

TAXONOMIC STATUS OF *SEISMOSAURUS HALLORUM*, A LATE JURASSIC SAUROPOD DINOSAUR FROM NEW MEXICO

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Abstract—The holotype of the Late Jurassic sauropod dinosaur *Seismosaurus hallorum* consists of part of the thoracic and caudal vertebrae, most of the sacrum and pelvis, some ribs and chevrons and an incomplete femur. Reexamination of the holotype indicates that *Seismosaurus hallorum* differs little from *Diplodocus*, and none of the morphological differences are significant enough to justify a separate genus. Particularly important to this conclusion has been careful re-examination and further preparation of the ischium of the *S. hallorum* holotype, which indicates that the distal, hook-like process originally described was actually the tip of a vertebral neural spine and sandstone matrix adhering to the ischium. We consider *Seismosaurus* to be a junior subjective synonym of *Diplodocus*. We suggest that *Diplodocus hallorum* is also a junior subjective synonym of *D. longus*, but a careful taxonomic revision of the species of *Diplodocus* is needed to verify this suggestion.

INTRODUCTION

The holotype (and only known) specimen of the diplodocid sauropod *Seismosaurus hallorum* Gillette was collected from the Upper Jurassic Brushy Basin Member of the Morrison Formation near San Ysidro in northern New Mexico (Fig. 1). The subject of a book (Gillette, 1994), scientific articles (e.g., Gillette, 1991) and numerous abstracts, *Seismosaurus* received much attention because of its alleged: (1) huge size (indeed, it was touted as the longest land animal in popular and scientific articles alike); (2) its generic distinctiveness, for which the colorful name *Seismosaurus* (earthquake lizard) was coined; and (3) its large array of gastroliths, 240 in number, which supposedly defined both a crop and a gizzard.

However, rigorous evaluation of these three claims calls them into question. Thus, Lucas (2000) restudied the “gastroliths” of *Seismosaurus* and concluded they are stream-deposited cobbles, not stones swallowed by the dinosaur to produce a gastric mill. Lucas (1993), Paul (1988) and Curtice (1996) re-evaluated Gillette’s (1991) maximum length estimate for *Seismosaurus* of 52 meters and concluded that *Seismosaurus* was much more reasonably estimated at 30–34 meters long. In a more extensive analysis, Herne and Lucas (2006) re-evaluated the length of *Seismosaurus*, concluding that it was approximately 33 meters long.

The taxonomic validity of *Seismosaurus* has also been questioned (Curtice, 1996; Lucas et al., 2004), but a detailed reappraisal of the taxonomic status of *Seismosaurus* has not been published. This article is such a reappraisal, and concludes that *Seismosaurus* is a junior subjective synonym of *Diplodocus*. In this paper, NMMNH refers to the New Mexico Museum of Natural History and Science, Albuquerque. Literature-based comparisons to diplodocid sauropods are primarily based on Hatcher (1901), Holland (1906, 1924a), Gilmore (1932) and McIntosh and Carpenter (1998) for *Diplodocus*; Lull (1919) for *Barosaurus*; and Gilmore (1936) and Ostrom and McIntosh (1966) for *Apatosaurus*. We note here that, in spite of the numerous cladistic analyses performed on sauropods in recent years (e.g., Upchurch, 1998; Wilson and Sereno, 1998; Wilson, 2002; Upchurch et al., 2004), generic- and species-level taxonomic problems are best addressed by reference to the classic literature just listed.

HOLOTYPE

Gillette (1991) described and named the new genus and species *Seismosaurus hallorum* based on a partial skeleton (Fig. 2) consisting of most of the thoracic vertebrae, various ribs, incomplete left and right ilia and ischia, the left pubis, the sacrum, caudal vertebrae that he identified as

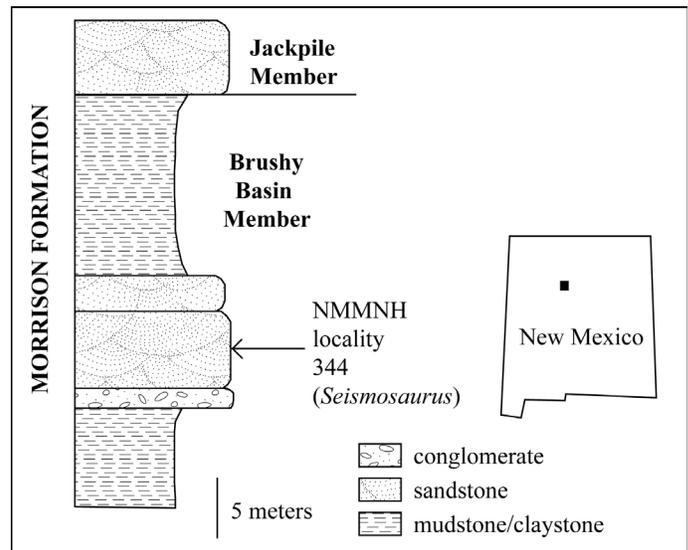


FIGURE 1. Measured stratigraphic section and the location of the *Seismosaurus* type locality in the NW1/4 NE1/4 sec. 26, T15N, R1W, Sandoval County, New Mexico (after Lucas, 2000).

caudals 8, 13, 20 through 27 and chevrons that he identified as the first through third chevrons. However, he only illustrated and discussed the pubis, ischium, chevrons, and selected caudal vertebrae. Gillette (1991) noted that the other elements were still in need of further preparation. Since Gillette’s (1991, 1994) published work, much preparation of the holotype material of *Seismosaurus* has been completed, so that the only substantial unprepared portion of that material is the dorsal block with thoracic vertebrae 4–10. However, the left lateral aspects of these vertebrae have been prepared, which allows much of their morphology to be determined. In addition, an incomplete right femur collected at the type locality of *Seismosaurus*, but catalogued under a number different from that of the holotype, is almost certainly from the same individual as the holotype (Herne and Lucas, 2006).

Curtice (1996) and Herne and Lucas (2006) re-examined the axial skeleton of *Seismosaurus* and concluded that some of the vertebrae were incorrectly placed in Gillette’s (1991) reconstruction. Specifically, the caudal vertebrae were reconstructed as more distal than they should have been

