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THE FIRST PACHYCEPHALOSAURINE (DINOSAURIA) FROM THE PALEO-ARCTIC OF ALASKA AND ITS PALEOGEOGRAPHIC IMPLICATIONS

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INTRODUCTION

THE LAST 15 years of field work along the beaches and bluffs of the Colville River, on Alaska's Arctic Coastal Plain, have produced a diverse record of high-latitude dinosaurs. Seven families and eight genera are documented with several other families and genera possibly being represented by less diagnostic remains and only a few scattered elements (Table 1; Nelms, 1989; Gangloff, 1994, 1998; Fiorillo et al., 1999; Fiorillo and Gangloff, 2000, 2001). Virtually all of the common major groups of theropods and ornithopods typical of the Late Cretaceous of northern North America are present. Most of the skeletal remains are found in rocks assigned to the Prince Creek Formation of the Colville Group (Detterman et al., 1963, 1975; Phillips, 1990). The diversity of the dinosaur record in Alaska has been significantly increased with the discovery of abundant tracks and trackways along the North Slope and Arctic Coastal Plain over the last six years. The majority of the ichnofossil record is contained in various terrestrial coal-bearing rocks assigned to the Early Cretaceous Nanushuk Group (Ahlbrandt et al., 1979). The dinosaur biozone spans the upper part of the Nanushuk group and all of the Colville Group, ranging from the mid to Late Cretaceous (Albian to Maastrichtian; Mull, 1985). The already diverse and abundant record of dinosaur skeletal fossils was increased by the discovery in 1999 of the first evidence of pachycephalosaurs from this region (Fig. 1). This taxon is now represented by a nearly complete left squamosal and the contiguous, posterior, basal part of the dome. The highly thickened bone with characteristic prismatic internal structure accompanied by the distinctive ornamentation diagnostic of this group allows for an unequivocal identification to the subfamily level. The specimen (UAM # AK-493-V-001, Fig. 2.2) is most of the left squamosal and includes a portion of a thickened dome. The specimen is bounded on three sides by parted sutures interpreted as representing the contacts with the quadrate, exoccipital, and the narrow descending portion of the parietal bone (see Fig. 2.2, 2.4). The remaining margin exhibits a broken surface that reflects the polygonal prismatic internal structure of a part of the parietal-frontal dome. The sutures are well preserved and show little or no evidence of fluvial abrasion or weathering due to subaerial exposure prior to burial.

The strength and basic pattern of the ornamental nodes or tubercles, although not identical to, most closely resemble those exhibited by *Pachycephalosaurus* Brown and Schlaikjer, 1943. This determination establishes, for the first time at paleolatitudes between 70° and 80° N (Witte et al., 1987), the presence of one of the more highly evolved lineages of this distinctive and exclusively Cretaceous taxon. This discovery significantly extends the paleolatitudinal range of the Pachycephalosaurinae, whose previously highest paleolatitudinal position was approximately 53°–55° N in the lower part of the Horseshoe Canyon Formation (late Campanian) of Alberta, Canada (Smith et al., 1981; Ziegler et al., 1982; Williamson and Carr, 2002). The presence of a pachycephalosaurine of this age and geographic position represents data consistent with the hypothesis that a major faunal exchange took place between Eurasia and North America during Campanian time.

INSTITUTIONAL ABBREVIATIONS

AMNH, American Museum of Natural History, New York, New York; CM, Carnegie Museum of Natural History, Pittsburgh, Pennsylvania; PAL, Institute of Paleobiology, Warsaw, Poland; UAM, University of Alaska Museum, Earth Science Collections, Fairbanks.

SYSTEMATIC PALEONTOLOGY

Order ORNITHISCHIA Seeley, 1888
Suborder PACHYCEPHALOSAURIA Maryanska and Osmolska, 1974
Family PACHYCEPHALOSAURIDAE Sternberg, 1945
Subfamily PACHYCEPHALOSAURINAE Sereno, 2000
Figure 2.1–2.5

