Cretaceous age for Ir-rich Deccan intertrappean deposits: Palaeontological evidence from Anjar, western India

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Sunil Bajpai
Indian Institute of Technology Roorkee

Guntupalli V R Prasad
University of Delhi

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SPECIAL

Cretaceous age for Ir-rich Deccan intertrappean deposits: palaeontological evidence from Anjar, western India

S. BAJPAI[1] & G. V. R. PRASAD[2]

[1] *Department of Earth Sciences, University of Roorkee, Roorkee 247 667, India (e-mail: sunilfes@rurkiu.ernet.in)*
[2] *Department of Geology, University of Jammu, Jammu 180 004, India*

Micropalaeontological investigations of an iridium-bearing, lacustrine intertrappean sedimentary sequence at the western margin of the Deccan volcanic province near Anjar, have revealed a profuse occurrence of theropod eggshell fragments (ornithoid type) in beds overlying the iridium-enriched levels. Associated late Cretaceous ostracods, lack of evidence of reworking, and the absence of any exclusively Palaeocene taxa above the iridium levels, taken together, indicate that the extinction of dinosaurs in the Indian subcontinent occurred after the deposition of Ir layers at Anjar, and that these Ir anomalies may significantly predate the K–T boundary.

Keywords: Cretaceous, K–T boundary, Deccan Traps, India, extinctions.

The non-marine record of the Cretaceous–Tertiary (K–T) boundary interval is of considerable importance in assessing the global nature of biotic and abiotic events which are considered to characterize this boundary at 65 Ma. However, data on continental sections are at present restricted largely to the Western Interior of North America and a few sections in Europe and China (e.g. Archibald 1996). In recent years, the Deccan Traps of peninsular India have been shown to represent a major episode of continental flood basalt volcanism nearly coincident with the K–T boundary (Courtillot *et al.* 1996 and references therein). This has given rise to hypotheses linking Deccan volcanic eruptions to the end-Cretaceous mass extinctions (e.g. Glasby & Kunzendorf 1996 and contained references), as an alternative to, or in conjunction with, the extra-terrestrial impact model of Alvarez *et al.* (1980). Until recently, the volcanic hypothesis for mass extinctions could not be tested in the absence of any record of anomalous iridium levels in the Deccan volcano-sedimentary province. Evidence is now available for the occurrence of high concentrations of iridium in sediments ('intertrappean beds') intercalated between the volcanic flows at a locality near Anjar, Kachchh (=Kutch) District on the western margin of the Deccan province (Bhandari *et al.* 1995, 1996; Shukla *et al.* 1997). This discovery has been interpreted as the consequence of a bolide impact unrelated to the Deccan volcanism (Bhandari *et al.* 1995), and has assumed considerable significance in the context of the ongoing K–T boundary debate. We undertook micropalaeontological investigations of this unique section in order to document a biotic turnover at the assumed K–T boundary, marked by the iridium levels. Our data provide new insight into the nature of the iridium spikes in relation to the highest stratigraphic occurrence of dinosaur remains in the Deccan province. The data strongly suggest that the extinction of dinosaurs does not coincide with any of the iridium levels in the Anjar intertrappeans, and that these iridium spikes may have been produced significantly before the K–T boundary. It must be emphasized, however, that palynological investigations are particularly required to test these conclusions. We believe that the occurrence of iridium spikes and a number of fossiliferous levels, together with the location of this site in the Deccan province, make the Anjar intertrappean section potentially important for a better understanding of K–T boundary events in the continental realm.

Geological background and previous work. The Anjar volcano-sedimentary sequence comprises as many as seven basaltic flows enclosing four intertrappean beds (Ghevariya 1988). At pit BG1 (Fig. 1), which forms the lowermost part of the third intertrappean sequence occurring sandwiched between the third and fourth lava flows, three levels of chocolate-coloured limonitic layers, less than 1 cm in thickness and separated from each other by about 25–30 cm, have yielded anomalously high values of Ir and other siderophile and chalcophile elements (Bhandari *et al.* 1995; Shukla *et al.* 1997). The middle and lower levels show similar Ir concentrations (about 1300 pg g^{-1}), with an enhancement factor of over 127 as compared to the underlying flows, whereas the upper level is less enriched (700 pg g^{-1}). The adjacent sediments have yielded values at *c.* 100 pg g^{-1}). $^{40}Ar/^{39}Ar$ dating has yielded indistinguishable plateau ages of about 65 Ma (Fig. 1) for the adjacent flows (Venkatesan *et al.* 1996).

