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The Chicxulub-Shiva extraterrestrial one-two killer punches to Earth 65 million years ago

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ABSTRACT

Two large asteroids struck Earth at almost the same time, 65 million years ago, causing the major extinctions recognized as ending the Mesozoic Era. Although occurring close together in time, the Earth's magnetic pole had moved from the South Pole to the North Pole in between, allowing a time difference between the impacts to be calculated. The first strike produced a ~180 km diameter crater named Chicxulub on the Yucatan shelf of southern Mexico. The second hit the shelf of the northward drifting Indian continent in the southern Indian Ocean, producing a crater ~450 × 600 km named Shiva. Hitherto, the main obstacle to verifying this scenario has been the paucity of geological sections containing evidence of both impacts. Here, we present such evidence, and conclude that the two impacts were separated by about 40,000 years.

1. Introduction

Evidence for two large extraterrestrial impacts on Earth at the time of the Cretaceous–Tertiary (K–T) boundary extinctions has come from opposite sides of the globe. A probable impact crater of approximate K–T boundary (KTB) age was pointed out by Hartnady (1986) in the Seychelles Islands area of the Arabian Sea. This possibility was further investigated and expanded upon in the next several years by investigators (Alt et al., 1988; Chatterjee, 1992) who re-assembled a now divided large (450 × 600 km) impact structure named Shiva. The impact occurred in the southern Indian Ocean on the western shelf of the India–Seychelles continent, which was drifting northward from the breakup of the super-continent Gondwanaland. Subsequently, another crater-like structure 150–180 km in diameter on the Yucatan Peninsula of southern Mexico was also interpreted to be an impact structure of KTB age named Chicxulub (Hildebrand et al., 1991).

The KTB is well established in recent Geomagnetic Polarity Time Scales (GPTS) as occurring near the middle of 0.6 myr-long reversed polarity magnetochron 29r (Gradstein et al., 2004). In western Canada, however, the boundary impact marker, the "K–T boundary clay" (KTBC), was found to occur near the middle of a relatively thin (~3 m) interval of normal polarity within magnetozone 29r (Lerbekmo et al., 1996). To date, this magnetosubzone represents the only identified magnetosubchron in 29r and is therefore labelled 29r•1n.

Because meltrock in the Chicxulub crater has reversed magnetic polarity (Urrutia-Fucugauchi et al., 1994), the polarity data indicate that the KTBC in western Canada was not produced by the Chicxulub impact. Thus, there are two candidate KTBs, of different age, attributable to two major impacts. It was the purpose of this study to differentiate between the two impacts stratigraphically, and to determine the difference in time between them.

2. North American evidence for two impacts

In northeastern Montana, in the dinosaur-rich badlands of the Hell Creek drainage, one of the KTBs occurs at the base of the Z coal, which separates the Upper Cretaceous Hell Creek Formation from the overlying lower Tertiary Tullock Formation. The coal is well preserved about 25 km north of Jordan, 50 m east of the Hell Creek State Park access road (HCPR). The coal is 130 cm thick and contains a ~10 cm bentonite 60 cm below the top. Diagnostic latest Cretaceous palynomorph species disappear 10 cm below the coal, at the base of a carbonaceous mudstone. An Ir peak of 0.646 ± 0.025 ppb is present 2 cm above the base of the coal. Shocked quartz with multiple planar dislocations (mpd) occurs within the 10 cm carbonaceous mudstone below the coal. An erosion surface at the top of the coal cuts down to the west to the extent that at the next

[1] Jack Lerbekmo passed away on November 29th 2012, a few days before his 88th birthday. At the time of his death, the manuscript of this paper was in its final form, ready for submission. The formal submission was therefore made by Jack's colleague, Ted Evans, with contributions from Art Sweet and John Duke.

