

NON-MARINE BORINGS IN DINOSAUR BONES FROM THE UPPER CRETACEOUS TWO MEDICINE FORMATION, NORTHWESTERN MONTANA

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INTRODUCTION

Evidence of physical and chemical modification of bone is widespread in the fossil record, with fossil bone showing an array of post-mortem alterations including scratch marks, tooth marks, abrasion, weathering, polish, and breakage (Behrensmeyer, 1975; Haynes, 1980a; Myers et al., 1980; Fiorillo, 1987, 1990; Behrensmeyer et al., 1989; Rogers, 1990). Experimental work has replicated many of these taphonomic features (Behrensmeyer, 1978; Haynes, 1980b, 1983; Fisher, 1981; Fiorillo, 1984; Morlan, 1984; Behrensmeyer et al., 1986; Olsen and Shipman, 1988) and clarified many causal processes. Analysis of bone modification data from paleontological sites can help resolve complex taphonomic histories, thereby allowing more accurate paleobiological and paleoecological reconstructions.

Borings within bone remain a relatively unexplored taphonomic modification feature, especially within the non-marine realm. This note documents the occurrence of macroborings in the fossilized bones of a new, as yet undescribed species of *Prosaurolophus* (family Hadrosauridae) recently recovered from terrestrial deposits of the Upper Cretaceous Two Medicine Formation of Montana. I describe the borings, review bone-boring organisms, and propose an organism that may be responsible for excavating the borings. Paleoenvironmental implications of the borings are also addressed.

GEOLOGICAL AND TAPHONOMIC SETTING

The Two Medicine Formation crops out to the east of the Rocky Mountain Overthrust Belt in northwestern Montana. Sediments comprising the formation accumulated along the western shore of the Western Interior Seaway throughout most of the Campanian (Gill and Cobban, 1973). Rock types and facies relationships suggest an alluvial origin; fine- to medium-grained sand bodies occur interstratified with thick sequences of pedogenically altered silty and muddy interchannel deposits. The extensive bone-bearing horizon that yielded the bored bones occurs within the upper lithofacies suite (Lorenz, 1981) of the Two Medicine Formation, approximately 50 m below the contact with the overlying Bearpaw Formation. Two quarries were opened in the productive horizon by field crews from the Museum of the Rockies (MOR) in the summer of 1986: Westside Quarry (MOR locality #447) and Southside Quarry (MOR locality #454). Both localities crop out in badlands along the Milk River in Glacier County, Montana, in Township 37 North, Range 8 West of the Landslide Butte (1:24,000) quadrangle (Fig. 1).

The taphonomy of Westside Quarry and Southside Quarry has been discussed in detail elsewhere (Rogers, 1990). Ap-

proximately 400 bones and bone fragments were collected from the bonebed, and at least five individuals, four adults and one juvenile, referable to a new species of *Prosaurolophus* (Horner, pers. comm.) are represented in the sample. Taphonomic and sedimentological evidence suggest that the bonebed preserves a monospecific fossil drought assemblage (sensu Shipman, 1975). Shed teeth of large and small theropod dinosaurs were recovered from the bonebed, suggesting that the assemblage was scavenged prior to burial. The prosaurolophan carcass assemblage was buried in fine-grained sediment deposited during an overbank flood.

DESCRIPTION OF BORINGS

Two bored bones, a left humerus (MOR 454/SSQ-86) and a right prefrontal (MOR 447/6-14-7-25), were discovered in the *Prosaurolophus* bonebed sample. Borings in both bones are solitary, non-tapering shafts. The boring in the humerus (Fig. 2A) has a maximum diameter of 16.6 mm, a minimum diameter of 13.2 mm, and a shaft length of 37.8 mm. This boring passes laterally through the medial epicondyle of the humerus at a shallow angle. A groove on the anterior surface of the lateral epicondyle marks the continuation of the boring (Fig. 2B). The total length of the boring from the medial surface of the medial epicondyle to the lateral extent of the groove on the lateral epicondyle (shaft and groove) is 76.1 mm. The boring in the prefrontal (Fig. 2C) has a maximum diameter of 10.1 mm, a minimum diameter of 8.7 mm, and a shaft length of 43.0 mm. This boring extends anteriorly from the posterolateral margin to the medial surface of the prefrontal, curving forward 28.0 mm from its external opening (Fig. 2D).

