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New sauropod dinosaur material from Jones Ranch: a large Comanchean nonmammalian tetrapod from Texas

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ABSTRACT: New sauropod dinosaur material is described from Jones Ranch, Early Cretaceous of Texas (USA). Originally described as *Paluxysaurus jonesi*, the material from Jones Ranch has recently been referred to *Sauroposeidon proteles*. Elements newly prepared from dense concretionary matrix include the sacrum, ilium and proximal portion of the tail. Reconstructions of the skull and sacrum plus pelvic girdles are presented. '*Paluxysaurus jonesi*' (= *S. proteles*) is a blunt-faced sauropod that was originally regarded as closely related to *Brachiosaurus*. Portions of the sacrum are now exposed and show that it is nearly complete, missing only parts of the first sacral (S1). The anterior sacrals are firmly fused, however, a newly discovered opisthocoelous last sacral (S6) remains unfused. A complete sequence of proximal caudal vertebrae shows a rapid transition from anteroposteriorly short and mediolaterally broad centra anteriorly, to more elongate cylindrical centra posteriorly. All proximal caudals have slightly amphicoelous centra. Some middle anterior caudals have a shallow longitudinal groove on the ventral surface of the centrum. Specimens from Jones Ranch exhibit characters of the sacrum and tail that clearly corroborate placement of '*P. jonesi*' (*Sauroposeidon proteles)* as a somphospondylan titanosauriform.

KEY WORDS: anatomy, Cretaceous, relationships, Sauropoda, USA

'*Paluxysaurus jonesi*' was designated the state dinosaur of Texas and when it was described, it was the only sauropod dinosaur of any age that had been named from the Lone Star State (Rose 2007). Recent work by D'Emic & Foreman (2012; and D'Emic, in press cited therein) synonymises '*Paluxysaurus jonesi*' with *Sauroposeidon proteles*. The latter was named from a series of large cervical vertebrae found in the nearly coeval Antlers Formation of Oklahoma (Wedel *et al.* 2000). D'Emic & Foreman (2012) also refer sauropod material from the Cloverly Formation of Wyoming to this taxon, greatly extending the range and significance of this dinosaur. We use the name '*Paluxysaurus jonesi*' below to clarify our references to the Jones Ranch, but accept use of the name *S. proteles* pending vetting of the referral.

Several individuals of this Early Cretaceous (latest Aptian–earliest Albian; approximately 112 Ma) sauropod were discovered at Jones Ranch (Hood County, Texas) in fluvial sediments of the Twin Mountains Formation (Winkler & Rose 2006; Rose 2007). Work at Jones Ranch, like many other dinosaur discoveries in Texas, can be credited to Wann Langston. He was among the students who investigated a dinosaur find, possibly at Jones Ranch, reported to the Smithsonian Institution in the 1940s and he led the parties that were responsible for the (re)discovery and initial excavations of '*Paluxysaurus*' in the 1980s. Wann and his students also discovered or described several other important sauropod specimens from the Early and Late Cretaceous of Texas (Langston 1974; Gallup 1989; Lehman & Coulson 2002). Our work builds on the solid foundation provided by Wann.

A minimum of four sauropod individuals are represented by semi-articulated to isolated and tumbled skeletal elements tightly associated within a restricted outcrop area at Jones Ranch (Winkler & Rose 2006). Seven femora represent the most common element that has been confidently identified. There is little significant taxonomically informative variation in morphology between individuals, corroborating the presence of a single sauropod taxon at Jones Ranch, with three individuals being approximately equal in size (Rose 2007). The forelimb of a fourth smaller individual has not been fully prepared, but field measurements indicate a specimen that is 15–25% smaller than the other individuals.

When Rose (2007) described '*P. jonesi*', many of the bones that had been excavated remained under preparation from intractable concretionary matrix. Previously unstudied elements have been prepared subsequently, and new reconstructions have been made in connection with the completion of a full skeletal mount that is now on display at the Fort Worth Museum of Science and History. '*Paluxysaurus jonesi*' (= *Sauroposeidon proteles*) from Jones Ranch was considered a primitive titanosauriform sauropod most closely related to *Brachiosaurus* (and now *Giraffatitan*) (Rose 2007; Taylor 2009; Carballido *et al.* 2011). D'Emic & Foreman (2012) suggest a more derived position as a basal somphospondylan. We report here on the newly prepared skeletal elements that include the proximal portion of the tail, and offer them and reconstructions of the skull and pelvis as a means to better understand the anatomy and relationships of '*Paluxysaurus*' = *Sauroposeidon*.

Institutional abbreviations: FWMSH, Fort Worth Museum of Science and History, Fort Worth, Texas USA; SMU, Shuler Museum of Paleontology, Southern Methodist University, Dallas, Texas USA.

