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# EARLY PALAEOCENE OSTRACODA FROM THE CRETACEOUS - TERTIARY (K-T) DECCAN INTERTRAPPEAN SEQUENCE AT JHILMILI, DISTRICT CHHINDWARA, CENTRAL INDIA

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## ABSTRACT

A taxonomically diverse ostracod fauna was recovered from a unique, recently discovered section of the Deccan intertrappean deposits at Jhilmili in central India (District Chhindwara, Madhya Pradesh), on the eastern fringe of the main Deccan volcanic province. This predominantly freshwater ostracod fauna was found in association with the recently described earliest Paleocene (P1a) planktic foraminifer assemblage that allows a precise link between the marine and terrestrial faunal records in the Deccan volcanic province. The Jhilmili ostracod fauna comprises seventeen species pertaining to twelve genera. Although bulk of the Jhilmili ostracod fauna (17 spp.) represents freshwater, lacustrine taxa, one abundant species (*Neocyprideis raoi*), indicates incursions of brackish/marine water from a nearby seaway. Furthermore, the striking similarity of these Palaeocene-aged freshwater ostracods from Jhilmili to latest Cretaceous (Maastrichtian) faunas known from several widely separated localities across the Deccan province, indicates limited influence of the Deccan volcanism, at least qualitatively, on contemporary freshwater aquatic ecosystems. Finally, the Jhilmili ostracod fauna shows that the extensive endemism encountered among the Indian Maastrichtian freshwater ostracods continued into the early Palaeocene, consistent with geophysical models that suggest an oceanically isolated Indian plate during Maastrichtian-Palaeocene.

**Keywords:** Ostracoda; Deccan intertrappean; India; Palaeocene; Cretaceous-Tertiary boundary

## INTRODUCTION

The Deccan Traps of peninsular India represents one of the most extensive continental flood basalt provinces in the world, with an area of about 500,000 km$^2$ in western, central and southern India. It has been known for some time, based on high resolution radioisotopic and paleomagnetic data (Chenet *et al.*, 2007, 2008 and references therein), that the bulk of the Deccan Traps eruptions occurred over a short period of time during the magnetic chron 29R and that they may have played a significant role in mass extinctions at the Cretaceous– Tertiary (K-T) boundary. However, it is only recently that critical evidence in this regard has emerged (Keller *et al.*, 2008; 2009 a, b). These studies demonstrate that the K-T extinctions took place at or near the end of the main phase of Deccan volcanism, thus pointing to a cause and effect relationship between the two events.

During the past two decades, diverse continental micro biotic assemblages of latest Cretaceous (Maastrichtian) age have been reported from a number of localities in the Deccan volcanic province where fossiliferous sedimentary deposits occur either below the Deccan basaltic flows (infratrappean or the Lameta Formation) or are intercalated within them (intertrappeans). The fossil assemblages include fishes, frogs, turtles, lizards, snakes, crocodiles, dinosaur, mammals, ostracods, charophytes and pollens (see Khosla and Sahni, 2003 for a summary).

Most recently, for the first time in the main Deccan province, an intertrappean section at Jhilmili (District Chhindwara, Madhya Pradesh) has yielded a planktic foraminifer assemblage of early Danian (P1a) age (Keller *et al.*, 2009 a, b). This major discovery has revealed the existence of a seaway that extended inland into central India, possibly from the west, through the Narmada-Tapti valleys. Foraminifers in this intertrappean section were found together with a diverse assemblage of fresh and brackish water ostracods, some of which were illustrated in Keller *et al.* (2009a, b). Subsequently, Khosla *et al.* (2009) described some of the ostracod taxa from Jhilmili. It should be noted that the planktic foraminifers from Jhilmili were first reported in January 2009 by Keller *et al.* (2009a). This paper describes the entire assemblage (17 spp.) of fresh and brackish water ostracod fauna from Jhilmili, which includes 9 species not recorded in Khosla *et al.* (2009). We also evaluate the significance of the Jhilmili ostracod fauna in the context of i) paleogeographic setting of peninsular India near the K-T transition, ii) influence of Deccan volcanic activity on contemporary freshwater faunas and ecosystems and iii) biogeographic affinities and intercontinental dispersal of Maastrichtian-early Palaeocene freshwater ostracods in the context of the current *Out-of-India* hypothesis.

## PREVIOUS WORK

Pioneering studies on the non-marine intertrappean Ostracoda date back to the nineteenth century (Sowerby, 1840; Carter, 1852; Jones, 1860). Following these early efforts, studies on the intertrappean freshwater ostracods remained neglected for well over a century until early 1980's, when Bhatia and co-workers revived interest in these faunas (Bhatia and Rana, 1984; Bhatia *et al.*, 1990a, b; 1996). Other notable studies on intertrappean freshwater ostracoda include those by Mathur and Verma (1988), Singh and Sahni (1996) and Bhandari and Colin (1999). In contrast to intertrappean Ostracoda, studies on Maastrichtian infratrappean (Lameta Formation) ostracoda are relatively few (Sahni and Khosla, 1994 a; Khosla and Sahni, 2000; Khosla *et al.*, 2005).

In recent years, a comprehensive study of the intertrappean freshwater Ostracoda has been undertaken by Whatley, Bajpai and co-workers (2000-2006). These authors described nonmarine Ostracoda from a number of widely separated intertrappean localities in the Deccan volcanic province (Whatley and Bajpai,

