nificant intervals of nondeposition. However, as all conodont subzones of the latest Frasnian and earliest Famennian are present in the section, any such intervals must have been less than the duration of a subzone.

Because of the strongly condensed nature of the section containing the iridium anomaly, the question arises of whether it could have resulted from steady rates of iridium accumulation magnified by extremely slow rates of associated sedimentation. However, this explanation seems unlikely, as the iridium concentration in the anomaly is about 20 times the background, compared with a factor of only 3 for the relative sedimentation rates. The decreased rate of sedimentation in the zone that includes the anomaly could reflect a decline in organic productivity associated with the Frasnian-Famennian mass extinction, although there is not the associated decrease in carbonate content that might be expected. However, carbon isotope analyses appear to support the suggested decline in productivity. There is a drop in overall $\delta^{13}C$ values of about 1.5 per mil extending from the base of the anomaly to the top of the section (Fig. 3); this finding suggests a decrease in biomass (*11*) for at least 1 million years. The values of $\delta^{18}O$ in calcite also decrease sharply above the anomaly, a possible indication of an increase in water temperature.

It is clear that the results of this study are equivocal with respect to the basic question of whether the Frasnian-Famennian mass extinction was associated with the impact on Earth of a large extraterrestrial body. On the face of it, the iridium anomaly could plausibly be linked to such an impact; however, the Canning Basin data do not point with any high degree of assurance to this explanation. The siderophile atom ratios, notably Co/Ir (160,000), Ni/Ir (245,000), Pt/Ir (14), Ni/Co (1.5), Au/Ir ($\leq$0.2), and possibly Os/Ir ($\leq$0.4), are not compatible overall with either chondritic or iron meteoroids. Furthermore, analyses of material extracted with a microdrill show that iridium and platinum are concentrated by a factor of 2 in microstromatolites of the fossil cyanobacterium *Frutexites*, and iron, manganese, cobalt, arsenic, antimony, and cerium also increase, by a factor of 5. We cannot say whether biological mechanisms were the sole cause of the anomaly, or whether the organisms were only able to accumulate these elements to such a degree because of abnormally high concentrations of the elements in seawater at that time. In addition, it is not known whether the concentrating mechanism was biochemical, mechanical, or even diagenetic.

One fact is clear—a significant geochemical anomaly is present at or near the Frasnian-Famennian boundary in the Canning Basin, associated with a mass-extinction event of global extent. The association of the anomaly with the extinction may be purely coincidental, but it seems more likely that there is some genetic relation between them, involving either the impact of a large extraterrestrial body or an unidentified terrestrial process. The occurrence of this iridium anomaly at or near a mass-extinction horizon is clearly important in the search for geochemical signatures of global extinctions and the continuing debate on their origins.

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A New Basis for Recognizing the Paleocene/Eocene Boundary in Western Interior North America

Abstract. *Fossil pollen grains from Paleocene-Eocene rocks of the Bighorn Basin of Wyoming allow important sequences of terrestrial vertebrate fossils to be correlated with standard marine microfossil zonations. The Paleocene/Eocene boundary as based on pollen evidence falls within the Wasatchian land mammal age, much higher than the boundary used by some fossil mammal workers. This discrepancy partly results from multiple definitions of the Paleocene/Eocene boundary but may also indicate faulty mammal-based correlations to the type Sparnacian of France.*

Fossils from Paleocene and Eocene strata of the contiguous Bighorn and Clarks Fork basins of Wyoming provide one of the longest, most complete, and best studied records of terrestrial life in the world (*1–3*). The relatively high stratigraphic completeness of the strata (*4*) and the dense spacing of fossiliferous horizons (*5*, *6*) have made these sequences an important testing ground for theories on evolutionary rate and mode (*7*, *8*) and on intra- and intercontinental dispersal (*9*, *10*). As a result, there is strong incentive to develop reliable correlations between these strata and rocks of similar age in other regions, particularly with deep-sea marine sequences and the type sections of stages in the Paleocene and Eocene of Europe. Previous correlations have been based largely on mammalian fossils, and particularly on similarities between European and North American species of the primate genus *Plesiadapis* (*11–13*). Stratigraphically important fossil pollen found in lower Tertiary rocks of the Bighorn Basin provides a means of correlating these continental sequences to standard marine zonations that can be traced over much of the earth.