1. Material and methods

Many of the bones from Jones Ranch (JR) are encased in dense matrix of calcite-cemented siliceous sand. One block containing much of a sacrum and pelvis (field block JR 1997–6) originally weighed 11 tons as removed from the field. Preparation to its current state has taken 15 years. Figure 1 shows the arrangement of relevant blocks discussed in this paper. Measurements

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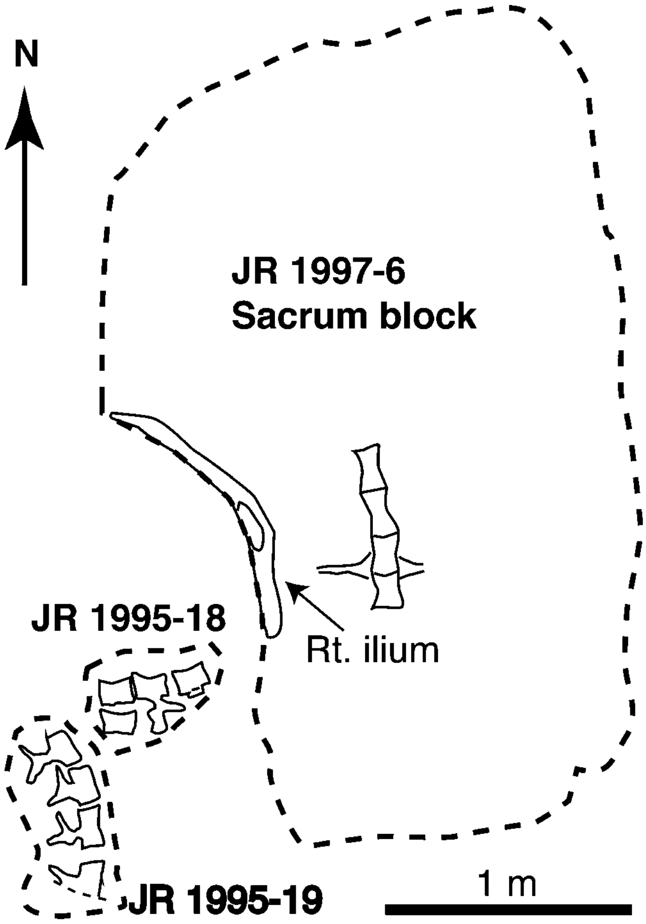

Figure 1 Sketch of field relationships of sacrum/pelvis block (JR 1997–6) and associated blocks containing more distal caudal segments (JR 1995-18 and 19).

of the height and widths of caudal vertebrae were made on the posterior surface of the centrum where possible.

In order to reconstruct missing or incomplete parts of the skeleton, elements of the skull, sacrum and pelvis were initially surface scanned with a NextEngine laser scanner. Laser scans were stitched with NextEngine ScanStudio. In the process of building the Fort Worth Museum mount, certain parts had to be fabricated in light material to accommodate weight constraints. For parts that were to be CNC milled for mounting, scans were exported as OBJ files. These were then simplified as spline models created in LightWave 3D using the surface models, and finally exported again as OBJ files. Zbrush was used on these OBJ files to sculpt missing parts and add surface texture where it was missing. The results were brought back to LightWave 3D and split into layers for the machining process. Accutrans was used to convert the LightWave files into STL format and these were imported into Mecsoft VisualMILL to generate tool paths for a CNC mill.

2. Description

The holotype left maxilla of '*Paluxysaurus jonesi*' has been further prepared since its original description (Fig. 2; FWMSH 93B10-18) facilitating comparison with more recently described taxa. *Abydosaurus mcintoshi* was described from a complete skull and several partial skulls from the Early Cretaceous of Utah (Chure *et al*. 2010). *A. mcintoshi* has a rostrally elongated maxilla, similar to that of closely related African and North American *Giraffatitan* and *Brachiosaurus*. Part of the anterior end of the maxilla from Jones Ranch is broken. The body of the maxilla thins at this point making it unlikely that the maxilla had a long anterior extension. We interpret the missing portion as triangular in shape, just filling the anterior space defined by linearly projecting the narial and ventral borders. The maxilla of '*P. jonesi*' is relatively taller and less expanded rostrally than that of *A. mcintoshi.* The ventral edge of the maxilla of '*P. jonesi*' steps up (dorsally) in lateral view, just posterior to

