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.

INTRODUCTION

Deccan continental flood basalts are one of the largest magmatic provinces, occupying an area of about 500000 km² in peninsular India.
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 *Aquilapollinates-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 *Aquilapollinates* 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
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 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.
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, 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 decamensis 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 palygorskite, 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 (δ13C and δ 18O) values have been recorded. The δ13C values (-4.3 %, JH17-JH19) of the foraminifera-bearing clasts reveal fresh to brackish water environments. The heavier δ13C values (-3.3-2.7 %, JH24-JH26) of the ostracod and foraminifera-bearing sediments point to brackish water environments. The δ18O 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 decamensis 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.

<table>
<thead>
<tr>
<th>Fossil element</th>
<th>Taxon</th>
<th>Size (long dimension)</th>
<th>Abundance in sediments</th>
<th>Presumed paleoenvironment and paleoecology</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valves</td>
<td>Buntonia sp.</td>
<td>~660 µm</td>
<td>Rare</td>
<td>Brackish-marine water</td>
<td>Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Centrocypris megalops</td>
<td>~690 µm</td>
<td>Rare</td>
<td>Non-marine, low energy aquatic</td>
<td>Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Cyclocypris amphibolos</td>
<td>~580 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer</td>
<td>Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Cypris cyrtomion</td>
<td>540-560 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer, lived in permanent water bodies</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Cypridopsis hysrectxphos</td>
<td>442-600 µm</td>
<td>Abundant</td>
<td>Non-marine, low energy aquatic, active swimmer, lived in permanent ponds and lakes</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Darwinula torpedo</td>
<td>~800 µm</td>
<td>Rare</td>
<td>Non-marine, low energy aquatic, poor swimmer, lived in permanent water bodies (ponds and lakes)</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Eucypris pelasgicos</td>
<td>~800 µm</td>
<td>Rare</td>
<td>Non-marine, low energy aquatic, active swimmer, lived in temporary water bodies</td>
<td>Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>E. strangulata (Jones, 1860)</td>
<td>820-890 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer/epibenthic walker/crawler</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Limnocythere sp.</td>
<td>~1900 µm</td>
<td>Rare</td>
<td>Non-marine, low energy aquatic, active swimmer, lived in temporary water bodies</td>
<td>Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Limnocythere deccanensis (Khosla, Nagori and Mohabey, 2005)</td>
<td>460-570 µm</td>
<td>Abundant</td>
<td>Non-marine, low energy aquatic, poor swimmer/epibenthic /endobenthonic or walker/crawler</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>L. falsicarinata (Whatley and Bajpai, 2000a)</td>
<td>~823 µm</td>
<td>Rare</td>
<td>Non-marine, low energy aquatic, poor swimmer/epibenthic/ endobenthonic or walker/crawler</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Mongolianella cylindrica (Sowerby, 1840)</td>
<td>~980 µm</td>
<td>Rare</td>
<td>Non-marine, low energy aquatic, active swimmer, lived in permanent water bodies (ponds and lakes)</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Neocypris raoi (Jain, 1978)</td>
<td>590-660 µm</td>
<td>Abundant</td>
<td>Brackish-marine water</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Paracandona firmamentum (Whatley and Bajpai, 2000a)</td>
<td>~590 µm</td>
<td>Abundant</td>
<td>Non-marine, low energy aquatic</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Paracypretta sp.</td>
<td>636-1013 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Paracypretta jonesi (Bhatia and Rana, 1984)</td>
<td>1460-1600 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>P. subglobosa (Sowerby, 1840)</td>
<td>1147-1460 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer</td>
<td>Sharma and Khosla (2009); Khosla et al. (2011); this study</td>
</tr>
<tr>
<td>Valves</td>
<td>Paracypretta verruculosa (Whatley, Bajpai and Srinivasan, 2002a)</td>
<td>800-1200 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer</td>
<td>Khosla et al. (2011)</td>
</tr>
</tbody>
</table>
Table 1 (continued). List of fauna and flora recovered from the Jhilmili intertrappean section, Chhindwara District, Madhya Pradesh, Central India.

