LATE CRETACEOUS-PALEOCENE MICROBIOTA FROM DECCAN VOLCANIC PROVINCE, PENINSULAR INDIA

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled **LATE CRETACEOUS-PALEOCENE MICROBIOTA FROM DECCAN VOLCANIC PROVINCE, PENINSULAR INDIA** in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from July 2004 to December 2008 under the supervision of Dr. Sunil Bajpai, Professor, Department of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other University/Institute.

(RITU SHARMA)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Sunil Bajpai)
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Date: 30/12/2008

The Ph.D. Viva-Voce Examination of **Miss Ritu Sharma**, Research Scholar, has been held on ______________________________.

Signature of Supervisor

Signature of External Examiner

ABSTRACT

This dissertation reports on biostratigraphic, paleoenvironmental, paleoecologic and biogeographic aspects of end Cretaceous-early Paleocene intertrappean deposits, based on investigations carried out in nine selected sections across the Deccan Traps volcanic province of peninsular India. These investigations (Dayapar, Virani, Lakshmipur, Anjar in District Kutch, Gujarat; Jhilmili in District Chhindwara and Phulsagar in District Mandla, both in Madhya Pradesh; Nahardi in District Jhalawar, Rajasthan; Papro in District Lalitpur, Uttar Pradesh; Duddukuru in East Godavari District, Andhra Pradesh) provide new insights into our understanding of ecosystems that existed during the Deccan Traps volcanic episode.

The discovery of planktic foraminifers and brackish water ostracods in the Deccan intertrappean deposits at Jhilmili in central India is one of the most important highlights of this dissertation with major implications for central India's paleogeography during the K-T transition. The discovery indicates that the main Deccan province, generally considered to be terrestrial in nature, may also contain intervals of brackish to marine deposition. The recovered assemblage comprises a number of early Danian (P1a) planktic foraminifers (including *Parasubbotina pseudobulloides, Subbotina triloculinoides, Praemurica taurica and Globigerina (E.) pentagona*) and a brackish water ostracod species (*Neocyprideis* cf. *N. raoi*) The discovery has a two-fold significance. First, it reveals a marine seaway in central India during the Maastrichtian - early Paleocene and second, it supports that the K-T boundary is at or near the end of the main phase of Deccan volcanism (e.g., top of the Ambenali Formation) consistent with recent results from Rajahmundry (Keller *et al.*, 2008; Jay and Widdowson, 2008). The proposed marine incursions during the K/T transition may possibly have followed the Narmada and Tapti rift zones where a major transgression is already known to have existed during the Cenomanian-Turonian (Bagh Beds).

The recovery of a freshwater ostracod assemblage (12 spp.), for the first time from the Paleocene-aged Deccan intertrappean deposits of Papro (District Lalitpur, Uttar Pradesh) is another important find being reported in this doctoral investigation. The assemblage, with strikingly similarities to those previously documented from a

number of Maastrichtian Deccan intertrappean deposits, including some with dinosaur remains (such as Dayapar and Anjar in Kutch), shows that the intertrappean freshwater ostracods were one of the least affected communities, at least qualitatively, across the Cretaceous-Tertiary transition.

Paleoecologically, the analysis of Deccan intertrappean ostracods from widely separated sections (Nahardi, Dayapar, Phulsagar, and Papro) reveals an admixed assemblage suggestive of a lacustrine system that comprised a core of permanent water and a periphery that was subject to intermittent desiccation during dry seasons. A preliminary attempt was made for the first time to analyze the carbon and oxygen stable isotopes of ostracod shells recovered from the Lakshmipur intertrappean deposits of Kutch. Although essentially tentative, the study suggests that evaporative conditions prevailed intermittently during the deposition of Lakshmipur intertrappeans. However, this tentative conclusion needs supportive evidence from the presence of evaporative minerals.

