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Mammalian femora across the Cretaceous–Paleogene boundary in eastern Montana

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ABSTRACT

Our understanding of latest Cretaceous and earliest Paleogene mammalian evolution is based almost entirely on the dental fossil record. Mammalian postcranial fossils are rare and mostly found as isolated elements in latest Cretaceous and earliest Paleogene vertebrate microfossil assemblages of North America. Although placing these fossils in a tooth-based taxonomic framework is difficult, they can provide insight into locomotor diversity and habitat preference to complement diet reconstructions and diversity estimates from dental fossils. Here, we describe 64 femora of mammals recovered from latest Cretaceous (Lancian) and earliest Paleogene (Puercan) localities in eastern Montana. We sorted these based on morphology and size (morphotypes). In some cases, morphotypes were tentatively assigned to dentally based taxa that are known from these strata.

Although our resulting femoral dataset is small relative to the study area's dental dataset, we show several key findings. First, there is a greater morphological diversity of multituberculate femora than previously recognized, especially in the latest Cretaceous sample. In contrast, metatherians, which have a high relative abundance in Lancian Hell Creek Formation dental assemblages, are absent from our postcranial samples; eutherian femora are only present in the Puercan assemblages. Second, we record a minor decrease in morphotype richness across the K–Pg boundary that is associated with an increase in mean specimen size, due to the appearance of a few significantly larger-bodied, immigrant taxa. Among the eutherians, there are two specimens of larger-bodied early Puercan archaic ungulates, a very large specimen of a middle/late Puercan taeniodont, pantodont, or triisodontid, as well as a specimen possibly attributed to a "plesiadapiform" archaic primate. Third, preliminary functional morphologic analyses of the more complete specimens suggest that locomotor diversity increased from mainly arboreal or terrestrial/saltatorial multituberculates in the latest Cretaceous to include a fossorial multituberculate and potentially an arboreal eutherian in the early Paleocene. These patterns parallel those previously reported from a dental dataset and indicate that postcranial data are valuable as an independent means to test hypotheses of taxonomic and ecomorphological diversity across the K–Pg boundary.

1. Introduction

The Cretaceous–Paleogene (K–Pg) boundary marks a critical turning point in mammalian evolution. The fossil record of Cretaceous and early Paleocene mammals consists predominantly of isolated teeth and fragmentary jaws. From this fossil material, researchers have tracked temporal patterns of taxonomic diversity and dental morphological disparity, reconstructed diets and body sizes, and interpreted these relative to K–Pg events (e.g., Alroy, 1999; Smith et al., 2010; Wilson et al., 2012; Wilson, 2013; Wilson, 2014). Relatively complete latest Cretaceous and earliest Paleogene mammal skeletons are rare, particularly in North America (e.g., Kielan-Jaworowska, 1977, 1979; Jenkins and Krause, 1983; Krause and Jenkins, 1983; Novacek et al., 1997; Muizon, 1998; Ji et al., 2002; Luo et al., 2003, 2011); however, older, relatively complete Mesozoic mammal skeletons suggest greater ecological diversification among early mammals than previously inferred from the dental record, and highlight the importance of postcranial data in more fully assessing K–Pg taxonomic, morphological, and ecological diversity (e.g., Luo, 2007).

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Our study area in eastern Montana has an extensive fossil record of mammals that is tied into a high-resolution chronostratigraphic framework across the K–Pg boundary (Archibald, 1982; Lofgren, 1995; Clemens, 2002; Wilson, 2005, 2014). The chronostratigraphic framework spans ca. 3.2 Ma and integrates data from the K–Pg boundary clay layer, radiometric ages, as well as litho-, bio-, and magnetostratigraphy from multiple local sections (see Swisher et al., 1993; Renne et al., 2013; Wilson, 2005, 2014; LeCain et al., 2014; Moore et al., 2014). A long history of paleontology field work in the study area (Clemens, 2002; Clemens and Hartman, 2014) has led to the recovery of thousands of latest Cretaceous and earliest Paleocene mammalian fossils. The resultant collections of isolated teeth and fragmentary jaws have been intensively studied (e.g., Archibald, 1982; Lofgren, 1995; Wilson, 2005); however, the hundreds of isolated postcranial elements have been largely neglected (Sloan and Van Valen, 1965; Clemens, 2002). There are a few exceptions, including analyses of the postcranial remains from the highly productive but temporally-mixed (latest Cretaceous–earliest Paleogene) Bug Creek Channel localities in western McCone County, Montana (e.g., Deischl, 1964; Sloan and Van Valen, 1965; Szalay and Decker, 1974) and analyses of the postcranial remains of a few select taxa and/or elements (e.g., Deischl, 1964; Szalay, 1994; Borths and Hunter, 2008; Chester et al., 2012a).

Here, we describe 64 partial mammalian femora from 27 localities in the Hell Creek and Tullock Formations of eastern Montana with the aim of improving our understanding of K–Pg mammalian evolution and ecology, as well as the magnitude and selectivity of the mass extinction and subsequent recovery. We assign these partial femora to 16 morphotypes and attribute many of these to genera, and in rare cases species, resulting in taxonomic working hypotheses. We also assess body-size patterns and analyze functional morphology of select specimens to assess temporal patterns of mammalian ecological diversity in our study area. These results complement ongoing analyses of other postcranial elements (e.g., humerus, astragalus, calcaneum), and provide an independent means of testing hypotheses of mammalian extinction and recovery that have previously only been evaluated on the basis of the dental fossil record from this study area.