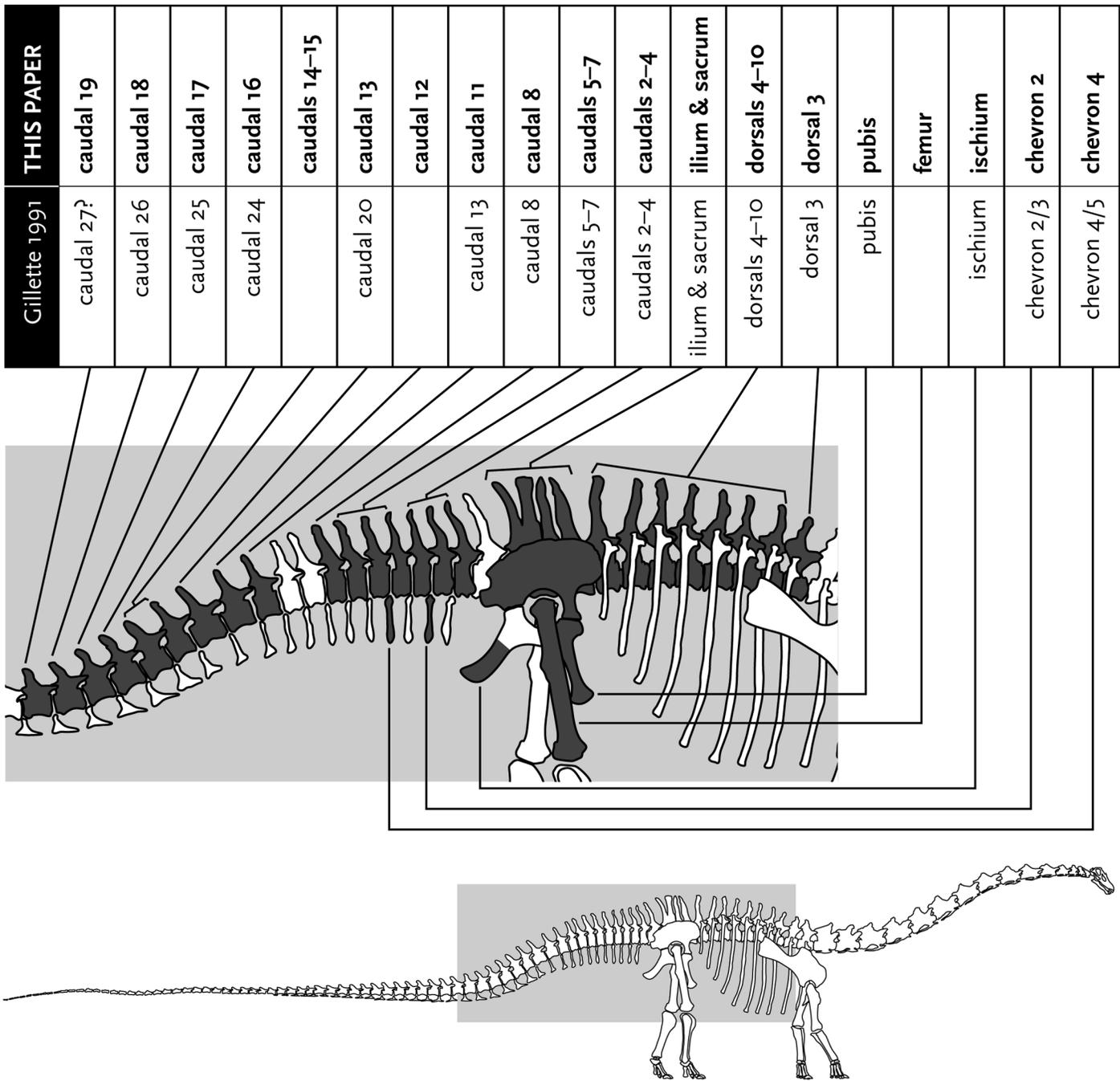


FIGURE 2. Restored skeleton of *Seismosaurus* showing the original positions of the caudal vertebrae according to Gillette (1991) and their revised positions based on Curtice (1996) and Herne and Lucas (2006). Drawing by Matt Celleskey.

(Fig. 2). This reassessment of the axial skeleton is the primary basis for the recalculation of the axial length of *Seismosaurus*. It also mandates a re-evaluation of the characters of the caudal vertebrae that Gillette (1991) deemed diagnostic of *Seismosaurus*.

As Gillette (1991) and Herne and Lucas (2006) have already extensively described the holotype of *Seismosaurus hallorum*, our descriptions are fairly brief. We thus summarize and photographically illustrate all currently prepared material of *Seismosaurus* and describe those elements that have yet to receive adequate description in the literature. One of our goals is to present as complete a photographic atlas of the type material of *S. hallorum* as is currently possible (Figs. 3-10).

Cervical Vertebra

There is a single possible cervical vertebra included with the holotype material, but even after extensive preparation it remains so fragmentary that no morphological information, other than that it is definitely longer than wide or tall, can be gleaned from it.

Thoracic Vertebrae

Thoracic vertebrae 1-2 are present but extensively weathered and unprepared. The third thoracic vertebra of *Seismosaurus* (Fig. 9G) is currently only visible in anterior view due to the posterior surface remaining



FIGURE 3. NMMNH P-3690, holotype of *Seismosaurus hallorum*. A-D, caudal vertebra 8 in A, right lateral, B, anterior, C, posterior, and D, left lateral view. E-H, caudal vertebra 11 in E, right lateral, F, anterior, G, posterior, and H, left lateral view. I-M, caudal vertebra 12 in I, anterior, J, posterior, K, right lateral, L, dorsal, and M, ventral view.

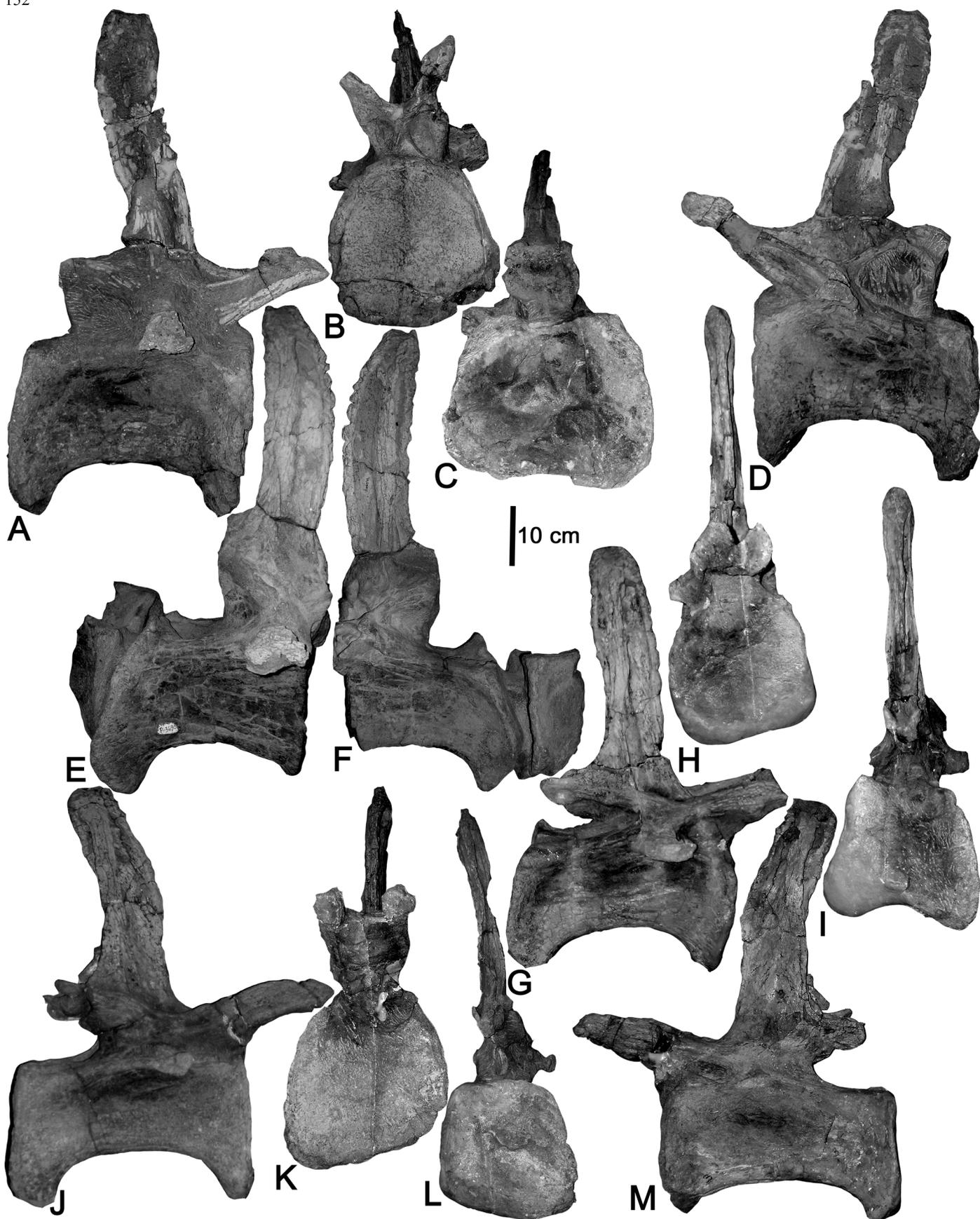


FIGURE 4. NMMNH P-3690, holotype of *Seismosaurus hallorum*. A-D, caudal vertebra 13 in A, right lateral, B, anterior, C, posterior, and D, left lateral view. E-F, caudal vertebra 14 and partial caudal centrum 15 in E, right lateral and F, left lateral view. G-I, caudal vertebra 16 in G, right lateral, H, anterior, and I, posterior view. J-M, caudal vertebra 17 in J, right lateral, K, anterior, L, posterior, and M, left lateral view.