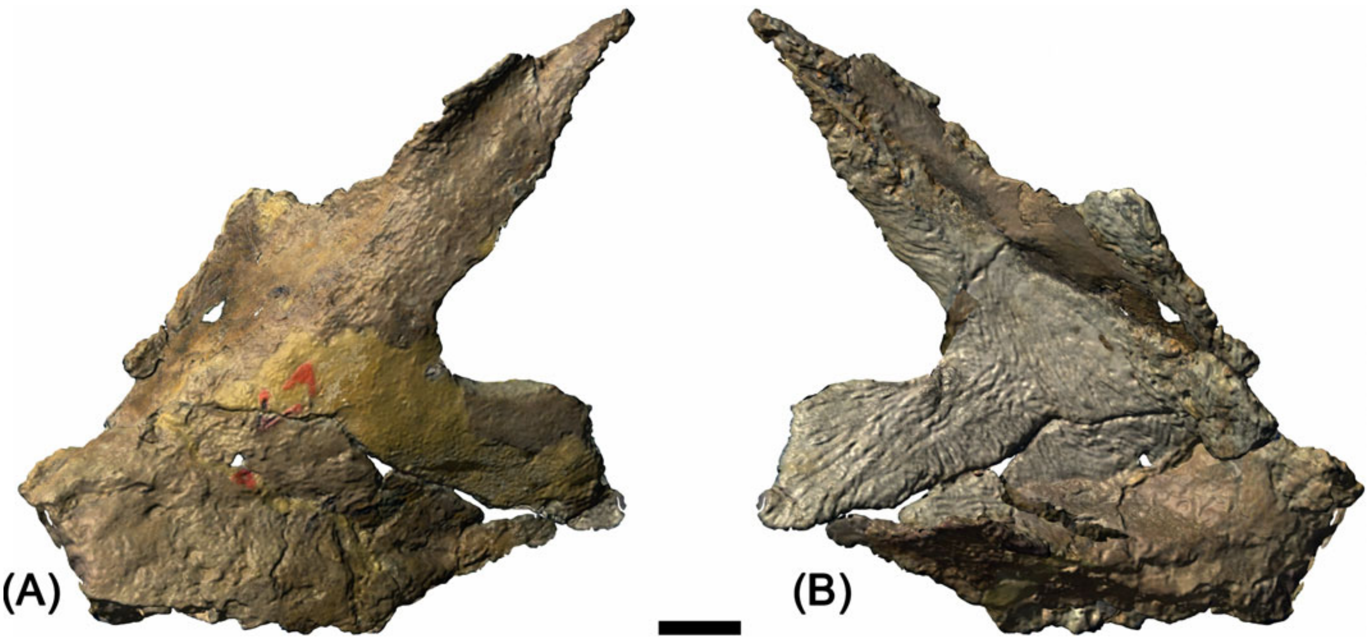

Figure 2 Left maxilla of '*Paluxysaurus jonesi*' (FWMSH 93B10-18; holotype) in (A) lateral view and (B) medial view; renderings from laser scans. Scale bar = 5 cm.

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Figure 3 Left maxilla of '*Paluxysaurus jonesi*' (FWMSH 93B10-18) showing broken anterior teeth and replacement tooth; medial view. Scale bar = 2 cm.

the end of the tooth row, unlike the maxilla of *A. macintoshi*. *Giraffatitan brancai* (Janensch 1950) and *Brachiosaurus* sp. (Carpenter & Tidwell 1998) also show this ventral step in the posterior portion of the maxilla. Some sauropods with elongate snouts also exhibit a ventral step posteriorly, but these maxillae and skulls are quite differently configured.

Rose (2007) estimated that 9–10 tooth positions were present. Seven tooth positions are now clear – the first two teeth are in place but have their crowns broken off and the crowns of two replacement teeth are visible *in situ* (Fig. 3). It appears that no more than nine teeth could have fit in the maxilla as it is preserved. Few, if any, tooth positions appear to be missing in the anterior triangle broken from the maxilla. All of the middle and posterior maxillary teeth that had been in functional use during life have fallen out of their sockets post-mortem. Four of the dislodged teeth, recovered immediately adjacent to the maxilla, are shown in Figure 4. The teeth are slightly longer mesiodistally than they are labiolingually, averaging 10–11 mm long and 9–10 mm wide. Tooth shape in '*P. jonesi*' is not greatly different from that described in *Abydosaurus mcintoshi* (Chure *et al*. 2010). The maxillary teeth are asymmetrical with a labial swelling off-center toward the mesial margin and carinae that twist upward, resulting in a tooth tip that is turned relative to the mesial-distal axis of the jaw. Some isolated sauropod teeth from the Cloverly Formation that were described (but not definitely allocated to *Sauroposeidon*) by D'Emic & Foreman (2012) also exhibit this twist in the crown.

