

## Supporting Information For “Taking a crack at the dome: histopathology of a pachycephalosaur (Dinosauria: Ornithischia) frontoparietal dome”

Aaron D. Dyer<sup>a\*</sup>, Aaron R.H. LeBlanc<sup>a</sup>, Michael R. Doschak<sup>b</sup>, Philip J. Currie<sup>a</sup>

<sup>a</sup> Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada,

<sup>b</sup> Department of Biomedical Engineering, University of Alberta, Edmonton, Alberta, Canada.

\* Corresponding author. Email: [adyer@ualberta.ca](mailto:adyer@ualberta.ca)

© The Authors, 2021

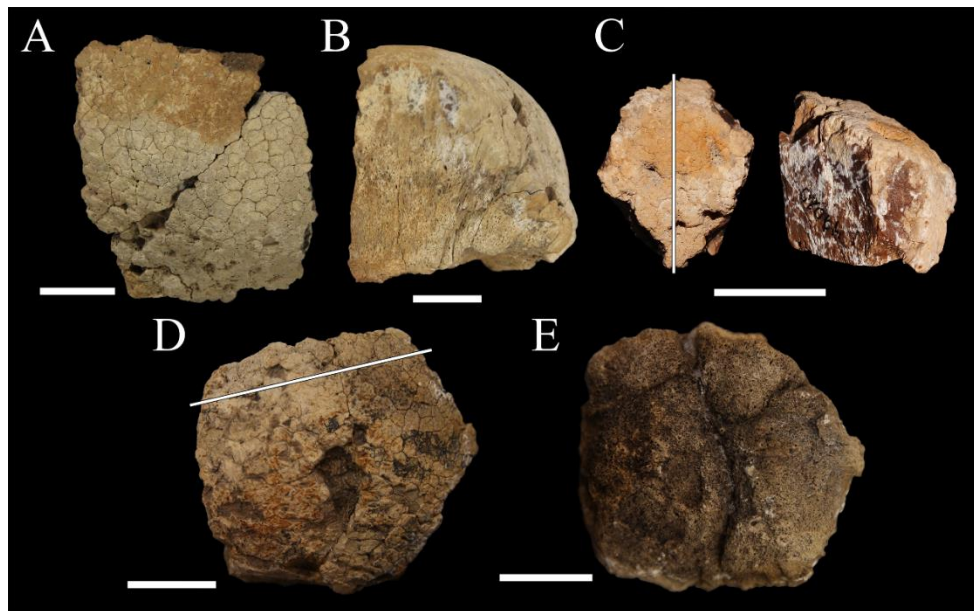
### Appendix S1

Histological description of UALVP 49020 and 54399

UALVP 49020

UALVP 49020 is an incomplete pachycephalosaur dome that consists of the left anterior portion of the dome and numerous associated unidentifiable cranial fragments (Fig. S1A-C). The specimen is mainly comprised of the left frontal. However, the most sagittal portion of the right frontal is present and fused to the left