Investigations of biogeographic aspects of the intertrappean freshwater ostracods have helped to reconcile a long standing apparent conflict between the geophysical and paleontological data. These freshwater ostracods show strong endemism at species level and do not indicate close Asian affinities as previously claimed. At the generic level, the intertrappean ostracods are cosmopolitan and show nearly as much affinity with European and North American Cretaceous ostracods as they do with other Asian faunas. The extensive ostracod endemism suggests India's geographic isolation around the K-T boundary time, consistent with the traditional geophysical data that show India as northward moving island continent during this interval.

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(Ritu Sharma)

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CHAPTER 1

INTRODUCTION

1.1 PROLOGUE

The transition from the Cretaceous to Tertiary period was marked by extensive volcanic eruptions in peninsular India, the Deccan Traps. These flood basalts presently cover about 500,000 sq. km. in central and western parts of peninsular India, with outlying occurrences extending as far as to the southeastern coast of India around Rajahmundry (Andhra Pradesh). The Deccan volcanism represents one of the largest occurrences of continental flood basalt in the world. During the past twenty five years, there has been a dramatic revival of interest in this volcanic activity mainly because of suggestions linking this massive volcanism to end-Cretaceous mass extinction. Recent high resolution radiometric, palaeomagnetic and biostratigraphic data indicate a close time correspondence between the Deccan eruptions and the K/T boundary, pointing to a significant causative role of Deccan volcanism in the K/T mass extinctions (see Chenet *et al.*, 2007, 2008; Keller *et al.*, 2008 and references therein).

Fossils occurring in sediments associated with the Deccan volcanics, particularly those intercalated within the lava flows (Deccan intertrappeans) are of much current interest and are important in addressing several issues. These issues are concerned with biochronological, biogeographic, paleoenvironmental/ paleogeographic and paleoecological aspects of contemporary ecosystems. Recent marine micropaleontological data from Rajahmundry (Andhra Pradesh, SE India) suggest that the main phase of the Deccan volcanic activity ended close to the K/T boundary (Keller *et al.*, 2008). However, such high resolution biostratigraphic data have been unavailable until now from the main part of the Deccan volcanic province owing to the absence of marine faunas, particularly foraminifers. Thus, the biostratigraphic delineation of the K/T boundary still remains elusive, even in sections where geochemical anomalies such as iridium enrichment are known (Bhandari *et al.*, 1996; Bajpai and Prasad, 2000; Courtillot *et al.*, 2000; Hansen *et al.*, 2001). The main part of the Deccan volcano-sedimentary sequence is now generally considered to be latest Cretaceous (Maastrichtian) in age, based mainly on fragmentary dinosaur remains and palynomorphs (e.g. Sahni and Bajpai, 1988; Sahni et al. 1996; Kar and Srinivasan, 1997; Khosla and Sahni, 2003; Samant et al. 2008). The only exception is an intertrappean section near Papro, District Lalitpur (Uttar Pradesh), on the eastern fringe of the Deccan Traps, where a Paleocene age has been suggested on the basis of palynomorphs (Singh and Kar, 2002). However no microfauna have yet been described from this important section.

Apart from chronological aspects, the issue of India's paleobiogeographic links around the time of Deccan eruptions is of much current interest from a geodynamic standpoint. The presence of a number of Laurasian elements (palaeoryctid mammals, discoglossid and paleobatid frogs, anguid lizards) in the Deccan intertrappeans has long been an evidence of terrestrial connections between India and Asia during the terminal Cretaceous (e.g. Jaeger *et al.*, 1989; Sahni and Bajpai, 1991; Prasad and Rage, 1991, 1995; Prasad and Sahni, 1999; Rage, 2003). To explain these early India-Asia biotic connections, a significantly older collision age, close to the K/T boundary (65 Ma), has been proposed (Jaeger *et al.*, 1989). However, others (Thewissen and McKenna, 1992; McKenna, 1995) question the biogeographic significance of the intertrappean fossils and do not support the idea of a K/T collision. Most recently, in a comprehensive review, the geological and geophysical data bearing on the issue of India's biological connectivity during the Cretaceous has been discussed at length by Ali and Aitchison (2008). According to these authors, the idea of Maastrichtian terrestrial (subareal) connections between India and Asia is inconsistent with the wealth of geophysical data that show the Indian subcontinent as an isolated landmass in the middle of the Neotethys during this period. These authors explain the presence of late Cretaceous Eurasian elements in India in terms of trans-oceanic (sweepstakes) dispersal rather than continuous terrestrial connections between the two landmasses.