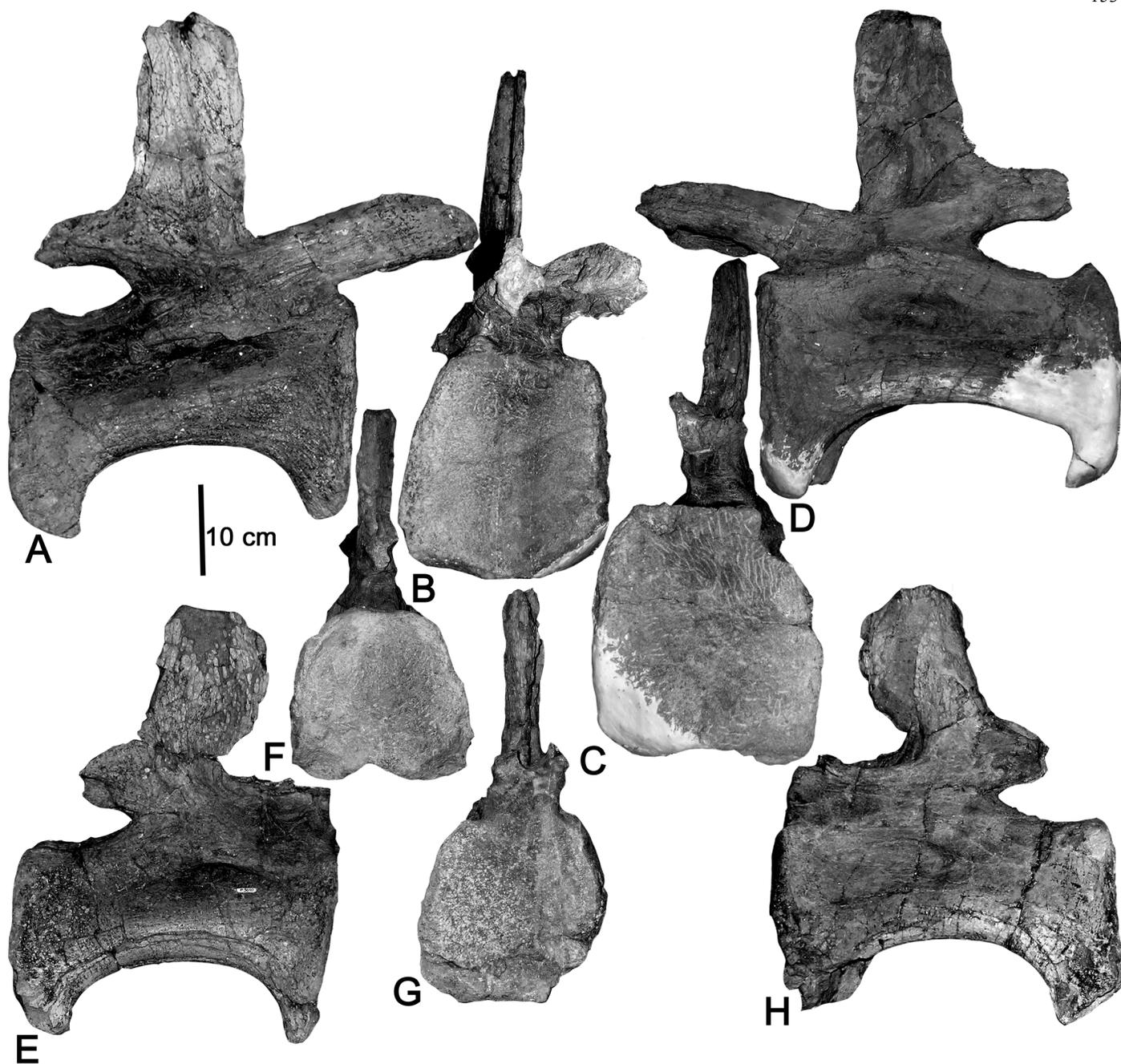


FIGURE 5. NMMNH P-3690, holotype of *Seismosaurus hallorum*. **A-D**, caudal vertebra 18 in **A**, right lateral, **B**, anterior, **C**, posterior, and **D**, left lateral view. **E-H**, caudal vertebra 19 in **E**, right lateral, **F**, anterior, **G**, posterior, and **H**, left lateral view.

unprepared. The centrum is opisthocoelous and has a single ventral keel. Dorsally, the neural spine is tall, bifurcated and appears similar to the dorsal neural spines of *Diplodocus* illustrated by Osborn (1899). The prezygapophyses are triangular, dorsomedially directed and concave in anterior view. In anteroposterior view, the neural canal is triangular. In thoracic vertebrae 4 and 5, the centra are detached from the neural arch; the neural spines are illustrated in Figure 10A, C.

Herne and Lucas (2006) describe many morphological details of thoracic vertebrae 3-10 (Fig. 10) and illustrate thoracic vertebrae 3, 4 and 8; we also provide some sketches and metrics of the thoracic vertebrae as they appear in the dorsal block (Figs. 11-12). Importantly, the transition from open (V-shaped in anteroposterior view) to fused, Y-shaped neural spines is evident on the incompletely prepared dorsal block that contains thoracic vertebrae 4-10. Moving posteriorly, the angle between the two

lateral projections of the neural spines decreases between thoracic vertebrae 4-5 (V-shaped) and 6-7, which have the Y-shaped neural spines. In all preserved thoracic vertebrae, the neural spines are more than twice the height of the centrum, a typical diplodocoid character (e.g., McIntosh, 1990a; Wilson and Sereno, 1998) but less than the four times centrum height, which is typical of dicraeosaurid sauropods (McIntosh, 1990a; Wilson, 2002). These features also distinguish *Seismosaurus* from the basal diplodocoid *Suuwassea*, recently described from the Morrison Formation in Montana by Harris and Dodson (2004).