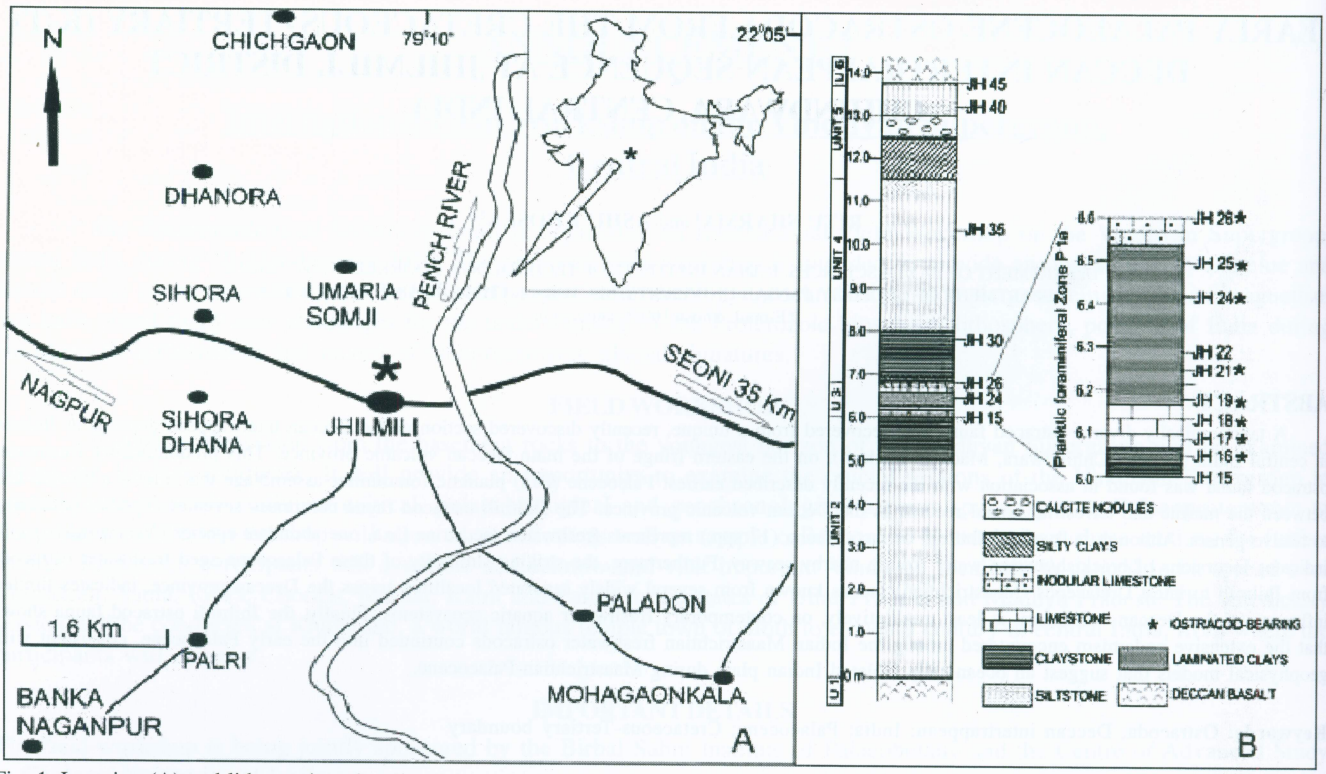



Fig. 1. Location (A) and lithostratigraphy (B) of the Jhilmili intertrappean section, District Chhindwara, Madhya Pradesh, peninsular India.

2000a, b, c; Bajpai and Whatley, 2001; Whatley *et al.*, 2002a, b, c; 2003a, b; Bajpai *et al.*, 2004). The described ostracod faunas include those from the Mohagaonkalan section of Chhindwara District (Whatley *et al.*, 2002b), less than 50 km from the presently investigated Jhilmili locality.

Whatley and Bajpai (2005) discussed the paleoecological implications of the intertrappean ostracoda and Whatley and Bajpai (2006) discussed the biogeographic aspects of the intertrappean Ostracoda. Significantly, with the recognition of extensive endemism of intertrappean ostracods (Whatley and Bajpai, 2006), a new biogeographic perspective has come to light that contrasts with previous notions of Asian affinities for the freshwater intertrappean ostracoda. Whatley and Bajpai (2006) argue in favour of India's protracted isolation during its northward flight before colliding with the Asian plate, and also provide evidence in support of Out- of-India hypothesis (e.g. Karanth, 2006).