The pelvic region is preserved upside-down. An articulated partial left hindlimb was previously removed and is among the material already referred (Rose 2007). The ventral portion of the sacrum and parts of its lateral aspects (FWMSH 93B-10-27) are now visible (Fig. 5). When Rose (2007) briefly described the sacrum, little except parts of the ventral portions of the centra and basal ribs were exposed. He designated the vertebrae that were visible S2–S5. Preparation has now exposed an additional posterior sacral vertebra not seen originally. The new sacral was not fused with the anterior group and had fallen dorsally post-mortem (below the others as preserved). We interpret the sacrum as preserving part of the first sacral (S1) and S2–S6. Sacral vertebrae S1 through S5 are fused, but the anterior-most section is poorly preserved. The last sacral (S6) is not co-ossified and, relative to the others, it has slipped dorsally exposing the anterior face of its centrum. It has a basal centrum length of 139 mm, shorter than preceding vertebrae (S5 estimated ventral centrum length = 210 mm). Lines of suture are not clear on the bases of the more anterior sacrals, preventing confident measurements of individual lengths. The preserved length of the fused sacrum (through S5 but missing parts of S1) is 875 mm, which means that the total sacral length was greater than 1014 mm. Mediolaterally, from yoke to yoke, the ventral surface of the sacrum is an estimated 817 mm wide at S3, and 802 mm wide posteriorly at S5. The sacral rib of S2 (and apparently S1) is strongly inclined posteroventrally. Sacral 4 has a nearly vertical rib and the penultimate sacral (S5) exhibits a rib that is inclined anteroventrally, so that the lateral buttress (sacricostal yoke) projects more posteriorly along its dorsal border. Posteriorly, S5 exhibits a distinctly concave centrum articulation.

Sacral 6 is in close proximity with S5, but had rotated posteriorly to rest obliquely on its dorsal and posterior surfaces (Fig. 6). Because it is rotated out of articulation it can be seen that its centrum bears a distinct ball anteriorly. The posterior face of its centrum is not visible. Projecting dorsomedially, a large laterally expanded plate formed of the ribs is widest ventrally. It is not clear how it articulated with the sacricostal yoke. Not all of the rib is exposed, preventing detailed description.

All sacral centra have a rounded to flattened ventral surface without a ventral keel or strong lateral pinching. Crushing may have exaggerated their planar bases. The anterior sacrals have a rugose fragment of bone across the bases of their centra. Lateral surfaces are not well exposed, but a lateral depression or possible pleurocoel is visible on the centrum of the first sacral above the base of the ribs.

Six proximal caudal vertebrae have been newly uncovered (FWMSH 93B10-27) and remain in matrix in close association with the sacrum. In addition, two blocks, each containing four articulated caudals, were recovered slightly offset to the

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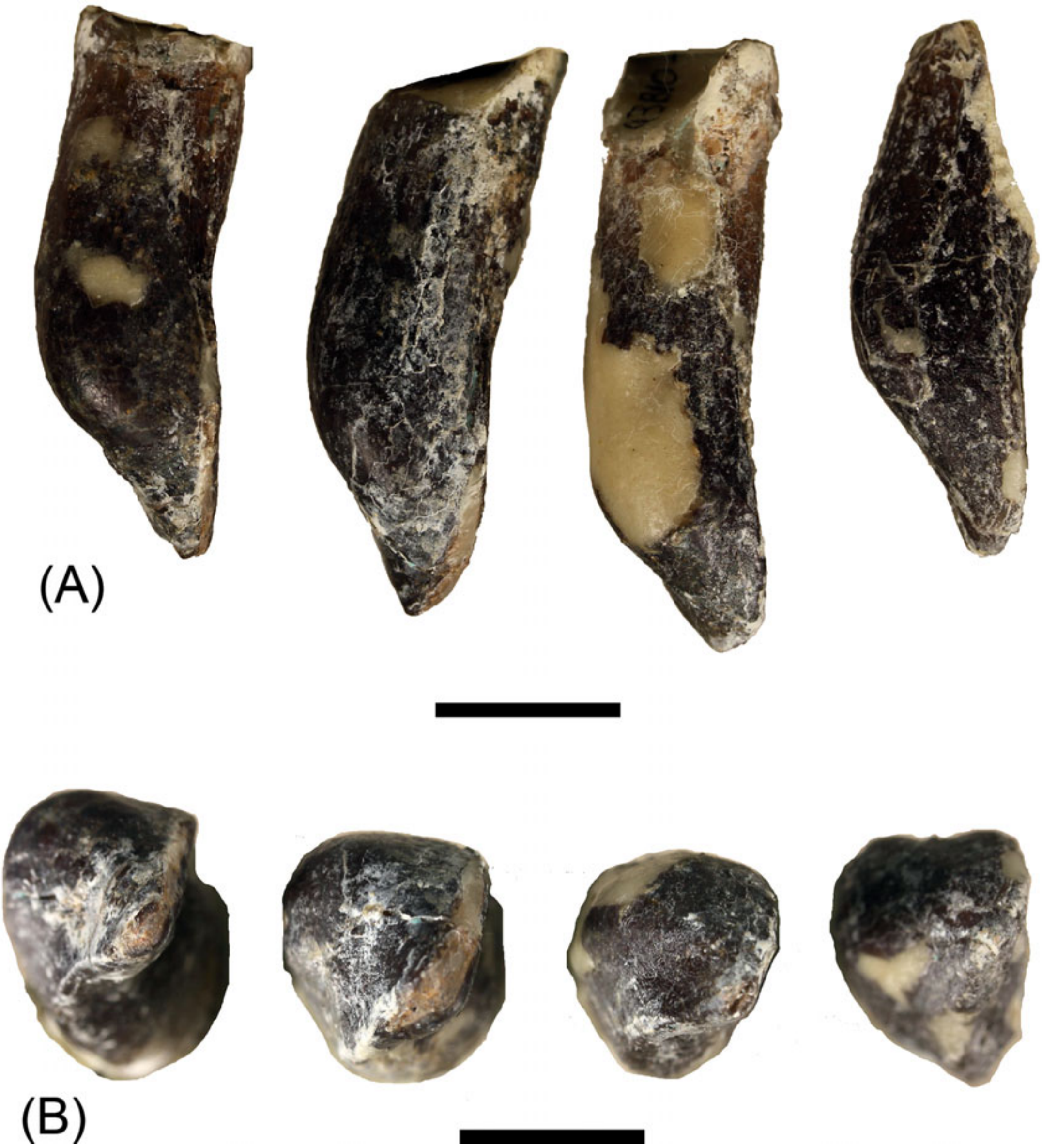