<table>
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<th>Fossil element</th>
<th>Taxon</th>
<th>Size (long dimension)</th>
<th>Abundance in sediments</th>
<th>Presumed paleoenvironment and paleoecology</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ostracods</td>
<td>Valves</td>
<td><em>Stenocypris cylindrica</em> (Sowerby, 1840)</td>
<td>~880 µm</td>
<td>Rare</td>
<td>Non-marine, low energy aquatic, active swimmer, fresh water environment</td>
</tr>
<tr>
<td></td>
<td>Valves</td>
<td><em>Strandesia jhilmiliensis</em> (Khosla et al., 2011)</td>
<td>850-900 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer, lived in shallow freshwater environment</td>
</tr>
<tr>
<td></td>
<td>Valves</td>
<td><em>Zonocypris spirula</em> (Whatley and Bajpai, 2000a)</td>
<td>340-350 µm</td>
<td>Common</td>
<td>Non-marine, low energy aquatic, active swimmer; heavily ornamented and represent sluggish conditions</td>
</tr>
<tr>
<td></td>
<td>Valves</td>
<td><em>Z. viriensis</em> (Khosla and Nagori, 2005)</td>
<td>340-350 µm</td>
<td>Abundant</td>
<td>Non-marine, low energy aquatic, active swimmer; heavily ornamented and represent sluggish conditions</td>
</tr>
<tr>
<td>Foraminifera</td>
<td>Tests</td>
<td><em>Eoglobigerina edita</em> (Subbotina, 1953)</td>
<td>40–100 µm</td>
<td>Common</td>
<td>Brackish-marine water</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>E. eobulloides</em> (Morozova, 1959)</td>
<td>40–100 µm</td>
<td>Common</td>
<td>Brackish-marine water</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Globanomalina compressa</em> (Plummer, 1926)</td>
<td>&gt;150 µm</td>
<td>Rare</td>
<td>Brackish-marine water</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Globigerina</em> (<em>Eoglobigerina</em>) <em>pentagona</em> (Morozova, 1961)</td>
<td>&gt;150 µm</td>
<td>Rare</td>
<td>Brackish-marine water</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Globigerinelloides aspera</em> (Koch, 1926)</td>
<td>&gt;150 µm</td>
<td>Rare</td>
<td>Brackish-marine water</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Globoconusa daubjergensis</em> (Branniman, 1952)</td>
<td>40–100 µm</td>
<td>Common</td>
<td>Brackish-marine water, persisted in highly stressful conditions</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Guembelitria cretacea</em> (Cushman, 1933)</td>
<td>40–150 µm</td>
<td>Rare</td>
<td>Brackish-marine water, disaster opportunist; persisted in highly stressful conditions and occurred in shallow continental shelf environments</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Hedbergella holmdelensis</em> (Olsson, 1964)</td>
<td>&gt;150 µm</td>
<td>Rare</td>
<td>Brackish-marine water, persisted in highly stressful conditions</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Parasubbotina pseudobulloides</em> (Plummer, 1926)</td>
<td>&gt;150 µm</td>
<td>Rare</td>
<td>Brackish-marine water, lived in muddy water in shallow environment conditions</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Parvularugoglobigerina eugubina</em> (Luterbacher and Premoli-Silva, 1964)</td>
<td>40–100 µm</td>
<td>Common</td>
<td>Brackish-marine water, lived in highly stressful conditions</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Praemurica taurica</em> (Morozova, 1961)</td>
<td>40–150 µm</td>
<td>Rare</td>
<td>Brackish-marine water</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Subbotina triloculinoides</em> (Plummer, 1926)</td>
<td>&gt;150 µm</td>
<td>Rare</td>
<td>Brackish-marine water</td>
</tr>
<tr>
<td></td>
<td>Tests</td>
<td><em>Woodringina hornerstownensis</em> (Olsson, 1960)</td>
<td>40–100 µm</td>
<td>Common</td>
<td>Brackish-marine water, lived in highly stressful conditions</td>
</tr>
<tr>
<td>Fishes</td>
<td><em>Lepisosteus</em> sp.</td>
<td>Not known</td>
<td>Rare</td>
<td>Non-marine, fluvio-lacustrine</td>
<td>Sunil Bajpai (personnel communication)</td>
</tr>
<tr>
<td></td>
<td><em>Pycnodus</em> sp.</td>
<td>Not known</td>
<td>Rare</td>
<td>Non-marine, fluvio-lacustrine</td>
<td>Sunil Bajpai (personnel communication)</td>
</tr>
<tr>
<td>Charophytes</td>
<td><em>Platychara sahnii</em> (Bhatia and Mannikeri, 1976)</td>
<td>450-700 µm</td>
<td>Common</td>
<td>Non-marine aquatic (submerged)</td>
<td>This study</td>
</tr>
</tbody>
</table>
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 anajarenis 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 ephymatus 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 microfossils 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 spongo 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, Globocoma daublengensis and Woodringa hornertonwouessn, 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
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, 1975; Jafar, 1982; Chiplonkar et al., 1977; Nayak, 2000; Keller et al., 2009a, b; Khosla and Verma, 2015). 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 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 *Spinzonocolpites echinitus*) 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 Papiro 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).
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 cyrtodon* (Whatley and Bajpai, 2000a) carapace, left lateral view; g) *Mongolianella cylindrica* (Sowerby, 1840) carapace, right lateral view; h) *Limnocypridea echynatos* (Whatley and Bajpai, 2000b) carapace, left lateral view; i) *Gomphocythere strangulata* (Jones, 1860), carapace, dorsal view; j) *Frambocythere tamiensis anjarenis* (Bhandari and Colin, 1999), carapace, dorsal view; k) *Frambocythere tamiensis anjarenis* (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) *Heilbergenella cf. holmdelenensis* (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).
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 Albion of Africa (Colin, 1993). Other genera such as limnocytherid *Gomphocythere, Limnocythere* and cyprids like *Paracandona* and *Cypria*, probably originated and evolved out from India (Whatley and Bajpai, 2006). The brackish water genus *Neocyprides* 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 *Mongolinaella, 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 Gondwana 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, 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 Guantatkal (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, silstones and calcrites 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 *Peysmonella*) 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 megafauna including palmes 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 bengalesis* and *Gabonisporites vigourouxi*) (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 hornestownensis, Eoglobigerina edita, E. eobulloides and Globoconusa daubjergensis, and rare Parasubbotina pseudobulloides, Praemurica taurica, Subbotina triloculinaoides, 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 Jhilmili 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 et 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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