Description.—The specimen is a nearly complete left squamosal that ranges in height from 5.63 to 6.82 cm and width from 4.29 to 6.49 cm. The thickness of this specimen ranges from 1.50 cm at the thinnest part of the nuccal shelf to 4.05 cm at the thickest part of the dome. A total of 12 nodes or tubercles are present on the external or dorsal surface. A shallow and narrow groove defines the base of the nodes along the contact with the dome above as well as the contact with the upper margin of the nuchal crest or ridge (Fig. 2.1, 2.2). Nine nodes are fully developed and three appear to be incipient. The largest node borders the descending part of the parietal bone and possesses the strongest apex. The largest node is followed by two diverging rows of smaller nodes. These two rows of nodes diverge at an angle of 30°. The smallest fully developed node is rectangular in shape, measuring 5.0 × 15.0 mm. The largest is polygonal and nearly equidimensional, measuring 18.0 × 20.0 mm. A single, distal, and fully developed node is located nearly halfway between the two rows of diverging nodes at the distal end of the nodal rows where it is in contact with one of the incipient nodes (Fig. 2.2).

The upper or dorsal margins of the upper row of nodes border the thickened bone of the dome. This part of the dome appears to be an extension of the squamosal because there is no suture dorsal to the row of nodes. The dome's surface slopes at an angle of 35°. The broken dorsal margin of the dome exhibits the typical prismatic structure of domed taxa such as *Pachycephalosaurus*, *Stegoceras* Lambe, 1902, and *Prenocephale* Maryanska and Osmolska, 1974.

The lower or ventral margin of the nodal rows is bordered ventrally by a distinct, narrow (1.62–2.02 cm), and rounded supraoccipital ridge (=nuchal crest). This ridge is equivalent to the

TABLE 1—Dinosaur suborders and families from The Prince Creek Formation, Colville River.

Theropoda
Tyrannosauridae
Troodontidae
Ornithomimidae
Dromaeosauridae
Ornithopoda
Hadrosauridae
Hypsilophodontidae
Ceratopsia
Ceratopsidae

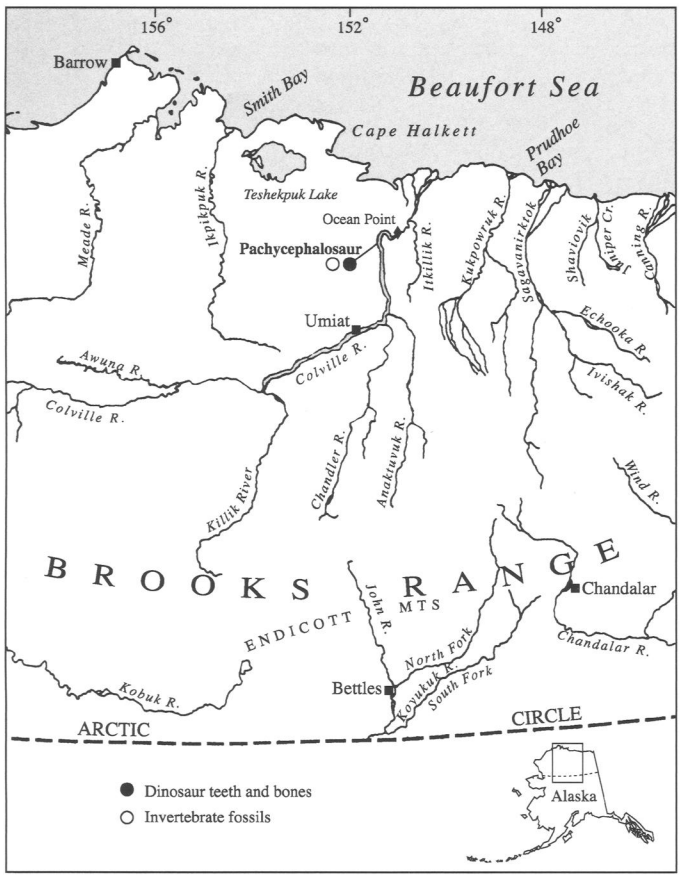

FIGURE 1—Symbols indicate common fossils found at this site, including bones of hadrosaurs and ceratopsians. Modified from Huffman Jr. (1985).

parietosquamosal shelf of Williamson and Carr (2002). The ventral margin of the ridge/crest forms a relatively deep (1.0–1.20 cm) sulcus that shows pitting and scars reflective of strong muscle attachments and functions as a nuchal crest. The lowermost (ventral) margin possesses strong ridges and grooves and is interpreted as articulating with the exoccipital bone (Fig. 2.2).