Significantly, extensive endemism has been noticed in recent years among late Cretaceous freshwater ostracods from a large number of Deccan intertrappean localities across the volcanic province (Whatley and Bajpai, 2006 and references therein). The intertrappean ostracod data provides a new biogeographic perspective which contrasts with the long held hypothesis of Eurasian connection.

Intertrappean terrestrial biotas also bear significantly on the current "Out-of-India" hypothesis (e.g. Karanth, 2006). According to this hypothesis, based on molecular phylogeny and divergence timings of modern groups, a number of Gondwanic forms arrived in Asia by rafting on the northward drifting Indian plate, following the collision between India and Asia around 55 Ma. This hypothesis is supported by diverse modern organisms as ranids and caecilian frogs, acrodont lizards, cichlid fishes, ratite birds, and crypteroniaceae plants (Macey *et al.*, 2000; Bossuyt and Milinkovitch, 2001; Cooper *et al.*, 2001; Conti *et al.*, 2002). Fossil evidence provides a direct means to test the hypothesis of Out-of-India dispersal. The Out-of-India hypothesis predicts a pre-collision, Cretaceous origin (Indian or Gondwanic) for the various groups. One such group is the Ranid frogs whose fossils have been described from the Cretaceous and early Eocene of peninsular India (Prasad and Rage, 2004; Bajpai and Kapur, 2007). The recently recognized late Cretaceous ostracod endemism in India also offers an excellent opportunity to test the out- of- India hypothesis (Whatley and Bajpai, 2006).

Another controversial issue concerns the paleogeography of peninsular India around the K/T boundary, particularly the issue of marine incursion. The idea of a marine incursion was advanced over 25 years ago based on limited paleobotanical evidence from the Deccan intertrappeans (e.g. Bande and Prakash, 1982) and sedimentological data on the late Cretaceous Lameta Formation, underlying the Deccan Traps of Jabalpur, central India (Singh, 1981). However, subsequent sedimentological investigations favoured a non-marine origin of the Lameta Formation (e.g. Brookfield and Sahni, 1987; Tandon *et al.*, 1995) and this idea found widespread acceptance during the past two decades. More recently, however, the dinosaur-bearing Lameta sediments of Jabalpur have been interpreted as a lagoonal deposit, implying a marine shore line in the proximity (Shukla and Srivastava, 2008). It is important to note that there is no faunal evidence until now for the presence of marine depositional conditions during the Deccan eruptive phase except in the well known Rajahmundry sections.

1.2 OBJECTIVES

Against the above background, the present investigation was carried out in a number of selected intertrappean sections (see list below) across the Deccan volcanic province of peninsular India. The objectives sought to be achieved during this investigation are listed as follows:

- Determining biostratigraphic implications of the recovered intertrappean biota for constraining temporal relationships between individual sections of the Deccan volcanic province
- Determining biogeographic implications of the freshwater intertrappean microbiota (with emphasis on freshwater ostracods) in a geodynamic context
- Determining paleoenvironmental, paleoecological and paleogeographic implications of the recovered intertrappean microbiota (emphasis on ostracods, including stable isotopic constraints from the Lakshmipur intertrappean section of Kutch)

1.3 METHODOLOGY

- Delineation and lateral tracing of fossiliferous intertrappean horizons in the following selected sections of central and western India: Dayapar, Virani, Lakshmipur, Anjar (District Kutch, Gujarat); Jhilmili (District Chhindwara), and Phulsagar, District Mandla (Madhya Pradesh); Nahardi, District Jhalawar

(Rajasthan); Papro, District Lalitpur (Uttar Pradesh); Duddukuru, East Godavari District, (Andhra Pradesh).