Ilium and Sacrum

Gillette (1991) and Herne and Lucas (2006) provide descriptions and measurements of the ilium and sacrum of *Seismosaurus*. The right ilium, illustrated here (Fig. 6A), is the more complete, but is

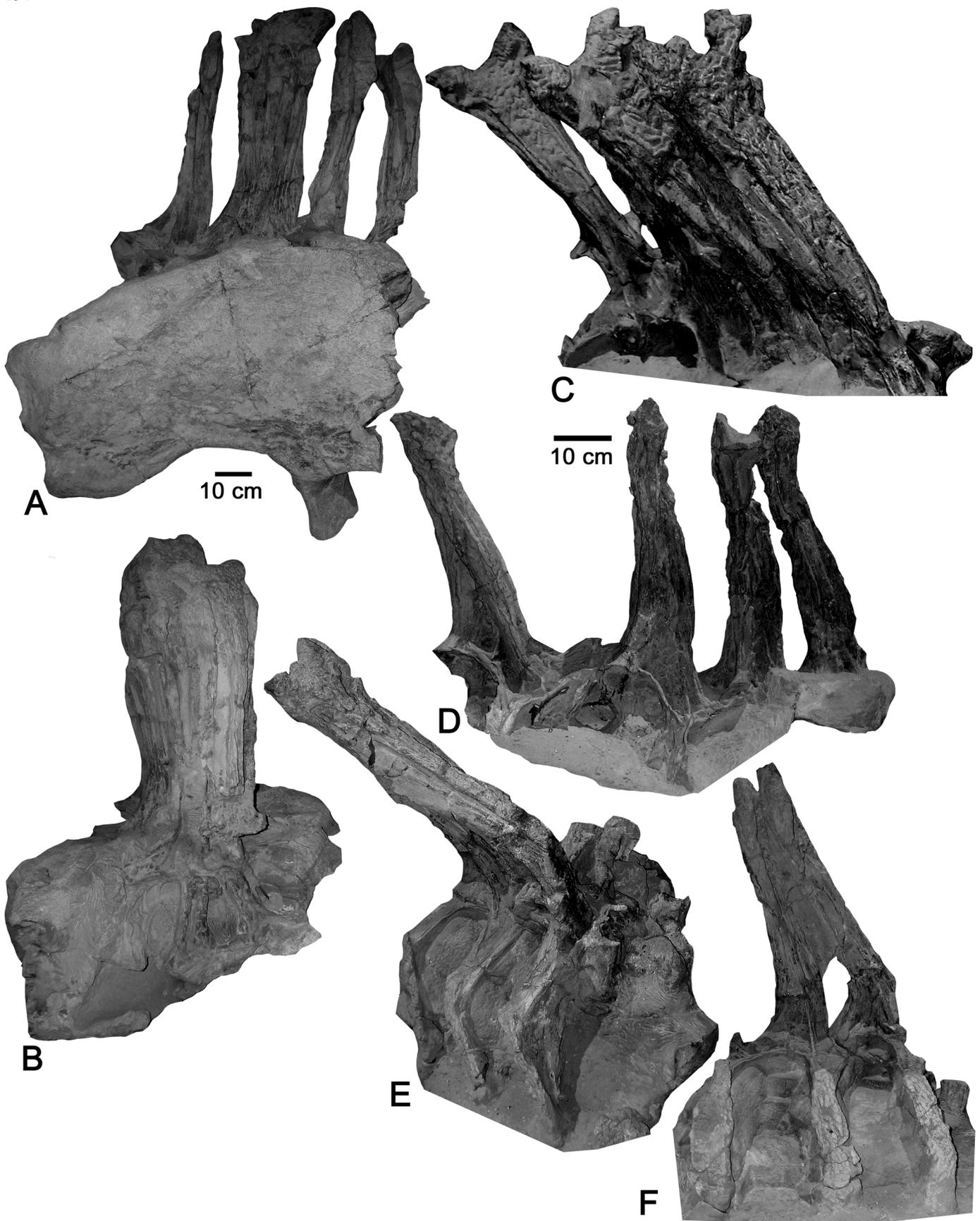


FIGURE 6. NMMNH P-3690, holotype of *Seismosaurus hallorum*. **A-B**, incomplete ilium and sacrum in **A**, right lateral and **B**, anterodorsal view. **C-D**, fourth through seventh caudal neural spines in **C**, right dorsolateral and **D**, right lateral view. **E-F**, second and third caudal neural arches in **E**, right dorsolateral and **F**, right lateral view.

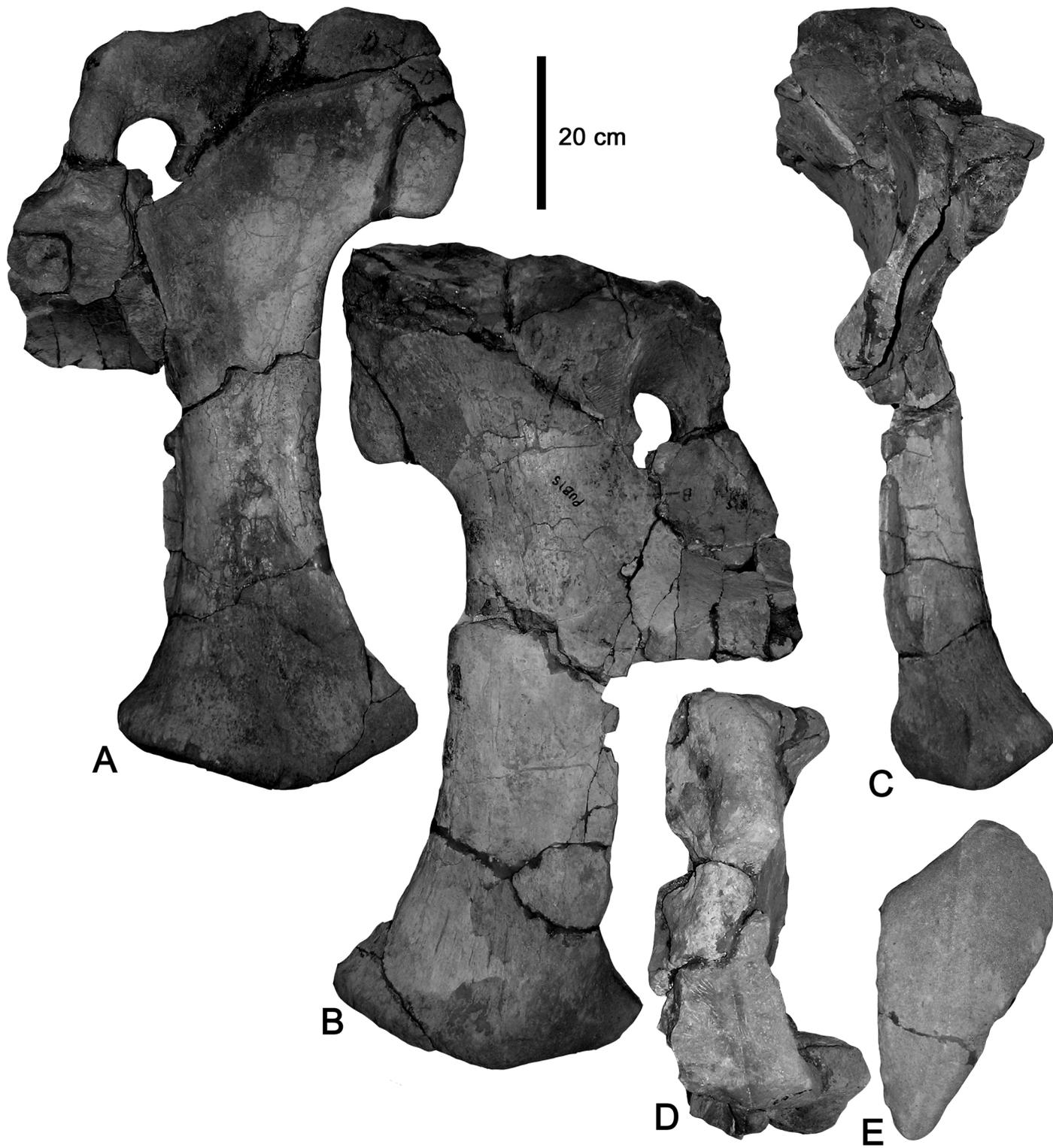


FIGURE 7. NMMNH P-3690, holotype of *Seismosaurus hallorum*. A-E, left pubis in A, medial, B, lateral, C, posterior, D, proximal, and E, distal view.