Forty-eight samples were collected from an 820-m-thick section in the Willwood and lower Tatman formations of the central Bighorn Basin (Elk Creek section, Fig. 1) (*6, 14, 15*). The Elk Creek section also contains one of the most completely known sequences of Wasatchian (early Eocene) mammal faunas, thus allowing direct comparison between stratigraphic changes in the fauna and palynoflora.

The pollen assemblage is dominated by Taxodiaceae-Cupressaceae, Juglandaceae, and by *Alnus*, a characteristic Paleocene to early Eocene assemblage in western North America. The Paleocene/Eocene boundary was placed at the 100-m level of the Elk Creek section, the level of the first occurrence of the Eocene index pollen species *Platycarya platycaryoides* (Fig. 1). Below this point the palynoflora is dominated by *Caryapollenites veripites* and other taxa typical of the late Paleocene [zone P6 of Nichols and Ott (*16*)]. Palynofloras above 100 m contain pollen of *Eucommia* and other genera found in lower Eocene palynofloras elsewhere in North America (*16–19*). The abundant occurrence of *Platycarya* leaf fossils and the great increase in the abundance of *P. platycaryoides* pollen at 700 m is typical of late early and early middle Eocene floras in much of North America (*18, 20, 21*).

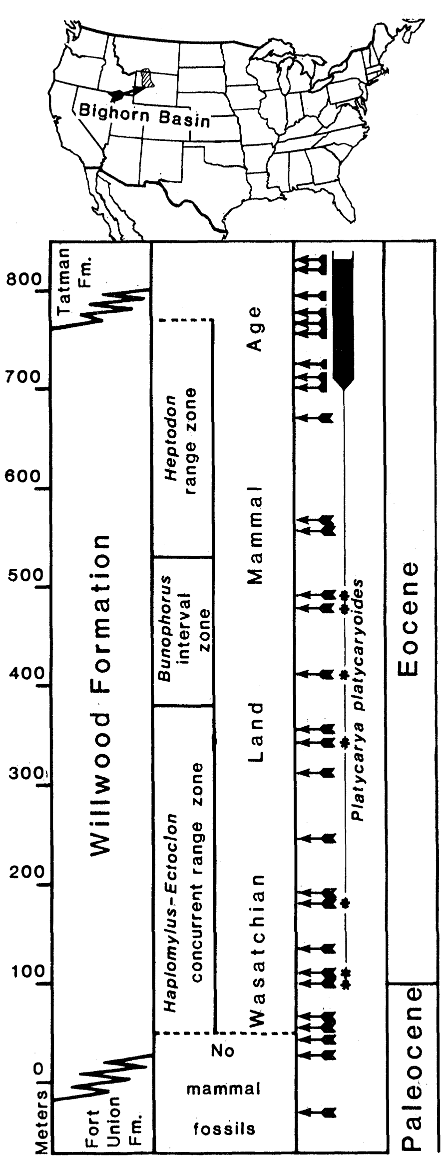

Fig. 1. The Elk Creek section of the Willwood Formation, showing stratigraphic position of pollen samples (arrows), the stratigraphic range of *Platycarya platycaryoides*, the local position of the Paleocene/Eocene boundary, and mammalian biostratigraphic zones. Mammalian biostratigraphy from Schankler (*6*). Map shows location of the Bighorn Basin.

