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AN UNUSUAL SACRAL NEURAL SPINE OSTEOPATHY OF A CHASMOSAURINE (DINOSAURIA: CERATOPSIDAE) FROM THE UPPER CRETACEOUS KIRTLAND FORMATION (HUNTER WASH MEMBER), SAN JUAN BASIN, NEW MEXICO

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ABSTRACT—An unusual paleopathology, in the form of an irregular-shaped bony plate that is fused to, and is part of, the fused neural spine complex, is the first of its kind to be described for a ceratopsid dinosaur. This pathology is a bony mass composed of a network of fused ossified tendons and secondary bone deposited in a rather thin plate that extends out from the neural spine centered over the 5th and 6th sacral vertebrae. The etiology of this unusual pathology is unknown. We interpret this paleopathology as the possible result of a bite, or bites, to the back of the chasmosaurine, although there is no direct evidence of this. The plate is inferred to have been within the compact dermal layer of the chasmosaurine's sacrum.

INTRODUCTION

Paleopathologies are well-known in dinosaur fossils (Tanke and Rothschild, 2002; Rothschild and Martin, 2006), though much more remains to be learned of the Mesozoic history of skeletal injuries and disease. Among the many dinosaur fossils collected from the Upper Cretaceous strata of the San Juan Basin, New Mexico, few pathological specimens have been recognized. Among them are healing stage dorsal rib fractures of an indeterminate hadrosaurid from the Fruitland Formation (Hunt and Lucas, 1992, fig. 8B-C) and a healing stage distal impact fracture in an indeterminate ornithomimid metatarsal (Sullivan et al., 2000). Here, we add to this meager record of dinosaur pathologies from the San Juan Basin Upper Cretaceous, a partial chasmosaurine sacrum with extensive mass of the fused neural spines in the form of an irregular-shaped bony plate, the likely result of an injury. A recent rigorous review of ceratopsid osteopathy, in specimens from the Upper Cretaceous of Alberta (Tanke and Rothschild, 2010), recorded nothing similar to the present specimen, making it noteworthy.

The specimen was found in association with microvertebrates, and other megavertebrate remains (the amiid, *Melvius*, the turtle *Denazinemys*, and an indeterminate crocodylian,), in the lower Kirtland Formation (Hunter Wash Member), southeast of Alamo Mesa, in the Bisti/De-na-zin Wilderness, San Juan Basin, New Mexico. The Hunter Wash Member is Kirtlandian (late Campanian) age, ~ 74 Ma (Sullivan and Lucas, 2006). It was collected at SMP (State Museum of Pennsylvania) locality 419; precise coordinates are on file at the State Museum of Pennsylvania, Harrisburg.

DESCRIPTION OF THE PATHOLOGICAL SPECIMEN

The pathological specimen (SMP VP-2083) consists of the anterior portion of the left ilium and part of the sacrum, notably three complete transverse processes (sacral ribs) and parts of two others as well as fused neural spines, parts of associated ossified tendons and a dorsal mass that forms an irregular-shaped bony plate (Figs. 1-3). The centra of the sacral vertebrae were not recovered. The overall size and fusion of elements indicates this was an adult individual.

SMP VP-2083 preserves much of the left ilium (Fig. 2B), an arcuate plate of convex dorsal bone that has a maximum preserved length of 540 mm and a width (at the 4th transverse process) of 183 mm. The ilium appears to be of normal structure when compared to other chasmosaurine ilia (e.g., Hatcher et al., 1907, figs. 55, 61; Fowler and Sullivan, 2006, fig. 1). We have identified this specimen as chasmosaurine based on: (1) anterior processes of the dorso-sacral vertebrae do not contact the ilia (as in centrosaurines); (2) viewed dorsally, the blades of the ilia are broad compared to those of centrosaurines and not constricted medially; and (3) lateral caudal margins of the cranial-most transverse processes of the second sacral vertebrae fused to the lateral cranial margin of the third sacral vertebra and are not in contact with the ilia. SMP VP-2083 has the same morphology as SMP VP-1900 (see Fowler and Sullivan, 2006), although it is slightly smaller, more gracile and less complete.