The internal or ventral surface of the specimen is marked by a rather deep (0.45–1.51 cm) and complex sulcus (Fig. 2.3). The distal end of the sulcus forms a flange with sutural surfaces that are interpreted as articulating with the ascending part of the quadrate bone (Fig. 2.1, 2.3). Portions of the distal or quadrate end of the sulcus are broken. The sulcus contains an oval (1.30 cm long) indentation that appears to be a primary feature rather than a puncture mark since it does not match any figured puncture marks sensu Fiorillo (1988, figs. 5, 6). The proximal end of the indentation has a broken margin (Fig. 2.3).

Material examined.—UAM # AK-493-V-001: A nearly complete left squamosal with an attached basal portion of the parietal dome from the Prince Creek Formation, Colville Group, North Slope Borough, Alaska. The specimen is housed in the Earth Science Collections, University of Alaska Museum.

Occurrence.—This specimen was found as talus on a narrow beach at the base of bluffs on the west side of the Colville River. The bluffs are mainly comprised of poorly indurated sandstones, siltstones, and mudstones assignable to the Prince Creek Formation (s. Mull et al., 2003) and topped by Quaternary age sediments of the Gubik Formation. This locality is 4 river km south of a series of highly productive hadrosaur-dominated bone beds (Gangloff, 1994, 1998) and 24.0 river km southeast of Ocean Point. The bone beds are interbedded with several rhyolitic tephra beds that have yielded a series of K-Ar and Ar/Ar dates. Conventional approaches using glass shards produced dates ranging from 68 to 71 My with a weighted mean of 69 My (Conrad et al., 1990). The best results of a reanalysis using $^{40}Ar/^{39}Ar$ single sanidine crystals (Obradovich, personal commun., 1993) would place the lowermost bone bed between 71 and 72 My. Therefore, the pachycephalosaur squamosal is assigned a late Campanian age based on the revised time scale of Obradovich (1993).

Discussion.—The squamosal from Alaska is clearly smaller (0.75×) than that found in *Prenocephale prenes* (Brown and Schlaikjer, 1943) (PAL MgDI/104) or *Pachycephalosaurus wyomingensis*, Gilmore, 1931 (0.5×; AMNH 1696). It is closest in size to *Prenocephale edmontonensis* (Brown and Schlaikjer, 1943) n. comb. and *P. brevis* (Lambe, 1918) n. comb. (Sullivan, 2000). Williamson and Carr (2002) consider the former taxon to be a nomen dubium and the latter to belong to *Stegoceras*. It is clear that the animal that belongs to this squamosal was a fully domed pachycephalosaur with a strong but unusual marginal nodal ornamentation pattern. The pattern is most similar to that found in *Pachycephalosaurus wyomingensis* and in particular, specimen CM 3180 (text-fig. 16b in Sues and Galton, 1987) in regard to the shape, number of rows, and distribution pattern of the nodes. This is quite different from the condition in *Prenocephale prenes* or *P. edmontonensis* in which the primary nodes form a single