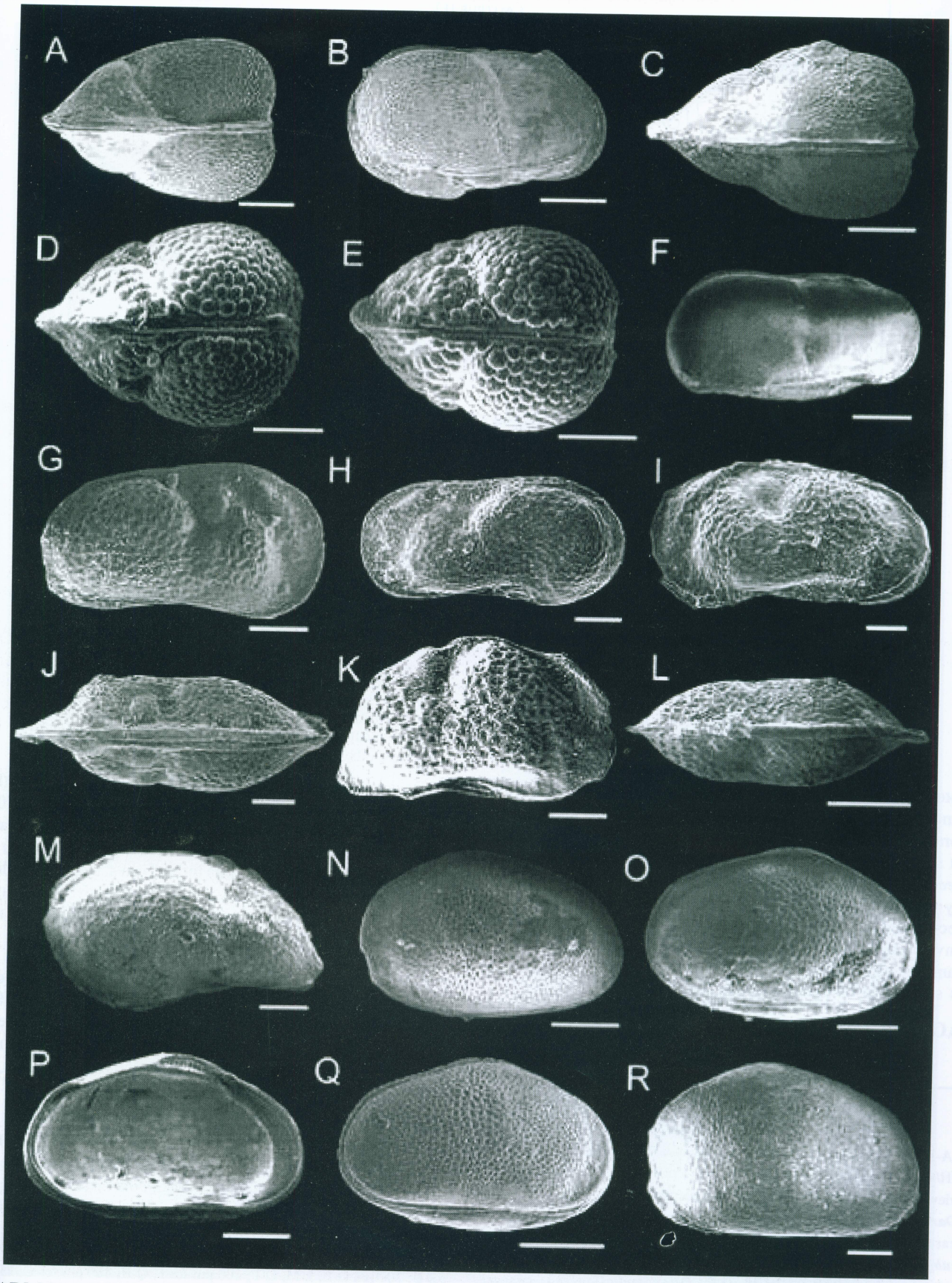
## LITHOSTRATIGRAPHY OF THE OSTRACOD-YIELDING SECTION AT JHILMILI

The Jhilmili intertrappean section is located near the village Jhilmili (Lat. 22° 02' 44" N: Long. 79° 09' 34" E), adjacent to the main road that links Seoni and Chhindwara (Fig. 1A) in Chhindwara District, Madhya Pradesh. This locality lies about 5 km NW of the well known village of Mohgaonkalan. The samples from Jhilmili on which this study is based were initially collected by one of us (RS). The section was subsequently sampled by a multidisciplinary and multi-institutional international team (Keller *et al.*, 2009 a, b). The intertrappean sedimentary deposit is about 14 m thick and is sandwiched between two basaltic flows (Fig. 1B). The lower 6 m thick unit of intertrappean sediments consists of red clayey siltstone with carbonate nodules and root traces, and the upper 6.5 m thick unit consists of red and green shales. Both these units have been interpreted primarily as paleosols (Keller *et al.*, 2009 a, b). The middle unit, which is of interest to this study, spans the interval from 6.0 to 6.6 m, and consists of yellow to pink, ostracod-rich shales and calcareous limestones with planktic foraminifera. The lower part of this unit consists of alternating yellow to pink clays and marly limestones. Ostracods and charophytes are common in this unit (JH17, JH19). Some clay layers and clasts in this unit have yielded early Danian planktic foraminifera (JH16, JH18, JH20–22, Keller *et al.*, 2009 a, b). The upper part of this unit consists mainly of pink clays with

## EXPLANATION OF PLATE I

(A-C) ***Gomphocythere strangulata*** A, carapace, dorsal view, IITR/SB/JH/1; B, carapace, right lateral view IITR/SB/JH/2; C. carapace, dorsal view IITR/SB/JH/3. (D-E) ***Frambocythere tumiensis anjarensis*** D. carapace, dorsal view, IITR/SB/JH/57; E. carapace, dorsal view, IITR/SB/JH/58. (F) ***Limnocythere falsicarinata*** F. carapace, left lateral view IITR/SB/JH/4. (G-J) ***Limnocythere deccanensis*** G. carapace, right lateral view IITR/SB/JH/5; H. carapace, right lateral view IITR/SB/JH/6; I. carapace, left lateral view IITR/SB/JH/7; carapace, dorsal view IITR/SB/JH/8. (K-M) ***Limnocythere*** sp., K. carapace, right lateral view IITR/SB/JH/10; L. carapace, dorsal view IITR/SB/JH/9; M. carapace, left lateral view IITR/SB/JH/11; (N-R) ***Neocyprideis*** cf. ***N. raoi*** N. carapace, left lateral view IITR/SB/JH/43; O. carapace, right lateral view IITR/SB/JH/44; P. valve, inner valve view IITR/SB/JH/45; Q. carapace, right lateral view IITR/SB/JH/46; R. carapace, left lateral view IITR/SB/JH/47. (Scale bar equals 200 μm for A-C, E-F, K, M, Q-R; 100 μm for D, G, L, N; 90 μm for H; 60 μm for I-J; 150 μm for O-P).

**Plate I**



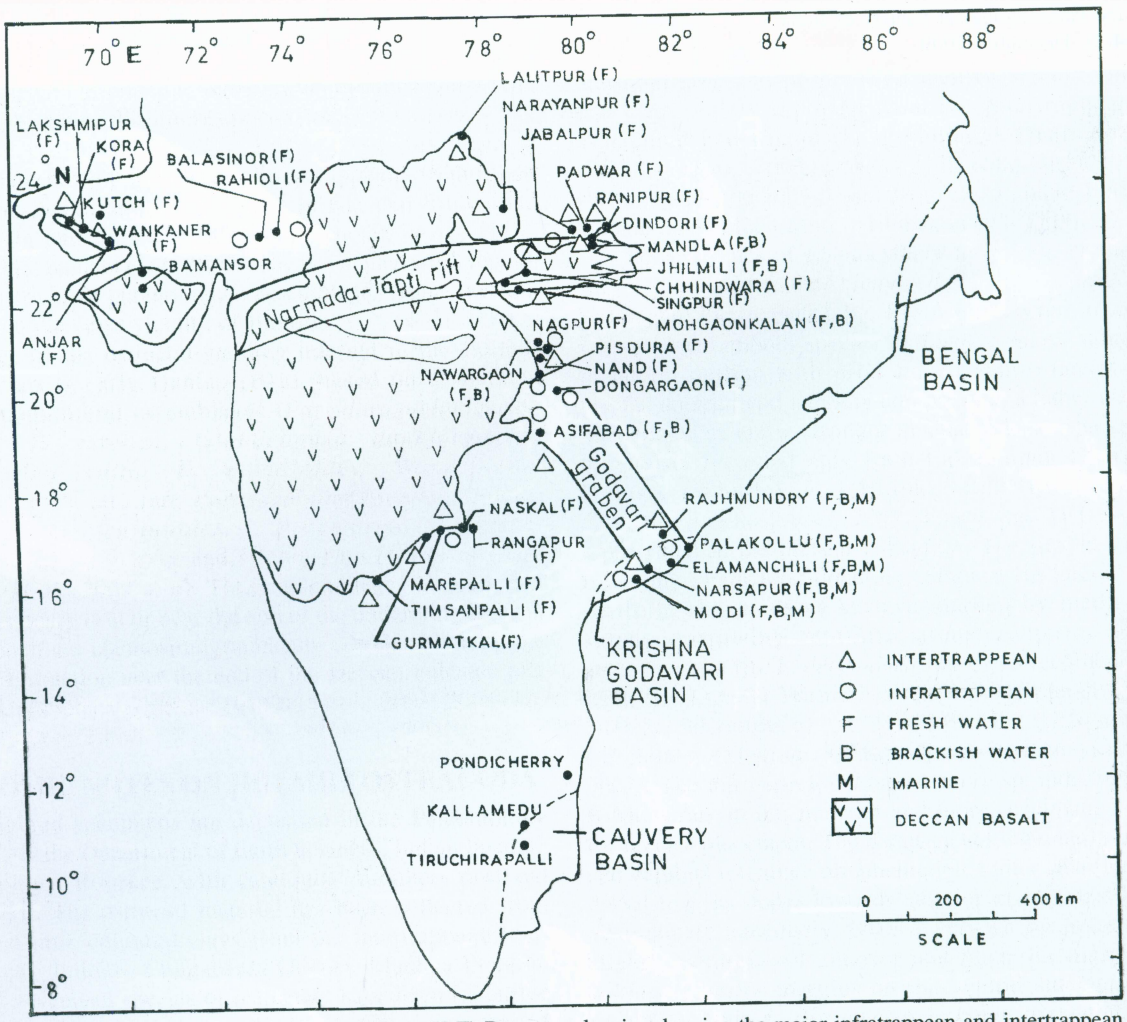



Fig. 2. Distribution of Cretaceous-Tertiary (K-T) Deccan volcanics showing the major infratrappean and intertrappean fossiliferous localities. The localities are marked by fresh water, brackish water and marine environments. Marine incursions are along the Narmada-Tapti rift and possibly also along the Godavari graben.

