Palaeoenvironmental, palaeoecological and palaeobiogeographical implications of mixed fresh water and brackish marine assemblages from the Cretaceous-Palaeogene Deccan intertrappean beds at Jhilmili, Chhindwara District, central India

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ABSTRACT

The Deccan infra- and intertrappeans volcano-sedimentary sequences have been considered as terrestrial to fluvio-lacustrine deposits. Presence of planktonic foraminifera and brackish water ostracods in the Jhilmili basal Danian intertrappean beds, recorded earlier, indicates complex palaeoenvironment, palaeoecology and palaeobiogeography. The intertrappean sediments span 14 m between two Deccan basaltic flows deposited under terrestrial, palustrine and flood plain environments. In the middle of this section is a 60 cm-thick layer (unit 3) that contains fresh water ostracods, charophytes and Early Danian planktonic foraminifera. Palaeoecologically, the ostracod assemblage includes active swimmers (*Cypridopsis*, *Cypria*, *Mongolianella*, *Paracypretta* and *Zonocypris*) and poor swimmers (*Limnocythere*, *Gomphocythere*, *Frambocythere* and *Darwinula*). The bulk of the ostracod fauna points to a freshwater, lacustrine depositional environment. Presence of planktonic foraminifera and two brackish water ostracod species (*Buntonia* sp. and *Neocyprideis raoi*) invigorates discussion of a marine seaway into central India, with this fauna carried through the Narmada and Tapti rift zones by seasonal offshore currents (short lived transgressive phase), which created temporary estuarine conditions and deposited marine micro-biota. Above this interval, sediments in unit 4 and 5 consist of reddish and greenish grey clayey siltstone with rare fine sand layers deposited in palustrine and terrestrial conditions. The ostracod fauna shows extensive endemism which come across among the Indian Maastrichtian non-marine ostracods sustained into the Early Danian, which further proposed geographically isolated Indian plate and intercontinental dispersal of Maastrichtian to early Danian freshwater ostracods that support the Out-of-India hypothesis. Age of the Jhilmili intertrappean beds is Early Danian-Maastrichtian based on planktonic foraminifera and few brackish water ostracods.

Key words: Micro biota; ostracoda; planktonic foraminifera; Deccan intertrappean; India; Paleocene; Cretaceous-Palaeogene boundary.

RESUMEN

Las secuencias volcanosedimentarias subyacentes e intercaladas en los "traps" de la meseta de Deccan se han considerado como depósitos terrestres y fluviales-lacustres. La presencia de foraminíferos planctónicos y ostrácodos de agua salobre en las capas Jhilmili del Daniano inferior intercaladas en los "traps", descritas con anterioridad, indica paleoambiente, paleoecología y paleobiogeografía complejos. Los sedimentos intercalados en los "traps" tienen 14 m de espesor y se encuentran entre dos flujos basálticos del Deccan; los sedimentos se depositaron en condiciones terrestres, palustres y de planicies de inundación. En medio de esta sección se encuentra una capa con espesor de 60 cm (unidad 3) que contiene ostrácodos de agua dulce, carofitas y foraminíferos planctónicos del Daniano temprano. Paleoecológicamente, el conjunto de ostrácodos incluye nadadores activos (Cypridopsis, Cypria, Mongolianella, Paracypretta y Zonocypris) y nadadores pobres (Limnocythere, Gomphocythere, Frambocythere y Darwinula). La mayor parte de la fauna de ostrácodos sugiere un ambiente de depósito de agua dulce, lacustre. La presencia de foraminíferos planctónicos y dos especies de ostrácodos de agua salobre (Buntonia sp. y Neocyprideis raoi) fortalece el argumento de la existencia de una vía marina en el centro de India, ya que se supone que esta fauna fue transportada por corrientes marinas estacionales a través de las zonas de "rift" de Narmada y Tapti (fase transgresiva de corta duración), la cual creó condiciones temporales de estuario y depositó micro biota marina. Por encima de este intervalo, los sedimentos de las unidades 4 y 5 consisten de limolita arcillosa gris rojiza y gris verdosa con escasas capas de arena fina, depositadas bajo condiciones palustres y terrestres. La fauna de ostrácodos muestra extenso endemismo, los cuales se incluyen entre los ostrácodos no marinos de la India del Maastrichtiano y que duraron hasta el Daniano temprano. Esto apoya la propuesta de una placa de la India geográficamente aislada, con dispersión intercontinental de ostrácodos de agua dulce del Maastrichtiano al Daniano temprano, lo que refuerza la hipótesis de "Fuera de la India". La edad de las capas Jhilmili intercaladas en los "traps" del Deccan es del Daniano temprano-Maastrichtiano, apoyados en foraminíferos planctónicos y algunos ostrácodos de agua salobre.

Palabras clave: Micro biota; ostrácodos; foraminíferos planctónicos; capas "intertrap"; Deccan; India; Paleoceno; límite Cretácico-Paleógeno.

INTRODUCTION

Deccan continental flood basalts are one of the largest magmatic provinces, occupying an area of about 500000 km^2 in peninsular India

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(Jay and Widdowson, 2008), and straddling the Cretaceous-Palaeogene (K-Pg) boundary (Courtillot *et al.*, 1986; Duncan and Pyle, 1988; Chenet *et al.*, 2007; Keller *et al.*, 2009a-c, 2010a, b, 2012; Malarkodi *et al.*, 2010; Khosla and Verma, 2015; Schoene *et al.*, 2015). The age and duration of the Deccan activity have come under intense scrutiny. In the decade of 1980, Courtillot *et al.* (1986) and Duncan and Pyle (1988) suggested that duration of volcanic eruptions spanning less than 1 m.y. in magnetic polarity chron 29r. More recently, radiometric dating confirmed the chron C29r age for the bulk of the eruptions followed by another pulse near the base of C29n (64.7± 0.6: Ma, Chenet *et al.*, 2007) and an initial smaller eruption at 67.4 Ma near the base of C30n. This indicates that Deccan eruptions occurred intermittently over an interval of at least 3 m.y., although some earlier studies suggest an even longer duration spanning 4 to 5 m.y. (Courtillot, 1990; Pande *et al.*, 2004) or even 7 to 8 m.y. (Sheth *et al.*, 2001).

Current palaeomagnetic, radiometric, biostratigraphic, and chemostratigraphic data suggest that the main phase of Deccan volcanism, which accounts for approximately 80% of the 3500 meter thick continental basalts, erupted within a short period (less than 1 m.y.) or even less (a couple of hundred thousand years) mostly near the end of C29r, which spans the K-Pg boundary (Chenet *et al.*, 2007; Keller *et al.*, 2008, 2009a, b, c, 2010a, b, 2011, 2012; Gertsch *et al.*, 2011; Khosla and Verma, 2015; Schoene *et al.*, 2015). Volcanic eruptions may have played a major role in mass extinctions at the K-Pg boundary. According to Schulte *et al.* (2003, 2010) Chicxulub impact had generated a tsunami, with impact spherules in the latest Maastrichtian sediments in Mexico and Texas. They regarded Deccan volcanism as much older in age and have not played any role in K-Pg mass extinction. Schulte *et al.* (2010) also considered Chicxulub impact as the solitary cause for the mass extinction at K-Pg boundary and they also assumed that Chicxulub and the iridium anomaly at the Cretaceous-Palaeogene are heritably related and are of similar age. Keller *et al.* (2010a, b) refuted the above listed assumptions as proposed by Schulte *et al.* (2010). Keller *et al.* (2010a, b) and Keller (2014) further stated that there is no record of iridium anomaly in alliance with Chicxulub ejecta, and impact spherules have never been recognized in the iridium enriched K-Pg clay layer in Mexico. Recent work on Deccan volcanism clearly indicates that the main mass extinction is linked with the major phase of Deccan eruptions in C29r (Keller *et al.*, 2009c, 2010a, b, 2012; Keller, 2014).

Chenet *et al.* (2007) suggested that the Deccan volcanism was at its acme at 65 Ma and initial eruptions took place in the Nasik and Narmada (north-western) region (Widdowson *et al.*, 2000). Later volcanism occurred on the southern sector (Beane *et al.*, 1986; Mitchell and Widdowson, 1991), and the final phase of eruption occurred in the southern part of the Deccan Province near Belgaum (Jay and Widdowson, 2008). However, it is only recently that decisive evidence in this regard has emerged (Keller *et al.*, 2008, 2009a, b, c, 2010a, b, 2011).