Figure 4 Teeth displaced from left maxilla of '*Paluxysaurus jonesi*' (FWMSH 93B10-18) in (A) lateral and (B) occlusal views. Scale bars = 1 cm.

west from the sacrum but continuing the caudal series from the sacral block. The articulated sets were excavated separately (as JR 1995-18 and JR 1995-19; Fig. 1). One additional caudal was lost in excavation. Thus, there were 15 caudals associated directly with the sacrum.

The caudals are offset 90° from the sacrum and arranged in a series from the left side of the body to right in a proximal to distal sequence. All of the anterior caudals are amphicoelous with mildly concave proximal and distal faces on the centra. Caudal vertebrae 1 and 2 are large in diameter but both have relatively compressed centra anteroposteriorly (caudal 1 is shortest anteroposteriorly), resulting in a much lower length to width ratio when compared to the succeeding vertebrae (Table 1). The centra of caudals 1 and 2 are wider mediolaterally than they are high dorsoventrally, but this ratio is most distorted in caudal 2 because of dorsoventral crushing. Ventrally, the centra are flattened giving a squared-off outline, also enhanced by crushing. They are both preserved upside-down. The weakly concave anterior surface of the centrum of caudal 1 suggests that the posterior surface of the centrum of S6 is also likely to be relatively flat. The neural spines are visible, in part, on caudals 1–3 (Figs 7, 8). Crushing has distorted the vertebrae to varying degrees, but the neural spines of all three are inclined posteriorly (enhanced by shearing). Neural spine tips in all anterior caudals are transversely expanded. An expansion of the transverse processes is present to a much greater degree in caudal 1 than in caudal 2, especially in its dorsolateral projection. Only a swelling remains of the dorsolateral expansion on caudal 2, where the transverse process meets the centrum and neural arch dorsally (Fig. 7). The lateral tip of the transverse process is also expanded dorsoventrally on caudal 1, but the terminus is a rounded knob on caudal 2. The neural spine of caudal 1 (partly covered and embedded in matrix below the centrum of caudal 2) displays a portion of a weak postspinal lamina. The lamina is developed only between the postzygopophyses and does not extend up the spine. A weak hyposphene articulation may have been present below the postzygopophysis on caudal 2, but the surface is eroded. No caudals exhibit a distinct hyposphene-hypantrum like the slightly younger sauropod (SMU 61732) from Texas described by Langston (1974) (see Tidwell *et al.* 1999; Rose 2007). Caudal vertebra 3 is partly exposed (abutted laterally against the posterior surface of the centrum of S6). On caudal 3, the full extent of the zygopophyses is visible. The centrum of the third caudal is more anteroposteriorly

Figure 5 Sacrum in ventral view (FWMSH 93B10-27). Left anterior section of sacricostal yoke is removed and the right ventral area is eroded off. Partial right ilium is under plaster. Scale bar = 10 cm.

Figure 6 Sacral 6 (FWMSH 93B-10-27) within block in oblique ventral view. Dashed line shows exposed edge of vertebra. Scale bar = 10 cm.

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Table 1 Sacral and caudal vertebrae of FWMSH 93B 10-27. Measurements in mm.