Similarly, the sacral transverse processes appear to be of normal structure, consistent with other known chasmosaurine sacra (Fig. 2B). Thus, transverse process number 2 (corresponding to sacral vertebrae 2) is incomplete but attached medially and laterally to transverse process 3, so there is a small dorsal opening between the two processes. Transverse processes 3 and 4 are also fused medially and laterally, but the dorsal opening between them is larger. The fusion of transverse process 3 with the iliac blade is complete, but there is some separation (an articular edge) between transverse process 4 and the iliac blade. Transverse process 5 is very similar to 4, and the four processes in SMP VP-2083 form a largely fused, plate-like shelf of bone pierced by ovoid foramina in dorsal view, as in other ceratopsids (e.g., Hatcher et al., 1907, pl. 49; Fowler and Sullivan, 2006, fig. 1). In SMP VP-2083, transverse process 6 is incomplete; only part of its anteromedial edge is preserved, and it is not fused medially to transverse process 5. Selected measurements are: width of transverse processes 3, 4, 5 = 159, 165, 170 mm, respectively; length (medially) of transverse processes 2-5 = ~270 mm; and length laterally (along the medial edge of the iliac blade) of transverse processes 3-5 = ~85 mm.

The dorsal-most surfaces of sacral vertebrae 2-6 are preserved as part of SMP VP-2083. The neural spines are fused, and form a narrow, long ridge along the dorsal portion of the sacrum, as in other chasmosaurines (e.g., Hatcher et al., 1907, pl. 49; Fowler and Sullivan, 2006, fig. 1). Lateral to this ridge, rod-like ossified tendons are present – seven prominent tendons on the left side and four prominent tendons on the right side (Fig. 2A).

What makes SMP VP-2083 unusual and different from a normal chasmosaurine sacrum is the large, nearly flat plate-like bone that is indistinguishably fused to the top of the fused sacral neural spines 4-6 (Figs. 1-3). It is also positioned over transverse processes 4-6, and appears to be centered over the sacrum (the caudal section of the sacrum is not preserved). In cross-sectional view, the plate-like structure is T-shaped, with the plate 30 to 35 mm above the dorsal surface of the transverse processes of the sacral vertebrae. This bony plate is at least 250 mm long and more than 210 mm in maximum width. It is relatively thin (maximum thickness, measured immediately lateral to the fused neural spines = ~14 mm), thinnest at the edges (~5mm), and slightly