The infra- and intertrappean sediments associated with the Deccan Traps have been widely studied for more than two decades leading to a better understanding of the biotic diversity (Figure 1; Khosla, 1994, 2001; Khosla and Sahni, 1995, 2000, 2003; Khosla *et al.*, 2004, 2009; Prasad *et al.*, 2007a, b, 2010; Keller *et al.*, 2009a-c, 2012) and the palaeobiogeographic relationships of the Indian subcontinent during its northward passage (Loyal *et al.*, 1996; Prasad *et al.*, 2010; Verma *et al.*, 2012; Khosla, 2014; Khosla and Verma, 2015; Fernandez and Khosla, 2015; Khosla *et al.*, 2015). Further, these unique deposits have permitted examination of the effects of volcanism on the biota (Bajpai and Prasad, 2000). The Deccan intertrappean outcrops have yielded diverse fauna and flora represented by vertebrates (fishes, anurans, lizards, snakes, turtles, crocodiles, dinosaurs and mammals), mollusks, ostracods, and plants (megaplants, palynofossils and charophytes; Khosla and Sahni, 2003). At present, the majority of intertrappean beds fringing the main Deccan basaltic province have been equated with the Ambenali and Poladpur formations of the classic Western Ghats sections (Widdowson *et al.*, 2000). These beds have produced dinosaur remains including eggshells, together with diagnostic Late Maastrichtian ostracod assemblages (Sahni and Khosla, 1994a, b; Whatley and Bajpai, 2000a, b; Whatley *et al.*, 2002a, b; Vianey-Liaud *et al.*, 2003; Whatley and Bajpai 2005, 2006; Khosla *et al.*, 2005; Khosla and Nagori 2007) and a palynofloral assemblage consisting of *Aquilapollenites-Gabonisporites-Ariadnaesporites* (Kar and Srinivasan, 1998). A few intertrappean outcrops, such as Papro in the Lalitpur District, Uttar Pradesh (Singh and Kar, 2002; Sharma *et al.*, 2008), Ninama in Gujarat (Samant *et al.*, 2014) and Rajahmundry, Andhra Pradesh, have been assigned to the early Paleocene (Keller *et al.*, 2008, 2009a, b, 2011; Malarkodi *et al.*, 2010) based on palynofossils, ostracods and foraminifera. It is interesting to note that the deep exploratory oil wells of the Oil and Natural Gas Commission (ONGC) at Narsapur have yielded Maastrichtian planktonic foraminiferal assemblages at depths exceeding 3 km (Govindan, 1981; Keller *et al.*, 2008, 2011), together with an *Aquilapollenites* pollen assemblage (Kar *et al.*, 1998). The documentation of a planktonic foraminiferal assemblage from Jhilmili intertrappean beds (Figures 2a, 2b) assigned to the Early Danian (P1a) (Keller *et al.*, 2009a-c; Sharma and Khosla, 2009) just north of Chhindwara town and in the heart of peninsular India, has interesting implications for constraining the age limits of basaltic flows. The occurrence of freshwater taxa such as vertebrates, mollusks and algae in association with brackish water ostracods (Kar and Srinivasan, 1998; Khosla and Nagori, 2007; Keller *et al.*, 2009a-c, 2010a, 2011; Samant and Mohabey, 2009; Sharma and Khosla, 2009) in the nearby Mohgaon Kalan and Singpur localities has also raised questions about the depositional environment of the intertrappean beds of this region. The fauna and floral assemblages recovered from the Jhilmili intertrappeans are listed in Table 1.

The main issue that is pertinent to the current discussion is how planktonic foraminifera could be found so far inland (Keller *et al.*, 2009a, b). Sahni (1983) proposed the presence of a marine seaway "Trans Deccan Strait" based on the occurrence of an admixture of freshwater, brackish water and marine forms in intertrappean beds of Asifabad and Nagpur and the Lameta Formation of Pisdura and Jabalpur. The record of planktonic foraminifera at Jhilmili revive interest in the role that the two major structural lineaments, namely the Narmada and Godavari, played in the anomalous admixture of the biota's representing diverse facies (Figure 1). The main objective of this paper is to analyze the palaeoenvironments, palaeoecology and palaeobiogeographical implications of the recovered micro biota from Jhilmili intertrappean beds.

GEOLOGICAL SETTING AND LITHOLOGY

The intertrappean section of Jhilmili (Lat. 22° 02' 44" N; Long. 79° 09' 34' E; Figures 2a, 2b and 3a, 3b) is situated about 5 km NW of the well known village of Mohgaon Kalan on the Seoni-Chhindwara road in the Chhindwara District, Madhya Pradesh (central India). This intertrappean section was discovered and sampled by A. Khosla and A. Sahni in 1999. Subsequently this intertrappean outcrop was studied by a multidisciplinary and multi-institutional international team (Keller *et al.*, 2009a, b). The exposed intertrappean deposit is 14 m thick and bounded by Deccan lava flows at the base and top (Figure 2b). The basal unit of this intertrappean section is 6 m thick and consists of red clayey siltstone with carbonate nodules and root traces. The upper unit spans 6.5 m and consists of red and green shales. Both units have been interpreted as paleosols (Keller *et al.*, 2009a, b). In between these two

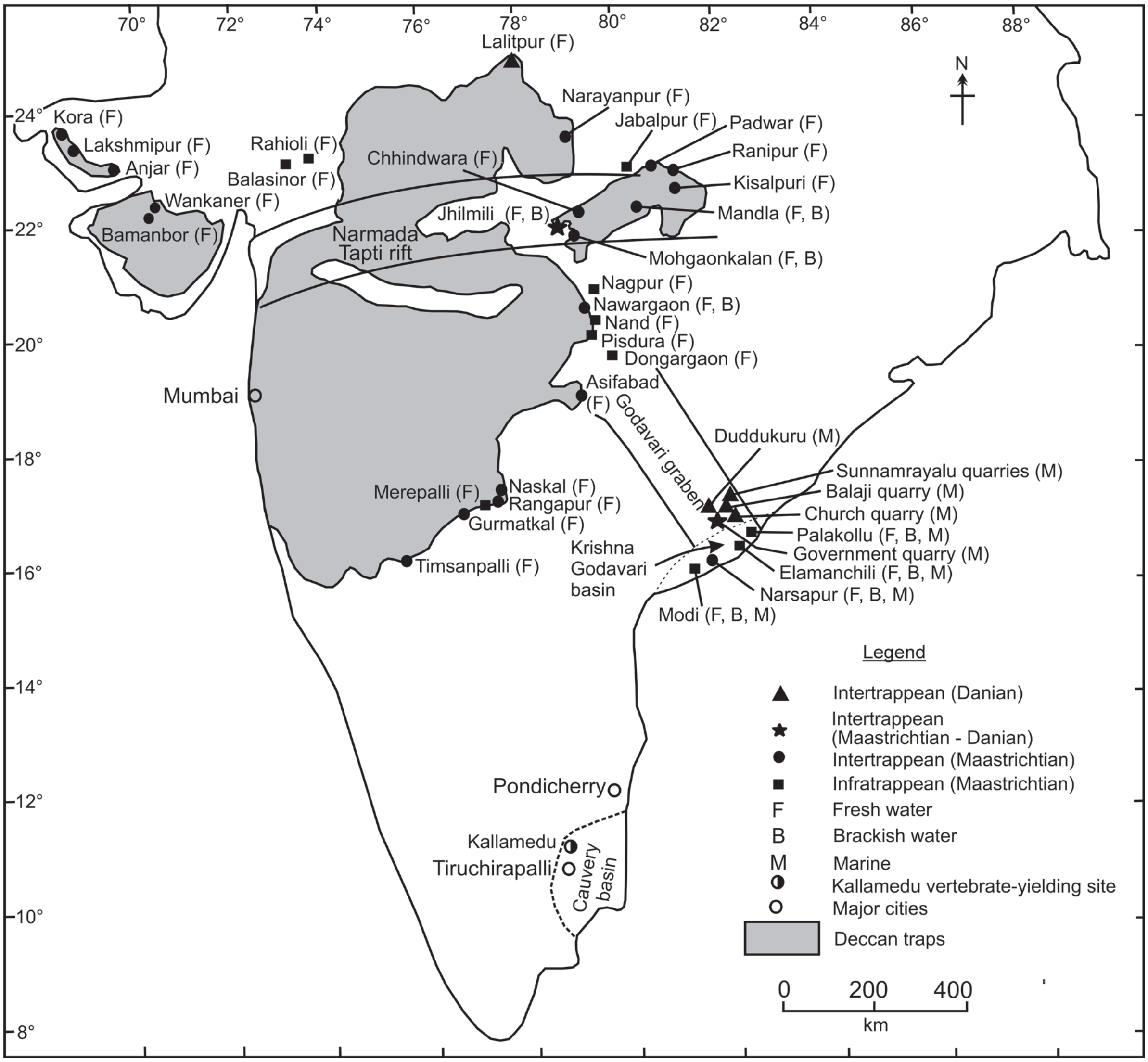

Figure 1. Distribution of Cretaceous-Palaeogene (K-Pg) Deccan volcanics, showing the major infratrappean and intertrappean fossiliferous localities. The localities are marked by fresh water, brackish water and marine environments. Marine incursions are along the Narmada-Tapti rift and possibly also along the Godavari graben.

paleosols is a 60 cm thick unit that consists of yellow to pink, ostracod-rich shale and calcareous limestone with planktonic foraminifera. The alternating yellow to pink clay and marly limestone mark the lower part of this short interval. Ostracods and charophytes are common in unit 3 (Figure 2b, Figure 4, samples JH17, JH19).