Borings were filled with sediment identical to the host matrix of the bonebed. Latex casts show no indication of surface modification such as scratches or grooves on walls of the borings. Boring walls are not smooth, however, because the borings pass through cancellous bone tissue. Unfortunately, the borings were not detected until after host bones were extracted from the quarries, and thus their orientations in the context of the bonebed remain uncertain. Both specimens are housed in the Museum of the Rockies, Bozeman, Montana.

BONE-BORING ORGANISMS

The absence of a body fossil preserved within the borings hampers unequivocal identification of the boring organism. However, geological and taphonomic data limit the number of possible excavators. The alluvial, interchannel depositional setting and drought-related taphonomic history of the

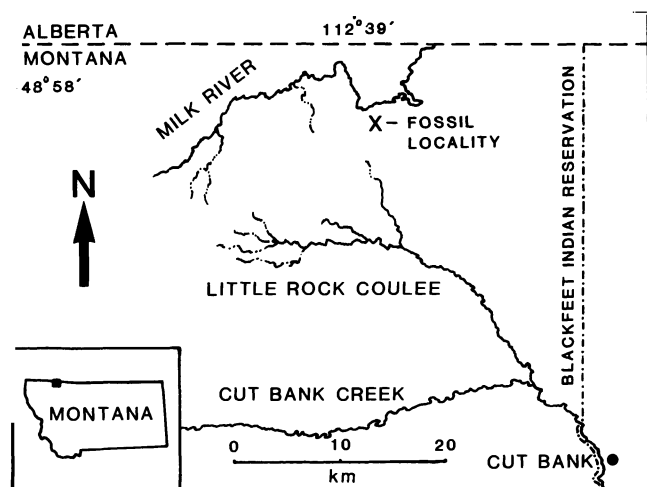


FIGURE 1. Map showing locality (indicated by X) of *Prosaurolophus* bonebed that yielded bored bones.

Prosaurolophus assemblage (Rogers, 1990) suggest a subaerial origin for the boring organism. A non-marine origin alone renders the borings unique because the vast majority of organisms (fossil and extant) capable of boring hard substrates inhabit marine ecosystems (Bromley, 1970). The groove on the anterior surface of the lateral epicondyle (Fig. 2B), clearly a continuation of the bore hole within the medial epicondyle, further suggests that the distal end of the humerus was interred when bored. A terrestrial organism boring or burrowing through the bone bed matrix conceivably encountered the humerus, grooved the bone surface (rather than deviate from its path), and eventually excavated a tunnel through the bone when its route was blocked (or vice versa). Whether or not the prefrontal was interred when bored is impossible to establish.

Morphological parameters of the borings also limit possible excavators. The borings reported here are far too large to be attributed to bone-boring micro-organisms (Marchiafava et al., 1974; Arnaud et al., 1978; Ascenzi and Silvestrini, 1984). Dimensions of the ichnofossils also preclude excavation by carrion-feeding termites or tenacid moths (Shipman, 1981; Thorne and Kimsey, 1983). In addition, the trajectories of the borings are inconsistent with deliberate feeding upon bone or domicile construction within bone.

Plant roots are unlikely causal agents because the intrusion of a root into a crack or crevice within bone should result in bone fragmentation during plant growth. The nearly cylindrical, non-tapering bore holes within the Two Medicine specimens could not have been produced by roots.

Marine pholadid bivalves are capable of excavating macroborings within bone (Boreske et al., 1972; Frey et al., 1975), but are improbable candidates due to the non-marine depositional setting of the bonebed. Transport of pholadid-bored bones from a marine setting to an alluvial burial site is similarly implausible due to the unabraded and relatively unsorted nature of the monospecific *Prosaurolophus* assemblage (Rogers, 1990).

Tobien (1965) interpreted elongate shallow pits developed upon the surfaces of mammal bones recovered from non-marine Pliocene deposits as puparial chambers excavated by carrion beetle larvae. Kitching (1980) also attributed macroborings in the limb-bones of terrestrial Plio-Pleistocene ver-

tebrates to carrion beetles (specifically dermestid larvae): fossilized puparial cases were discovered in association with these bored bones. Graham (pers. comm.) attributes macroborings in bones of Pleistocene vertebrates to crayfish. These borings are restricted to thin bones such as scapulae, which were apparently softened by chemical degradation at the bottom of a Pleistocene lake prior to boring.