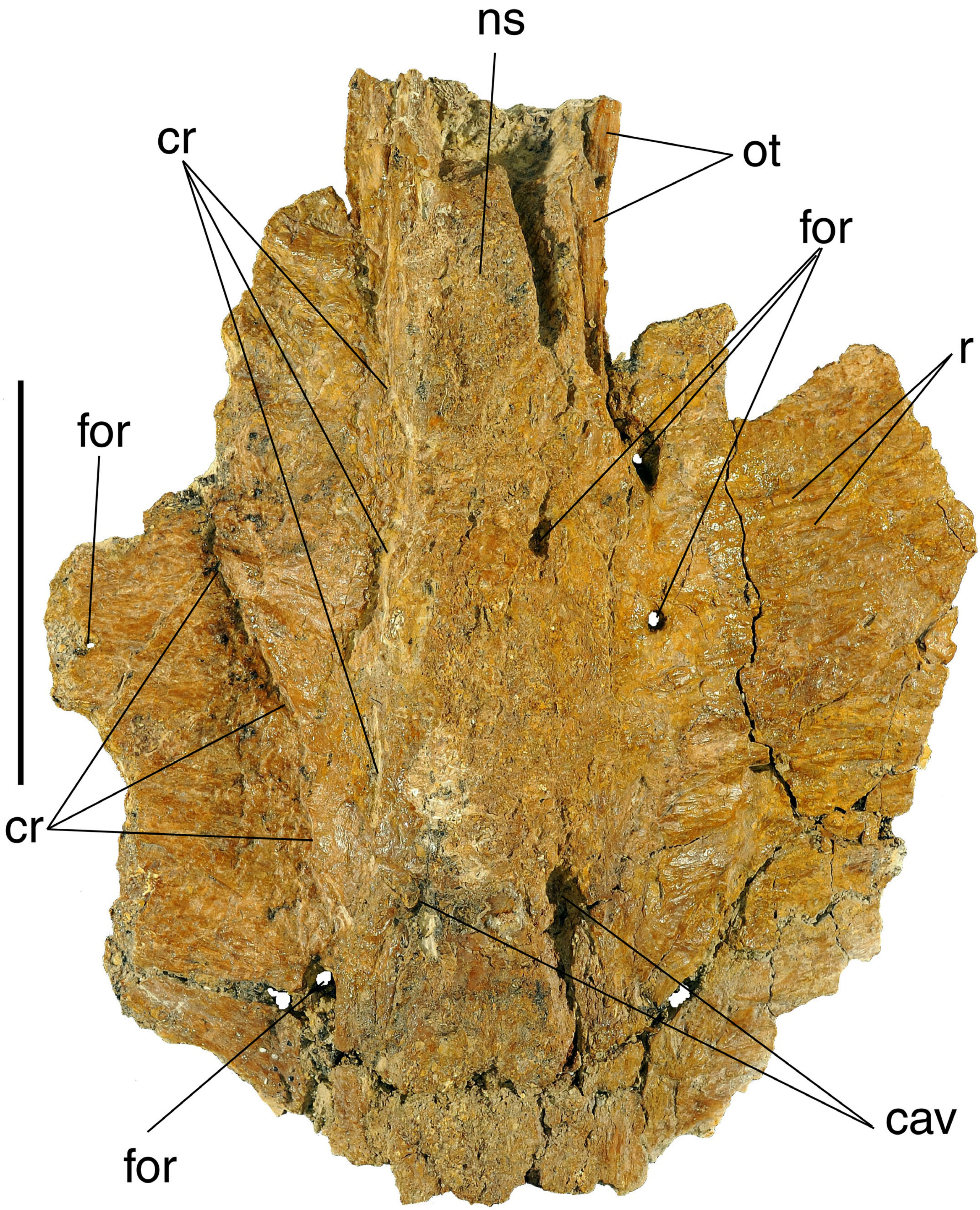

FIGURE 1. Chasmosaurine neural spine pathology (SMP VP-2083) in dorsal view. Anterior direction is up. **Abbreviations: cav**, inlet cavity; **cr**, postmortem crack; **for**, foramen; **ns**, fused neural spine; **ot**, ossified tendon; and **r**, ridge. Scale bar = 10 cm.