MATERIALS AND METHODS

To date five palaeontological field expeditions were carried out and nearly 500 kg of sediments collected, processed and analyzed in the palaeontological laboratories of Indian Institute of Technology (IIT), Roorkee and the Panjab University, Chandigarh. Most samples were collected from the 60 cm thick middle unit 3 composed of yellow to pink ostracod-rich shale and calcareous limestone, which also yielded planktonic foraminifera. This intertrappean unit (Figures 2 and 3) preserves a relatively diverse micro biota (Sharma and Khosla, 2009), that includes ostracods, foraminifera, fishes and charophytes (Table 1). For the recovery of microfossils standard sample processing methods were applied (Keller *et al.*, 1995). The sediment was crushed into small pea-sized pieces and immersed in water for 24 hours to allow complete disaggregation into mud slurry. The sample was then washed through various sets of sieves and the residue was oven dried. The dried residue was scanned under a stereoscopic binocular microscope for microfossils. SEM photomicrographs of planktonic foraminifera and ostracods were taken at Indian Institute of Technology, Roorkee and Panjab University, Chandigarh, by means of a JEOL JSM 6400 SEM (Figures 5a - 5r). The described specimens are housed in the Department of Earth Sciences, IIT Roorkee and Vertebrate Paleontological Laboratory of the Department of Geology, Panjab University, India.

PALAEOENVIRONMENTAL AND PALAEOECOLOGICAL IMPLICATIONS OF THE FOSSIL FINDS

Palaeoenvironmental interpretations are based on lithological variations and microfossil assemblages. Six lithological units have been identified within the Jhilmili intertrappean section (Figure 2b). Unit

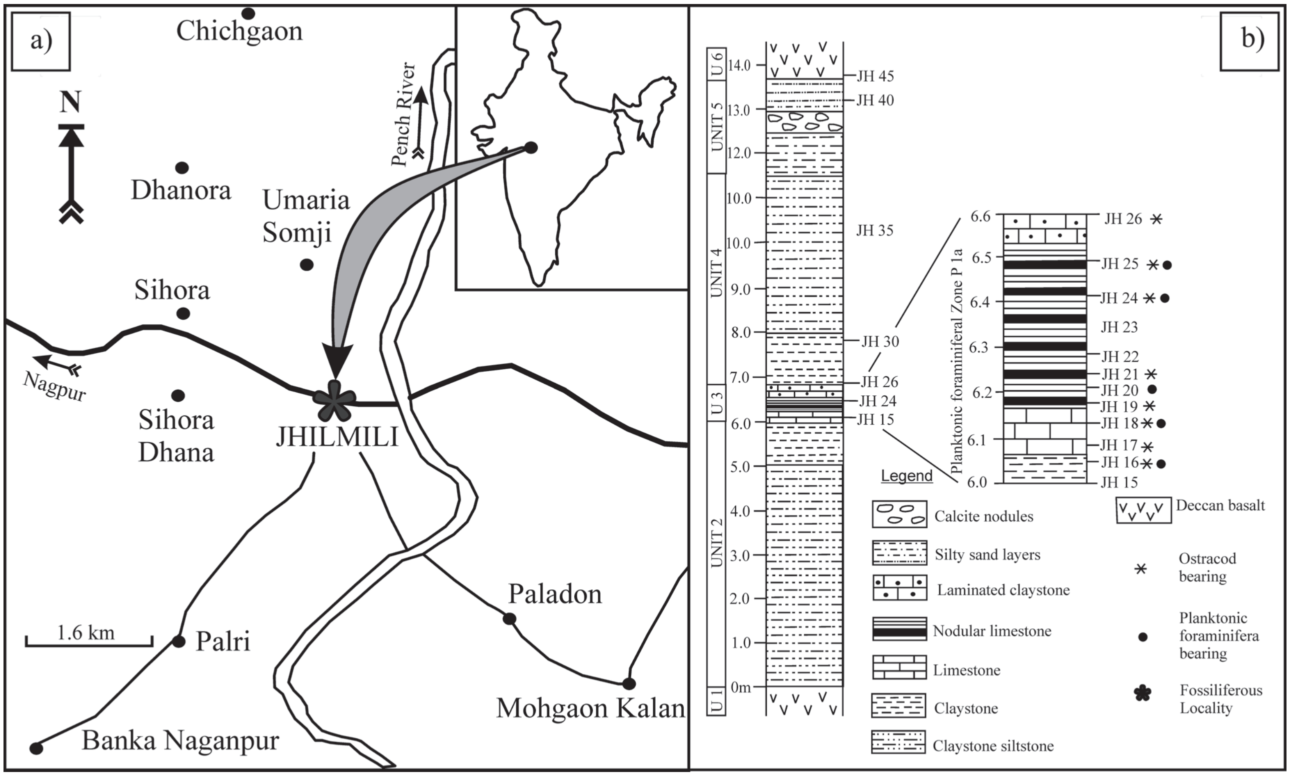

Figure 2. Location (a) and lithostratigraphy (b) of the Jhilmili intertrappean section, District Chhindwara, Madhya Pradesh, peninsular India.

1 is the basalt, and the lower part of unit 2 is a paleosol; lithologically, it consists of purple siltstone and contains clasts of basalt, which have been derived from the lower part of the basalts. Other palaeosol features include slickenslide structures and rotated quartz grains (Keller *et al.*, 2009a, b). The upper part of unit 2 (JH11) also contains red clayey siltstone with carbonate nodules, manganese streaks and slickensides, which are undoubtedly deposited in terrestrial, palustrine and flood plain environments (Keller *et al.*, 2009a, b). Paleosols (JH14) are well recorded which might be due to the weathering of basalts resulting in a thin purple- coloured paleosol. Unit 2 contains the clay mineral smectite, which has been derived from basalts and indicates semi-arid to sub-humid climatic conditions (Keller *et al.*, 2009a, b; Pal *et al.*, 2013). The middle unit 3 (Figure 2b, Figure 4, JH16, JH19, JH22, JH23) of the Jhilmili intertrappean section is 60 cm thick and contains fresh water ostracods and brackish to fresh water charophytes (JH17, JH19), and foraminifera of marine water in nature (Figure 2b, JH16, JH18, JH20-22). The number of ostracod taxa recovered from screen-washed residue (*i.e.* rare <10, common 10-20 and abundant > 20, Figure 4) suggests that six out of twelve species are common to abundant in, at least, some intervals. Other taxa are rare and intermittently present (Keller *et al.*, 2009a, b). The abundance of various ostracod taxa is shown in Figure 4. Most of the ostracods have been richly recovered from samples JH24 and JH25 (Figures 2b and 4). Of all the ostracod species, *Limnocythere deccanensis* dominates the ostracod assemblages (80-90 %), whereas *Zonocypris viriensis* dominates in samples JH17 and JH18 (Keller *et al.*, 2009a, b). Dry and arid climatic conditions have also been recorded in unit 3 because of the presence of clay mineral assemblages such as palygorskyte, and red clayey siltstone with scanty rhizo concretionary structures (Keller *et al.*, 2009a-c; Pal *et al.*, 2013). The upper part of unit 3 (JH 24 and JH25) consists of laminated claystone with fresh water and brackish ostracods, charophytes and planktonic foraminifera. This mixed assemblage indicates a shallow marine to brackish water environment. The topmost part of unit 3 (JH26) is characterized by packstone with no foraminifera but containing ostracod shells fragments and charophytes, which mark high energy wave action (Keller *et al.*, 2009a, b). Unit 4 (Figure 2b) is interpreted as a paleosol horizon, and is characterized by red clayey siltstone with abundant Microcodium, whereas unit 5 is a greenish grey siltstone with rare, fine sand layers, which indicates the return of terrestrial deposition (Keller *et al.*, 2009a, b). In units 4 and 5, poorly crystallized illite is present which may have been derived from the degradation of smectite. Both units indicate arid climatic conditions with alternating wet and dry cycles (Keller *et al.*, 2009a, b). Very negative stable isotope ($\delta^{13}C$ and $\delta^{18}O$) values have been recorded. The $\delta^{13}C$ values (-4.3 %, JH17-JH19) of the foraminifera-bearing clasts reveal fresh to brackish water environments. The heavier $\delta^{13}C$ values (-3.3-2.7 %, JH24-JH26) of the ostracod and foraminifera-bearing sediments point to brackish water environments. The $\delta^{18}O$ values (-6.2 to -9.5 %) also indicate fresh to brackish water environments (Keller *et al.*, 2009a, b).

