* Mymoorapelta maysi *MWC 1838 showing small scutes fused to large central scute. Heavy bar = 2 cm.*

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