Considering the limited assemblage of known "bone-borers" and constraints placed upon the boring organism, dermestid beetle larvae, or the larvae of a similarly adapted carrion beetle, seem to be the most likely excavators. Carrion beetles inhabit a range of terrestrial habitats, and the larvae of some extant dermestid species (e.g., *Dermestes lardarius*, *D. maculatus*, *D. caninus*) are capable of boring holes in a diverse array of substrates including desiccated animal skins, soft and hard woods, cork, lead, mortar, plaster, and stonework (Hinton, 1945; Peterson, 1951; Reed, 1958; Skaife, 1979). The alleged presence of carrion beetles in the Two Medicine ecosystem is supported by the discovery of ellipsoidal carbonate "concretions" deemed to be carrion beetle "egg cases" (puparial cases) by Lorenz (1981) at the Two Medicine "Egg Mountain" nesting locality.

Necrophagous beetles actively search out carrion, which serves as a food source for their larvae; a decaying carcass assemblage consisting of several large hadrosaurs would certainly constitute a strong attractant. Eggs are deposited on and within carrion by adult beetles, and upon hatching, larvae occupy and feed upon the corpse. When larvae mature they seek a safe place to pupate, and often burrow and/or bore into nearby substrates to construct puparial chambers (Hinton, 1945; Skaife, 1979). The limited number of borings in the sizeable *Prosaurolophus* bonebed sample seems compatible with chance encounters during subterranean excavation of puparial chambers.

The coleopteran families Dermestidae, Carabidae, Scarabaeidae, Staphylinidae, Histeridae, and Silphidae include several extant necrophagous species (Bornemissza, 1957; Reed, 1958; Crowson, 1981; Blacklith et al., 1988). The fossil record of the Carabidae, Scarabaeidae, Staphylinidae, Histeridae, and Silphidae extends back to the Jurassic (Crowson, 1981; Ponomarenko, 1988). Ponomarenko (1988) placed the first occurrence of the Dermestidae in the early Paleocene. Crowson (1981), however, reported a dermestid body fossil (as yet undescribed) from Lower Cretaceous (Neocomian) amber from Lebanon (Schlee and Dietrich, 1970; Whalley, 1980). Dermestid beetles were apparently extant during the Cretaceous, and they may have formed as integral a part of carrion biotas during the Cretaceous as they do today.

PALEOENVIRONMENTAL IMPLICATIONS

Evidence of scavenging by carrion beetles provides useful paleoenvironmental constraints for the *Prosaurolophus* carcass assemblage. Fully terrestrial beetles are apt to deposit their eggs in a locality where larvae have little chance of drowning, and soil-dwelling larvae of terrestrial Coleoptera will migrate vertically within a soil profile to remain above the water table (Crowson, 1981). In addition, Crowson (1981) asserts that there are no known water-beetles specifically adapted for a necrophagous diet. Thus, it can be inferred that the depositional setting of a fossil locality with evidence of scavenging by carrion beetles was subaerial when scavenging occurred. Furthermore, studies of arthropod succession on carrion (Bornemissza, 1957; Reed, 1958) indicate that several species of carrion beetles prefer to feed upon dried muscular and skeletal tissue. In fact, many carrion beetles, in-