Palaeoecologically, the Jhilmili freshwater ostracod assemblage (Figures 5a - 5l) represents an admixture of drifters or benthic crawlers/diggers and swimmers. *Limnocythere deccanensis* and *Zonocypris viriensis* dominate the recovered assemblage of 26 species from the Jhilmili intertrappean beds (Table 1). Most of the taxa are non- or poor swimmers, such as the cytheraceans (*Limnocythere, Gomphocythere, Frambocythere*) and darwinulaceans (*Darwinula*). According to McKenzie (1971), some species of *Limnocythere* are endobenthonic and spent part of the day within the sediment while the majority of the family members occupied permanent waters and some species of *Limnocythere* lived in temporary pools. The other two species *Gomphocythere* and *Frambocythere* have been considered as epib-

Table 1. List of fauna and flora recovered from the Jhilmili intertrappean section, Chhindwara District, Madhya Pradesh, Central India.

	Fossil element	Taxon	Size (long dimension)	Abundance in sediments	Presumed paleoenvironment and paleoecology	References
Ostracods	Valves	?*Buntonia* sp.	~660 µm	Rare	Brackish-marine water	Khosla *et al.* (2011); this study
	Valves	*Centrocypris megalops* (Whatley and Bajpai, 2000a)	~690 µm	Rare	Non-marine, low energy aquatic	Khosla *et al.* (2011); this study
	Valves	*Cyclocypris amphibolos* (Whatley, Bajpai and Srinivasan, 2002a)	~580 µm	Common	Non-marine, low energy aquatic, active swimmer	Khosla *et al.* (2011); this study
	Valves	*Cypria cyrtonidion* (Whatley and Bajpai, 2000a)	540-560 µm	Common	Non-marine, low energy aquatic, active swimmer, lived in permanent water bodies	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
	Valves	*Cypridopsis hyperectyphos* (Whatley and Bajpai, 2000a)	442-600 µm	Abundant	Non-marine, low energy aquatic, active swimmer, lived in permanent ponds and lakes	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
	Valves	*Darwinula torpedo* (Whatley, Bajpai and Srinivasan, 2002a)	~800 µm	Rare	Non-marine, low energy aquatic, poor swimmer, lived in permanent water bodies (ponds and lakes)	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
	Valves	*Eucypris pelasgicos* (Whatley and Bajpai, 2000a)	~800 µm	Rare	Non-marine, low energy aquatic, active swimmer, lived in temporary water bodies	Khosla *et al.* (2011); this study
	Valves	*Frambocythere tumiensis anjarensis* (Bhandari and Colin, 1999)	320-390 µm	Common	Non-marine, low energy aquatic, poor swimmer/ epibenthonic walkers /crawler	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
	Valves	*Gomphocythere paucisulcatus* (Whatley, Bajpai and Srinivasan, 2002b)	~660 µm	Rare	Non-marine, low energy aquatic, poor swimmer/ epibenthonic walker /crawler	Khosla *et al.* (2011); this study
	Valves	*G. strangulata* (Jones, 1860)	820-890 µm	Common	Non-marine, low energy aquatic, poor swimmer/ epibenthonic walker /crawler	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
	Valves	*Heterocypris* sp.	~1900 µm	Rare	Non-marine, low energy aquatic, active swimmer, lived in temporary water bodies	Khosla *et al.* (2011); this study
	Valves	*Limnocypridea ecphymatos* (Whatley and Bajpai, 2000b)	919-3000 µm	Rare	Non-marine, low energy aquatic	Sharma and Khosla (2009); this study
	Valves	*Limnocythere* sp.	950-1128 µm	Rare	Non-marine, low energy aquatic, temporary pools, poor swimmer/ epibenthonic / endobenthonic or walker /crawler	Sharma and Khosla (2009); this study
	Valves	*Limnocythere deccanensis* (Khosla, Nagori and Mohabey, 2005)	460- 570 µm	Abundant	Non-marine, low energy aquatic, poor swimmer/ epibenthonic / endobenthonic or walker/crawler	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
	Valves	*L. falsicarinata* (Whatley and Bajpai, 2000a)	~823 µm	Rare	Non-marine, low energy aquatic, poor swimmer/ epibenthonic/ endobenthonic walker /crawler	Sharma and Khosla (2009); this study
	Valves	*Mongolianella cylindrica* (Sowerby, 1840)	~980 µm	Rare	Non-marine, low energy aquatic, active swimmer, lived in permanent water bodies (ponds and lakes)	Sharma and Khosla (2009); this study
	Valves	*Neocyprideis raoi* (Jain, 1978)	590-660 µm	Abundant	Brackish-marine water	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
	Valves	*Paracandona firmamentum* (Whatley and Bajpai, 2000a)	~590 µm	Abundant	Non-marine, low energy aquatic	Sharma and Khosla (2009); this study
	Valves	*Paracypretta* sp.	636-1013 µm	Common	Non-marine, low energy aquatic, active swimmer	Sharma and Khosla (2009) ; this study
	Valves	*Paracypretta jonesi* (Bhatia and Rana, 1984)	1460-1600 µm	Common	Non-marine, low energy aquatic, active swimmer	Sharma and Khosla (2009);Khosla *et al.* (2011); this study
	Valves	*P. subglobosa* (Sowerby, 1840)	1147-1460 µm	Common	Non-marine, low energy aquatic, active swimmer	Sharma and Khosla (2009); this study
	Valves	*Paracypretta verruculosa* (Whatley, Bajpai and Srinivasan, 2002a)	800-1200 µm	Common	Non-marine, low energy aquatic, active swimmer	Khosla *et al.* (2011)

continues

Table 1 (continued). List of fauna and flora recovered from the Jhilmili intertrappean section, Chhindwara District, Madhya Pradesh, Central India.

	Fossil element	Taxon	Size (long dimension)	Abundance in sediments	Presumed paleoenvironment and paleoecology	References
Ostracods	Valves	*Stenocypris cylindrica* (Sowerby, 1840)	~880 µm	Rare	Non-marine, low energy aquatic, active swimmer, fresh water environment	Khosla *et al.* (2011)
	Valves	*Strandesia jhilmiliensis* (Khosla *et al.*, 2011)	850-900 µm	Common	Non-marine, low energy aquatic, active swimmer, lived in shallow freshwater environment	Khosla *et al.* (2011)
	Valves	*Zonocypris spirula* (Whatley and Bajpai, 2000a)	340-350 µm	Common	Non-marine, low energy aquatic, active swimmer; heavily ornamented and represent sluggish conditions	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
	Valves	*Z. viriensis* (Khosla and Nagori, 2005)	340-350 µm	Abundant	Non-marine, low energy aquatic, active swimmer; heavily ornamented and represent sluggish conditions	Sharma and Khosla (2009); Khosla *et al.* (2011); this study
Foraminifera	Tests	*Eoglobigerina edita* (Subbotina, 1953)	40–100 µm	Common	Brackish-marine water	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*E. eobulloides* (Morozova, 1959)	40–100 µm	Common	Brackish-marine water	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Globanomalina compressa* (Plummer, 1926)	>150 µm	Rare	Brackish-marine water	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Globigerina* (*Eoglobigerina*) *pentagona* (Morozova, 1961)	>150 µm	Rare	Brackish-marine water	Keller *et al.* (2009a, b); Sharma and Khosla (2009)
	Tests	*Globigerinelloides aspera* (Koch, 1926)	>150 µm	Rare	Brackish-marine water	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Globoconusa daubjergensis* (Bronniman, 1952)	40–100 µm	Common	Brackish-marine water, persisted in highly stressful conditions	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Guembelitria cretacea* (Cushman, 1933)	40–150 µm	Rare	Brackish-marine water, disaster opportunist; persisted in highly stressful conditions and occurred in shallow continental shelf environments	Keller *et al.* (2009a); Sharma and Khosla (2009); this study
	Tests	*Hedbergella holmdelensis* (Olsson, 1964)	>150 µm	Rare	Brackish-marine water, persisted in highly stressful conditions	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Parasubbotina pseudobulloides* (Plummer, 1926)	>150 µm	Rare	Brackish-marine water, lived in muddy water in shallow environment conditions	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Parvularugoglobigerina eugubina* (Luterbacher and Premoli-Silva, 1964)	40–100 µm	Common	Brackish-marine water, lived in highly stressful conditions	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Praemurica taurica* (Morozova, 1961)	40–150 µm	Rare	Brackish-marine water	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Subbotina triloculinoides* (Plummer, 1926)	>150 µm	Rare	Brackish-marine water	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
	Tests	*Woodringina hornerstownensis* (Olsson, 1960)	40–100 µm	Common	Brackish-marine water, lived in highly stressful conditions	Keller *et al.* (2009a, b); Sharma and Khosla (2009); this study
Fishes		*Lepisosteus* sp.	Not known	Rare	Non-marine, fluvio-lacustrine	Sunil Bajpai (personnel communication)
		Pycnodus sp.	Not known	Rare	Non-marine, fluvio-lacustrine	Sunil Bajpai (personnel communication)
Charophytes	Gyrogonites	*Platychara sahnii* (Bhatia and Mannikeri, 1976)	450-700 µm	Common	Non-marine aquatic (submerged)	This study