Excavation at the site (pits BG2 to BG5) revealed a total thickness of about 4 m stratigraphically above BG1, consisting mainly of shale, marl and cherty limestone (Fig. 1). Sedimentological investigations indicate a lacustrine depositional setting proximal to the coast (Khadkikar *et al.* 1999), an interpretation also supported by the pulmonate molluscs and ostracods (Bajpai 1996; Bhandari & Colin 1999).

Processing of silty shales at pit BG1 yielded a fossil assemblage that includes abundant two-layered ornithoid eggshell fragments in association with occasional theropod teeth (indet.) sauropod eggshells, the ray *Igdabatis* and ostracodes *Altanicypris szczechurae* (Stankevitch), *Mongolianella palmosa* Mandelstam (Bajpai 1996). Large sauropod bones have also been found (Ghevariya 1988), but theropod bones are lacking. This assemblage occurs sandwiched between the middle and upper Ir levels (Ir2 and Ir1) and is indicative of a Late Cretaceous, probably Maastrichtian age. Several additional ostracode taxa described recently from these shales also favour a Maastrichtian age (Bhandari & Colin 1999). Palynological data are still lacking for the Anjar intertrappeans, but preliminary investigations revealed the presence of a Maastrichtian spore *Gabonisporites* between the upper and middle Ir levels (unpublished data, R. K. Kar, BSIP, Lucknow, India). It is important to note that besides Kachchh, the presence of dinosaur remains has been documented from several other

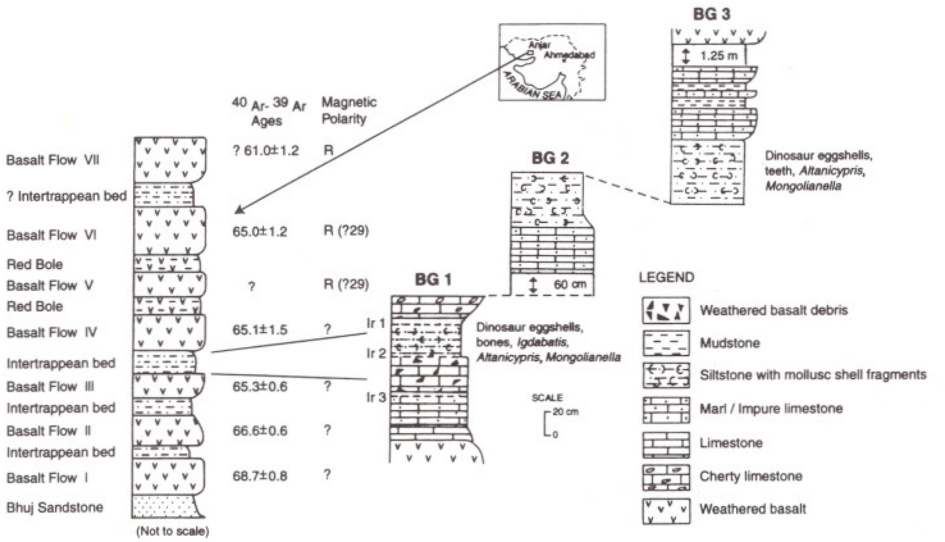

Fig. 1. Stratigraphic position of iridium and fossil-bearing levels in the Anjar volcano-sedimentary sequence (radiometric, palaeomagnetic and geochemical data after Venkatesan *et al.* 1996; Bhandari *et al.* 1996 and Shukla *et al.* 1997). Inset, location map.

widely separated intertrappean localities across peninsular India (e.g. Rao & Yadagiri 1981; Sahni & Bajpai 1988; Prasad 1989; Sahni & Tripathi 1990; Srinivasan 1996). Significantly, at some of the intertrappean localities (Ranipur, central India) dinosaur remains occur in association with Maastrichtian pollen assemblages including *Aquillapollenites* (see Sahni *et al.* 1996). Although not as common as in the underlying Lameta Formation, intertrappean dinosaurs are represented by diverse elements including bones, isolated theropod teeth and a variety of eggshell fragments. Complete eggs and nesting sites have not yet been found in the intertrappeans, but this evidently reflects strong facies control since such occurrences are largely restricted to hard, calcretized limestones common in the Lameta Formation (Sahni *et al.* 1994).