Vertebral position	Centrum Length	Centrum Width	Centrum Height
S6	176	212	144** (visible)
Caudal 1	72	199	184
Caudal 2	98	212	115**
Caudal 3	110**	95** (crushed)	170**
Caudal 4	109*	125**	170**
Caudal 5	119* (visible)	–	–
Caudal 6	–	160	140**
Caudal 8	120*	–	–
Caudal 9	115	91**	136*
Caudal 10	138**	–	139**
Caudal 11	133**	–	130**
Caudal 12	120**	110**	–
Caudal 13	120**	–	–

* estimated; ** as preserved

Figure 7 Caudal 2 (FWMSH 93B10-27) in posterior view as exposed. Scale bar = 5 cm.

elongated compared to the first two. Caudals 3 through 6 are rotated relative to 1 and 2 so that they rest on their right sides and the centra suffer some lateral crushing. Caudals succeeding the 3rd demonstrate a continued anteroposterior elongation of the centra compared to their height (Table 1). Only parts of the centra of caudals 4 to 6 can be seen. The transverse processes remain simple, rod-like and large through caudal 6. Caudals 8–11 were recovered nearly articulated in a block (JR 1995-18) adjacent to the caudal 6 (7 was lost) from the sacral/pelvic block. Of those, caudal 9 is the most complete (Fig. 9). All of the vertebrae from this block, including caudal 9, are crushed mediolaterally, distorting their width and dorsoventral height. All except caudal 9 are missing the neural arches. The centra appear weakly amphicoelous and have no lateral depressions. Despite the crushing, ventrolateral ridges and shallow ventral hollows are observable on the centra of caudals 9 and 10, and questionably on 11. Other isolated caudals from Jones Ranch, referred by Rose (2007), also display a shallow ventral groove and are presumably from a similar position in the tail. More anterior caudals and more posterior caudals are not grooved ventrally. Reduced transverse processes were present in the vertebrae of block JR 1996-18, but they are crushed. This can be seen most clearly on caudal 9, which retains a distinct swelling representing the transverse process. Block JR 1995-19 was found adjacent to JR 1995-18. It contains caudals 12–15, but remains unprepared. Estimated measurements were made on several of these caudals while in the field (Table 1) and some morphology could be determined. It appears that the transverse processes are absent by approximately caudal 14.

Both ilia were preserved in articulation with the sacrum. The right ilium is fused to the sacrum and is still attached. The left ilium was lightly fused and has been removed from the block. It is shown in Figure 10 as it was originally preserved in articulation (upside-down) and after removal in Figure 11. The pre-acetabular blade of the ilium of FWMSH 93B10-27 is distinctly flared laterally and meets the body of the ilium at a more abrupt angle than the gradual curve seen in sauropods such as *Camarasaurus*. The longest axis of the left ilium (anterolateral to posteromedial) as preserved measures 980 mm, missing only the distal tip. The pubic process of the ilium is partially preserved, and the ischiadic peduncle is eroded but was clearly a low process.

3. Reconstructions

Laser scans of the left maxilla and nasal were used to reconstruct skull shape in '*P. jonesi*' for exhibit. The dorsoventral to anteroposterior dimensions of the maxilla demonstrate a dorsally expanded, blunt snout for the Jones Ranch specimen. We cannot predict the premaxilla shape with confidence; however, based on other blunt-snouted sauropods like *Camarasaurus* and *Euhelopus*, we predict an anteroposterioly short premaxilla. Contours of the anterior portion of the skull were dictated by articulating the mirrored nasals with the maxilla. The shape of the nasals resembles those of *Abydosaurus mcintoshi* but the maxilla does not. The nasals and dorsal edge of the maxilla constrain the posterior shape of the external nares. We used *Camarasaurus* (Madsen *et al.* 1995), *Euhelopus* (Wilson & Upchurch 2009) and *Abydosaurus mcintoshi* (Chure *et al.* 2010) as models for the shape of the posterior portion of the skull. The maxilla and nasal as oriented in the reconstruction are shown in Figure 12.

To facilitate the mount of '*P. jonesi*', the sacrum and pelvic bones were laser scanned. Dorsal aspects of the sacrum were modeled after *Giraffatitan* (Janensch 1950) and South American titanosaurs, but spine heights were matched to known dorsal and caudal vertebrae from Jones Ranch. The right ilium was mirrored from the left. High-density foam polyurethane was CNC milled to shape, and casts of bone surfaces were used for outer texture on the resin in order to finish the exterior of the foam cores. For the process of milling, the size of the composite sacrum and pelvis required it to be sectioned into manageable segments and subsequently reassembled. That process is shown in Figure 13.

4. Discussion

The shape of the maxilla of the Jones Ranch specimen indicates a skull proportionately higher dorsoventrally and shorter rostrally than the skull of *Abydosaurus* (Chure *et al.* 2010), and a snout shape more like that of *Camarasaurus* or *Euhelopus*. A maxillary tooth count of nine for '*P. jonesi*' compares well with that of *Camarasaurus*, and *Abydosaurus mcintoshi*,

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Figure 8 Overview of caudals 1–6 and sacrum (FWMSH 93B10-27) in posteroventral view. Sacral 6 and caudal positions are numbered.

Figure 9 Caudals 8 through 11 in left lateral view (JR 1995-18). Scale bar = 5 cm.