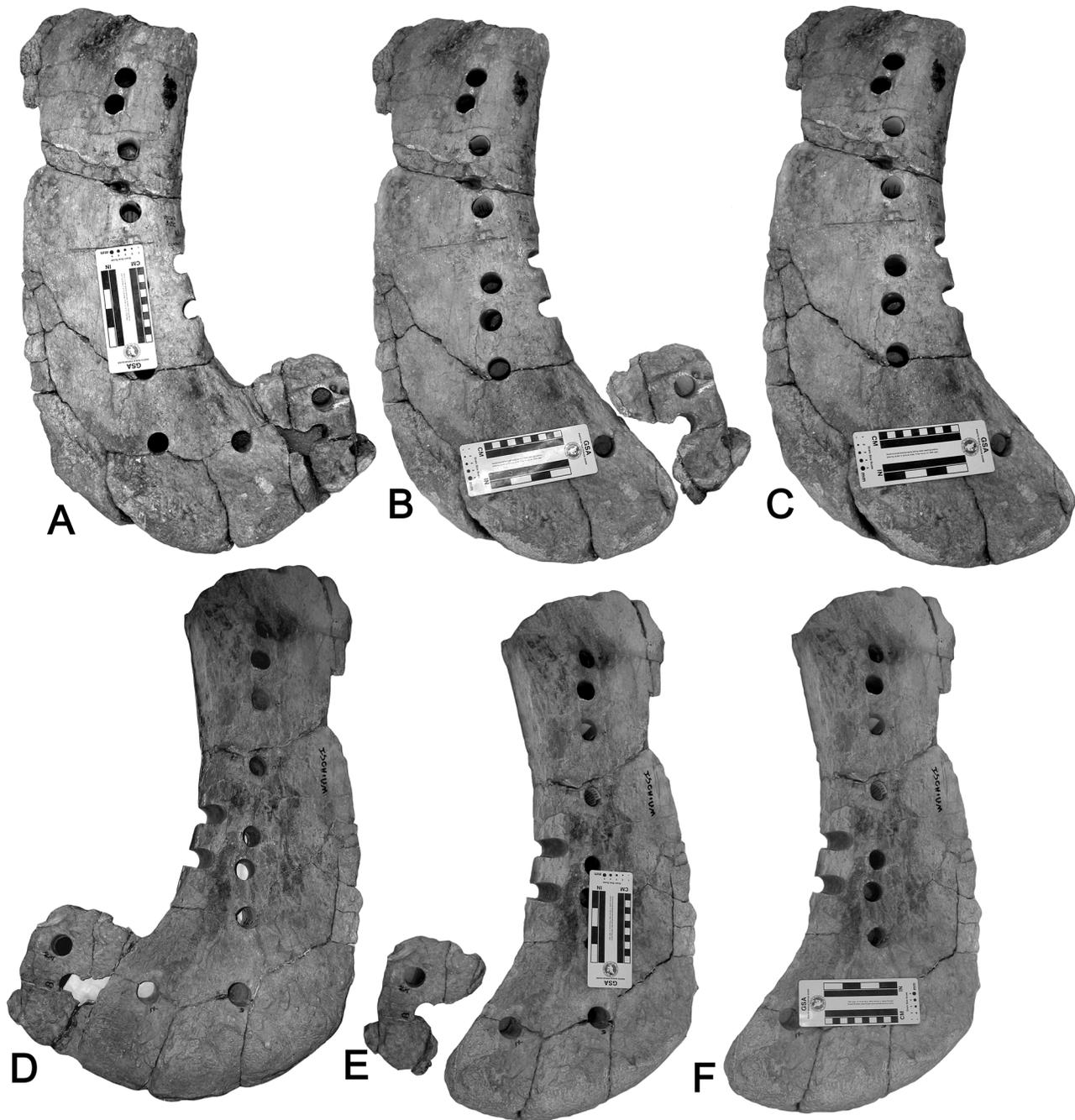


FIGURE 8. NMMNH P-3690, holotype of *Seismosaurus hallorum*, incomplete left ischium in A-C, lateral and D-F, medial views. In A and D, the piece of vertebral neural spine is still attached to the ischium. In B and E it has been removed, and C and F show the fully prepared, incomplete ischium.

missing the anterior prong. It is slightly arched and is firmly connected to the five sacral vertebrae. The sacrum (Fig. 6A-B) has tall, anteriorly-angled neural spines, of which the second, third and fourth are firmly fused together.

Caudal Vertebrae

The vertebral centra of the second through sixth caudal vertebrae are unprepared. These vertebrae were collected in two large blocks, one containing the first and second (Fig. 6E-F) and the other containing the fourth through seventh caudal vertebrae (Fig. 6C-D). The first caudal neural spine is sharply angled posteriorly (this is taphonomic distortion) where it is fused to the third caudal neural spine. The fourth

through seventh caudal neural spines are tall and slightly triangular in lateral view, and they are also slightly directed posteriorly, but not to the same extent as the first caudal neural spine. All these neural spines share the dorsal bifurcation that gives them an overall Y-shape in anteroposterior view similar to that seen in thoracic vertebrae 6-10. This contrasts with the anterior thoracic vertebrae, which have neural spines that are bifurcated near their bases not their dorsal tips, giving them a V-shape in anteroposterior view.

The other caudal vertebrae (Figs. 3-5) are now assigned positions 8 and 11-19 (Fig. 2). They have been described by Gillette (1991), Curtice (1996) and Herne and Lucas (2006).