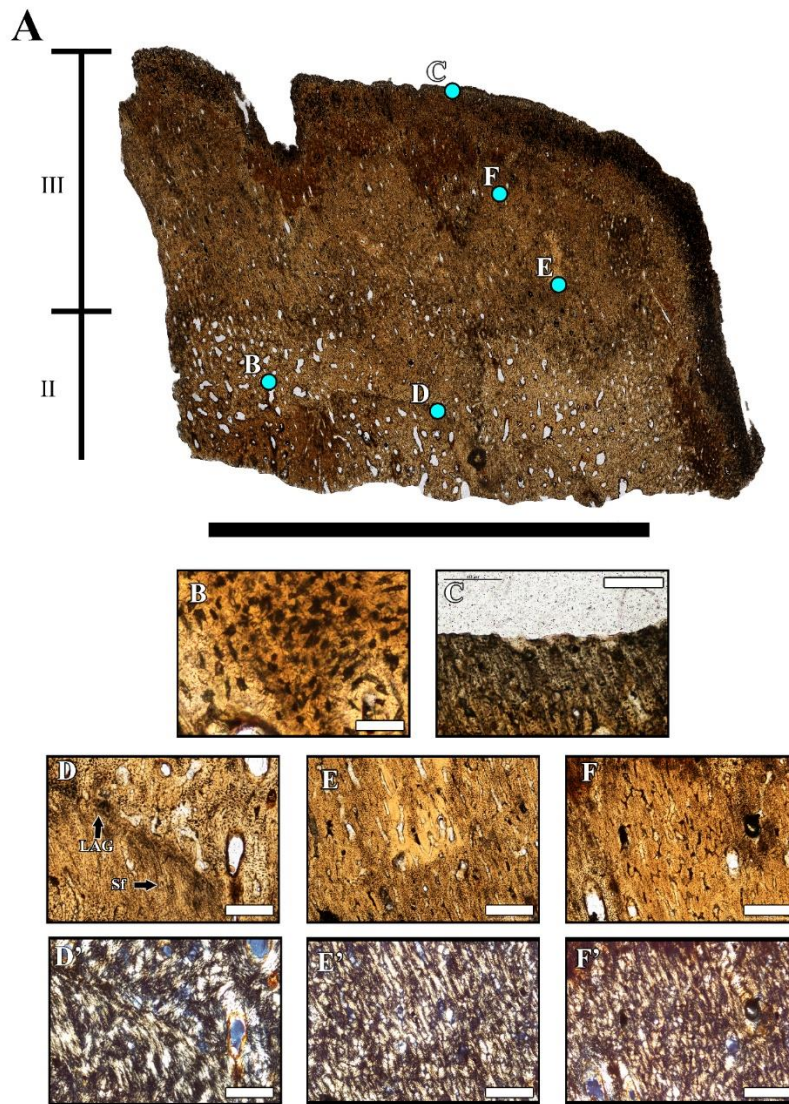
frontal, indicating an osteologically mature stage for the individual. The fragmentary nature of the dome makes exact taxonomic assignment impossible, although the size of the specimen is comparable to *Stegoceras* and *Hanssuesia*. The thin-sectioned fragment possessed two undamaged surfaces, which meet at an obtuse angle. One of these surfaces is pitted with neurovascular foramina (inferred to be the dorsal surface), similar to those seen on the dorsal surfaces of other pachycephalosaur domes and cranial elements (Williamson & Carr 2002; Schott & Evans 2016).



**Figure S1.** Non-pathological and weathered dome specimens. **Notes:** (A) UALVP 49020 (Pachycephalosauridae indet.), an incomplete frontoparietal dome used as a non-pathologic specimen in dorsal view. (B) UALVP 49020 in anterior view. (C) UALVP 49020 isolated dome fragment; dorsal view (left); anterior view? (right). White line denotes cutting plane. (D) UALVP 54399 (Pachycephalosauridae indet.) an incomplete frontoparietal dome used as a taphonomically weathered specimen in dorsal view. White line denotes cutting plane. (E) UALVP 54399 in ventral view.

Most of the thin-section of UALVP 49020 (UATSN 16; Fig. S2) was useful for histologic analysis; however, heavy mineral staining obscures the peripheral margins. The ventral and interior borders of the specimen are broken, limiting the extent of histologic analysis. UALVP 49020 is predominantly comprised of primary fibrolamellar bone with a minor contribution of primary parallel fibered bone and secondary lamellar bone (Figs. S2D-F). Primary vascular canals are abundant, and maintain a radial orientation throughout the specimen. Osteocyte lacunae

are hyper-abundant, and canaliculi are clearly visible (Fig. S2B). Bundles of Sharpey's fibers extend between primary vascular canals, conforming to a radial orientation. Secondary vascular canals (lined with secondary lamellar bone) are restricted to the interior regions of the section and may be transverse or radial in orientation (Fig. S2D). The restriction of large vascular canals corresponds with pachycephalosaur dome histologic Zone II, and the relatively dense area dorsal to this represents Zone III (Goodwin & Horner 2004).