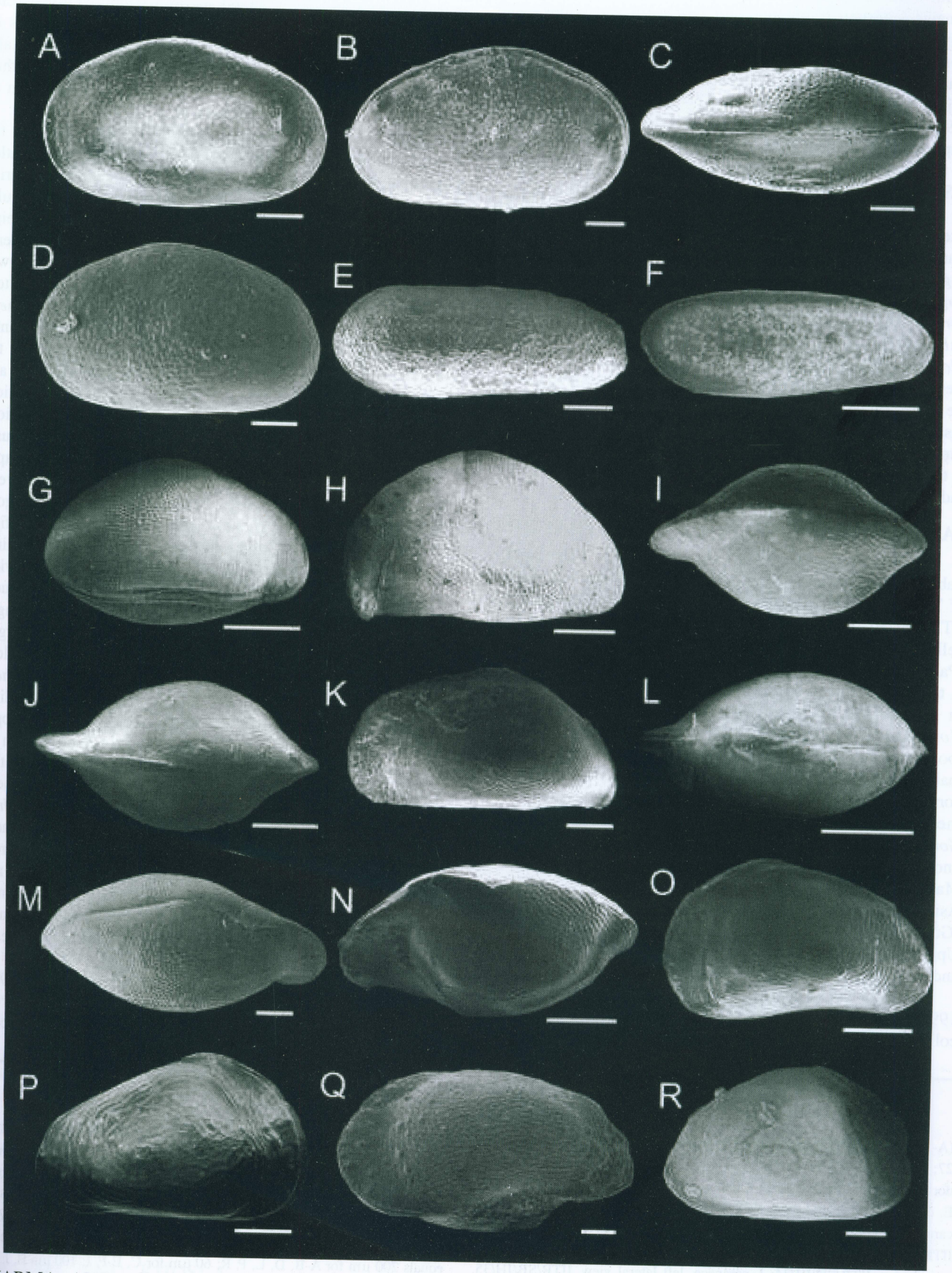
intercalations of algal mats with freshwater ostracods and laminated claystones with rare brackish ostracods and planktic foraminifera. Most of the ostracod species were found to occur in samples JH24 and JH25 (Fig. 1B). Overall, *Limnocythere deccanensis* dominates the assemblage (80-90 %), followed by *Zonocypris viriensis* in JH17 and JH18. Most of the recovered ostracod assemblage indicates a fresh water environment, whereas one species (*Neocyprideis raoi*) in samples numbers JH21-JH26 along with planktic foraminifera is suggestive of brackish water environments.

## AGE OF THE JHILMILI OSTRACOD FAUNA

During the past two decades, intertrappean deposits across the Deccan province have yielded a wealth of fossil data (Fig. 2, e.g. Prasad and Khajuria, 1995; Bajpai and Prasad, 2000; Mohabey *et al.*, 1993; Khosla and Sahni, 1995, 2003; Whatley and Bajpai, 2005, 2006; Prasad and Sahni, 1999; Prasad *et al.*, 2007 a, b). However, bulk of this biota (fishes, frogs, crocodiles, turtles, snakes, dinosaurs, mammals, ostracods, charophytes and molluscs) is terrestrial or freshwater (e.g. Khosla and Sahni, 2003) and therefore could not lead to a precise age determination and delineation of the Cretaceous-Tertiary (K-T) boundary in the main Deccan volcanic province. Based on megafloral evidence, early workers (Bande *et al.*, 1981, 1988; Bande and Prakash, 1982; Mehrotra, 1989) suggested a Paleocene-Eocene age for the Deccan intertrappean sediments

## EXPLANATION OF PLATE II

(A-D) ***Neocyprideis* cf. *N. Raoi*** A. carapace, left lateral view IITR/SB/JH/48; B. carapace, right lateral view IITR/SB/JH/49; C. carapace, dorsal view IITR/SB/JH/50; D. carapace, left lateral view IITR/SB/JH/51. (E-F) ***Darwinula torpedo*** E. carapace, right lateral view IITR/SB/JH/12; F. carapace, right lateral view IITR/SB/JH/13. (G-H) ***Paracypretta subglobosa*** G. carapace, right lateral view IITR/SB/JH/15; H. carapace, left lateral view IITR/SB/JH/16. (I-N) ***Paracypretta jonesi*** I. carapace, dorsal view IITR/SB/JH/17; J. carapace, dorsal view IITR/SB/JH/18; K. carapace, left lateral view IITR/SB/JH/19; L. carapace, dorsal view IITR/SB/JH/20; M. carapace, dorsal view IITR/SB/JH/21; N. carapace, left lateral view IITR/SB/JH/22. (O-R) ***Paracypretta*** sp., O. carapace, left lateral view, IITR/SB/JH/24; P. carapace. right lateral view, IITR/SB/JH/25; Q. carapace, left lateral view IITR/SB/JH/26. R. carapace, right lateral view, IITR/SB/JH/71. (Scale bar equals 600 μm for A, C; 800 μm for B; 200 μm D-E, I, M, O-P; 100 μm for F, Q-R; 400 μm for G; 250 μm for H, J-K, N; 500 μm for L).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of Nagpur-Chhindwara region of central India. On the other hand, studies on associated fossils, especially dinosaur remains (eggshell fragments, and rare teeth and bones), and palynomorphs from the intertrappean localities of the east, west and central peninsular India have favoured a Maastrichtian age for the Deccan intertrappeans (Sahni and Bajpai, 1988; Sahni and Khosla 1994 b; Kar and Srinivasan, 1998; Khosla and Sahni, 2000, 2003; Khosla *et al.*, 2004; Kapgate, 2005; Samant *et al.*, 2008). The last named work reports on the Maastrichtian palynological assemblages from a section at Singpur, in the close vicinity of Jhilmili.