- Screenwashing of soft lithologies (e.g. clays) from promising sections for recovery of microfossils
- Processing of relatively hard (indurated) lithologies using chemical and mechanical methods in the lab.
- Taxonomic identification using both Scanning Electron Microscopy (SEM) and optical microscopy.
- Oxygen and carbon isotope analysis of well preserved forms, particularly ostracods (in collaboration with Physical Research Laboratory, Ahmedabad)
- Data interpretation for biostratigraphic correlation, biogeographic affinities, paleoecological/paleoenvionmental reconstructions.

1.4 SECTIONS UNDER STUDY

A brief introduction to the 9 sections (Figure 1.1) investigated for this dissertation is as follows:

1.4.1 Lakshmipur intertrappeans, District Kutch (Gujarat)

The Lakshmipur intertrappean locality is located about 1.5 km of the village Lakshmipur (N23°26'45" E69°2'50"). The investigated section is exposed in a stream (=*nala*) cutting. Recently, this section has yielded one of the best known and well preserved intertrappean ostracod faunas in the Deccan province (Whatley and Bajpai, 2000), hence an attempt (in collaboration with PRL, Ahmedabad) was made for the first time to analyze carbon and oxygen isotopic composition of ostracods from this locality as a test case with the objective of reconstructing the intertrappean environments.