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Figure 10 Left ilium as preserved in contact with sacral ribs, anterior view (FWMSH 93B10-27). Dorsal rim of ilium capped in plaster; ventral is up. Scale in cm.

Figure 11 Left ilium (FWMSH 93B10-27) in ventral view. Anterior is to the left. Scale in cm.

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Figure 12 Maxilla and nasal oriented as used in the skull reconstruction of the Jones Ranch specimen of '*Paluxysaurus jonesi*' (*Sauroposeidon*) in left lateral view (see scale in Figs 2 & 3). Based on skulls of *Camarasaurus* (Madsen *et al.* 1995), *Abydosaurus* (Chure *et al.* 2010) and *Euhelopus* (Wilson & Upchurch 2009).

but is lower than the 11–13 maxillary teeth in *Giraffatitan brancai* or the 14–15 teeth known in one North American specimen allocated to *Brachiosaurus* sp. (Carpenter & Tidwell 1998).

Our interpretation that six vertebrae comprise the sacrum of the Jones Ranch specimen corroborates the allocation of '*Paluxysaurus*' (*Sauroposeidon*) to the Somphospondyli (D'Emic & Foreman 2012).

The proximal caudal series described here helps constrain the total caudal count. Based on the sequences of articulated middle and distal caudals described by Rose (2007), it is estimated that '*P. jonesi*' had approximately 50 vertebrae in the tail. The caudal sequence is clearly unlike diplodocids and South American titanosaurs in retaining amphicoelous or amphiplatyan centra. Some dorsal expansion of the transverse processes on caudal 1 is present in *Brachiosaurus* and *Giraffatitan*, and the transverse processes are even more expanded in *Camarasaurus* (Gallina & Otero 2009). Caudal 1 of '*P. jonesi*' is more similar to the latter in this regard. The transformation from a triangular plate to simple rod-like transverse processes occurs rapidly between caudals 1 and 3 of FWMSH 93B10-27, as in *Camarasaurus*, but unlike the case in diplodocids in which more of the anterior caudals share the expanded fan-like morphology (Gallina & Otero 2009). The transition from anteroposteriorly short, wide centra anteriorly (caudals 1 and 2: length/width ratio approximately 0·5), to more elongate centra in caudals 3 and 4 (length/width ratios = 0·87–1·15; distorted by crushing), is much more acute in '*P. jonesi*' than in *Camarasaurus* or *Giraffatitan*. D'Emic & Foreman (2012) described specimens of *Sauroposeidon* from Wyoming, and cited short, wide and squared-off centra of the anterior caudals as an autapomorphy of this taxon. Characters of the proximal caudals from Jones Ranch' support placement of '*Paluxysaurus*' (*Sauroposeidon*) as a somphospondylan titanosauriform, more derived than *Brachiosaurus* and *Giraffatitan*. Previously referred specimens of mid-anterior caudals from Jones Ranch have ridges on the bases of the centra, with a shallow groove between them. This character has been used independently to unite groups of diplodocids and Titanosauria (Wilson 2002; Mannion & Calvo 2011). D'Emic & Foreman (2012) cited the absence of that character in their assessment that *Sauroposeidon proteles* lacks synapomorphies of the Titanosauria. Incipient grooving of the ventral centrum is present in at least some mid-anterior caudals from Jones Ranch described above.

Brontomerus mcintoshi was described from the Cedar Mountain Formation in Utah by Taylor *et al.* (2011). It occurs in deposits similar in age to those in Texas (Aptian–Albian), but is distinguished by a distinctly tall ilium that is essentially without a postacetabular lobe (Taylor *et al.* 2011). Those characters are not present in the Jones Ranch specimens, but their ilia do resemble one another in having reduced ischiadic peduncles. That peduncle is even more reduced in *B. mcintoshi*.

5. Conclusions

All the major postcranial elements are now known for '*Paluxysaurus jonesi*' = *Sauroposeidon proteles*. Documentation of the sacrum, ilium and anterior caudals, as well as skull and pelvic reconstructions, serve as a means to help define the place of this taxon within the context of sauropod evolution. Possession of six sacral vertebrae is a derived feature, supporting placement of '*P. jonesi*' (*S. proteles*) as a basal somphospondylan titanosauriform. The proximal caudal vertebrae also demonstrate a blend of characters supporting placement of this taxon as derived with respect to *Brachiosaurus* and *Giraffatitan*, and basal to the more derived titanosaurs. The tail transitions from relatively broad (mediolaterally), and anteroposteriorly short first and second caudals to progressively narrower (laterally) and more anteroposteriorly elongate mid-caudals. Transverse processes become simplified and rod-like by the third caudal, and disappear between the 10th and 15th caudals. Ventral grooves on some anterior caudals foreshadow the condition in derived titanosaurs.