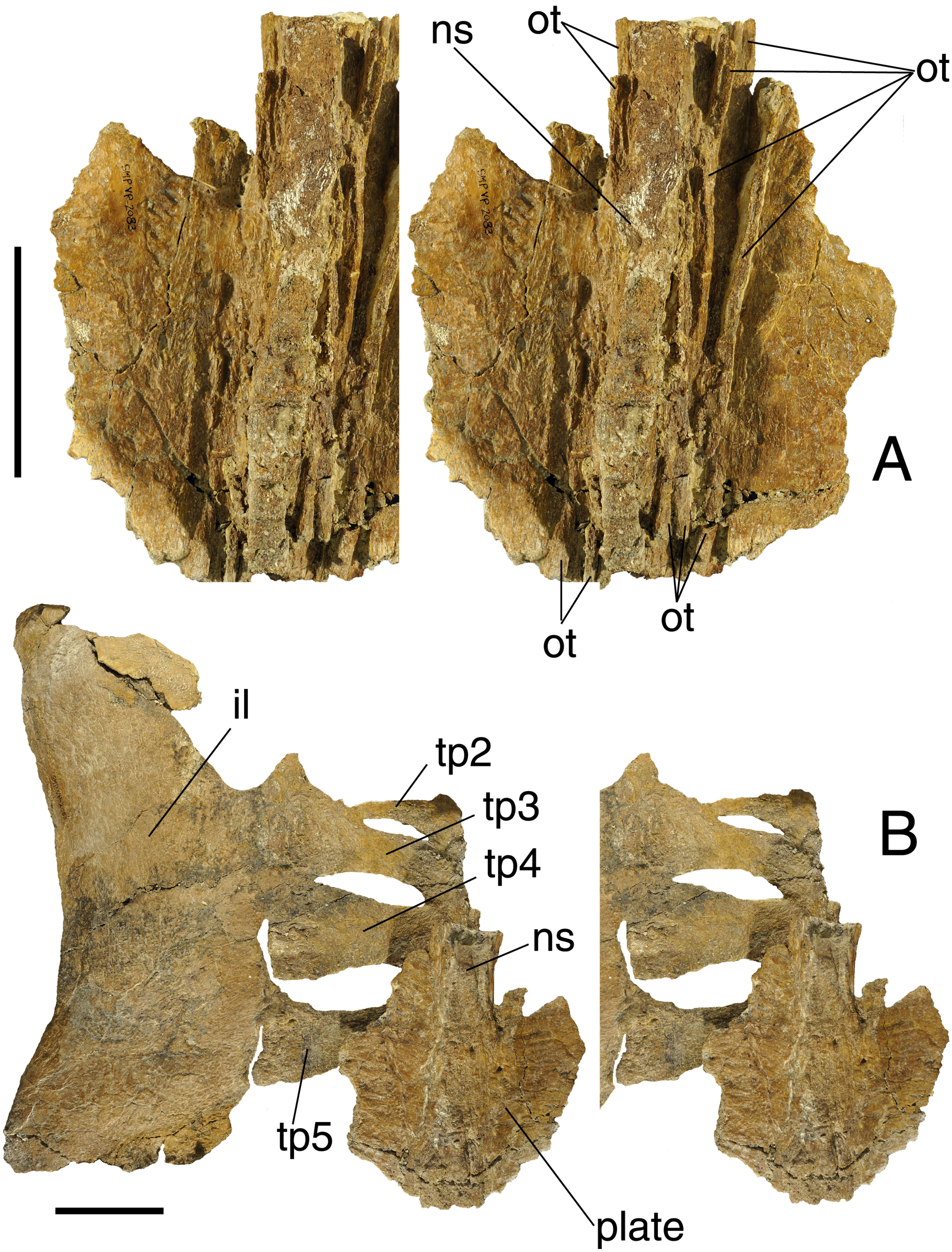

FIGURE 2. Incomplete chasmosaurine pelvis with neural spine pathology (SMP VP-2083). **A**, ventral surface of pathological bony plate (stereo pair); **B**, complete specimen with plate attached to the neural spine (stereo pair). Anterior (cranial) direction is up for both **A** and **B**. Identity of the transverse processes are based on the position of their corresponding sacral vertebrae. **Abbreviations: il**, nearly complete left ilium; **ns**, fused neural spines; **ot**, ossified tendon; and **tp**, transverse process (the medial part of tp 6 is hidden by the plate). Scale bar = 10 cm.

convex dorsally, concordant with the neural spines. The periphery of the plate is broken but thin and probably approximates its complete size and shape.

Over the neural spines the surface texture of this plate is mostly eroded, except over the region of sacral vertebra 5, where the texture appears to be smooth to slightly rugose with the rugose, texture oriented cranially-caudally. But, lateral to the fused neural spines, the plate has a texture of ridges and furrows that are medio-laterally oriented and somewhat irregularly spaced to anastomosing. Thicker ridges (~4-5 mm diameter) appear to be superimposed on a more finely lineated texture.

Viewed dorsally, on the right side of the bony plate, three foramina are present toward the cranial end, above sacral vertebra 5 and the junction of sacral vertebrae 5 and 6 (Fig. 1). These foramina are prominent, vertically-oriented pits (diameter 4-5 mm); the anterior pit completely perforates the bony plate. On the left dorsal side, two foramina are present, a tiny anterolateral foramen at the edge of the plate and a larger posteromedial one located caudally (Fig. 1). Ventrally, there are a few tiny “pits” on the left side that do not perforate the plate. Also on the dorsal side are two prominent cavities toward the caudal end whose inner wall is formed by the neural spine, and the lateral walls formed by the plate and/or ossified tendons (Fig. 1). These cavities are unossified “inlets” of the posterior edge of the plate, where the plate reaches forward and meets with the neural spine on both sides. This is essentially the same situation as seen on the anterior (cranial) end where the plate meets the fused neural spine.

