Geochemical characterisation of the Cretaceous-Tertiary Boundary sediments at Anjar, India

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Geochemical, geochronological, palaeomagnetic and palaeontological evidences that show that the third intertrappean bed at Anjar encompasses Cretaceous-Tertiary boundary are described. Presence of three well separated iridium rich horizons indicates multiple depositional events. Their origin in volcanic or multiple cometary impacts is discussed. The results are compared with the chemical anomalies observed in Um Sohryngkew River Section in Meghalaya.

Key-words—Cretaceous-Tertiary Boundary, Iridium anomaly, Kutch Basin, India.

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साराँश

भारत में अंजर की क्रीटेश्यस-टर्शियरी सीमा के अवसादों के भूरासायनिक लक्षण

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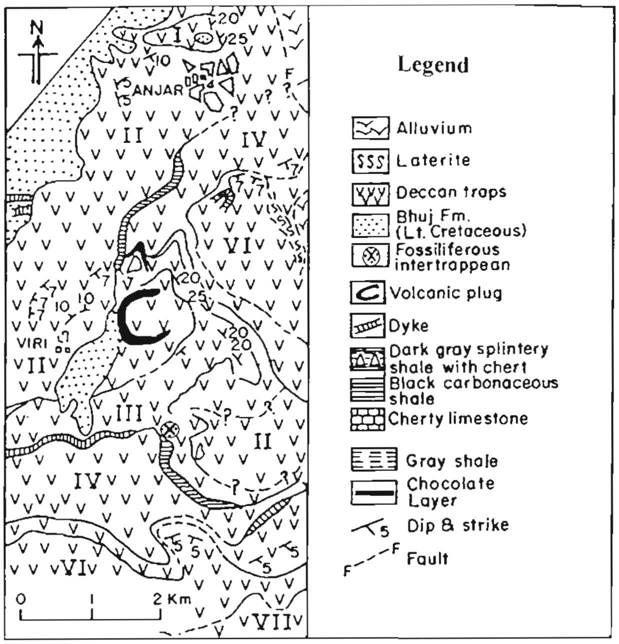
भूरासायनिक, भूकालानुक्रमिक, पुराचुम्बकीय एवं पुरातात्विक प्रमाणों जिनसे कि अंजर की तृतीय अन्तर्ट्रेपी संस्तर में क्रीटेश्यस-टर्शियरी सीमा की विद्यमानता व्यक्त होती है, का वर्णन किया गया है। तीन स्पष्ट पृथक इरीडियम से भरपूर संस्तरों की उपस्थिति से विविध निक्षेपणीय घटनायें प्रदर्शित होती हैं। ज्वालामुखीय अथवा विभिन्न धूमकेतु सम्बन्धी प्रभावों में इनकी उत्पत्ति की विवेचना की गई है। उपलब्ध परिणामों की तुलना मेघालय में उम्शौरिंगीव नदी खंड में प्रेक्षित रासायनिक विसंगतियों से की गई है।

THE Deccan volcanism, because of its magnitude (>10^6km^3), duration (0.5 to 3 Ma) and high frequency of flows, has played a significant role in the Cretaceous to Tertiary transition, about 65 Ma ago. The Cretaceous-Tertiary Boundary (KTB) is chemically marked by a global iridium rich layer (Alvarez *et al.*, 1980). Two sections within and close to the Deccan volcanic province, containing this characteristic iridium rich layer, have been identified and studied in our laboratory (Bhandari, Shukla & Pandey,1987; Bhandari, Gupta & Shukla, 1993a; Bhandari, Shukla & Castagnoli, 1993b; Bhandari *et al.*, 1994, 1995). One of them is located in a shallow marine section in the Um Sohryngkew River Basin in Meghalaya and the other one in a continental volcano-sedimentary section at Anjar, Kutch Basin. The Anjar section has given an opportunity to understand the sequential succession of events close to KTB with a high time resolution and their causative factors. In this paper, we describe chemical and sedimentary characteristics of this section. Upper Cretaceous fossils in this section have been described by Ghevariya (1988), Bajpai *et al*. (1993) and Bajpai (1996). In their high resolution study, Bhandari *et al.* (1996) found three iridium-rich layers, separated by about 25 - 30 cm from each other, in the third intertrappean samples. Here we describe the nature of sediments at the KT transition and also compare the main features of the two KT sections from India on the basis of their geochemical characteristics.