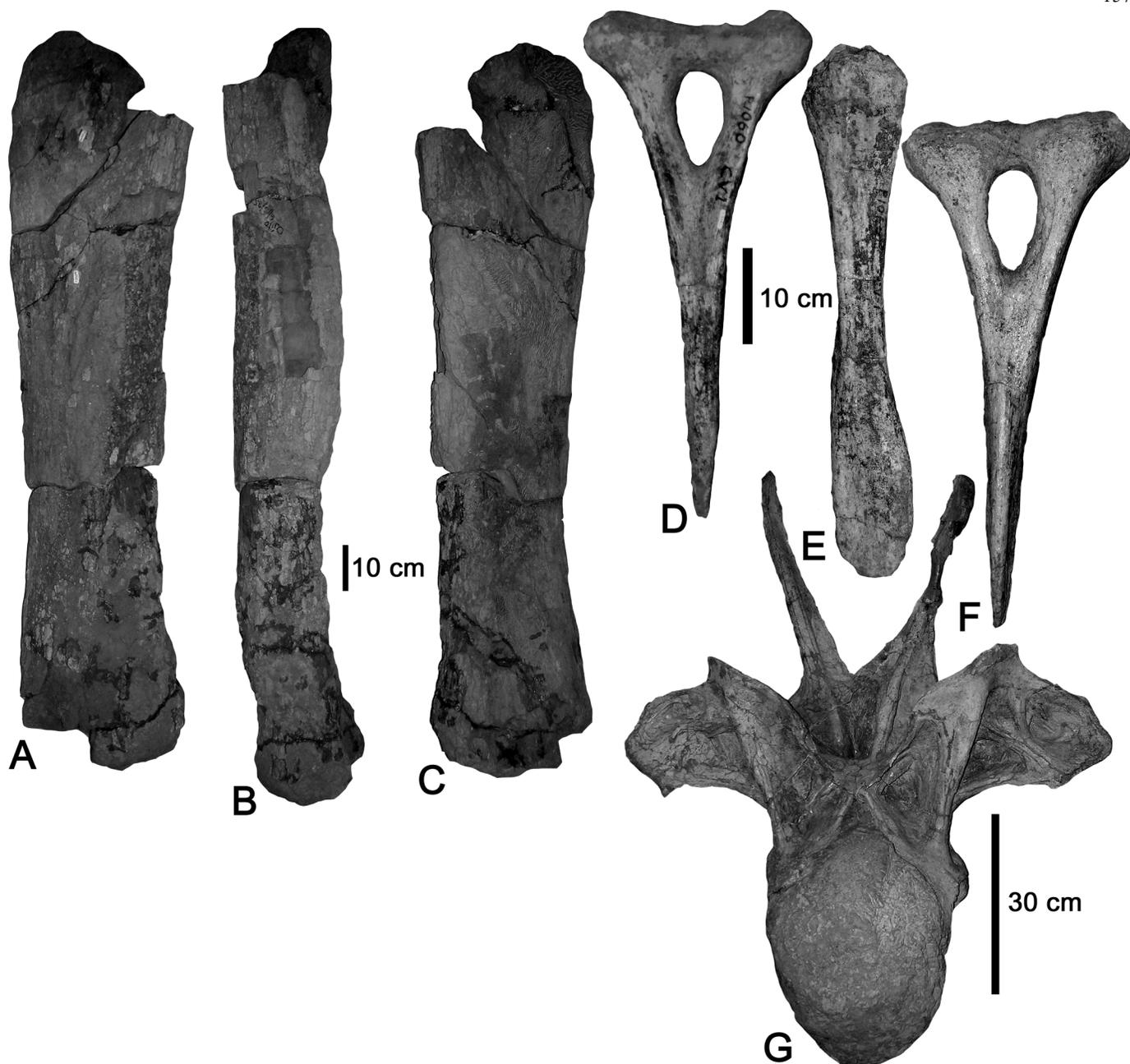


FIGURE 9. A-C, NMMNHP-25079 right femur in A, anterior, B, medial, and C, posterior view. D-G, NMMNH P-3690, holotype of *Seismosaurus hallorum*. D-F, second chevron in D, anterior, E, left lateral, and F, posterior view. G, thoracic vertebra 3 in anterior view.

Ribs and Chevrons

Ribs of the holotype of *Seismosaurus hallorum* (Gillette, 1991; Herne and Lucas, 2006) display no features that distinguish them from the ribs of other diplodocids. Gillette (1991, figs. 9-11) illustrated three chevrons, but one of these (his fig. 11) is obviously part of the proximal end of a cervical rib. The anterior chevrons (e.g., Fig. 9D-F) have expanded, paddle-shaped distal ends.

Pubis and Ischium

Gillette (1991) and Herne and Lucas (2006) described the essentially complete pubis (Fig. 7) and incomplete ischia (Fig. 8). Gillette drilled and removed several cores from the left ischium (Fig. 8). The incomplete right ischium preserves a portion of the ischial shaft that

provides no information beyond that seen in the left ischium.

Close examination of the left ischium indicates that the distal, hook-like expansion of the ischium was the tip of a vertebral neural arch and sandstone matrix adhering to the ischium (Fig. 12). Indeed, this y-shaped tip of a neural spine is probably from a caudal vertebra, some of which are missing this portion of the neural spine. Further preparation has defined the real shape of the distal end of the ischium by uncovering the actual posterior edge of the bone to the distal tip (Fig. 8). This shape is not a hook-like expansion, but instead a slight posterior swelling of the distal end.

Femur

Herne and Lucas (2006) described the incomplete right femur (Fig. 9A-C), which is now included in the holotype of *Seismosaurus hallorum*.

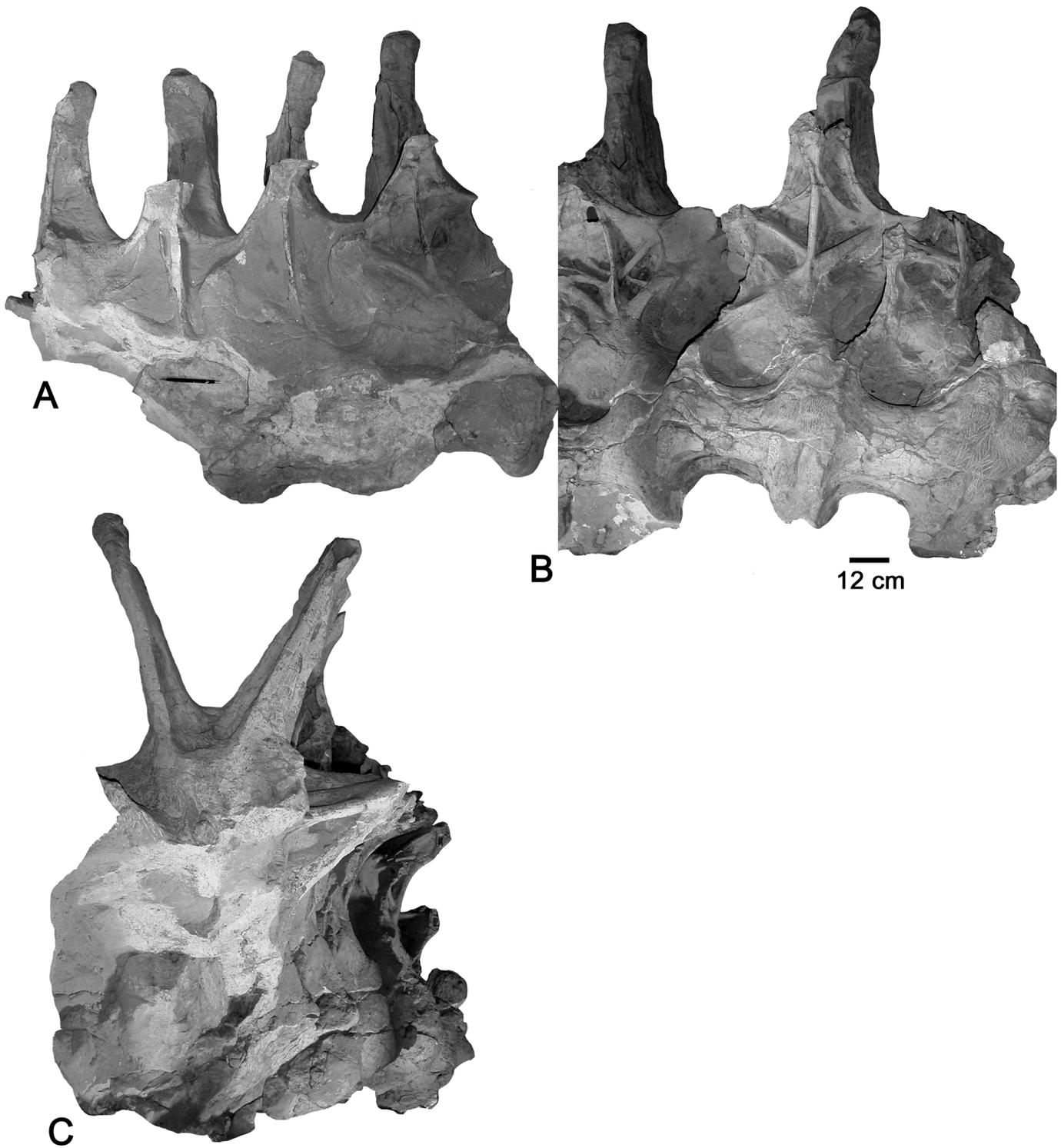


FIGURE 10. NMMNH P-3690, holotype of *Seismosaurus hallorum*. Partially prepared dorsal block. **A**, dorsal vertebrae 4 through 7 in left lateral view, **B**, dorsal vertebrae 8 (partial) through 10 (without neural spine), **C**, dorsal vertebrae 4 through 10 in anterior view. The pen in **A** is for scale and is 14.5 cm long.