The age of the ostracod-yielding interval in the Jhilmili intertrappeans is early Danian (P1a), based on associated planktic foraminiferal assemblages (*Parvularugoglobigerina eugubina, P. extensa, Globoconusa daubjergensis, Eoglobigerina edita, E. eobulloides, Woodringina hornerstownensis* and rare *Parasubbotina pseudobulloides, Subbotina triloculinoides, Praemurica taurica, Globanomalina compressa* and *Globigerina (E.) pentagona*, see Keller *et al.*, 2009 a, b). These assemblages indicate that the K-T boundary is at or near the end of the underlying Deccan basalts, which are chemostratigraphically correlatable with the Ambenali Formation near the end of the Deccan volcanic pile in the Western Ghats sequence (Chenet *et al.*, 2007, 2008; Jay and Widdowson, 2008).

## TAXONOMIC NOTES ON JHILMILI OSTRACODA

All figured specimens are deposited in the Paleontology Laboratory at the Department of Earth Sciences, Indian Institute of Technology, Roorkee, with catalogue numbers prefixed IITR/SB/JH/. The ostracod material has been collected from yellow and pink coloured clays from the intertrappean beds (Palaeocene), Jhilmili, Chhindwara District, Madhya Pradesh. A total of seventeen species of ostracods have been identified in the Jhilmili intertrappean beds. A large species of *Gomphocythere* (Plate I, figs. A-C). showing reticulate (polygonal and hexagonal) ornamentation, deep and sinuous main median sulcus and a smaller anterior sulcus, two tubercles dorsally between the two sulci and a flatter tubercle just above the position of the adductor scars, is identified as *Gomphocythere strangulata* (Jones, 1860). This species is also known from the intertrappean beds of Takli (Bhatia *et al.*, 1996); Mamoni in Kota District, Rajasthan (Bhatia *et al.*, 1990b); Asifabad in Andhra Pradesh (Bhatia *et al.*, 1996); Yanagundi (Gulbarga District, Karnataka, Whatley *et al.*, 2002a) and the Upper Cretaceous Lameta Formation of Maharashtra (Udhoji and Mohabey, 1996).

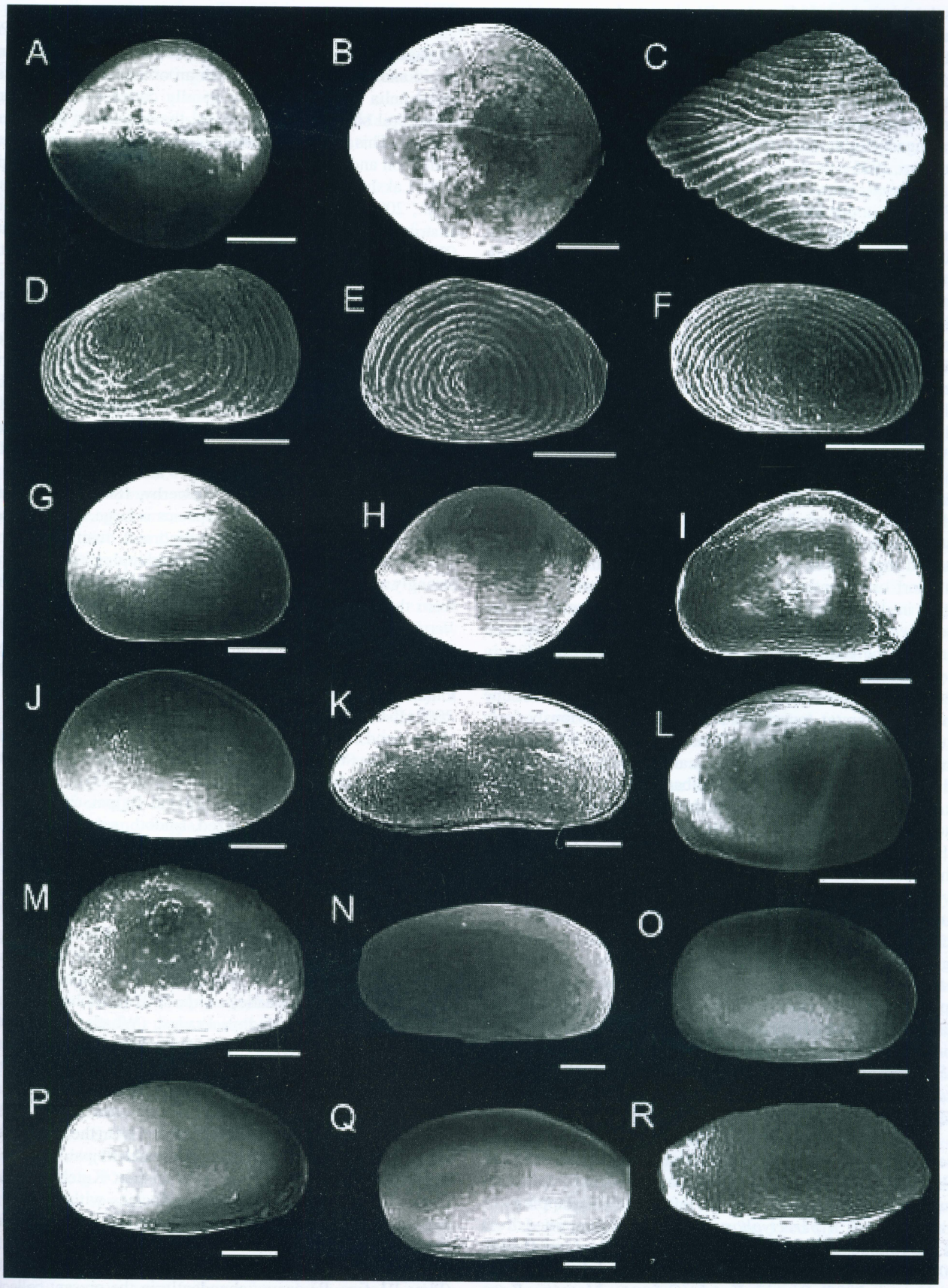
*Frambocythere tumiensis anjarensis* (Bhandari and Colin, 1999) (Plate I, figs. D-E) is not abundant in the present collection. It is characterized by its very small size and inflated shape, anterior margin more rounded, and an ornamentation of papillate tubercles, tubercles on the dorsal part of the antero-marginal area and pronounced median sulcus. This species has been widely reported from the intertrappean beds of Yanagundi and Chandarki in Gulbarga District, Karnataka (Whatley *et al.*, 2002a), Mamoni in Kota District, Rajasthan (Whatley *et al.*, 2003a) and from the Lameta Formation of Dongargaon, Maharashtra (Khosla *et al.*, 2005).