GEOLOGICAL SETTINGS

The volcano-sedimentary sequence at Anjar (23°15'N, 75 ° 15'E; Survey of India topo-sheet 41/I4) in Kutch region (Text-figure 1) consists of seven basalt flows (Ghevariya, 1988). The site is shown in satellite imagery in Plate 1. Between six of these flows (F I to F IV and F VI to F VII), there are several meters thick well-developed intertrappean (IT) sediments, whereas the Flow V is sandwiched between two red bole horizons. A variety of obser-



Text-figure 1— Location of Anjar volcano-sedimentary sequence (after Ghevariya, 1988). Various flow units are shown.

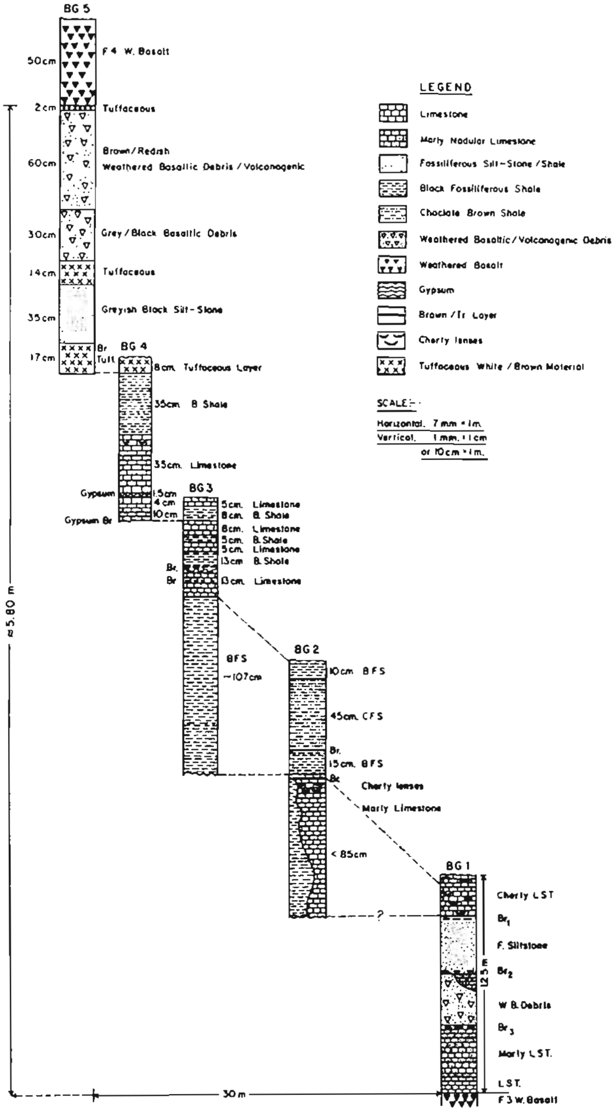
vations suggests that this sequence was emplaced during the uppermost Cretaceous. During November, 1995 a field workshop was held at Anjar in which participants from several institutions examined the sequence. Several pits were made through the intertrappean III in which iridium-rich layers have been observed. Text-figure 2 shows the composite litholog of the Intertrappean-III.

The IT-III is about 6 m thick and consists of clay, shales and limestone (Text-figure 2) in which the three thin and patchy horizons, rich in iridium have been identified. Limited search in other intertrappeans did not show any iridium enrichment. The 25 cm thick horizon between Layer I and Layer II is highly fossiliferous.

PALAEONTOLOGICAL OBSERVATIONS

Ghevariya (1988) and Bajpai *et al.* (1993) have reported the presence of dinosaur bones, egg shell fragments and other Upper Cretaceous fossils in the second and third (IT-II and IT-III) intertrappeans. Ghevariya (1988) also noted presence of invertebrate fossils in the V intertrappean bed. Palaeontological studies made in the II and III intertrappean sections suggest the presence of taxonomically diverse faunal and floral assemblages. In the intertrappean III, the fossils are abundant between Ir layer 1 and 2. These include bones, teeth and egg shells of sauropods and theropods, as well as ornithoid egg shells. Bulk screening of the third IT level has yielded isolated teeth, otoliths, scales of fishes, Geckonid (lacertilian) egg shells, ostracods and micro-pelecypods (Bajpai *et al.*, 1993; Bajpai, 1996). Fish teeth *Igdabatis* and *otoliths* (*Serranidae* and *Ariidae*) have also been reported by Bajpai (1996). The presence of stratigraphically important ostracod taxa such as "*Mongolianella*" and "*Altanicypris*" is also noticed. Initial palynological studies by R.K. Kar (Pers. Comm., 1996) suggest the presence of the latest Cretaceous (Maastrichtian) elements, including *Gabonisporites*. This fossil assemblage found in the horizon

ANJAR INTERTRAPPEAN III



Text-figure 2— Lithologs of Anjar Intertrappean III as constructed from study of five pits (BG1 to BG 5).