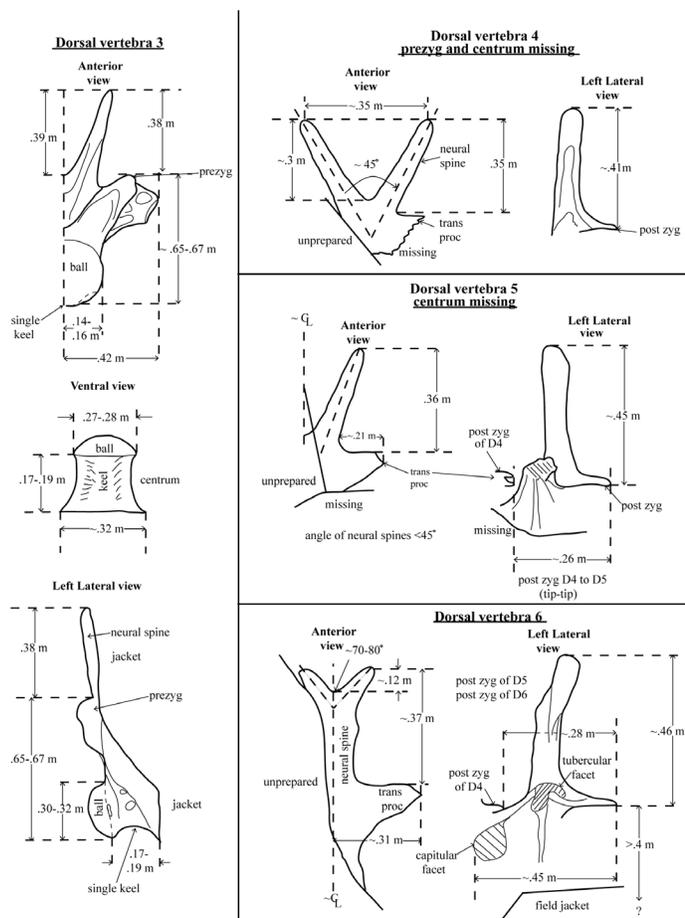


FIGURE 11. NMMNH P-3690, holotype of *Seismosaurus hallorum*. Sketches and measurements of thoracic vertebrae 3-6 of the unprepared dorsal block. Abbreviations are: pre zyg = pre-zygopophysis, post zyg = post-zygopophysis, trans proc = transverse process.

This element was found as float in close proximity (~6 m) to the caudal vertebrae that were the first fossils of *Seismosaurus* found. Consequently, it was assigned a different specimen number (P-25079). As Herne and Lucas (2006) document, restoration of this element to its proper (uneroded) size agrees remarkably well with femoral size estimates for the skeleton of *Seismosaurus* based on the vertebrae, so we are certain that it is part of the holotype skeleton.

VALIDITY OF *SEISMOSAURUS*

Gillette (1991, p. 418) listed putative diagnostic features of *Seismosaurus*, which we re-evaluate here. These are features of the pubis, ischium, caudal vertebrae and caudal chevrons. Here, we review these features to demonstrate that they fail to differentiate *Seismosaurus* from *Diplodocus*.

Pubis

The putative diagnostic features of the pubis of *Seismosaurus* can be summarized as pubis relatively shorter and more robust than in other diplodocids. Gillette (1991) expressed this in his diagnosis of *Seismosaurus* as two metric ratios: (1) ratio of transverse diameter to anteroposterior diameter lower than in *Diplodocus* and *Apatosaurus*; and (2) transverse diameter of distal expansion and minimum transverse diameter greater than corresponding diameters. Overall shape of the pubis of *Seismosaurus* is very similar to that of *Diplodocus* in having a squared-off proximal end for articulation with the ilium around the acetabular margin, a relatively short articular process for the ischium and a distal end that is expanded ante-

riorly but not posteriorly. These features distinguish the pubes of *Seismosaurus* and *Diplodocus* from those of *Apatosaurus* and *Barosaurus*. Indeed, the isolated pubis of *Seismosaurus* can simply be viewed as a relatively robust pubis of *Diplodocus* and well within the confines of variation within that genus.

Ischium

The shape of the ischium has been considered unique to *Seismosaurus*, in particular, it supposedly has a convex anterior margin and is markedly hooked posteriorly because of the expanded distal prong. Gillette expressed the putative distinctiveness of the ischium in four supposedly diagnostic characters: (1) ratio of transverse and antero-posterior diameters to length less than in other diplodocids; (2) shaft margins parallel and weakly curved medially; (3) expansion of distal end relative to shaft minimum diameter greater than in other diplodocids; and (4) distal extremity of ischium not fused at midline. Upchurch et al. (2004, p. 305) argued that the hook-like process of the distal end of the ischium is the only morphological character that diagnoses the genus *Seismosaurus*.

Note that, at most, the first two characters listed above are relatively minor variations in proportions, comparable to those in the pubis of *Seismosaurus*. Furthermore, character 1 is based on the estimated length of the incomplete *Seismosaurus* ischia, so its reliability is questionable. And, character 3 has been altered greatly by further preparation of the ischium.

As noted above (also see Fig. 8) the hook-like distal process of the holotype of *Seismosaurus hallorum* was not real. The more completely prepared distal ischium has a shape much like that of *Apatosaurus* and *Diplodocus* and even lacks the pronounced postero-distal process Jensen (1985, fig. 7A) illustrated in "*Supersaurus*." Indeed, the differences between the ischia of *Diplodocus* and *Seismosaurus* are no greater than the differences between the ischia of *Apatosaurus ajax* and *A. excelsus* illustrated by McIntosh (1990b, fig. 4.7). These are differences in robustness and particularly in the degree and manner of expansion of the distal end of the ischium.

Caudal Vertebrae and Chevrons

According to Gillette (1991), the caudal vertebrae and chevrons are unique in *Seismosaurus*. He listed this as six characters: (1) caudal vertebrae longer than in other diplodocids; (2) neural spines of median caudals taller and more erect than in other diplodocids; (3) ratio of overall height of caudal vertebrae to height of centra greater than in other diplodocids; (4) pleurocoels small in or absent from more distal caudals; (5) anterior caudal chevrons larger than in other diplodocids and expanded distally into paddle-shaped lateral profile; and (6) mid-caudal chevrons larger than in other diplodocids, triangular in lateral aspect.

Repositioning of the caudal vertebrae eliminates some of these features as diagnostic (Curtice, 1996; Herne and Lucas, 2006). Caudals 11-19 of *Seismosaurus* are longer than those of *Apatosaurus* and *Diplodocus*, but the more proximal caudal vertebrae are close in length to the holotype of *D. carnegii*. The caudal neural spines of *Seismosaurus* are unusually tall, but this is a variable character in diplodocids (Gilmore, 1932; Curtice, 1996). *Seismosaurus* is like other diplodocids in having caudal vertebrae with erect neural spines and double-keeled ventral surfaces. Curtice (1996) noted that pleurocoels are present on all the caudal vertebrae of *Seismosaurus*.