Institutional abbreviations.—**AMNH**, American Museum of Natural History, New York, New York, U.S.A.; **CCMGE**, Czernyshev's Central Museum of Geological Exploration, St. Petersburg, Russia; **CR**, indicates specimens in the Cernay-lès-Reims collection, collected from the Mont du Berru locality, that are curated at the Musée National d'Histoire Naturelle, Paris, France; **DMNH**, Denver Museum of Nature and Science, Denver, Colorado, U.S.A.; **LSUMG**, Louisiana State University Museum of Geoscience (now the LSU Museum of Natural History), Baton Rouge, Louisiana, U.S.A.; **MOR**, Museum of the Rockies, Montana State University, Bozeman, Montana, U.S.A.; **MNHN**, Musée National d'Histoire Naturelle, Paris, France; **PM**, Paleontological Center of the Mongolian Academy of Sciences, Ulaanbaatar, Mongolia; **TMM**, Texas Memorial Museum, Austin, Texas, U.S.A.; **UALVP**, University of Alberta, Edmonton, Alberta, Canada; **UCM**, University of Colorado Museum, Boulder, Colorado, U.S.A.; **UCMP**, University of California Museum of Paleontology, Berkeley, California, U.S.A.; **UM**, University of Michigan Museum of Paleontology, Ann Arbor, Michigan, U.S.A.; **UMVP**, University of Minnesota, Minneapolis, Minnesota, U.S.A.; **UNM**, Department of Geology, University of New Mexico, Albuquerque, New Mexico, U.S.A.; **USGS**, U.S. Geological Survey, Denver, Colorado, U.S.A.; **USNM**, United States National Museum, Washington, D.C., U.S.A.; **UWBM**, University of Washington Burke Museum of Natural History and Culture, Seattle, Washington, U.S.A.; **ZPAL**, Institute of Paleobiology, Polish Academy of Sciences, Warsaw, Poland.

Other abbreviations.—**Eu**, Eutherian; **Mu**, Multituberculate; **m1**, first lower molar; **NALMA**, North American Land Mammal "age"; **Pu1**, early Puercan NALMA; **Pu2/3**, middle-late Puercan NALMA.

2. Materials

2.1. Study area and specimens

Our collection of partial femora across the Cretaceous–Paleogene boundary derive from channel-lag and overbank vertebrate microfossil sites in the Hell Creek and Tullock Formations of the Williston Basin in eastern Montana (Garfield and McCone counties, with additional material from Carter and Dawson counties; Clemens, 2002; Fig. 1). The fine-grained sediments characteristic of the Hell Creek Formation are fluvial in origin, largely flood-plain and crevasse-splay deposits representative of a broad, alluvial plain with meandering rivers of moderate size (Fastovsky, 1987). Water table increases coincident with the deposition of the overlying Tullock Formation resulted in a landscape with more standing water and large ponds, and a formation that is characterized by larger and more laterally continuous coals and much larger channels than in the Hell Creek Formation (Fastovsky, 1987). As in many other fluvial deposits, the microvertebrate localities in both the Hell Creek and Tullock formations are spatially and temporally averaged to varying degrees, such that deposits in some cases likely broadly sample the landscape rather than specific microhabitats (Fastovsky, 1987; Lofgren, 1995; Clemens, 2002).

In the Western Interior of North America, the K–Pg boundary approximates the boundary between the Lancian and Puercan North American Land Mammal "ages" (NALMAs; Cifelli et al., 2004; Lofgren et al., 2004). The fossil assemblages from the Hell Creek Formation are for the most part Lancian in age (ca. 68–66.04 Ma; Swisher et al., 1993; Renne et al., 2011, 2013; Wilson, 2014). Those from the lowermost Tullock Formation are typically early Puercan in age (Pu1 interval zone, 66.04–65.99 Ma; Swisher et al., 1993; Renne et al., 2011, 2013; Wilson, 2014), although in eastern Garfield and western McCone counties a few Pu1 assemblages are from the uppermost Hell Creek Formation and a few assemblages from the lowermost Tullock Formation are reworked across the K–Pg

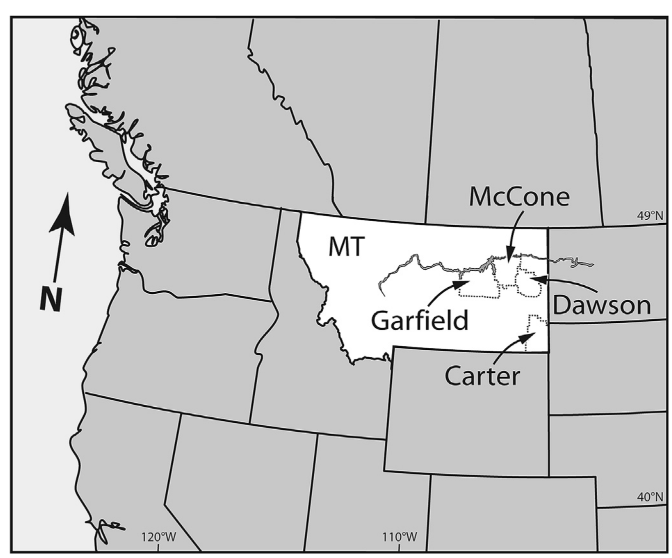

Fig. 1. Map showing Montana and the four counties where the Cretaceous and Paleogene femora included in this study were recovered. Modified from Wilson (2005).