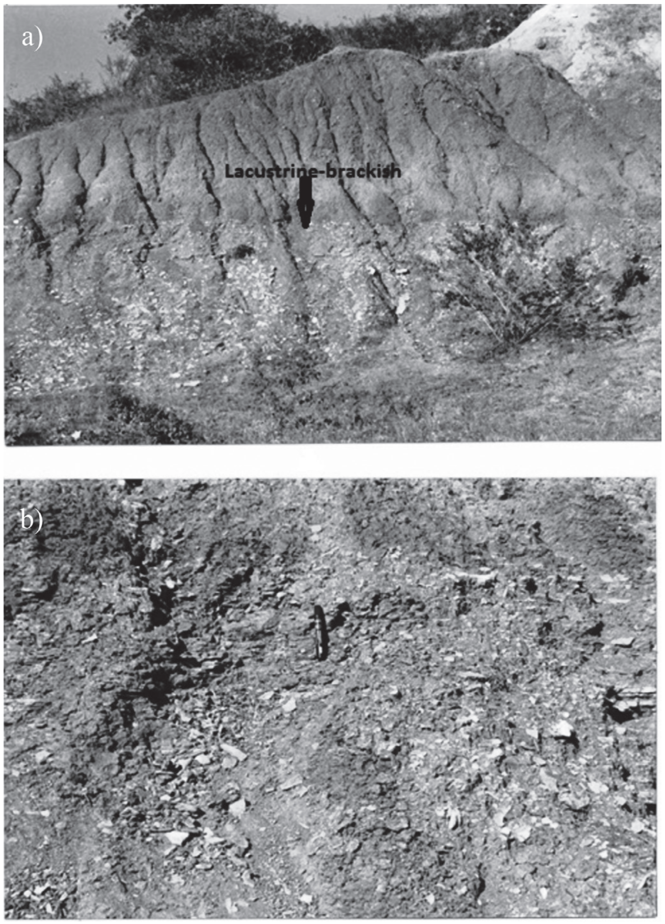

Figure 3. a) Field photograph of the Jhilmili intertrappean beds showing a narrow interval of lacustrine to brackish marine unit 3 (60 cm thick), which has yielded ostracods and planktonic foraminifera. b) Enlarged, close up view of the fossiliferous light yellow clays with hard claystone bands. Scale (Marker pen) = 15 cm.

enthonic crawlers (McKenzie, 1971). *Darwinula* occurs in streams but prefers to live in permanent water bodies such as lakes and ponds (Whatley and Bajpai, 2005). On the other hand, taxa such as *Paracypretta, Zonocypris, Cypridopsis, Cypria* and *Mongolianella* are active swimmers (Table 1). The genus *Cypridopsis* preferred to live in permanent water bodies like ponds and lakes (Whatley and Bajpai, 2005; Khosla *et al.*, 2011). The genus *Strandesia* is mainly found in shallow, freshwater environments (Khosla *et al.*, 2011). The extinct genus *Mongolianella*, with its close morphological similarity (*i.e.* long, cylindrical shape) to modern *Herpetocypris,* was probably also a good swimmer (Whatley and Bajpai, 2005). The taxa like *Mongolianella* and *Cypridopsis* preferred to dwell in more permanent waters that would allow retreat to the deeper parts of the water body (Whatley and Bajpai, 2005).

Genera like *Heterocypris*, *Eucypris* and *Strandesia* are indicative of temporary water bodies. All of these taxa listed above suggest the presence of a permanent freshwater lake/pond. Further, a clear augmentation in the alkalinity of the environments is indicated by greater calcification of the heavily ornamented ostracods (*e.g.* in *Frambocythere tumiensis anjarensis* Bhandari and Colin, 1999; *Gomphocythere strangulata* Jones, 1860; *Paracypretta subglobosa* Sowerby, 1840; *Paracypretta jonesi* Bhatia and Rana, 1984; *Zonocypris spirula* Whatley and Bajpai 2000a; *Zonocypris viriensis* Khosla and Nagori, 2005; *Limnocypridea ecphymatos* Whatley and Bajpai, 2000b; *Limnocythere* sp. and *Paracandona firmamentum* Whatley and Bajpai, 2000a). Heavily ornamented ostracods particularly *Zonocypris* indicates sluggish conditions (Khosla *et al.*, 2011).

Presence of a brackish water ostracod species (*Neocyprideis raoi*) in sample numbers JH21 to JH26 along with rare planktonic foraminifera points to intervals of a brackish-marine environment. *Neocyprideis* are mostly represented by moult stages in the present collection and lived with other fresh water ostracod assemblages in the lake at times of low mesohaline salinities (Sharma and Khosla, 2009; Khosla *et al.*, 2011). The brackish water species *Neocyprideis raoi* was previously recorded from the intertrappean beds of the Rajahmundry area near the southeast coast (Jain, 1978). The occurrence of *Neocyprideis* in a brackish water environment was indicated by Keij (1957), Morkhoven (1963), Keen (1977), and Neale (1988). Another exclusively shallow marine/brackish water ostracod taxon *Buntonia* sp. has been recovered from sample JH21 from the Jhilmili intertrappean beds (Khosla *et al.*, 2011). Furthermore, presence of holostean fish taxa such as *Pycnodus* sp. and *Lepisosteus* sp. also indicates fluvio-lacustrine environments of deposition for the Jhilmili intertrappean sediments (Sunil Bajpai, pers. comm.).

Foraminiferal as well as microfacies data (Keller *et al.*, 2009a, b) point towards temporary or short term marine incursions into freshwater environments ensuing in shallow marine to brackish water conditions. Seasonal currents could have transported planktonic foraminifera from a nearby marine seaway. Absence of benthic foraminifera attests that marine conditions did not continue long enough at Jhilmili for benthics to invade the environments (Keller *et al.*, 2009a, b). Most of the foraminifera recovered from the maceration techniques are not identifiable because many of them were mechanically compressed and deformed because of tectonic stress and pressure (Keller *et al.*, 2002; Punekar *et al.*, 2014). As a result they were diagenetically altered and have calcite overgrowths and are characterized by a recrystallized test and are difficult to identify. However, the presence of a cancellate spinose wall texture in numerous specimens corroborates the evidence that they are planktonic in nature (Figure 6, Keller *et al.*, 2009a).

The planktonic foraminiferal assemblage from Jhilmili intertrappeans (Table 1, 5m-5r) is not as diverse as that of the Rajahmundry intertrappean beds (southeastern coast of India). However, the presence of *Guembelitria cretacea* (Figure 5n, disaster opportunist) in the Jhilmili intertrappean beds, known universally in earliest Danian zones (P0 and Pla), indicates they continued to live in most stressful conditions especially during the late Maastrichtian along with other species (Abramovich and Keller, 2002; Pardo and Keller, 2008). *Guembelitria cretacea* occurred in shallow continental shelf environments and in areas of intense volcanism (Keller and Pardo, 2004). *Guembelitria cretacea* and *Hedbergella* sp. are considered as ecological generalists of varying environmental conditions and linked with warm humid climates, low salinity, temperature and low oxygen conditions (Boersma and Premoli-Silva, 1988; Keller, 1993; Malarkodi *et al.*, 2010).

Apart from *Guembelitria* and *Hedbergella*, other earliest Danian species, such as *Parvularugoglobigerina eugubina*, *P. extensa, Globoconusa daubjergensis* and *Woodringina hornerstownensis*, also persisted in highly stressful conditions and turned over in great numbers or disappeared when circumstances changed after zone Pla (Malarkodi *et al.*, 2010). The species *Parasubbotina pseudobulloides* (Figure 5p) contains a typical broad lip that covers the aperture and this may be due to the presence of muddy water in shallow environment conditions (Keller *et al.*, 2009a, b).