The anterior chevrons of *Seismosaurus* (e.g., Fig. 9E) have expanded, paddle-shaped distal ends that differ from the unexpanded tips of the chevrons of *Diplodocus*. The anterior chevrons of *Seismosaurus* thus are more like those of *Apatosaurus* (e.g., Ostrom and McIntosh, 1966, pl. 35, figs. 4-5). The caudal vertebrae of *S. hallorum* thus do not differ from those of *D. carnegii* except in some dimensions. The only feature of the anterior chevrons of *S. hallorum* that distinguishes them from anterior chevrons of *Diplodocus* are their paddle-shaped distal ends. Nevertheless, one of us (JRF) has seen isolated chevrons in the Morrison Formation

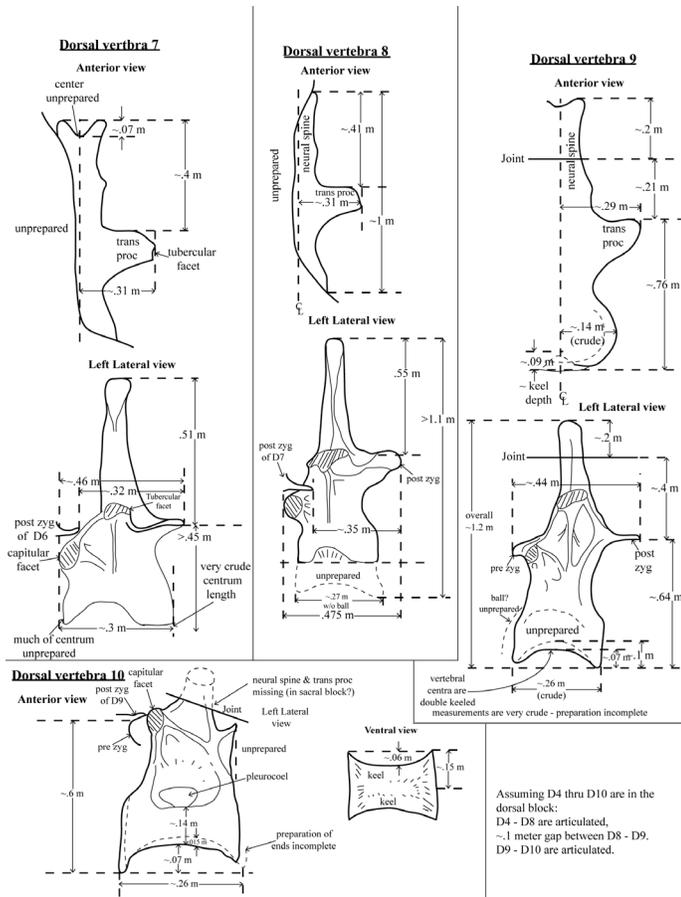


FIGURE 12. NMMNH P-3690, holotype of *Seismosaurus hallorum*. Sketches and measurements of thoracic vertebrae 7-10 of the unprepared dorsal block. Abbreviations are: pre zyg = pre-zygopophysis, post zyg = post-zygopophysis, trans proc = transverse process.

with such paddle-shaped ends, some isolated and at least one associated with an *Apatosaurus* skeleton, so these chevrons may not be unique to *Seismosaurus*.

Seismosaurus* = *Diplodocus

Upchurch et al. (2004, p. 305) stated that other than the hook-shaped distal ischium, the purportedly diagnostic features of *Seismosaurus* “are either subtle differences in proportion that could reflect the large size of *Seismosaurus* or plesiomorphic characters that are widespread among other sauropods.” We agree with this statement, and note that the elimination of the hook-shaped distal ischium as a valid characteristic makes it impossible to differentiate *Seismosaurus* from *Diplodocus* other than on minor and/or subtle differences in size and robustness of some bones. These differences do not provide a valid basis for generic distinction, so we consider *Seismosaurus* a junior subjective synonym of *Diplodocus*.

THE SPECIES OF *DIPLODOCUS*

There are four named species of *Diplodocus*: *D. longus* Marsh, 1878 (the type species), *D. lacustris* Marsh, 1884, *D. carnegii* Hatcher, 1901 and *D. hayi* Holland, 1924. These species are routinely listed as valid (e.g., McIntosh, 1990a, b; Upchurch et al., 2004), although convincing arguments for their validity are difficult to construct. Thus, *D. longus* and *D. carnegii* are not demonstrably distinct (Gilmore, 1932). *D. lacustris* is based on fragmentary premaxillary, maxillary and dental material, elements that do not demonstrably vary among *Diplodocus* species, so it is best considered a *nomen dubium* (*nomen vanum*) (Curtice, 1996). *D.*

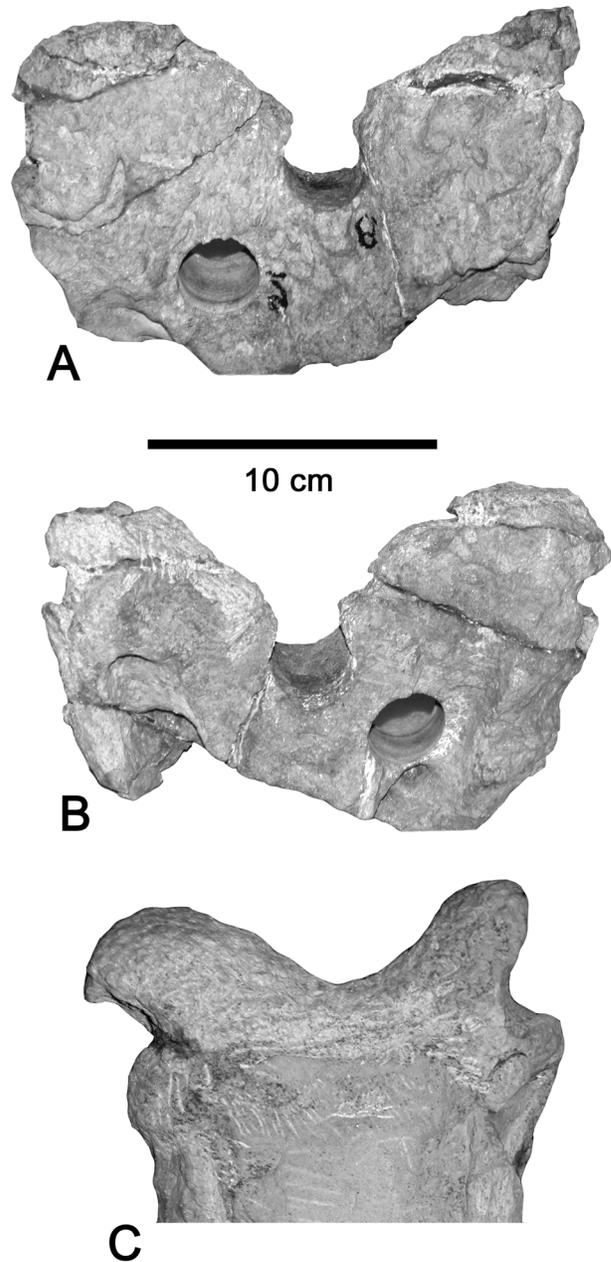


FIGURE 13. NMMNH P-3690, neural spine tips of *Seismosaurus hallorum*. A-B, the neural spine tip removed from the distal end of the left ischium, anterior (A) and posterior (B) views. C, Tip of neural spine of thoracic vertebra 9 in anterior view for comparison.

hayi, however, can be distinguished from *D. longus* and *D. carnegii* by characteristics of the skull and caudal vertebrae according to McIntosh (1990b).

Obviously, a rigorous revision of the species-level taxonomy of *Diplodocus* is needed, though such a revision faces the obstacle of needing to compare species that are not all known from (or diagnosed on) overlapping anatomical parts. In the absence of such a revision, we consider the holotype of *Seismosaurus hallorum* to represent a fifth species of *Diplodocus*, *Diplodocus hallorum*, distinguished by the minor morphological differences between it and other *Diplodocus* listed above, such as the more robust pubis and paddle-shaped expansions of the distal chevron ends. We have little confidence that these are even valid species-level differences, and suggest it is likely that *D. hallorum* is a

junior subjective synonym of *D. longus*. However, this suggestion can only be verified by a complete study of species-level variation in *Diplodocus* that is beyond the scope of this paper. This is a significant problem. Without a better understanding of the real morphological variation present within a genus of sauropod dinosaurs, at least some of the characters and character-states coded in the numerous phylogenetic hypotheses of sauropod relationships now available must be taken with the proverbial grain of salt.

ACKNOWLEDGMENTS

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