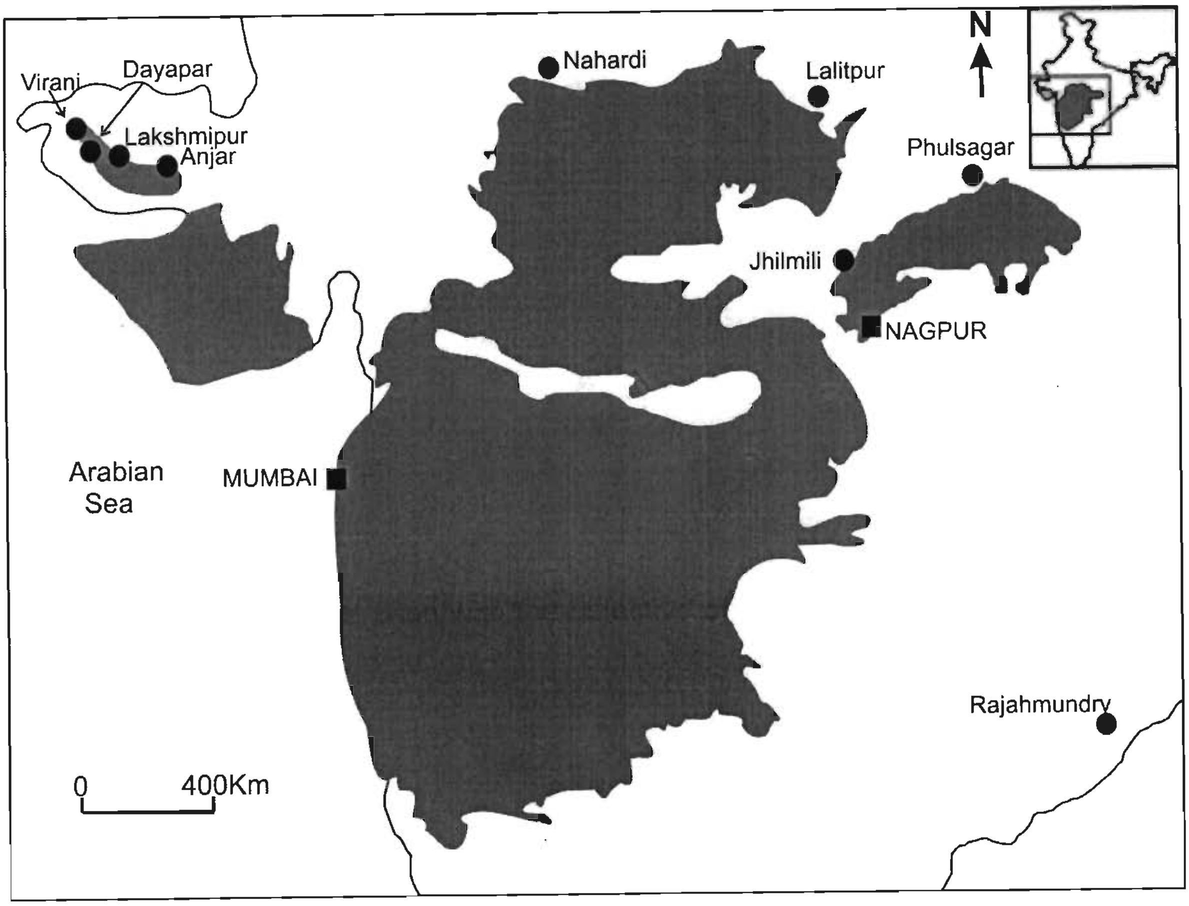

Figure 1.1 Map showing location of the presently investigated sections in the Deccan volcanic province of peninsular India

1.4.2 Dayapar Intertrappeans, District Kutch (Gujarat)

This poorly known section is situated about 800 m NW of the village Dayapar (N23° 38' E 68° 54'). Approximately 6 m in thickness, this section is exposed in a hillock and consists of creamish marl and red clays. Here, the Deccan Traps rests over the Bhuj sandstone of early Cretaceous age. Fifteen ostracod species have been recorded for the first time from this section in association with charophytes and fishes. Prior to this work, a small ostracod assemblage was described from this locality over 40 years ago (Khanna and Mohan, 1965).

1.4.3 Virani intertrappeans, District Kutch (Gujarat)

Approximately 2.5 km west of the Dayapar intertrappean locality, a new intertrappean section was located. This section is approximately 3 m thick and consists of mudstones. A small ostracod assemblage comprising eight species, in association with a few fishes, has been recovered from this newly identified intertrappean section.

1.4.4 Anjar Intertrappeans, District Kutch (Gujarat)

A well- developed intertrappean succession is exposed in a railway-cutting near the village Viri (N23°04'22.6"; E70°01'23.4") situated near the town of Anjar. This section originally came to light for dinosaurian fossils (Ghevariya, 1988) in a close by locality (pits) and later became famous with the detection of an iridium anomaly there (Bhandari *et al.*, 1995). The original pits do not exist now, but the rail-cutting now exposes a much better section, with the contact of intertrappeans with both the underlying and overlying basalts clearly visible. The succession, approximately 3 m thick, consists mainly of an alternation of shales and carbonates. Significantly, fragmentary dinosaur bones, possibly belonging to a titanosaurid, were found in this section in association with small microfauna comprising ostracods and molluscs. Some of the ostracods recovered from this section are illustrated in this dissertation. This section was included in the present investigation mainly for purposes of reconstructing depositional conditions.

1.4.5 Phulsagar Intertrappeans, District Mandla (Madhya Pradesh)

The Phulsagar intertrappean section (N22°41'40":E80°20'50") has a thickness variable between less than 1 m to 2.5 m lithologically, the sediments here consist of black, grey, and red to buff coloured chert. Most of the outcrop occurs as boulders and debris in the field that are excavated in the course of filling of the field surrounding the Deccan Traps hills. 8 ostracod species (including 2 new) have been recorded from grey and black chert bands. The ostracod fauna of this locality has been described recently by this worker (in Bajpai *et al.*, 2004)

1.4.6 Nahardi Intertrappeans, District Jhalawar (Rajasthan)

This section of the Deccan intertrappean deposits in the state of Rajasthan represents one of the northernmost extensions of the Deccan volcano-sedimentary sequence. Intertrappeans in this area of the volcanic province are amongst the most poorly known. The intertrappean beds studied here are exposed near the village of Nahardi (24°26'35"N; 76° 11'49" E) about 10 km SE of the town of Jhalarapatan, to the south of Jhalarapatan- Ujjain road, in the Jhalawar District of Rajasthan. The section consists of about 2 m thick calcareous mudstone, overlain by the Deccan Traps. A fairly diverse assemblage of freshwater ostracods (13 species) and fishes (2 species) was previously recovered from this section during the present investigation.