PLATE 1

Landsat imagery showing geological configuration around Anjar town. Several flows can be clearly seen. Location of the intertrappean III is shown by circle.

encompassed by iridium rich layer I and II is of Maastrichtian age. This horizon also contains significant amount of soot, presumably from forest fire.

GEOCHRONOLOGICAL FRAMEWORK

The seven basalt flows have been dated by ^{39}Ar-^{40}Ar method. Three of them FI (68.7 ±0.8 Ma), FII (66.6 ±0.6 Ma), FIII (65.3± 0.6 Ma) yield good plateau ages (Venkatesan *et al.*, 1996). Flows IV, V and VI do not yield good age plateaus but give integrated ages of 65.1±1.5, 65.9 ±1.6 and 65.0 ±1.2 million years (all errors are 2), which are consistent with their isochron ages. F VII also gives an apparent age of 61 ±1.6 Ma. The samples have also been dated by French Group (Hofmann *et al.*,1997) and their results are essentially similar. The data indicate that the sequence was a prolonged one in time covering 7.7 ± 2 Ma but if Flow I and VI are excluded, than all the five flows were quickly laid between 65 Ma and 67 Ma, covering two million years or less. A finer time resolution is not possible because of uncertainties due to errors.

PALAEOMAGNETIC OBSERVATIONS

Palaeomagnetic studies carried out by S. Kusumgar (Pers. Comm., 1995) show that the secondary component is very prominent in most basalts. The three lower flows (F I, II and III) show a dominant normal magnetisation, most of it is secondary in nature, imprinted on a faint primary magnetisation whose direction could not be established with certainty. The secondary and primary components could be resolved in flow V, VI and VII and they show primary reverse magnetisation. Based on the geochronological and magnetic data, we place flows V and VI in Chron 29R. Flow IV gives erratic magnetisation and statistically poor data. The results so far indicate a N-R sequence but there is a contradiction between Mahabaleswar and Anjar data. Both of them represent the same time span 61-68 Ma (Venkatesan *et al.,* 1993) but Mahabaleswar flows show only a reverse chron. If there is a faint primary reversed component in the lower flows at Anjar, it needs to be confirmed by a more detailed study.

CHEMICAL ANOMALIES

The intertrappean sediments IT-III consist of a 6 m thick sequence of gypseous clays, splintery black-grey shales, cherty limestone and bedded chert. The grey and black shale contains three sub-centimeter thick, chocolate-coloured layers (Br 1, 2 & 3) separated by about 32 and 25 cm, respectively. All the three layers are patchy but are continuously traceable in pit BG1. The second layer, Br 2, is the most prominent and sometimes bifurcates into two closely spaced layers, 2A and 2B. Above each of these horizons, a white sub-centimeter thick continuous band, probably calcareous in nature, exists.

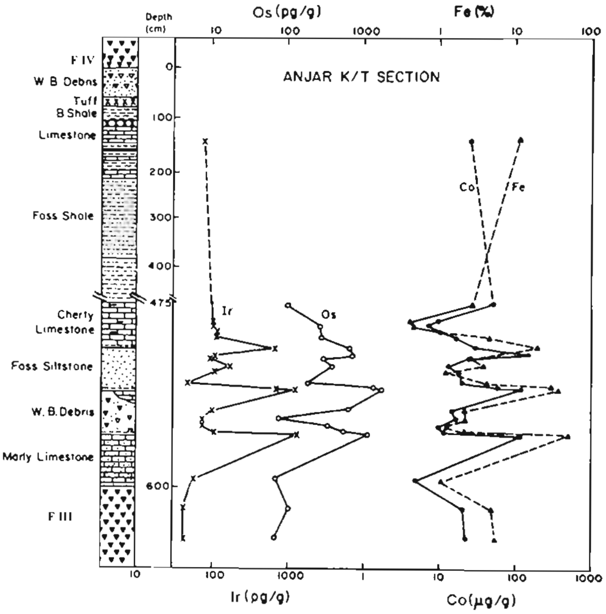
Concentration of several siderophiles (Fe, Co, Ni, Ir, Os), chalcophiles (Sb, Se, As Zn, Ag, Cu) and lithophiles (Al, Mg, Na, K, Ca, Ba, Sc, Hf, Th & 9 REE : La, Ce, Nd, Sm, Eu, Gd, Tb, Yb & Lu) has been determined using AAS INAA and RNAA procedures on closely spaced samples in IT-III. The elements which are characteristic of the KTB, e.g., platinum group elements like Ir and Os are enriched in the three layers together with chalcophile elements like Sb, As, Zn, Ag, etc.