Three species of *Limnocythere* have been recorded in the Jhilmili ostracod fauna. *Limnocythere falsicarinata* (Whatley and Bajpai, 2000 a, Plate I, fig. F) is extremely rare in our material. It is a large, smooth species of *Limnocythere*, subrectangular in lateral outline with pronounced ventro-lateral rib being visible, anterior end laterally compressed, a rather weak antero-median sulcus and a stronger median sulcus. The species was previously recorded only from Lakshmipur, District Kutch, Gujarat (Whatley and Bajpai, 2000 a). *Limnocythere deccanensis* (Khosla *et al.*, 2005) (Plate I, figs. G-J) is abundantly represented in the present collection. The species exhibits the following characters: quadrate carapace (in lateral view) and fusiform shape; valve surface marked by median vertical sulcus, narrowing ventrally; arcuate anterior depression; antero-ventral rib. *L. deccanensis* has been recorded previously from the Lameta Formation of Dongargaon in Chandrapur District (Khosla *et al.*, 2005) and Mohagaon-Haveli, Chhindwara District, Madhya Pradesh (Khosla and Nagori, 2007). The third species (*Limnocythere* sp. indet., Plate I, figs. K-M) is rare in our material and more specimens are required for precise placement. The carapace is triangular in lateral view and exhibits reticulate ornamentation. Other characters include: dorsal margin slopes towards anterior margin at a high angle, ventral margin medially concave; very narrow posterior margin; slightly compressed anterior and posterior margins; sulcus towards anterior margins on the ventral side. *Limnocythere* sp. differs from *L. deccanensis* in being triangular in outline, unlike the quadrate outine of the latter. The dorsal margin slopes towards anterior margin at a high angle whereas in *L. deccanensis* the slope towards anterior margin is much gentler. *L. falsicarinata* described from Lakshmipur intertrappean locality, District Kutch, Gujarat is different from *Limnocythere* sp. in having a smooth surface, in having a very pronounced ventro-lateral rib and in being rectangular in shape whereas *Limnocythere* sp. is having reticulate ornamentation, and triangular in lateral view. The present species is higher than *L. falsicarinata* and *L. deccanensis*. This is probably a new species but will be formally named when additional material becomes available.

The brackish water species *Neocyprideis raoi* (Jain, 1978) (Plate I, figs. N-R; Plate II, figs. A-D) has been recorded for the first time from a continental intertrappean locality in the Deccan

## EXPLANATION OF PLATE III

(A-B) ***Cypridopsis hyperectyphos*** A. carapace, dorsal view IITR/SB/JH/27; B. carapace, IITR/SB/JH/70. (C-E) ***Zonocypris spirula*** C. carapace, dorsal view IITR/SB/JH/28; D. carapace, right lateral view IITR/SB/JH/29; E. carapace, left lateral view IITR/SB/JH/30. (F-J) ***Zonocypris viriensis*** F. carapace, right lateral view IITR/SB/JH/31; G. carapace, left lateral view IITR/SB/JH/32; H. carapace, dorsal view IITR/SB/JH/33; I. carapace, right lateral view IITR/SB/JH/34; J. carapace, left lateral view, IITR/SB/JH/35. (K) ***Mongolianella cylindrica*** K. carapace, right lateral view, IITR/SB/JH/36. (L-M) ***Cypria cyrtonidion*** L. carapace, left lateral view IITR/SB/JH/38. M. carapace, right lateral view IITR/SB/JH/39. (N-Q) ***Limnocypridea ecphymatos*** N. carapace, right lateral view IITR/JH/SB/41; O. carapace, left lateral view IITR/SB/JH/42; P. carapace, left lateral view IITR/SB/JH/40; Q. carapace, left lateral view, IITR/JH/SB/71. (R) ***Paracandona firmamentum*** R. carapace, right lateral view IITR/SB/JH/37. (Scale bar equals 200 μm for A-B, D, L, P, R; 60 μm for C, E-F, I; 100 μm H, J; 150 μm for M; 400 μm for G, K, N, Q; 800 μm for O).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volcanic province. It occurs abundantly in the present collection. Important features include: carapace subrectangular or subovate in lateral view, dorsal and ventral margin convex; anterior end broadly rounded, posterior end narrowly rounded, surface pitted; left valve larger than right valve; greatest height slightly anterior to the middle; dorsal margin arched. The species was previously described as *Ovycytheridea raoi* by Jain (1978) from the intertrappean beds of Kateru and Duddukuru, near Rajahmundry in the East Godavari District of Andhra Pradesh (Bhandari, 1995).

*Darwinula torpedo* (Whatley *et al.*, 2002 a) (Plate II, figs. E-F) is rare in our material. The species is characterized by a medium, smooth or micro-papillate, elongate and sub-cylindrical in lateral outline; anterior margin much more narrowly rounded than the posterior. The species has been recorded from Gulbarga, Karnataka (Whatley *et al.*, 2002a).

Three species of *Paracypretta* have been recorded at Jhimili. The first of these, *Paracypretta subglobosa* (Sowerby, 1840) (Plate II, figs. G-H), is one of the most common intertrappean ostracods, characterised by large, subovate, highly inflated, strongly laterally compressed anterior margin and papillate ornamentation.

The second species *Paracypretta jonesi* (Bhatia and Rana, 1984) (Plate II, figs. I-N) is abundant in the present collection. This species is also large, inflated, subtriangular in lateral view; umbonate dorsal margin; laterally compressed anteriorly, posterior margin slightly compressed; anterior margin broadly rounded and posterior margin narrowly rounded than the posterior; ornamentation is punctate. *Paracypretta jonesi* is similar in dorsal and ventral view to *P. subglobosa* but in the latter species the ornamentation is papillate and not oriented parallel to the ventral margin. It differs from *P. elizabethae* in its greater tumidity as seen in dorsal view and in its more laterally compressed and projecting anterior margin in the same view. *Paracypretta jonesi* has been reported previously from Gitti Khadan, Nagpur District (Bhatia and Rana, 1984), Anjar (Bhandari and Colin, 1999; Whatley and Bajpai, 2000b; Khosla and Nagori, 2007), Chandarki, Gulbarga District (Whatley *et al.*, 2002b), Lameta Formation of Jabalpur Cantonment, Madhya Pradesh (Sahni and Khosla, 1994a; Khosla and Sahni, 2000) and Lameta Formation of Dongargaon area, Chandrapur District (Khosla *et al.*, 2005).