A diverse group of sauropods have now been described from the Early Cretaceous of North America. Several different sauropod taxa are also apparently present within the Trinity Group of Texas, however, they occur in disparate localities and strata. The new material described here demonstrates that '*Paluxysaurus*' (*Sauroposeidon*) is among the best-known taxa anatomically that have been named from Early Cretaceous North American faunas and helps document this unexpected diversity.

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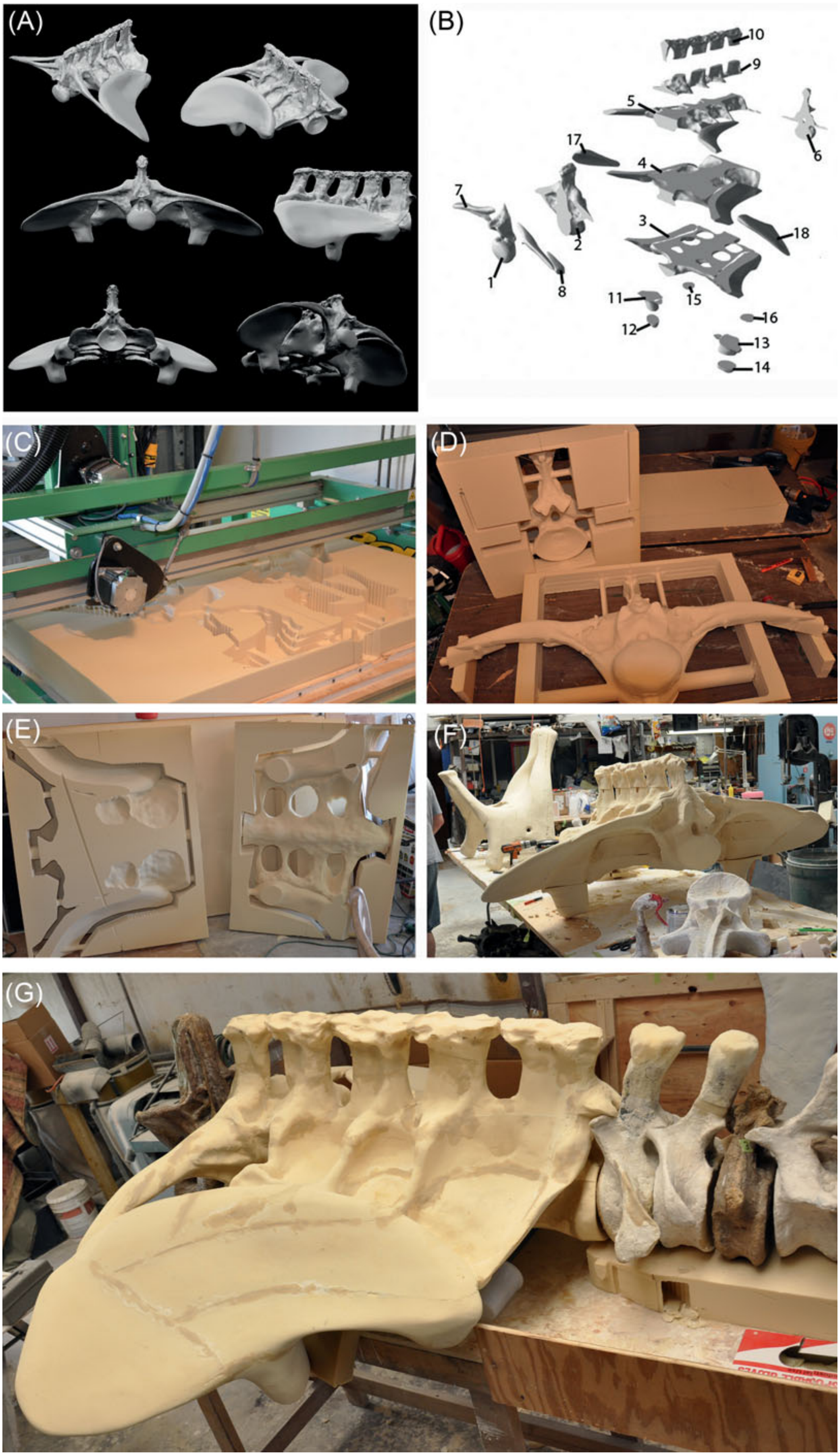

Figure 13 Sacral and pelvic reconstruction of '*Paluxysaurus jonesi*' (*Sauroposeidon*): (A) Fully modelled pelvis in left anterodorsal and posterodorsal views, anterior view, left lateral, posterior and right anteroventral views; (B) pelvis and sacrum model split into manageable-sized segments for CNC milling; (C) milling process of foam core; (D) final milled sections of sacrals 1 and 5 before removal from blanks; (E) lower section of sacrum body segment; (F) assembled sacrum/ilia and pubes/ischia segments; (G) final articulation of foam core sacrum/ilia with dorsal and caudal vertebrae.

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