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exposure, 0.8 km to the west (HCPRW), the 60 cm of coal above the bentonite is missing. The magnetostratigraphy of this section (Fig. 1) shows normal polarity for 1.1 m below the base of the coal. This is the Cretaceous portion of magnetosubzone 29r•1n. Shocked quartz with mpd associated with the Z coal first appears in a sample 8–12 cm below the base of the coal. A 5 cm concretionary layer occurs 3.5 m below the base of the coal, overlying a few centimetres of grey shale. The upper 1 cm of the shale contains an Ir anomaly of 0.290 ppb over a background of 0.03–0.05 ppb, and shocked quartz with mpd (Fig. 1). This is in magnetosubzone 29r•2r, corresponding to the Chicxulub impact. Scattered dinosaur bones occur 0.5 m below the concretions.

Roughly 5 km west of HCPR is Brownie Butte. About 0.8 km to the east, a KTBC is preserved for a few metres laterally at the base of a slope below an 8 cm coal, at a locality known as Rick's Place (Hotton, 2002). Four magnetostratigraphic samples taken 15 and 30 cm above, at the base, and 25 cm below the boundary clay have reversed polarity and are assigned to 29r•2r, embracing the Chicxulub impact. There is also a record of the Chicxulub impact ~600 m south of Rick's Place at what is herein called "Jack's Place". This was a sandier environment and the impact level is represented by 1 cm of poorly-sorted siltstone carrying abundant very fine sand-sized shocked quartz with mpd.

Approximately 1 km south of Brownie Butte is a smaller butte, herein called "Baby Brownie". It exposes a Z coal-equivalent interval, including the bentonite, rarely preserved west of HCPR. Only 16 cm is continuous coal, the remainder being carbonaceous shale, including a 30 cm unit below the coal. The pervasive disconformity is present at the top of the Z coal interval, cutting off the top of 29r•1n, which continues downward for 1 m below the base of the coal (Fig. 2). The basal 2 cm of the lower carbonaceous shale unit contains shocked quartz with mpd. At 1.45 m below the base of the Z coal carbonaceous shale is another 5 cm carbonaceous shale. This is in reversed polarity subzone 29r•2r, 75 cm below the base of 29r•1n. It carries shocked quartz with mpd, is equivalent to the Rick's Place coal, and represents the Chicxulub impact.

In the Raton Basin of Colorado–New Mexico, a continental KTB has been studied in detail in at least 17 sections by Izett (1990). During the present study, 3 magnetostratigraphic samples were taken straddling the boundary coal at the Starkville South locality. All have the reversed polarity of Chicxulub time and 29r•2r.

A KTB is also present in a 14 m coal seam on the MacKenzie River in the Northwest Territories of Canada, known as the Police Island section (Sweet and Braman, 2001). Twenty mid- to late Maastrichtian palynomorphic taxa disappear at the KTB within 5 cm of the appearance of shocked quartz. An Ir anomaly peaks at 0.364 ± 0.008 ppb in the 5 cm interval above the shocked quartz. Normal polarity (29r•1n) was found in two available samples 4 m above and 1 m below the KTB. There is no KTBC.

Two different KTBCs have been identified in western North America. The first was deposited during magnetosubchron 29r•2r; the second was deposited during magnetosubchron 29r•1n. The time interval between them can be calculated approximately if the average rock accumulation rate (ARAR) can be determined in sections where both impacts are represented. Cyclostratigraphic studies have resulted in a relatively small range for the duration of 29r of 603–608 kyr, and a proportioning of ~335 kyr to the Maastrichtian and ~270 kyr to the Paleocene (Preisinger et al., 2002; D'Hondt et al., 1996). In the HCPRW section (Fig. 3), the preserved Paleocene portion of 29r is ~23 m thick, yielding an