The usefulness of *P. platycaryoides* as an Eocene index fossil in North America (*22*) has been shown by its lowest occurrence at or near the boundary of standard nannofossil zones 9 and 10 (NP9/NP10) in marine sections from coastal areas of Virginia (*23, 24*), South Carolina (*25, 26*), Alabama (*27*), and California (*28*). Furthermore, *P. platycaryoides* is known from strata in Texas (*29*), North Dakota (*17*), and Ellesmere Island (*30*) that have been dated as earliest Eocene by independent biostratigraphic or magnetostratigraphic methods.

Confidence in the synchroneity of the first occurrence of *P. platycaryoides* in North America is increased by considering its paleoecology. Early Tertiary *Platycarya* species had small, winged fruits presumably dispersed by wind or water; the tendency for *Platycarya* megafossils to dominate assemblages where they are found suggests that, like the living species, they were early successional "weedy" forms (*31*). Such species are capable of rapid geographic spread.

Assuming that the lowest occurrence of *P. platycaryoides* is a reliable datum, the 100-m level of the Elk Creek section is equivalent to the NP9/NP10 boundary, the generally accepted Paleocene/Eocene boundary in marine strata (Fig. 2) (*32, 33*). This places the Paleocene/Eocene boundary within the lower part of the Wasatchian land mammal age, higher than the traditional position based on mammalian fossils (the Clarkforkian/Wasatchian boundary) (*34*), and much higher than the position advocated by Gingerich (*11, 35*) and Rose (*12*) (the top of the lowest biozone of the Clarkforkian, Cf1).

Some of the conflict in correlation of the Paleocene/Eocene boundary to the Bighorn Basin may result from multiple definitions of the boundary in the type sections of Europe. The limits of the Paleocene have been controversial almost since the first use of the term in 1874 (*36*). Some paleontologists consider the Paleocene/Eocene boundary to fall at the base of the Sparnacian (*37, 38*); most micropaleontologists place it at the top of the Sparnacian (*33, 39, 40*); and the original placement on the basis of plant megafossils appears to have been at the top of the Cuisian (*41*). Thus the offset of the vertebrate and pollen boundaries in the Bighorn Basin could result from the former being correlated to the bottom of the Sparnacian and the latter to the top.

However, paleomagnetic data (*32, 35*) indicate that the mammal-based correlation of Gingerich (*11*) and the dinoflagellate-based correlation of Costa *et al.* (*40*) to the type Sparnacian cannot both be correct (Fig. 2). Gingerich (*11*) and Rose (*12*) correlated the basal Sparnacian to the Cf1/Cf2 boundary in the Bighorn Basin; this latter boundary occurs in rocks with reversed remanent magnetism that occur above paleomagnetic anomaly 25 (*35*). Costa *et al.* (*40*) correlated the basal Sparnacian to basal NP9 strata that occur within anomaly 25 (*32*). Clearly one or both correlations are faulty. This may contribute to the discrepancy between the pollen and vertebrate definitions of the Paleocene/Eocene boundary in the Bighorn Basin.

Paleocene-Eocene sections in the Bighorn Basin are now correlated to marine microfossil zonations using the first appearance of *P. platycaryoides* and to terrestrial strata in the Paris Basin using vertebrate faunas. However, it is not

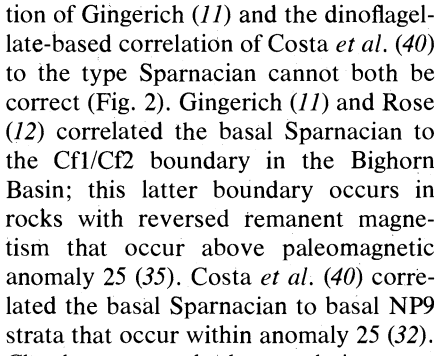

Fig. 2. Paleocene-Eocene correlations. The proposed correlation is based on the first occurrence of *Platycarya platycaryoides*. Correlations by Costa *et al.* (*40*) were based on dinoflagellates; correlations by Gingerich (*11*) and Rose (*12*) were based on mammals. Paleomagnetic data from Berggren *et al.* (*32*) and Butler *et al.* (*35*). Note that the correlations to the base of the Sparnacian are contradictory. Mammalian biozone abbreviations: HEZ, *Haplomylus-Ectocion* range zone; BIZ, *Bunophorus* interval zone; and HRZ, *Heptodon* range zone.