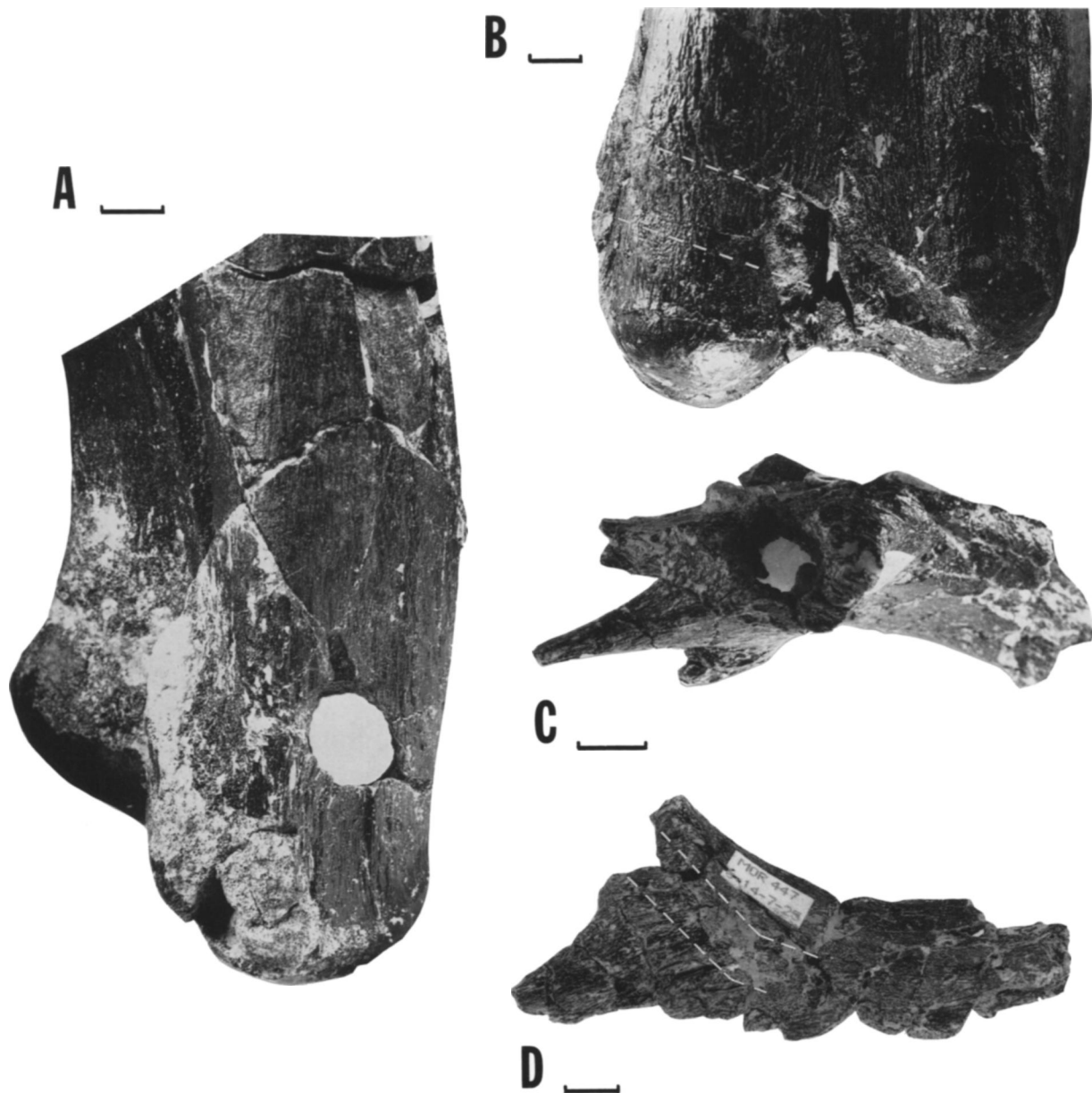


FIGURE 2. Borings in bones of *Prosaurolophus*. **A**, boring in medial epicondyle of humerus (MOR 454/SSQ-86), viewed from medial surface. **B**, groove on anterior surface of lateral epicondyle of same humerus marking the continuation of the boring. Trace of boring through medial epicondyle is indicated by dashed white lines. **C**, boring in prefrontal (MOR 447/6-14-7-25), viewed from posterior margin. **D**, trace of boring through prefrontal, viewed from ventral surface. All scale bars equal 1 cm.

cluding several dermestid genera, focus almost exclusively on the drier stages of carrion and thus avoid direct competition with dipteran larvae and many vertebrate scavengers (Crowson, 1981). The "dry-stage" preference of carrion beetles would be consistent with the drought-related taphonomic history of the *Prosaurolophus* bonebed proposed by Rogers (1990).

CONCLUSIONS

Bored bones from the Two Medicine Formation, along with fossil puparial cases reported by Lorenz (1981), suggest

the activity of carrion beetles in the Two Medicine ecosystem, and may provide the first record, albeit ichnological, of the coleopteran family Dermestidae in the Cretaceous of North America. These borings also provide unique paleoenvironmental constraints. Evidence of scavenging by carrion beetles at a burial site supports a subaerial depositional setting and a paleoclimate susceptible to desiccation. Borings in bones provide yet another tool for paleoenvironmental and taphonomic analysis of vertebrate localities.

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