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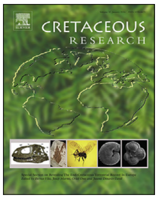

The Hell Creek Formation and its contribution to the Cretaceous–Paleogene extinction: A short primer

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ABSTRACT

Although it represents but one geographic data point, the uppermost Maastrichtian Hell Creek Formation (HCF), exposed in the upper Great Plains of the North American craton, remains the most studied source for understanding the final ~1.5 Myr of the Mesozoic Era in the terrestrial realm. Because it lies conformably below the earliest Paleocene Fort Union Formation, and together these two units preserve a rich fauna and flora, much of what is understood about the terrestrial Cretaceous–Paleogene (K–Pg) boundary comes from this sequence.

The HCF has been reconstructed as an expansive, fluvially drained, low coastal plain, built out, to the west, against the Laramide Orogen, and to the east, against the ultimate transgression (Cannonball) of the Western Interior Sea. Its meandering rivers and moist soils supported a multi-tiered angiosperm-dominated flora and rich insect and vertebrate faunas, including dinosaurs, crocodilians, squamates, turtles, and mammals. A dramatic facies change representing the initiation of catastrophic flooding is preserved, within available levels precision, at the K–Pg boundary.

High-precision stratigraphy has proven difficult in this lenticular fluvial system. Where present, the boundary can be recognized by the bipartite boundary claystone; otherwise, palynostratigraphy has proven a powerful tool. Numerical dates have been successfully obtained from in tonsteins at the boundary and above, in the Fort Union; however, these have proven elusive below the boundary within the HCF. The K–Pg boundary in this region is dated at 66.043 Ma (Renne et al., 2013). Magnetostratigraphic studies have been carried out in the HCF; although all but one have lacked numerical dates, these have been used for correlations of widespread, disjunct exposures and for the estimation of sedimentation rates.

The palynoflora is largely homogenous through the HCF; at the K–Pg boundary, it shows an abrupt ~30% extinction. This makes it a powerful tool for identification of the K–Pg boundary, although because the boundary is identified on absence of Cretaceous taxa rather than presence of earliest Paleocene taxa, several competing methods have been applied to identifying the K–Pg boundary using pollen.

The macroflora, consisting largely of leaves, consists of three successive floras, showing increasing diversity through the HCF. The ultimate of these three floras undergoes an abrupt 57% extinction; taken as a whole, however, the macroflora undergoes a 78% extinction at the K–Pg boundary.

The best data available for dinosaurs – including archaic Aves – show an abrupt extinction. By contrast, salamanders and other lissamphibians, as well as chelonians, cross the boundary virtually without perturbation. Squamates appear to have suffered significant extinctions at the K–Pg boundary, as did euselachians (elasmobranchs) and insects. Mammals suffered a 75% extinction; however, some of this figure cannot be shown to have occurred in less than the last 500 kyr of the Cretaceous, and thus has been potentially attributable to causes other than a bolide impact. Taken together, the survivorship patterns are concordant with the catastrophic inception of ubiquitous flooding characterizing the K–Pg boundary.

While the key K–Pg boundary question in the HCF was once the rate of the biotic extinction, it has moved to the distinction between single-cause scenarios, with the Chicxulub bolide as agent of extinction, and multi-cause scenarios, uniting habitat partitioning, Deccan flood-basalt volcanism,

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climate change, competition, and bolide impact. Not every potential environmental perturbation need be a mechanism for the extinction: parsimony and the data continue to be concordant with a bolide impact as the single agent of the terrestrial K–Pg mass extinction.

1. Introduction

The Hell Creek Formation (HCF), from the upper Great Plains of the North American Western Interior remains the global standard for understanding terrestrial Cretaceous–Paleogene (K–Pg) extinction events. This is because the HCF preserves an extraordinarily abundant and diverse terrestrial biota within the same stratigraphic units. The biota is comprised of fossil floras (plant fossils and palynomorphs), vertebrates (fish to dinosaurs; mega-to microvertebrates), invertebrates, non-palynomorph microfossils, and a range of trace fossils. Along with these, the HCF contains critical geochemical markers such as multiple iridium anomalies (e.g., Bohor, Foord, Modreski, & Triplehorn, 1984; Nichols, Murphy, Johnson, & Betterton, 2000) and a putative K–Pg isotopic excursion (Arens & Jahren, 2000, 2002; Arens, Jahren, & Kendrick, 2014; but see below). In turn, these indicators can all be assessed in their proper paleoenvironmental and paleoecological context(s). Moreover, the HCF records these latest Cretaceous terrestrial biotas and markers with, by the standards of terrestrial deposits, a high degree of stratigraphic resolution (Dingus, 1984).