The ostracod fauna is in common agreement with faunal survivorship in fresh water fluvial systems across the K-Pg boundary in the Deccan volcanic province. Ostracods are not crucial for age dating; in

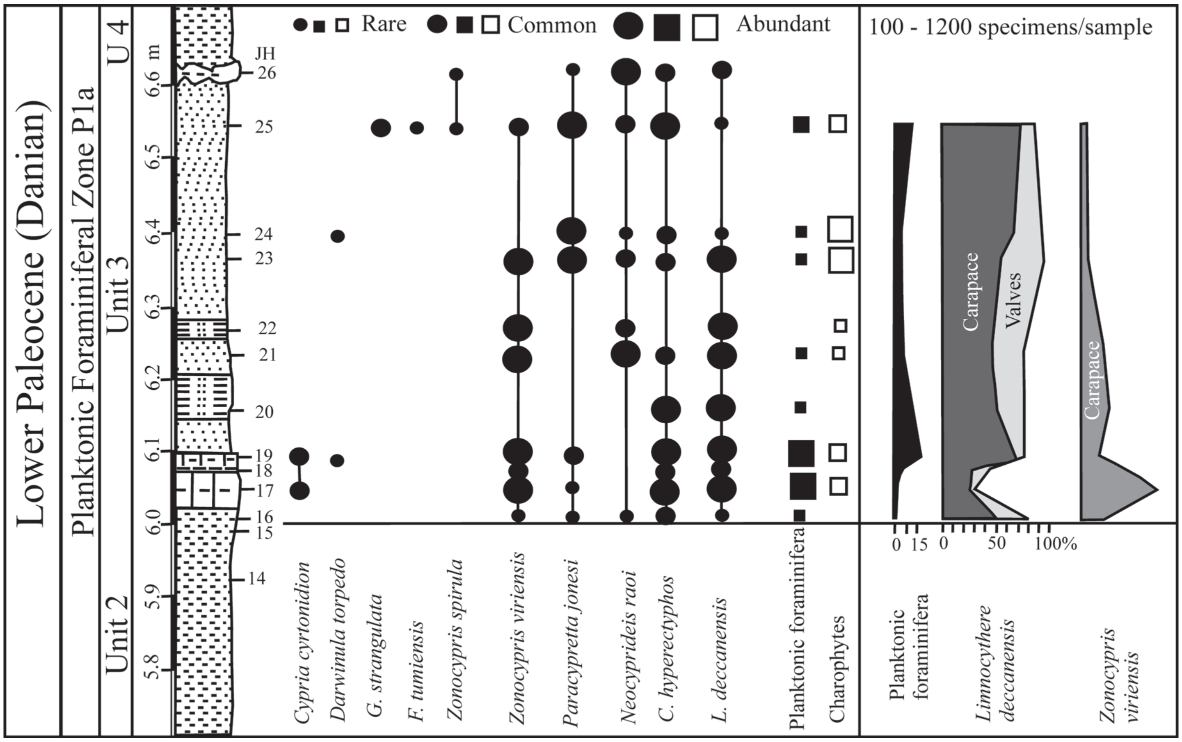

Figure 4. Relative abundance of Jhilmili ostracods (rare, 10 carapaces; common, 10–20 carapaces; abundant, 20 carapaces), charophytes and planktonic foraminifera in unit 3 of the Jhilmili intertrappean sediments. Ostracod assemblages mark predominantly freshwater environments, except for *Neocyprideis raoi* (Jain, 1978). Modified after Keller *et al.* (2009 b).

fact, as discussed above, the ostracod assemblages from Jhilmili in the uppermost Maastrichtian and lowermost Danian are similar, and their age is inferred by planktonic foraminifera. However, a few brackish water ostracods were dated as early Danian (P1a) (Sharma and Khosla, 2009; Keller *et al.*, 2009a, b; Khosla *et al.*, 2011). Taxonomically analogous ostracod assemblages have been described from Upper Cretaceous intertrappean sections across peninsular India (Whatley and Bajpai, 2005, 2006). The nonmarine ostracod assemblage recorded earlier from the intertrappean beds in Papro village, Lalitpur District, Uttar Pradesh, has been dated as Paleocene in age because the presence of pollen marker species (*Lakiapollis ovatus*, *Dandotiaspora pseudoarticulata*, *D. dilata* and *Spinizonocolpites echinatus*) also points to similarities in the taxonomic composition of ostracod faunas, though there are differences in the relative profusion of the diverse taxa (Singh and Kar, 2002; Sharma *et al.*, 2008). A possible explanation is that the intertrappean freshwater ostracods were not considerably affected, at least qualitatively, by Deccan volcanic eruptions. Khosla *et al.* (2005, 2011) observed a strong resemblance of nonmarine ostracod taxa between the Upper Cretaceous (Maastrichtian) Lameta Formation, which lies below the Deccan volcanics and the Deccan intertrappean beds. This condition is evocative of other intertrappean freshwater organisms for instance molluscs (Hartman *et al.*, 2007). The molluscan assemblage at the Papro intertrappeans consists of four taxa: *Lymnaea, Physa* and *two* species of *Viviparus.* These taxa can be compared to equally sized molluscs from Upper Cretaceous intertrappean beds of central India. The present ostracod data from Jhilmili (Madhya Pradesh) and Papro (Uttar Pradesh) support suggestions already made by Hartman *et al.* (2007) and Sharma and Khosla (2009). The fact that these taxa were able to repopulate during periods between basaltic flows in peninsular India imply that refugia were situated comparatively nearby. The intertrappean beds of Bombay region, has also yielded palynoassemblage of early Paleocene age and has been interpreted as showing no major floral declines (Cripps *et al.*, 2005).

DISCUSSION

The seasonal offshore currents considered as short lived marine transgressive phase could have been the probable reason for bringing brackish water ostracods and planktonic foraminifera into the intertrappean beds of Jhilmilli, central India (Figure 1). This further develops provisional estuarine conditions leading to deposition of a marine biota (Keller *et al.*, 2009a, b). Further evidence of marine transgression along the Narmada rift zone in stratigraphically older Bagh Beds in districts Dhar and Jhabua during late Cenomanian-early Turonian time was based on the presence of marine invertebrates, for example planktonic foraminiferas, ostracods, gastropods, ammonoids, bivalves, brachiopods, nannofossils and algae (Dassarma and Sinha, 1975; Jafar, 1982; Chiplonkar *et al.*, 1977; Nayak, 2000; Keller *et al.*, 2009a, b; Khosla and Verma, 2015). However, on the basis of sedimentological data of the Upper Cretaceous Lameta Formation it was proposed marine conditions in central India (Singh, 1981; Shukla and Srivastava, 2008). Other studies (Brookfield and Sahni, 1987; Tandon *et al.*, 1995; Khosla, 2014) opposed this view by proposing a fresh water origin for these deposits.

Palaeobiogeographical implications

The ostracod fauna from the Indian infra- and intertrappeans, including the present discussed locality Jhilmili, are highly endemic and many Indian taxa seem to have dispersed out from India, such as *Mongolianella*, *Limnocythere*, *Cyclocypris* and *Eucypris* to many parts of the Maastrichtian world (Whatley and Bajpai, 2006). Of the