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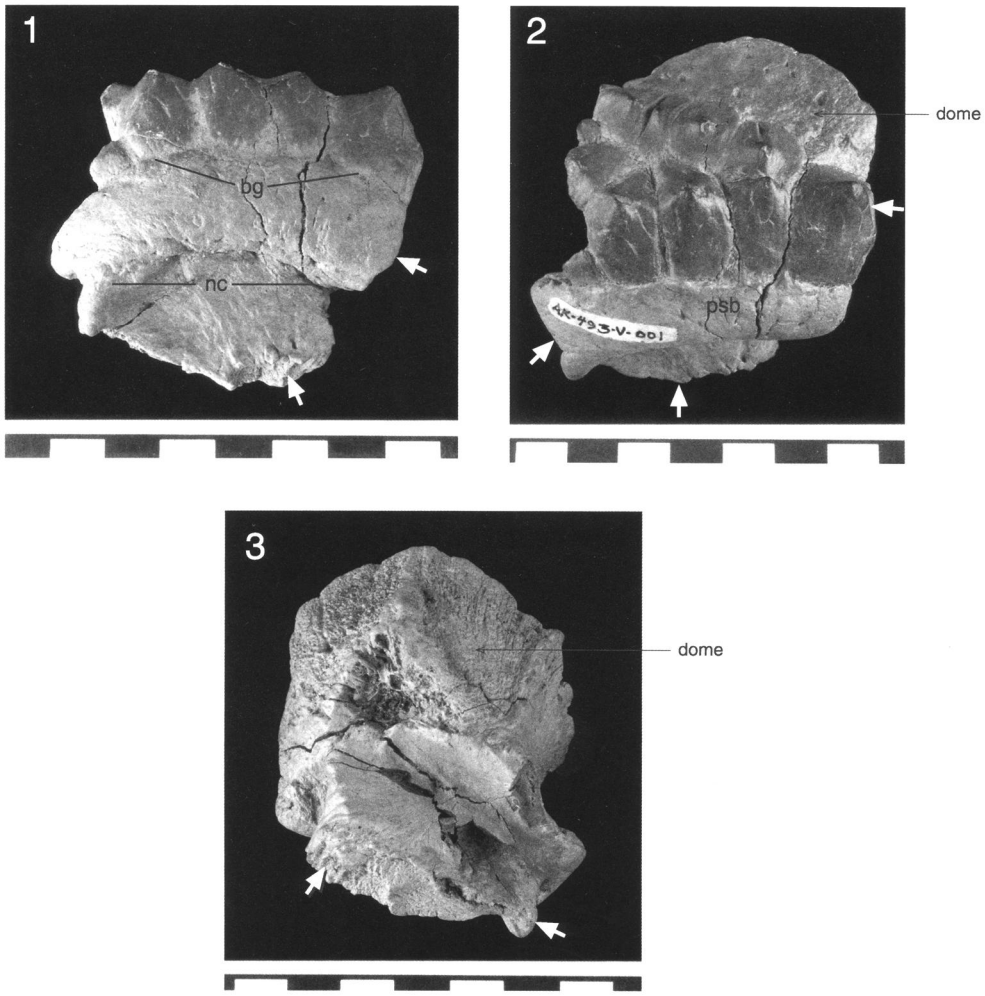
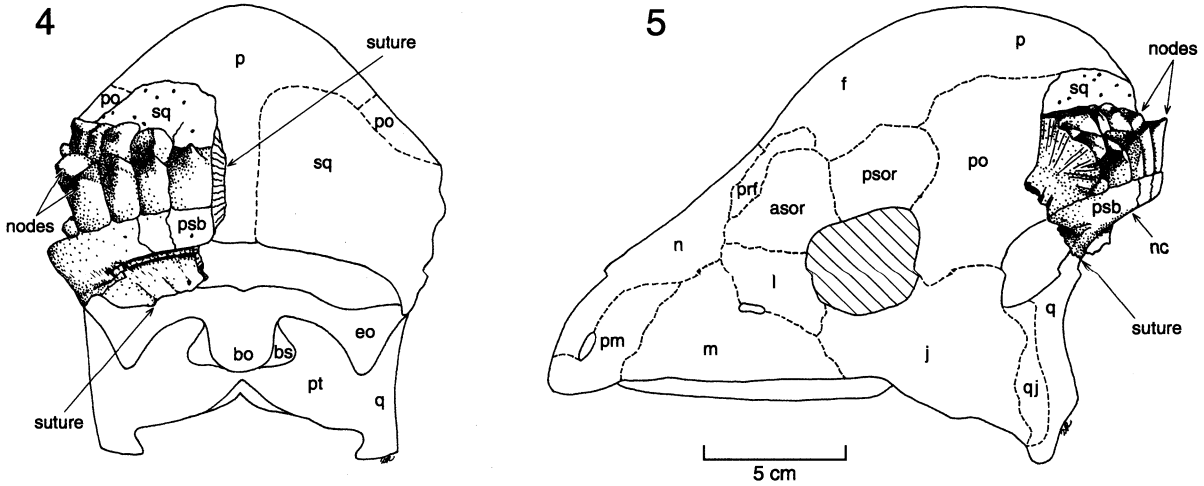
FIGURE 2—Left squamosal of pachycephalosaurine, UAM # AK-493-V-001. Specimen is oriented with the basal portion of the dome up and the sutural contact with the exoccipital at the bottom (see *4, 5*). All scale increments are in centimeters. *1,* Oblique-posterior view showing ornamentation consisting of four primary nodes and two incipient or incomplete nodes above a narrow, rounded, supraoccipital ridge or shelf. Note the deep ventral margin of this shelf and what appear to be muscle attachment scars. Arrows point to sutural margins; bg, basal groove of nodes; nc, nuchal crest. *2,* Medial-posterior view showing the bifurcation of the nodes as well as the three incipient nodes at the left-hand margin of the photo. Note the basal portion of the dome at the top of the photo and the largest of the primary nodes forming part of the parietal margin on the right side of the photo. Arrows point to sutural margins; psb, parietosquamosal bar. *3,* Ventral view showing the prismatic structure of the dome, upper margin in photo, and the ventral sulcus with its long axis running from the upper left to the lower right. Note the indentation and flange in the lower right or quadrate end of the sulcus. The lower margin of the photo exhibits the well-preserved sutural surfaces (arrows) where the squamosal articulates