The third species of *Paracypretta* at Jhilmili (*Paracypretta* sp.) (Plate II, figs. O-R) is also large, inflated, subtriangular in lateral view; laterally compressed anteriorly, posterior margin slightly compressed; anterior margin broadly rounded and posterior margin narrowly rounded than the posterior. The most important character is the presence of reticulate ornamentation. This species differs from other species of *Paracypretta* in its reticulate ornamentation, unlike the punctate ornamentation in *P. jonesi* and *P. elizabethae* and papillate ornmanentation in *P.subglobosa*. *Paracypretta* sp. is not known from any other intertrappean locality.

*Cypridopsis hyperectyphos* (Whatley and Bajpai, 2000 a) (Plate III, figs. A-B). This medium sized species is strongly inflated with a triangular subovate lateral outline, delicately punctate ornamentation and the left valve overlapping the right valve. *C. hyperectyphos* was previously reported from the intertrappean beds of Lakshmipur (Whatley and Bajpai, 2000 a), Kora (Bajpai and Whatley, 2001) and Anjar (Khosla and Nagori, 2005) District Kutch (Gujarat); Mamoni, Kota, Rajashtan (Whatley *et al.*, 2003a), Yanagundi, Gulbarga District, Karnataka (Whatley *et al.*, 2002a) and Lameta Formation of Dongargaon, Chandrapur District, Maharashtra (Khosla *et al.*, 2005).

*Zonocypris spirula* (Whatley and Bajpai, 2000 a) (Plate III, figs. C-E) is a very small species of *Zonocypris* strongly tumid and fusiform dorsally with an ornamentation of a single spiral helix and a single rib, spirally coiled about mid-valve; initial coil somewhat angular and the remainder more or less circular. This species is abundantly represented in the present collection and has been widely recorded from the intertrappean beds: Lakshmipur (Whatley and Bajpai, 2000 a), Kora (Whatley *et al.*, 2002c) and Anjar (Khosla and Nagori, 2005) in Kutch District, Gujarat and Yanagundi, Gulbarga District, Karnataka (Whatley *et al.*, 2002a), Mohagaonkalan, Chhindwara District, Madhya Pradesh (Khosla and Nagori, 2007) and from the Lameta Formation of Dongargaon, Chandrapur District, Maharashtra (Khosla *et al.*, 2005). *Zonocypris viriensis* (Khosla and Nagori, 2005) (Plate III, figs. F-J). More than a hundred specimens have been collected and the most important character of this species is the ornamentation of fine striations arranged concentrically in the peripheral region and irregularly disposed in the middle. This species is subovate; the greatest height is ¾ of length and slightly anterior to middle and the ventral margin is sinuate.

*Mongolianella cylindrica* (Sowerby, 1840) (Plate III, figs. K) is rare in our material. This species is large, elongate (bean-shaped), subrectangular to subcylindrical, fusiform in dorsal view, with left valve larger and overlapping the right valve strongly around the free margins. The species is widely recorded from the intertrappean beds of Narli, Rajasthan (Mathur and Verma, 1988); Asifabad, Andhra Pradesh (Bhatia *et al.*, 1996); Gitti Khadan, Nagpur (Bhatia and Rana, 1984), Takli, Nagpur, Maharashtra (Bhatia *et al.*, 1996; Khosla and Nagori, 2007); Chandarki (Gulbarga District), Karnataka (Whatley *et al.*, 2002a); Lakshmipur (Whatley and Bajpai, 2000a) and Kora (Bajpai and Whatley, 2001) in District Kutch (Gujarat); Mamoni in Rajasthan (Whatley *et al.*, 2003a); Phulsagar, Mandla District, Madhya Pradesh (Bajpai *et al.*, 2004).

*Cypria cyrtonidion* (Whatley and Bajpai, 2000 a) (Plate III, figs. L-M) is medium- sized, smooth, subquadrate to sub-circular with left valve larger than right valve, overlapping all round except dorsally where right valve overreaches the left valve. The species has been widely recorded from the intertrappean beds: Lakshmipur (Whatley and Bajpai, 2000 a), Kora (Bajpai and Whatley, 2001) and Anjar (Khosla and Nagori, 2005), District Kutch, Gujarat; Takli, Nagpur, Maharashtra (Khosla and Nagori, 2007); Yanagundi and Chandarki, Gulbarga District, Karnataka (Whatley *et al.*, 2002a); Mohagaonkalan in Chhindwara District, Madhya Pradesh (Whatley *et al.*, 2002b; Khosla and Nagori, 2007) and the Lameta Formation of Dongargaon, Chandrapur District, Maharashtra (Khosla *et al.*, 2005).

*Limnocypridea ecphymatos* (Whatley and Bajpai, 2000 b) (Plate III, figs. N-Q), previously recorded from the Maastrichtian intertrappean beds of Anjar (Whatley and Bajpai, 2000 b) and Kora (Bajpai and Whatley, 2001), District Kutch, Gujarat, is large, strongly sexually dimorphic species with rounded end margins, left valve strongly overlapping the right valve, and a characteristic ornamentation of dense papillae.

*Paracandona firmamentum* (Whatley and Bajpai, 2000 a) (Plate III, figs. R) occurs abundantly in the present collection. The species is subovate to subrectangular in lateral view and

asymmetrically fusiform in dorsal view with anterior margin more rounded than posterior. Small, scattered spinose tubercles are present all over the surface. The species, though comparable in overall outline to *Paracandona jabalpurensis* (Khosla and Sahni, 2000) described from the Lameta Formation of Jabalpur, Madhya Pradesh is distinguishable in being substantially larger, more ovate and inflated and less laterally compressed anteriorly. *P. firmamentum* is also known from the Maastrichtian intertrappean beds of Lakshmipur, Kutch District, Gujarat (Whatley and Bajpai, 2000 a).