**Figure S2.** Histology of UALVP 49020. **Notes:** (A) UATSN 16 - thin-section of UALVP 49020; Zones II and III labeled; scale bar = 2 cm. (B) Osteocyte lacunae with canaliculi; scale bar = 100µm. (C) Rough and irregular dorsal surface with Sharpey's fibers extending to the dorsal surface; scale bar = 250µm. (D) Line of arrested growth (arrow) associated Sharpey's fibers under normal polarized light; scale bar = 500µm. (D') Same region under cross polarized light; scale bar = 500µm. (E) Acellular region of the dome under normal

polarized light; scale bar = 500 $\mu$ m. (E') Same region under cross polarized light, no changes in bone fiber in this region; scale bar = 500 $\mu$ m. (F) Region of Zone III showing the fibrolamellar matrix of the dome under normal polarized light; scale bar = 500 $\mu$ m.) (F') Same region under cross polarized light (F'); scale bar = 500 $\mu$ m.

The secondary vascular canals in Zone II are orientated more or less transversely, unlike the overall radial orientation of the primary vascular canals. The dorsal margin of Zone II is marked by a decrease in the number and size of secondary vascular canals (Fig. S2A). The lower boundary of Zone II is not observable due to the fragmentary nature of the specimen. A LAG within Zone II extends from the broken ventral surface to the broken interior surface, and conforms to the outline of the dorsal surface (Fig. 2D). An abundance of Sharpey's fibers are associated with the LAG. In addition to radially oriented Sharpey's fibers, numerous fiber bundle extend parallel to the LAG, overlapping the radially oriented fibers. This feature may indicate a pliable epidermal covering (Goodwin & Horner 2004).

Primary vascular canals and osteocyte lacunae are abundant in Zone III (Fig. S2C), however, several irregular patches of acellular bone occur within the interior of the zone (Fig. S2E). Primary vascular canals begin to anastomose as they near the dorsal surface. Bundles of Sharpey's fibers continue to the periosteal surface (Fig. S2C). The dorsal surface of UALVP 49020, including the neurovascular pit is extremely rough and irregular (Fig. S2C). This irregularity is formed by vascular canals as they exit the dorsal surface.

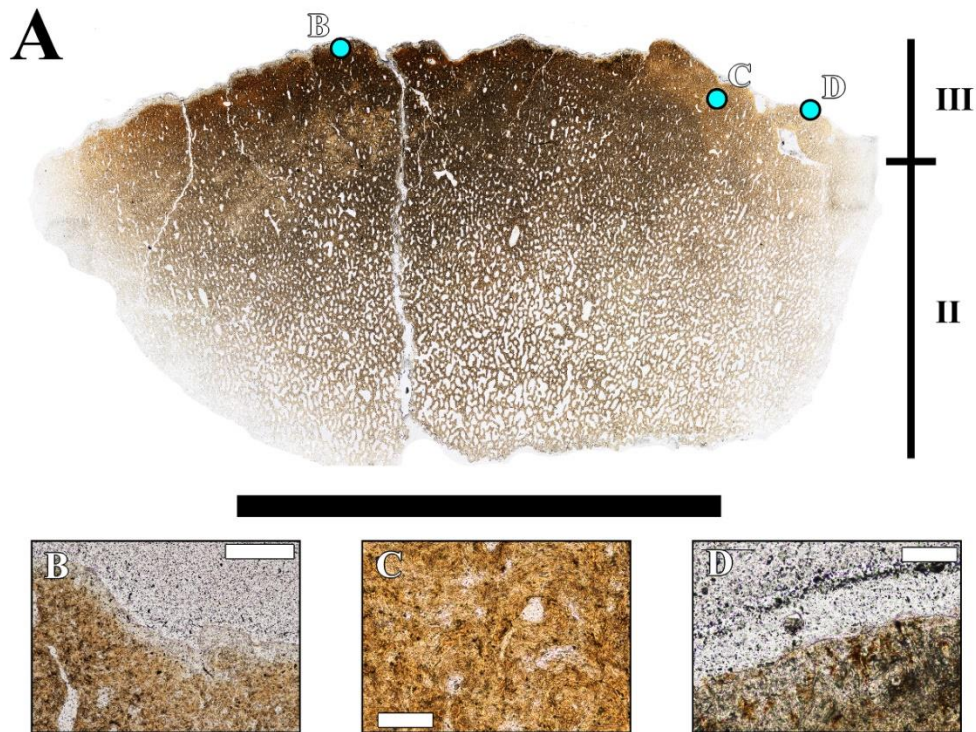
#### UALVP 53499

UALVP 53499 is an incomplete, heavily abraded frontoparietal dome (Fig. S1D, E). The ventral surface of the dome is completely worn. All

margins of the dome are abraded or broken. The heavy degree of weathering makes taxonomic identification impossible, and is consistent with stage 3 weathering of pachycephalosaur domes (Mallon & Evans 2014).