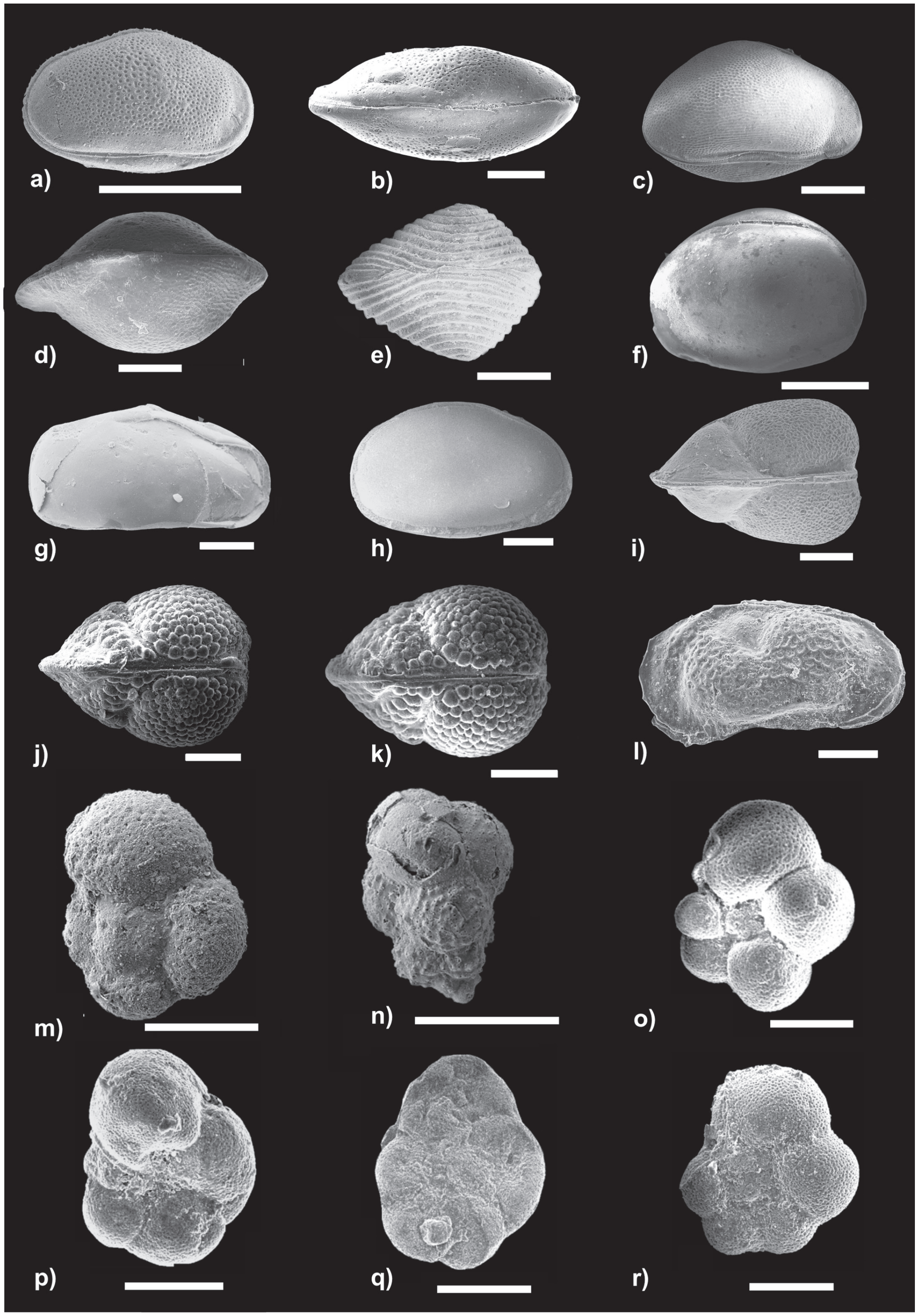

Figure 5. a) *Neocyprideis raoi* (Jain, 1978), carapace, right lateral view; b) *Neocyprideis raoi* (Jain, 1978), carapace, dorsal view; c) *Paracypretta subglobosa* (Sowerby, 1840), carapace right lateral view; d) *Paracypretta jonesi* (Bhatia and Rana, 1984), carapace, dorsal view; e) *Zonocypris spirula* (Whatley and Bajpai, 2000a), carapace, dorsal view; f) *Cypria cyrtonidion* (Whatley and Bajpai, 2000a) carapace, left lateral view; g) *Mongolianella cylindrica* (Sowerby, 1840) carapace, right lateral view; h) *Limnocypridea ecphymatos* (Whatley and Bajpai, 2000b) carapace, left lateral view; i) *Gomphocythere strangulata* (Jones, 1860), carapace, dorsal view; j) *Frambocythere tumiensis anjarensis* (Bhandari and Colin, 1999), carapace, dorsal view; k) *Frambocythere tumiensis anjarensis* (Bhandari and Colin, 1999), carapace, dorsal view; l) *Limnocythere deccanensis* (Khosla *et al.*, 2005), carapace, left lateral view; m) *Subbotina triloculinoides* (Plummer, 1926); n) *Guembelitria cretacea* (Cushman, 1933); o) *Hedbergella* cf. *holmdelensis* (Olsson, 1964); p) *Parasubbotina pseudobulloides* (Plummer, 1926); q) *Globanomalina compressa* (Plummer, 1926); r) *Globigerina* (*Eoglobigerina*) *pentagona* (Morozova, 1961). Scale bar equals 100 µm for a; 800 µm for b; 250 µm for c; 200 µm for d; 60 µm for e; 200 µm for f; 400 µm for g; 200 µm for h; 200 µm for i; 100 µm for j; 200 µm for k; 60 µm for l; 100 µm for m, n, o, p, q, r. (Figures a to l modified after Sharma and Khosla (2009) with permission from the Journal of the Palaeontological Society of India and m to r after Keller *et al.* (2009a) with permission from Journal of the Foraminiferal Research).

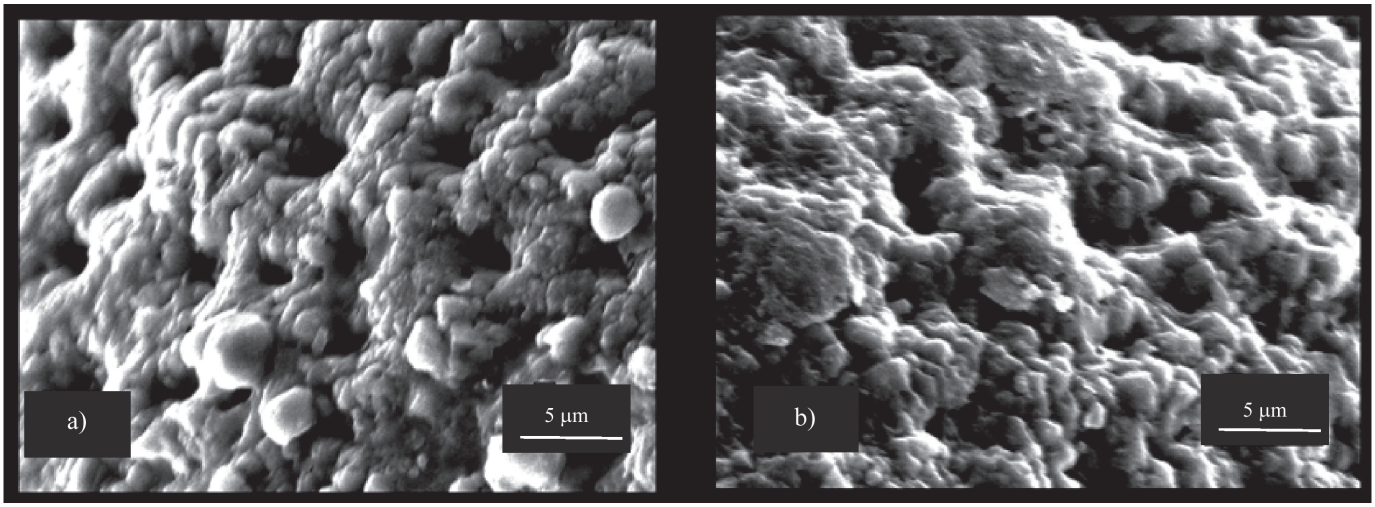

Figure 6. Planktonic foraminifera showing the cancellate spinose wall texture with calcite overgrowth of chambers; a) and b) *Subbotina triloculinoides* (Plummer, 1926). Photographs from Keller *et al.* (2009a).

26 taxa recorded so far from the Jhilmili intertrappean beds (Table 1), *Paracypretta* and *Gomphocythere* are exclusively endemic to peninsular India (Whatley and Bajpai, 2006). The genus *Frambocythere* is widely recorded from the Indian intertrappeans, but *Frambocythere tumiensis* was first recorded (outside India) from the Late Cretaceous of Spain (Helmdach, 1978). Other species of *Frambocythere* have been recorded from the Montian of Belgium (Tambareau, 1984) and Albian of Africa (Colin, 1993). Other genera such as limnocytherids *Gomphocythere*, *Limnocythere* and cyprids like *Paracandona* and *Cypria*, probably originated and evolved out from India (Whatley and Bajpai, 2006). The brackish water genus *Neocyprideis* has been earlier recorded from the Rajahmundry intertrappeans (Jain, 1978) and outside India the species has been described from assemblage IV of the upper Eocene beds of the Hampshire Basin, England (Keen, 1977). According to Whatley and Bajpai (2006) and Whatley (2012) the Upper Cretaceous ostracod species have nearly 98% endemism in India but genera like *Limnocypridea*, which has been widely recorded from the Maastrichtian of China and Mongolia, somehow were able to overcome competition and colonise India (Whatley and Bajpai, 2006). Thus as a whole, the Indian ostracod fauna has its own dominants like *Mongolianella, Cypridopsis* and *Gomphocythere,* and important endemics, such as *Paracypretta* (Whatley and Bajpai, 2006). The high species diversity of the Indian Maastrichtian freshwater ostracoda fauna provides evidence that around 88 Ma ago India was separated from Madagascar (Storey *et al.*, 1995) and enjoyed protracted isolation during its northward drift through the Indian Ocean for 40 m.y. before colliding with the Asian landmass circa 50 Ma, carrying with it Gondwanan forms to Asia (Karanth, 2006). Therefore, the fauna from the Jhilmili intertrappeans and other localities of peninsular India supports the "Out of India" hypothesis (Whatley and Bajpai, 2006).