The analyses indicate that the concentration of iridium in basalts, F III and F IV, is low, $\leq$10 pg/g. The intertrappean III sediments generally contain iridium at ~100 pg/g, which is higher than the values found in other intertrappeans in Deccan (Bhandari, Gupta & Shukla, 1993a; Bhandari, Shukla & Castagnoli, 1993b). However, just above and below the uppermost horizon, containing dinosaur fossils, the concentration of iridium increases abruptly reaching peak values of 700 to 1333 pg/g in the three layers. Text-figure 3 shows the depth profiles of some of these elements in the section. The high Ir is accompanied by unusually high Os, Fe, Co, Sb, Zn, Se, As and Ag. The peaks persist even when we correct for the clay content by normalizing to Sc. Thus the observed Ir enhancement appears unlikely to be due to secondary processes.

The concentrations of various siderophile and chalcophile elements in the layer Br 2, when compared with those in basalt FIII, show enhancement by large factors: Ir(>127), Fe(4.1), Co(2.6), Ni(1.8), Sb(795), Se(14.5), Zn(1.9) and Cu(1.8). Some lithophiles, i.e., Sc, Hf, Th, Mg, K and Na are relatively depleted by factors of 5 or more whereas others, i.e., Al, Cr, Mn and REE are depleted by factors of 1.5 to 22. The concentration of iridium in layer Br 2 is not only the highest amongst Anjar intertrappeans but also 10 to 20 times higher compared to several other intertrappean sediments studied so far, e.g., from nearby Bhachao site as well as far away sections from the eastern periphery of Deccan Plateau, i.e., from Nagpur, Jabalpur, Bargi and Padwar (Bhandari, Shukla & Castagnoli, 1993a). The Os/Ir ratio in the three layers is close to the meteoritic value of 1.

DISCUSSION

The occurrence of iridium-rich layers in the Anjar intertrappeans, deposited in lacustrine condition, above three basalt flows clearly ruled out the impact



Text-figure 3—Profiles of Ir, Os, Fe and Co in III intertrappean bed (pit BG1). **W. B.** is weathered basalt and **B.** is black.

origin of Deccan Volcanism proposed by Alt *et al.* (1988) and Rampino and Caldeira (1993). We have extensively searched other intertrappeans in the Deccan province for iridium-rich horizons (see Bhandari *et al.*,1993) but were not able to find any significantly enriched horizon except at Anjar. The other horizon in the Indian sub-continent where Ir rich layer exists is the shallow marine Um Sohryngkew River section in Meghalaya (Bhandari *et al.*, 1987). Palaeontological controls (Pandey,1990), Garg and Jain (1995) and presence of meteoric spinels (Robin *et al.*, 1997) clearly establish the presence of KTB in this section where Ir peak exists. Here the peak having concentration of Ir = 12.1 ng/g is much stronger than in Anjar (max. concentration 1.3 ng/g) but there is a significant difference. In Meghalaya, the peak is superimposed on a broad hump extending over 70 cm having Ir concentration of 0.1 ng/g whereas at Anjar three peaks of moderate Ir concentration occur on sediments which are also little bit enriched in Ir (0.1 ng/g). In spite of these differences in Ir profile which may be due to better resolution available at Anjar because of faster sedimentation rate, the integrated amount of Ir in the two sections is nearly the same ~70 ng/cm^2. This indicates identical source strength of Ir. If Ir originated in the Chicxulub impact of a bolide, similar fallout of Ir can be expected in far away locations as at Anjar and Meghalaya. Only a single Ir peak is expected from an asteroidal impact but observation of multiple peaks and enriched intervening sediments is consistent with multiple cometary impacts if there are no post-depositional disturbances. Graup and Spettel (1989) also found three iridium rich layers in Bavarian Alps K/T section. Volcanism can give rise to such a profile but absence of high iridium in other intertrappeans at Anjar and at other locations preclude such a possibility.

SUMMARY

The available geochronological, palaeomagnetic, geochemical and palaeontological data suggest that the Anjar Intertrappean III encompasses the K/T boundary. However, better palaeontological control is required to confirm this conclusion. Impact signatures such as shocked quartz, Ni-rich spinel, etc. have not yet been found in this section. Shocked quartz may not be expected since India was located in the forbidden zone of the fall-out ejecta of the Chicxulub impact according to the model of Alvarez *et al.* (1995). Absence of impact ejecta debris in Anjar intertrappeans does not confirm the suggestion of a giant 600 km impact crater at the India-Seychelles rift zone (Chatterjee & Rudra,1997), or another small crater proposed near Bombay (Negi *et al.*,1993) since the proximal ejecta expected at this site has not been found.

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