possible to close the circle of correlation (and thus to test the pollen and vertebrate correlations against each other) because of the uncertain relation of the type Sparnacian to marine microfossil zonations (*32, 34, 40*). Because it has proved exceptionally difficult to establish correlations between the type Sparnacian and other sections, many authors prefer to correlate to a datum based on nannoplankton (NP9/NP10), planktic foraminifera (P6a/P6b), and dinoflagellates (*Apectodinium hyperacanthum/Wetzeliella astra*). Since fossil pollen now provides a link between land mammal succession and these marine microfossil zonations, it is preferable to recognize the marine datum rather than to continue attempting correlation with a less precise and less useful Paleocene/Eocene boundary based on the type Sparnacian of the Paris Basin.

Precise correlation of terrestrial strata on different continents is important for evolutionary and paleobiogeographic syntheses. Recent studies on centers of origin and evolution for early Tertiary mammals (*10, 11*) and on the effect of early Tertiary climates on the evolution and migration of many lineages of plants and animals (*30*) have stimulated interest in the detection of diachronous events in the fossil record. Too often paleobiologists are forced into the logically tenuous position of studying purportedly diachronous events in the same group of organisms that they use for correlation. Precise, mutually agreed upon boundaries that are based on a broad array of taxonomic groups are a necessary framework for recognizing diachronous evolutionary and migrational events in the fossil record.

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Cretaceous-Paleocene Terrestrial Faunas of India: Lack of Endemism During Drifting of the Indian Plate

Abstract. *Recent paleontological investigations of six sections fringing the Deccan volcanic outcrops of the Indian peninsula indicate that terrestrial faunas during the Cretaceous-Paleocene transition lacked the endemism predicted by geophysical models of an oceanically isolated Indian subcontinent. At the generic and familial level there is a close correspondence between the Cretaceous vertebrates of peninsular India, Africa, and Madagascar. This suggests that a dispersal corridor, consisting of presently submerged aseismic elements (the Mascarene Plateau and the Chagos-Laccadive Ridge), existed between these landmasses about 80 million years ago as India drifted close to eastern Africa.*

In geophysical models the Indian landmass is envisaged as a northward-drifting, isolated subcontinent before its collision with the Tibetan Block (*1, 2*). Until recently, paleontological data on terrestrial faunas during India's phase of isolation (Cretaceous, Paleocene, and Lower Eocene) were not available to support the hypothesis that biotic endemism resulted from the supposed isolation. During the past 4 years, however, the subject has been reexamined (*3, 4*) in light of studies of several previously known and newly discovered localities (*4, 5*) fringing Deccan Basalt outcrops in peninsular India (Fig. 1).

The material collected from measured sections represents a diversified vertebrate fauna from a coastal plain environment. The faunal list is given in Table 1. Associated fossils in most localities include a rich assemblage of charophytes (*Microchara, Platychara*), cyprid ostracods, unionid pelecypods, and pulmonate gastropods. In at least two central Indian localities (Jabalpur and Asifabad), the presence of shallow-water foraminifera has been recorded (*4*). The paleontological data on peninsular India are therefore now fairly extensive, and they suggest not a general endemism but rather a cosmopolitan distribution at the generic level.

Although Cretaceous-Paleocene taxa in peninsular India have a wide distribution, they appear to be closest to those from the same time interval in Africa and Madagascar. This affinity is consistent with geophysical models (*1*) that envisage a contact with the eastern coast of Africa that was maintained much later than that with Australia and Antarctica, for which an Early Cretaceous separation is considered likely. Striking similarities are noted among African and Indian fish, turtles, and dinosaurs. The coastal