## DISCUSSION

The Unit 3 of the Jhilmili intertrappean section, which is 60 cm thick, contains abundant freshwater ostracods (Fig 1B), associated with early Danian planktic foraminifers and charophytes. Palaeoecologically, the Jhilmili freshwater ostracod assemblage represents an admixture of non-swimmers and swimmers and provides a reasonably good evidence for the nature of the water body that they inhabited. Two freshwater species (*Limnocythere deccanensis* and *Zonocypris viriensis*) dominate the recovered assemblage of 17 species. A large majority of taxa from Jhilmili are non- or poor swimmers, such as the cytheraceans (*Limnocythere, Gomphocythere, Frambocythere*) and darwinulaceans (*Darwinula*). Although some species of *Limnocythere* live in temporary pools, the majority requires permanent waters (Mckenzie, 1971). Similarly, *Darwinula* is also found in streams but it 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* and *Mongolianella* are active swimmers. 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). All of these taxa suggest the presence of a permanent body of freshwater lake/pond. Further, a marked increase in the alkalinity of the environments is indicated by greater calcification of the heavy ornamented ostracods (e.g. in *Gomphocythere strangulata* Jones, 1860, *Paracypretta subglobosa* Sowerby, 1840, *Paracypretta jonesi* Bhatia and Rana, 1984, *Zonocypris spirula* Whatley and Bajpai, 2000 a, *Zonocypris viriensis* Khosla and Nagori, 2005, *Limnocypridea ecphymatos* Whatley and Bajpai, 2000 b, *Limnocythere* sp. and *Paracandona firmamentum* Whatley and Bajpai, 2000 a). This increase in the precipitation of calcium carbonate was probably favoured by the presence of algae and tropical to sub-tropical climatic conditions.

The presence of a brackish water ostracod species (*Neocyprideis raoi*) in sample numbers JH21 to JH26 along with common planktic foraminifera points to intervals of a brackish-marine environment. This brackish water species has long been known from the intertrappean beds of Rajahmundry area near the southeast coast (Jain 1978; Khosla and Nagori, 2002) where it occurs in association with benthic and planktic foraminifers (Keller *et al.*, 2008). The occurrence of *Neocyprideis* in brackish water environment has long been established (e.g. Keen, 1977; Neale, 1988). Another marine/brackish water species (*Buntonia* sp.), which was listed (but not illustrated) in Keller *et al.* (2009b) could not be encountered in the present material. Foraminiferal as well as microfacies data on the Jhilmili section have been interpreted to indicate temporary or short term influx of marine incursions into freshwater environments resulting in shallow marine to brackish-estuarine conditions (Keller *et al.*, 2009 a, b). Seasonal currents could have transported planktic foraminifera from a nearby marine seaway. However, the absence of benthic foraminifera at Jhilmili suggests that the marine conditions did not exist long enough at this locality for benthics to invade the substrate.

The discovery of planktic foraminifers at Jhilmili suggests that intertrappeans in the main Deccan volcanic province, particularly those along the Narmada valley, which are generally considered to be terrestrial in nature, may also contain intervals of brackish to marine deposition. The intertrappean beds at Jhilmili are located in central India and are about 800 km from the ocean to the west. It has been hypothesized that a marine transgression would have originated from the west along the Narmada and Tapti rift valleys (Keller *et al.*, 2009 a, b) and possibly also from the southeast along the Godavari valley (Sahni, 1983). The discovery of an admixed fresh and brackish water ostracod fauna at Jhilmili and the overall distribution of freshwater and marine faunas of intertrappeans/Lameta (Fig. 2) is not inconsistent with the idea of a closeby marine seaway as postulated by Keller *et al.* (2009b).

Apart from the palaeogeographic implications, the Jhilmili ostracod data presented here is important as it potentially offers an opportunity to address the issue of faunal survivorship in fresh water aquatic systems across the Cretaceous-Tertiary boundary in the Deccan. As discussed above, these ostracods are precisely dated as early Danian (P1a) based on planktic foraminifers. Strikingly similar ostracod assemblages (with the exception of *Neocyprideis raoi*) have been described previously from a number of continental Maastrichtian intertrappean sections across the Deccan province (Whatley and Bajpai, 2005). The recently described freshwater ostracod fauna from a palynologicaly-dated Palaeocene intertrappean section at Lalitpur (Uttar Pradesh) also shows similarities in the taxonomic composition of ostracod faunas in different sections in the main Deccan province, although there are differences in the relative abundance of the various taxa (Singh and Kar, 2003; Sharma *et al.*, 2008). The most plausible explanation for this overall similarity between Maastrichtian and early Danian intertrappean freshwater ostracods is that they were not significantly affected, at least qualitatively, by the initiation of Deccan volcanic activity. It is important to note that Khosla *et al.* (2005) also noted a strong similarity of freshwater ostracod taxa between the Maastrichtian Lameta Formation (pre-Deccan) and the Deccan intertrappeans. This situation is reminiscent of other intertrappean freshwater organisms such as molluscs (Hartman *et al.*, 2007). Initial observations by Hartman *et al.* (2007) show that the Palaeocene aged freshwater molluscs from Deccan intertrappeans Papro locality in Lalitpur, Uttar Pradesh (*Physa, Lymnaea* and 2 species of *Viviparus*) are closely comparable to similarly sized molluscs from Maastrichtian intertrappean beds of central India. It is apparent, as Hartman *et al.* (2007) suggest, that these taxa were able to repopulate during periods of quiescence between basaltic flows, also suggests that refugia were located relatively close by. The present ostracod data from Jhilmili (Madhya Pradesh) supports Hartman's *et al.* (2007) interpretations based on Papro's molluscs. It is also to be noted that the palynofacies data from the Bombay intertrappeans (early Paleocene) has been interpreted as showing no significant floral declines (Cripps *et al.*, 2005). Although it is hard to interpret conclusively, the Jhilmili and Lalitpur data suggest that the

impact of volcanic activity on adjacent freshwater ecosystems was limited.

Finally, the zoogeographical implications of the Indian Maastrichtian freshwater ostracods from the Deccan intertrappean deposits of peninsular India have been discussed at length in the series of papers (Whatley and Bajpai, 2000 c, 2005, 2006). It has been suggested that the intertrappean ostracod faunas are highly endemic at the species level and support the traditional models favouring India's oceanic isolation during Maastrichtian. In addition, it has also been shown that several intertrappean ostracod taxa support the *Out-of-India* hypothesis, i.e. their origin in India and subsequent dispersal to other parts of the world (Whatley and Bajpai, 2006). Of the seventeen species being recorded herein from the early Palaeocene Jhilmili intertrappeans, nearly all of them are endemic to India and have been previously described the continental Maastrichtian intertrappeans of the Deccan province. This would seem to imply a significant geographic isolation across the K-T boundary in India, consistent with recent geophysical models (e.g. Ali amd Aitchison, 2008).

## CONCLUSIONS

1. A diverse freshwater-brackish admixed ostracod assemblage of early Danian (P1a) age (based on planktic foraminifer assemblages) has been discovered for the first time from a Deccan intertrappean section at Jhilmili, District Chhindwara in central India, on the eastern fringe of the main Deccan volcanic province.
2. The striking similarity between the intertrappean freshwater ostracods (and molluscs) of the Maastrichtian and early Palaeocene age suggests limited influence of the Deccan volcanic activity, at least qualitatively, on contemporary freshwater aquatic ecosystems.
3. The presence of brackish water ostracod species (*Neocyprideis raoi*) and planktic foraminifera at Jhilmili reveals the existence of a major seaway in central India. The marine incursion probably took place from the west along and the Narmada and Tapti rift zones (Keller *et al.*, 2009 a, b).

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