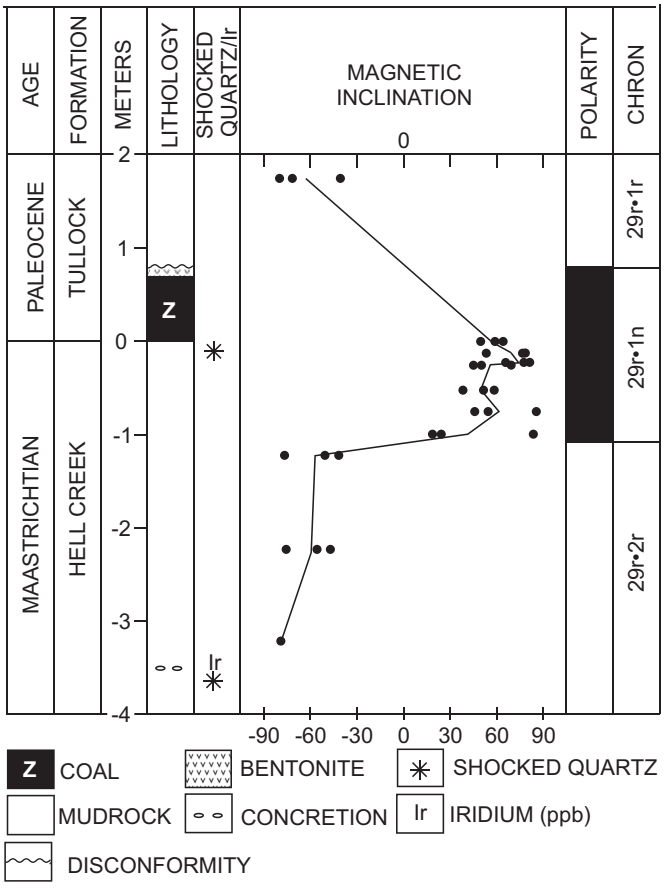

Figure 1. Stratigraphy of the HCPRW K–T interval. Lithostratigraphy, magnetostratigraphy and mineralogy of the Hell Creek Park Road West (HCPRW) section K–T boundary (KTB) interval. Solid inclination line is drawn between the means of 3 independently oriented percussion core samples perpendicular to bedding, if available, otherwise to inclination of a single sample.

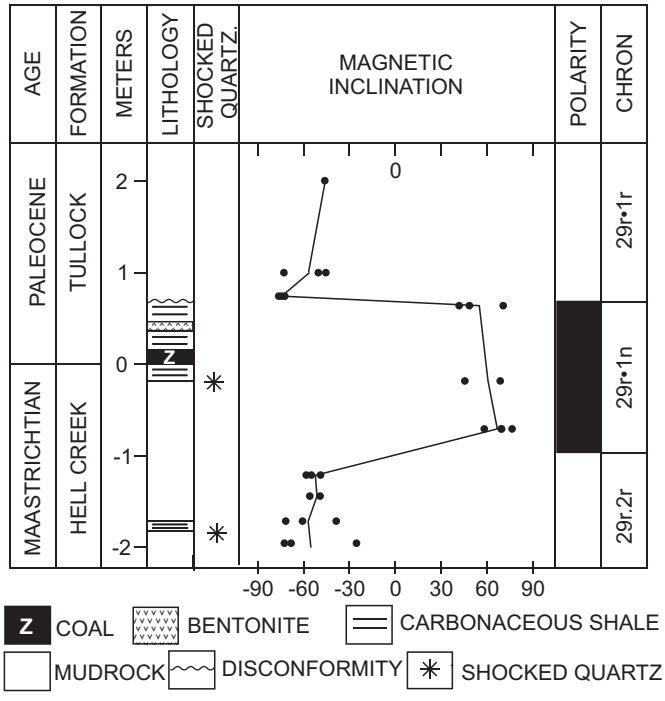

Figure 2. Stratigraphy of the Baby Brownie K–T interval. Lithostratigraphy, magnetostratigraphy and mineralogy of the Baby Brownie section KTB interval. See Figure 1 for additional explanation.