The dorsal surface of the dome is weathered, rugose, and irregular. A large pit is present in the center of the specimen, buttressing the plane of breakage where the specimen was broken in half, suggesting this damage occurred after weathering ex-situ. Polygonal cracks cover most of the dorsal surface, indicating a long arid exposure prior to burial. Shallow, smooth, hummocky erosional depressions occur along one edge of the specimen. These are poorly defined, unlike the well-defined borders of pathologic lesions (Peterson et al. 2013).

Permineralization has overprinted most histologic features (Fig. S3C), limiting the histologic analysis of the specimen. The ventral portion of the dome is well vascularized, corresponding with histologic Zone II. This becomes progressively denser towards the dorsal surface, grading into histologic Zone III. Zone I was likely obliterated by weathering. The fiber orientation in the bone cannot be determined (due to permineralization), and thus differences between primary and secondary bone cannot be determined. The weathered dorsal surface in UATSN 36 is rough and irregular (Fig. S3D). The preservation in some areas makes the surficial layer of bone nearly clear, and so viewing the actual surface impossible in these areas (Fig. S3B).



**Figure S3.** Histology of UALVP 54399. **Notes:** (A) UATSN 36 - thin section of UALVP 54399; Zones II and III labeled; scale bar = 2 cm. (B) Poorly preserved dorsal surface; scale bar = 250 $\mu$ m. (C) Area of Zone III where permineralization has obliterated most histologic features; scale bar = 100 $\mu$ m. (D) Well preserved dorsal surface, which is rough and irregular; 100 $\mu$ m.

### References

- Goodwin, M.B., & Horner, J.R. (2004). Cranial histology of pachycephalosaurs (Ornithischia: Marginocephalia) reveals transitory structures inconsistent with head-butting behavior. *Paleobiology*, 30(2), 253–267. [https://doi.org/10.1666/0094-8373\(2004\)030%3C0253:CHOPOM%3E2.0.CO;2](https://doi.org/10.1666/0094-8373(2004)030%3C0253:CHOPOM%3E2.0.CO;2)
- Mallon, J.C., & Evans, D.C. (2014). Taphonomy and habitat preference of North American pachycephalosaurids (Dinosauria, Ornithischia). *Lethaia*, 47, 567–578. <https://doi.org/10.1111/let.12082>
- Peterson, J.E., Dischler, C., & Longrich, N.R. (2013). Distributions of cranial pathologies provide evidence for head-butting in dome-headed dinosaurs (Pachycephalosauridae). *PLoS One*, 8(7), e68620. <https://doi.org/10.1371/journal.pone.0068620>
- Schott, R.K., & Evans, D.C. (2016). Cranial variation and systematics of *Foraminacephale brevis* gen. nov. and the diversity of pachycephalosaurid dinosaurs (Ornithischia: Cerapoda) in the Belly River Group of Alberta, Canada. *Zool J Linn Soc.*, 179(4), 865–906. <https://doi.org/10.1111/zoj.12465>
- Williamson, T.E., & Carr, T.D. (2002). A new genus of derived pachycephalosaurian from western North America. *J Vertebr Paleontol*, 22(4), 779–801. [https://doi.org/10.1671/0272-4634\(2002\)022\[0779:ANGODP\]2.0.CO;2](https://doi.org/10.1671/0272-4634(2002)022[0779:ANGODP]2.0.CO;2)



**Publisher's note:** Eurasia Academic Publishing Group (EAPG) remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

**Open Access** This article is licensed under a Creative Commons Attribution-NoDerivatives 4.0 International (CC BY-ND 4.0) licence, which permits copy and redistribute the material in any medium or format for any purpose, even commercially. The licensor cannot revoke these freedoms as long as you follow the licence terms. Under the following terms you must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorsed you or your use. If you remix, transform, or build upon the material, you may not distribute the modified material.

To view a copy of this license, visit <https://creativecommons.org/licenses/by-nd/4.0/>.