While there has been ongoing interest in the HCF since the turn of the 20th century (see Clemens & Hartman, 2014), attention to the unit and its fossil biota increased considerably after the publication of the Alvarez, Alvarez, Asaro, and Michel (1980) hypothesis of dinosaur extinction by asteroid impact. Because of its rich biota and stratigraphic completeness, the HCF has uniquely been the object of a significant history of quantitative study (see Fastovsky & Sheehan, 2005) to address key questions about the terrestrial K–Pg extinction. In general, such treatments have generally revolved around the rate at which the extinction took place; an instantaneous extinction would be concordant with the hypothesis of an asteroid impact as cause; a more gradual extinction, or ecosystemic deterioration have been interpreted as concordant with other – perhaps more earthbound – causes.

A sense for the magnitude of the interest in the HCF can be obtained from the fact that two large Geological Society of America Special Paper edited volumes have been published (nos. 361 and 503; Hartman, Johnson, & Nichols, 2002; Wilson, Clemens, Horner, & Harman, 2014; respectively), exclusively devoted the HCF, its fauna, and its bearing upon the K–Pg boundary. This contribution, therefore, is a necessarily brief, introductory abstract of a very large literature.

2. Geological setting

The HCF is a fine-grained, fluvially derived, siliciclastic ~100 m-thick unit preserved throughout the Williston Basin in the upper Great Plains of the Western Interior of the United States and southern Canada (Fig. 1). It arose as a sedimentary prism derived from materials shed from the Rocky Mountain Laramide Orogeny (Fastovsky, 1986; Peterson, 1986; Murphy, Hoganson, & Johnson, 2002) and may have existed for less than the very last 1.4 Myr of the latest Cretaceous (Hicks, Johnson, Obradovich, Tauxe, & Clark, 2002). Superjacent to it is the Fort Union Formation, the basal part of which is (confusingly) known as the "Tullock Formation" in eastern Montana and the "Ludow Member" in western North Dakota. For simplicity here, we use the designation "basal Fort Union" to refer to the Tullock/Ludlow sedimentary interval. Below the HCF is the transitional marine-to-brackish Fox Hills Formation. These relationships are shown in Fig. 2.

The Hell Creek is generally reckoned to have been "discovered" (at least named) by the legendary Barnum Brown, the early 20th century, peripatetic American Museum of Natural History fossil collector (see Dingus & Norell, 2010). He eventually described the unit (Brown, 1907), although the focus of his interest and description was largely paleontological (he had discovered the type specimen of *Tyrannosaurus rex* there in 1902). During the next ~60 years, interest in the area was driven largely by the search for coal, natural gas and oil, by the development of the Fort Peck dam (and reservoir), and by the continued recovery of fossils by field parties from several (generally) eastern U.S. museums.

By the early 1960s, a recognizably modern concept of the K–Pg boundary in the region had crystalized, and pioneering work by B. Erickson, R.E. Sloan and L. Van Valen included working hypotheses about the nature of the boundary and associated extinction(s). Concomitantly, a modern understanding of the regional geological relationships of the relevant formations and members was developed by the early 1950s, driven largely by workers from the U.S. and relevant state geological surveys. A very complete, detailed, and informative account of this history through 1980 is given in Clemens and Hartman (2014).

Early studies by Moore (1976), Frye (1969) and Butler (1980) attempted to characterize the paleoenvironments of the Hell Creek. These studies established formal members that generally proved to be unrecognizable outside the limited area where they were described. In time, however, modern sedimentological approaches by Fastovsky and Dott (1986), Fastovsky (1986; 1987), Fastovsky and McSweeney (1987), Belt et al. (1984); Belt, Hicks, & Murphy (1997), Johnson (1989), Retallack (1994), Murphy, Nichols, Hoganson, and Forsman (1995), Murphy, Hoganson, and Johnson, (2002), all converged on the recognition of HCF deposits as representing a meandering fluvial system, generally draining to the SE, with forested, low-lying, extensive floodplain sedimentation. All of these workers identified a variety of facies (Fig. 3A–C) representing repetitive architectural elements in an aggrading fluvial system.

Fastovsky and McSweeney (1987) and Retallack (1994) reconstructed catenary sequences of hydromorphic paleosols suggesting an abundance of water with a very high water table. Observing the distinctive facies change that characterizes the lithostratigraphic HCF – Fort Union contact, Fastovsky (1987) proposed that the K–Pg boundary occurred concomitantly with the surface expression of the water table, forming regional "ponding". This is manifested by an abrupt transition from gleyed hydromorphic paleosols in the HCF (Fig. 3F, G) to extensive ponds or lakes, and peat mires (see below) that characterize the lowest deposits of the Fort Union (Fastovsky & McSweeney, 1987; Retallack, 1994). The extensive ponds and lakes are today represented by a distinctive, widespread iron-stained laminated siltstone facies (Fig. 3F; the "variegated beds" of Archibald, 1982). This facies shows an unusually pervasive signal of suspension settling, as if wholesale landscape flooding took place that resisted conventional draining. The peat mires are