A PHOSPHATIC COPROLITE LACKING DIAGENETIC PERMINERALIZATION FROM THE UPPER CRETAUCEOUS HELL CREEK FORMATION, NORTHEASTERN MONTANA: IMPORTANCE OF DIETARY CALCIUM PHOSPHATE IN PRESERVATION

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ABSTRACT

A single, low-density (1.58 g/cm3), phosphatic coprolite recovered from a fluvial Triceratops site in the Upper Cretaceous Hell Creek Formation of eastern Montana contains small quantities of minute bone or tooth fragments, kerogenized plant residues (pollen, spores, sporangia, and cuticle), hyphae of probable fungal origin, and small detrital mineral grains in a fine-grained, highly porous matrix. Roughly 30% of the matrix, composed almost entirely of microcrystalline francolite (carbonate-fluorapatite), is composed of thin-walled vesicles of roughly spherical shape, 0.5–3 μm in diameter. These vesicles are interpreted as mineral pseudomorphs of organic particles, probably including fecal bacteria, existing in the original scat. This structurally well-preserved coprolite is likely derived from the scat of a bone-digesting carnivorous animal, contains much or all of the autochthonous apatite of the original scat, and lacks permineralization that commonly produces a densely lithified object of low porosity. This is the first detailed description of a coprolite of this type from Mesozoic fluvial deposits. This evidence supports the view that dietary calcium phosphate could precipitate rapidly in the scat of ancient carnivorous animals, providing the structural strength to allow preservation of internal organic forms in great detail.

INTRODUCTION

The purpose of this paper is to establish that dietary calcium phosphate in the scat of bone-dissolving carnivorous animals can, through its rapid precipitation, supply a critical structural element during the conversion of scat into coprolite. This is done by the study of a single, low-density (1.58 g/cm3), phosphatic coprolite recovered from a Triceratops site preserved in fluvial deposits in the Upper Cretaceous Hell Creek Formation of eastern Montana. The coprolite contains small quantities of minute bone or tooth fragments, kerogenized plant residues (pollen, spores, sporangia, cuticle, etc.), hyphae of probable fungal origin, and small detrital mineral grains in a fine-grained, highly porous matrix. Our objective is to show that preserved organic and inorganic microstructures required rapid solidification and that the calcium phosphate of the coprolite must have been endogenous.

There are many reports on coprolites from Mesozoic continental sedimentary deposits (e.g., Matley, 1939a, 1939b; Amstutz, 1958; Hantschel et al., 1968; Hallgren, 1987; Thuillorn, 1991; Hunt et al., 1994, 2007; Chin, 1996; Hollocher et al., 2001, 2005; Northwood, 2005; Sharma et al., 2005; also see Duffin, 2009). Phosphatic coprolites—those containing abundant calcium phosphate minerals with or without the presence of bone, scales, or teeth—are the most common type and thought to be derived from the scat of carnivorous animals. Most studies of Mesozoic terrestrial coprolites have focused on form and gross chemistry, and only a few (Hallgren, 1987; Chin and Brassell, 1993; Chin, 1996; Chin et al., 1998, 2003; Hollocher et al., 2001, 2005; Northwood, 2005) have attempted to deduce their taphonomy and geologic history through the application of detailed microscopic, chemical, and mineralogical analyses.

In the case of phosphatic coprolites, one would like to infer when and how rapidly dietary calcium and phosphate precipitated in the original scat. Some evidence (e.g., Hollocher et al., 2005) suggests that phosphates can precipitate rapidly to form a microcrystalline slurry, as is the case with scat of extant alligators (Coulson and Hernandez 1964; Skoczyłas, 1978; Hallgren, 1987), and that this microcrystallinity can be preserved over tens of millions of years. Insight concerning the precipitation and crystallization of autochthonous minerals in phosphatic coprolites can be obscured by artifacts, however, including subsequent permineralization that fills void spaces originally occupied by organic material, gas, and fluids, diogenetically induced recrystallization, replacement of autochthonous minerals by others, and early compaction by overburden (Bradley, 1946; Amstutz, 1958; Hollocher et al., 2005; Northwood, 2005). Consequently, in order to best study the early precipitation and crystallization of autochthonous minerals of ancient phosphatic coprolites, one ideally would like to find coprolites in shallow sedimentary basins that have escaped permineralization and where other diagenetic changes are minimal. We report herein the properties of a phosphatic coprolite that seems largely to fulfill these criteria.

EXCAVATION SITE AND SPECIMEN

During excavation in 2003 of a Triceratops site in the Hell Creek Formation (latest Maastrichtian; Hartman et al., 2002) by Fort Peck Paleontology, a single coprolite (FPP TRU03-101; Fig. 1) was found embedded in undisturbed siltstone at the bone level. The site is located at 47°32'6.4"N, 107°2'54.3"W, between Jordan, Montana, and Hell Creek, and is estimated to lie about 20 m below the K-P boundary. The specimen was initially intact but was broken to show interior surfaces in Figure 1. It has a smooth dark brown outer surface, a somewhat fibrous, lighter brown interior, contains many smooth walled 1–3 mm voids suggestive of gas bubbles, and is highly porous at smaller scales. The shape of the specimen is ovoid in the classification of Sawyer (1981), and its dimensions were approximately 4 × 4 × 6 cm prior to analytical workup.

The gently dipping sediments in the region around the excavation site are largely gray overbank siltstone and channel deposits of gravel-bearing sandstone up to 1 m thick, the latter making up about 10% of the local rock. At the excavation site, 2–3 m of overburden was removed during the summer of 2003 to reach the bottom of the bone layer where the coprolite was found. In this section, sediments were finely laminated and consisted of relatively soft siltstone that contained varying proportions of sand and fine gravel with grain sizes <1 cm. Small siltstone rip-up clasts were encountered infrequently. Ripple marks were observed, as well as 0.5–1-m-thick, low angle crossbeds. Plant residues consisted chiefly of stems, sticks, and branches; leaf