Revised age for Deccan intertrappeans and biostratigraphic implications for Jhilmili intertrappeans

The delineation of the K-Pg boundary and determining the age of Deccan traps and interbedded intertrappean sediments in central India was not possible previously because age diagnostic fossils were not known. For the last decade intertrappean sediments yielded a wealth of fossil data (Sahni and Khosla, 1994a, b; Loyal *et al.*, 1996; Bajpai and Prasad, 2000; Khosla, 2001; Khosla and Sahni, 2000, 2003; Khosla *et al.*, 2004, 2009; Whatley *et al.*, 2002a, b; Whatley and Bajpai, 2005, 2006; Prasad *et al.*, 2007a, b, 2010; Samant and Mohabey, 2009; Keller *et al.*, 2008, 2009a-c, 2010a, b, 2011; Malarkodi *et al.*, 2010; Bajpai *et al.*, 2013). Biotic elements, i.e. fishes, frogs, crocodiles, turtles, dinosaurs, mammals, ostracods, charophytes and molluscs, point to a mainly freshwater, lacustrine depositional setting developed under semi-arid conditions for the intertrappean sediments of the District Dindori (Khosla *et al.*, 2004; Prasad *et al.*, 2007a, b, 2010), near Jabalpur (Mathur and Sharma, 1990). The intertrappean assemblages of Nagpur, Naskal, Mamoni, Kachchh and Gurmatkal (Bajpai and Prasad, 2000; Whatley and Bajpai 2000a, b; Whatley *et al.*, 2002a, b; Vianey-Liaud *et al.*, 2003) are also dominated by alike freshwater fauna and flora. The intertrappean beds show a diversity of lithotypes ranging from clays, claystones, marls, mudstones, siltstones and calcretes to limestone, which are strongly indicative of fluctuating lake levels (Khosla and Sahni, 2003). The freshwater biota is stratigraphically long ranging and is not useful in constraining the K-Pg boundary.

Early workers (Bande and Prakash, 1982; Bande *et al.*, 1988) assigned a Paleocene-Eocene age to the Deccan intertrappean sediments of the Nagpur-Chhindwara region, interpreting a seashore palaeoenvironment based on marine algae (*Solenopora* and *Peyssonnelia*) and fossil palm fruits for example *Cocos*, *Sonneratia* and *Nypa*. The record of other fossils, for instance dinosaur eggshells, teeth and bones, fishes, frogs, turtles, crocodiles, ostracods and charophytes from the intertrappean localities of peninsular India other than Jhilmili, and the absence of Paleocene strata and fossils suggested a Maastrichtian age (Prasad and Cappetta, 1993; Loyal *et al.*, 1996; Kar and Srinivasan, 1998; Bajpai and Prasad, 2000; Khosla and Sahni, 2000, 2003; Khosla *et al.*, 2004, 2009; Whatley and Bajpai, 2005, 2006; Prasad *et al.*, 2007a, b, 2010; Khosla, 2014; Khosla and Verma, 2015; Fernandez and Khosla, 2015; Khosla *et al.*, 2015). The classic intertrappean beds exposed in the Chhindwara region especially in the Mohgaon Kalan area (Sahni and Rode, 1937; Kar and Srinivasan, 1998; Whatley *et al.*, 2002b; Khosla and Nagori, 2007) are located about 5 km southeast of the Jhilmili section. The Mohgaon Kalan locality has a rich and diversified megaflora including palms and conifers suggesting estuarine and freshwater environments (Prakash, 1960; Kapgate, 2005). Apart from the flora, other Maastrichtian fauna include ostracods, charophytes, gastropods, dinosaur eggshells and pollen assemblages (*Azolla cretacea*, *Aquilapollenites bengalensis* and *Gabonisporites vigourouxii* (Kar and Srinivasan, 1998; Whatley *et al.*, 2002a, b; Kapgate, 2005; Khosla and Nagori, 2007). Other intertrappean locality is exposed in the close vicinity of the Jhilmili area, in Singpur, which like Mohgaon Kalan contains a Maastrichtian palynoflora (Samant *et al.*, 2008). Lithologically, Jhilmili intertrappean beds are virtually different from those of Mohgaon Kalan and Singpur localities, and do not contain any megaflora and palynofloral remains, as are present in the above mentioned localities. Therefore the intertrappean beds at Jhilmili show different age and palaeoenvironments. Based on the planktonic foraminiferal assemblage (*Parvularugoglobigerina eugubina, P. extensa, Woodringina hornerstownensis, Eoglobigerina edita, E. eobulloides* and *Globoconusa daubjergensis*, and rare *Parasubbotina pseudobulloides, Praemurica taurica, Subbotina triloculinoides, Globanomalina compressa* and *Globigerina (E.) pentagona*) an early Danian zone P1a age has been assigned to the intertrappeans of Jhilmili (Keller *et al.*, 2009a, b). The occurrence of *P. eugubina* in the Jhilmilli intertrappeans shows that the deposition of the foraminifera bearing horizon took place about 100-150 ka later than the K-Pg boundary (Keller *et al.*, 2009a, b). The upper part of the intertrappean sediments consisting of green and red shales and characterized by paleosols and deposited in a palustrine environment were considered the upper part of zone P1a (2) whereas the lower part of the intertrappean sediments which are 6 m thick and lithologically consists of paleosols (red shale), were possibly deposited during the early Danian P0–P1a (1) interval (Keller *et al.*, 2009a, b). These intertrappean beds are correlative to the shallow marine intertrappean beds exposed in the Rajahmundry quarries, which also has yielded early Danian zone planktonic foraminiferal assemblages between the lower and upper basalt traps of C29r and C29n magnetic polarity zones (Keller *et al.*, 2008). Keller *et al.* (2009a, b) reported magnetostratigraphic data for Jhilmili that demonstrate that the occurrence of the K-Pg boundary flanked by the lower traps is in 29r and upper trap is located at C29r/C29n, which are correlative to the upper Ambenali and lower Mahabaleshwar formations, correspondingly (Jay and Widdowson, 2008; Keller *et al.*, 2008). Therefore the lower volcanic flows at Jhilmili put the K-Pg boundary close to the end of the main Deccan volcanic eruptions, as indicated by early Danian planktonic foraminiferal assemblages overlying the last part of lower traps (Keller *et al.*, 2009a).

CONCLUSIONS

Diverse ostracod and planktonic foraminifera assemblages (mixed fauna) have been recorded earlier by Keller *at al.* (2009a, b) from the Jhilmili intertrappeans, central India. The presence of planktonic foraminifera modifies the age from earlier assigned Maastrichtian to early Danian. The ostracod assemblage recovered from unit 3 (60 cm thick) indicates the presence of a freshwater lake or pond, dominated by two species (*Limnocythere deccanensis* and *Zonocypris viriensis*). Active swimmers include *Mongolianella*, *Paracypretta* and *Zonocypris*, whereas the bulk of the ostracod assemblage is dominated by poor swimmers (*Darwinula* and cytheraceans *Gomphocythere*, *Frambocythere* and *Limnocythere*). Two brackish water ostracod species (*Neocyprideis raoi* and *Buntonia* sp.) and planktonic foraminifera recovered from sample numbers (JH21 to JH26) indicates brackish-marine environment. The assemblage further reveals the existence of a marine seaway in central India during the Maastrichtian to early Paleocene along the Narmada and Tapti rift zones (Keller *et al.*, 2009a, b). Palaeoenvironmentally, deposition at Jhilmili occurred in predominantly terrestrial semi-humid to arid environments, followed by a short aquatic interval (<60 ka) of fresh water ponds and lakes, which led to shallow coastal marine/estuarine conditions with brackish ostracods and early Danian P1a planktonic foraminifera.

Palaeobiogeographically, the ostracod fauna from the Jhilmili intertrappeans is somewhat endemic to India. The Jhilmili fauna includes endemic forms such as *Gomphocythere* and *Paracypretta* and two of its dominant forms like *Cypridopsis* and *Mongolianella*. Most of the Jhilmili ostracod taxa, such as *Cypridopsis*, *Eucypris*, *Limnocythere* and *Mongolianella* appear to have disseminated out from India to sundry parts of the Upper Cretaceous (Maastrichtian) world.

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