Present data. In anticipation of the recovery of an early Palaeocene fauna from Anjar, we undertook bulk sampling from pits BG2 and BG3 overlying the upper Ir level (Ir1). Surprisingly, these beds have yielded a fossil assemblage identical to that found below Ir1. Ornithoid (theropod) eggshells are equally abundant and occur in association with relatively uncommon sauropod eggshell fragments and denticulated theropod teeth (Fig. 2). Although there are considerable similarities in the eggshell structure of theropods and birds (e.g. Mikhailov 1997), the presence of theropod teeth and the total lack of any bird bones rule out the possibility that these ornithoid eggshells are avian. Furthermore, ostracodes include the same late Cretaceous taxa *Altanicypris szczechurae* and *Mongolianella palmosa,* which occur below Ir1 and which have been previously described from other dinosaur-bearing intertrappean localities (e.g Nagpur, Asifabad) (Bhatia *et al.* 1996). In addition, *Candona* cf. *sinensis* Ho and *Limnocypridea* Lyubimova, both known from the upper Cretaceous of China, have also been identified (Bhandari & Colin 1999; R. Whatley, joint work in progress).

Several observations indicate that the fossil assemblage above the iridium levels cannot have been reworked from older intertrappean deposits. Ostracodes, although not very common, show no evidence of size sorting and taxonomic bias, include adults and are fairly well preserved (Fig. 2), with articulated carapaces being much more common than single valves (R. Whatley pers. comm.). Gastropods, both fragmentary and complete, are highly abundant, ruling out the possibility of dissolution due to reworking. Pelecypods, both micro and mega, also occur, though in lesser abundance as compared to gastropods. Fragmentation of molluscan shells is evidently due to sediment compaction and littoral abrasion. Similarly, ornithoid eggshells are not size-sorted, show negligible signs of rounding of their margins and are frequently associated with even more delicate lacertilian (gecko) eggshells

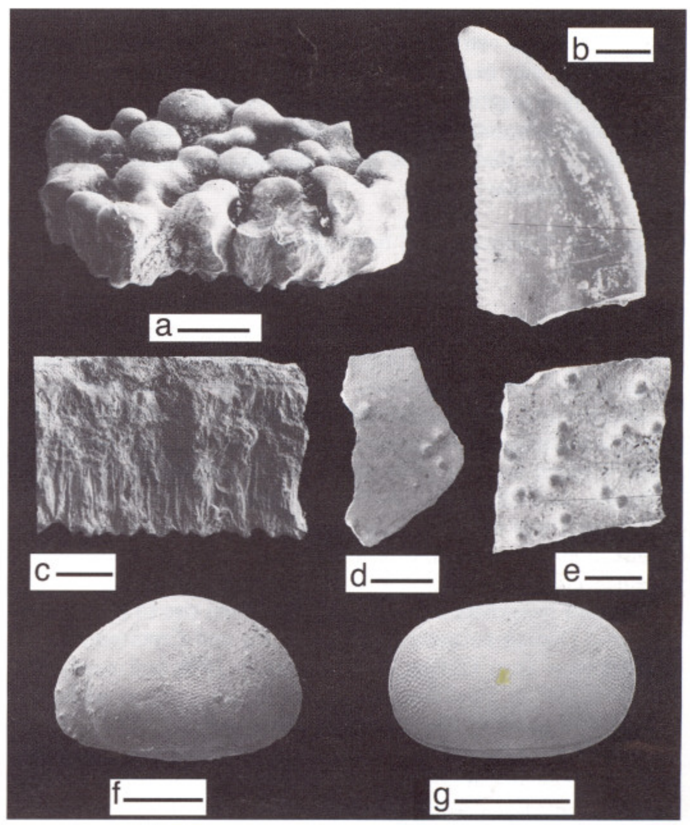

Fig. 2. (**a**) External surface of sauropod eggshell; (**b**) Lateral view of theropod tooth; (**c**) Radial view of ornithoid eggshell; (**d**) and (**e**) external surface of ornithoid eggshells; (**f**) and (**g**) ostracodes *Altanicypris* and *Limnocypridea.* Bar equals 1 mm for (a), (b), (d), (e) and (g); 100 μm for (c) and 500 μm for (f).

and some other still unidentified eggshell types. However, no large bones have been found so far above the upper iridium level. The presence of basalt fragments in the lower part of the succession does indicate some amount of fluvial reworking of the underlying basalt flow, but it is unlikely that the older intertrappean material underlying a sizeable thickness of this lava flow would have been reworked into the iridium-bearing, higher intertrappean level. Furthermore, the possibility of reworking from the pre-Deccan rocks clearly does not arise because no infratrappean correlatives of the Lameta Formation are known to occur in Kachchh and the Deccan basalts are underlain directly by unfossiliferous sandstones of the Bhuj Formation (Lower Cretaceous). It is to be noted that a similarly preserved eggshell assemblage occurs between the same two flows at another intertrappean exposure about 400 m to the west (Bajpai *et al.* 1993). Whether or not this section also shows anomalous Ir concentration is not known but there are no limonitic layers here.