with the parietal and exoccipital bones and indicates that there was little transportation prior to burial. Separation along several sutures suggests that the individual died prior to complete fusion of skeletal components. *4,* Posterior view of a hypothetical reconstruction of a skull with the left squamosal-partial dome put in its probable orientation. Hypothetical skull is a composite based primarily on the features of *Pachycephalosaurus wyomingensis* Gilmore, 1931 (AMNH 1696, Sues and Galton, 1987) and *Prenocephale prenes* (PAL MgDI/104, Sereno, 2000). Abbreviations are as follows: bo, basioccipital; bs, basisphenoid; eo, exoccipital; po, postorbital; psb, parietosquamosal bar; pt, pterygoid; q, quadrate; sq, squamosal. *5,* Left-lateral view of the same hypothetical skull reconstruction as in *4.* Abbreviations are the same as in *4* and asor, anterior supraorbital; f, frontal; j, jugal; l, lacrimal; m, maxilla; n, nasal; pm, premaxilla; prf, prefrontal; psor, posterior supraorbital; qj, quadratojugal; nc, nuchal crest.

row. The divergence of the two rows as seen in the Alaskan specimen sets it apart from all known pachycephalosaurs. However, near the contact between the quadrate and the squamosal, one large node and three incipient nodes form between the primary bifurcating rows and may represent clustering. Sullivan (2000) and Sereno (2000) cite the clustering of nodes as typical of *Pachycephalosaurus*. It should be noted that there appears to be quite a bit of variation in the shape of the nodes within *Pachycephalosaurus*. In *P. wyomingensis* AMNH 1696, the nodes are more spherical and often lack the polygonal bases and distinct apices seen in the Alaskan specimen and *P. wyomingensis* CM 3180. Specimen AMNH 1696 may represent a more mature individual with more spherical nodes that exhibit a higher degree of clustering. It is difficult to assess the importance of these differences, given the high degree of variation in ornamentation that characterizes the pachycephalosaurs.

Galton and Sues (1983:469) demonstrated that *Pachycephalosaurus* is unique among pachycephalosaurs in having a quadrate that is sutured to the squamosal. All other pachycephalosaurs have a quadrate with a rounded dorsal end that fits into a socket on the squamosal (Sues and Galton, 1987:26). The specimen from Alaska does appear to possess a flangelike ventral end that is interpreted (Fig. 2.1, 2.3) as articulating with the quadrate as in *Pachycephalosaurus*. If this interpretation is correct, then the Alaskan specimen is most probably a member of this genus. However, the fragmentary nature of the material and the distinctiveness of the ornamentation do not allow for an assignment to *Pachycephalosaurus* at this time. Prudence dictates an assignment only to the subfamily level and therefore a designation as a pachycephalosaurine. An alternative conclusion would be that the specimen from Alaska represents a new genus and species that is closest phylogenetically to *Pachycephalosaurus* within the *Prenocephale–Pachycephalosaurus* clade of Sues and Galton, 1987 or *Stygimoloch–Pachycephalosaurus* clade of Sereno, 2000 and Williamson and Carr, 2002.

In his discussion of the biogeography of dinosaur assemblages, Russell (1993) argues that North America was a poorly defined zoogeographic province. Further, he suggests that the major groups of dinosaurs in North America during the Late Cretaceous had their origins in central Asia. This presumed dispersal route would have been a land bridge connection between these continents through present-day Alaska. Though several workers (Williamson and Carr, 2002; Sullivan, 2003) have argued for the dispersal of the Pachycephalosauridae to North America prior to the Campanian, the discovery of a pachycephalosaurine in the paleo-Arctic of Alaska is consistent with the general biogeographic model because it establishes that pachycephalosaurids did exist at high latitudes and, therefore, that high latitudes did not necessarily exclude this route as a potential route of dispersal.

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