The dorsal surface of the plate is cracked on the left side, resulting in a slight irregular separation along the neural spine. There is another lateral crack with a pronounced bend that runs sub-parallel to the neural spine (Fig. 1). The ventral side of the plate shows no trace of either of the two cracks. Both cracks seem to be postmortem features.

The dorsal surface texture of the plate consists of fine ridges that extend sub-perpendicular to sub-anterolaterally, from the midline. Ventrally, the ossified tendons are clustered together on both sides of the neural spine and they decrease in size and prominence laterally towards the periphery of the plate. The tendons appear to be fused within the mass of new bone growth and some tendons appear to be fused together. In lateral view, the left side shows that the predominant direction of the ossified tendons is anterior to posterior (cranial to caudal) and anteroventral to posterodorsal. The lateral ventral textural of the plate is one of cranially-caudally oriented fine anastomosing ridges, more like a woven bone texture than the prominent laterally-directed rugae of the dorsal surface. The ossified tendons characterize the ventral surface of the plate and form the component along with the fine anastomosing ridges.

INTERPRETATION

Because no other chasmosaurines or centrosaurines have been described as having a similar structure, the unusual bony plate on top of the neural spines of the sacrum of SMP VP-2083 is undoubtedly pathological. The plate appears to be a calcification surrounding the ossified tendons that fused predominately to the top of the 4rd to 6th neural spines. Two layers are identified: (1) a lower, ventral layer, consisting of sub-parallel ossified tendons that grade laterally towards the periphery of the plate; and (2) an upper, dorsal layer, consisting of ridges that run sub-perpendicular to the neural spines. This osseous bony mass is perforated by several foramina that may be perforation of blood vessels (Rothschild, pers. commun. to RMS, 2010). The development of this unusual structure with its plate-like form and T-shaped cross-section (Fig. 3), is possibly the result of an injury (heterotopic bone formation related to trauma). Healing and unhealed bite injuries have been documented in dinosaurs (Erickson and Olson, 1996; Carpenter, 1998; Tanke and Currie, 2000; Farlow and Holtz, 2002; Rothschild and Martin, 2006; Fowler and Sullivan, 2006; Bell and Currie, 2010; Hone and Rauhut, 2010). Several ceratopsid pelvic specimens show unhealed tooth marks made by large tyrannosaurids, suggesting this was an area of interest for biting (Erickson and Olson, 1996; Fowler and Sullivan, 2006; Hone and Rauhut, 2010). The plate could have been formed in response to an injury or due to abnormal soft-tissue ossification. Whatever the reason, the plate appears to have been largely formed by a hyperossification of the tendons concomitant with deposition of bone extending out from the central area of the fused neural spines. The bony plate was probably embedded within the compact dermal integument of the chasmosaurine.

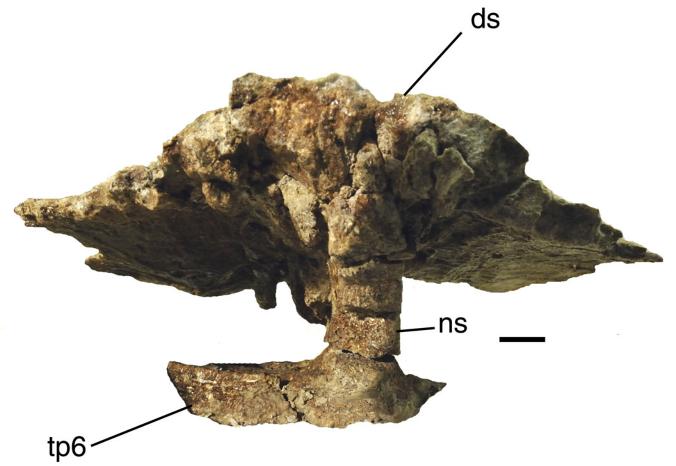

FIGURE 3. Axial oblique view (looking cranially) of the neural spine pathology (SMP VP-2083). **Abbreviations: ds**, dorsal surface of pathologic plate; **ns**, fused neural spines; and **6tp**, sixth left transverse process (medial part). Scale bar = 1 cm.

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