Discussion. Our data from the Anjar intertrappeans have important implications for the ongoing debate on the K–T boundary extinctions. If any of the Ir levels at Anjar represents the K-T boundary, then the occurrence of dinosaur fossils above the upper Ir level implies the survival of dinosaurs into the Palaeocene. There have been several previous claims of dinosaurs persisting into the early Palaeocene (see Charig 1989). Although doubts have been cast on a majority of such records on grounds of reworking, wrong age assignments or even wrong identification, some of the dinosaur remains do seem to extend into the Tertiary (e.g. Rigby *et al.* 1993; see also Stets *et al.* 1996). In the present case, the possibility of dinosaurs surviving into the Palaeocene appears unlikely because of the associated late Cretaceous fossils and the complete absence of any exclusively Palaeocene taxa in beds above the last Ir level.

The presence of late Cretaceous elements across the three Ir-enriched levels clearly suggests that none of these Ir levels represent the K–T boundary (Chicxulub event). Hence, the assertion that these Ir levels represent the K–T boundary (Chicxulub event) (Bhandari *et al.* 1996; Venkatesan *et al.* 1996) is based solely on $^{40}Ar/^{39}Ar$ dates of the overlying and underlying basalts, and is not supported faunally. Whether the K–T boundary lies higher up section or has been removed by erosion cannot be determined at present due to lack of data on palynological assemblages or any younger Ir levels. Available palaeomagnetic data indicate reverse polarity for flows V, VI and VII, whereas the magnetization of the flows immediately adjacent to the Ir-bearing intertrappeans (F III & IV) is yet to be determined. This makes it difficult to ascertain the exact position of the intertrappean sequence in the Magnetic Polarity Time Scale (MPTS). However, the known $^{40}Ar/^{39}Ar$ ages strongly suggest that the reverse polarity recorded in the Anjar sequence corresponds to the central reverse chron of the typical N–R–N sequence in the Deccan, correlated convincingly with 29R as opposed to 31R (Vandamme *et al.* 1991; Courtillot *et al.* 1996). This implies that the Ir-levels and the overlying dinosaur-bearing sequence, which lie stratigraphically well below the reversely magnetized flows V and VI, may correspond to the lower part of Chron 29 R or even to Chron 30 N. The weathered horizons ('boles') separating the overlying flows do not contain any fauna (Bhandari *et al.* 1995), but their presence is indicative of fairly prolonged breaks in eruption, possibly within chron 29R.

The origin of three clustered Ir peaks is still unclear, as most K–T sections worldwide are characterized by a single Ir spike. Shukla *et al.* (1997) suggested the possibility of multiple cometary impacts. Alternatively, and more likely, the occurrence of three Ir peaks in sediments with moderate enrichment of Ir (*c.* 100 pg g^{-1}), is consistent with a protracted (but possibly within magnetic chron 29R) supply of volcanically-derived Ir, although some remobilization may have occurred. It is to be noted that no diagnostic extraterrestrial markers (shocked minerals, tektites/microtektites, Ni-rich spinels) have yet been found in the Anjar sequence. A similar volcanic origin has been favoured to explain the occurrence of multiple Ir anomalies in a marine K–T section in the Bavarian Alps (Graup & Spettel 1989). We believe there is compelling current evidence for the possibility of plume-related contribution to PGE concentrations at or near the K–T boundary.

Further, the extinction of dinosaurs cannot be attributed solely to the initiation of Deccan volcanism. Data from the intertrappean beds of eastern and southern portions of the Deccan basaltic province clearly indicate that dinosaurs survived the initial phases of volcanic activity (Prasad & Khajuria 1995). The present record of dinosaur fossils higher up in the local volcano-sedimentary pile lying along the western periphery of the Deccan province, indicates their persistence even after several eruptive events. This also holds true for other terrestrial communities in the Deccan intertrappeans, most of which are also known to occur in the pre-Deccan Lameta Formation. The episodic nature of Deccan volcanism may possibly explain this survival, although the environmental stresses that accumulated through a series of eruptive events over an extended period of time, often with substantial pyroclastic component, could have deleteriously affected the biota (Cox 1988; Widdowson *et al.* 1997).

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