1.4.7 Papro Intertrappeans, District Lalitpur (Uttar Pradesh)

The Lalitpur intertrappean locality occupies a special place in the Deccan volcanic province, as it is possibly the only known locality in India that was assigned a Paleocene age (based on palynomorphs). Samples from this locality were collected by Prof. M.P. Singh (Geology Department, Lucknow University) who kindly provided these to Prof. S. Bajpai (IIT Roorkee) for the present study. Intertrappeans in this locality are exposed in a stream-cutting about 3 km north east of the Papro village ($24^0$48'20":$24^0$14'). The Deccan Traps in this region rest over conglomerates that mark an unconformity with the underlying Kaimur Sandstone of the Vindhyan Supergroup (Late Precambrian). Intertrappeans here consist mainly of silicified tuff and chert. This section has yielded 12 species of ostracods for the first time (Sharma *et al.*, in press), together with a few molluscs and fishes. Prior to this work, only charophytes were known from this section (Singh, 1978).

1.4.8 Jhilmili Intertrappeans, District Chhindwara (Madhya Pradesh)

The discovery of this intertrappean section is one of the most important contributions made during this investigation. The section is located on the Chhindwara- Mandla road near the village Jhilmili (22°02'41"N; 079°09'43"E), District Chhindwara. Very significantly, this locality has yielded earliest Paleocene foraminifers (planktic) for the first time in the main part of the Deccan volcanic province. Associated fauna includes a diverse assemblage of freshwater ostracods, a brackish water ostracod species (*Neocyprideis* cf. *N. raoi*), charophytes and a few fishes. The discovery of planktic foraminifers has important implications for the paleogeography of peninsular India around the time of Cretaceous-Tertiary transition, and for the age and correlation of intertrappeans in the context of K-T extinctions.

1.4.9 Duddukuru intertrappeans, East Godavari District (Andhra Pradesh)

This long known marine section near Rajahmundry was included in the present investigation mainly for purposes of comparison with foraminifer-bearing section discovered during this investigation at Jhilmili (See 1.4.8 above). A number of quarries around Duddukuru near Rajahmundry expose the intertrappean beds. These deposits consist of compact, massive, white to pinkish limestone in the lower part, and alternating impure limestone and shale bands in the upper part. Based on foraminifers and nanoplankton, this section has recently been dated as earliest Paleocene (Keller *et al.*, 2008). A small assemblage of fishes was recovered from this section during this investigation.

1.5 REPOSITORY

The entire fossil assemblage described in this dissertation is housed in the Paleontology Laboratory, Department of Earth Sciences, Indian Institute of Technology, Roorkee under the acronym IITR/SB/XX, with XX referring to individual intertrappean sections under investigatation (DI, Dayapar; LI, Lalitpur (Papro); NI, Nahardi; RI, Rajahmundry; VI, Virani; PH, Phulsagar; AN, Anjar; LKP, Lakshmipur; JH, Jhilmili).

CHAPTER 2

GEOLOGICAL SETTING

2.1 GEOLOGY OF THE STUDY AREA

During this investigation, a total of nine intertrappean sections across the Deccan volcanic province of peninsular India were selected for micropaleontological studies. This chapter gives an account of geological setting including previous work on these sections, with emphasis on paleontological and stratigraphic data.

2.2 DISTRICT KUTCH, GUJARAT, WESTERN INDIA

The Kutch basin is a pericratonic sedimentary basin lying in the western margin of peninsular India. The Deccan Traps in this region represent the northwesternmost part of the Deccan volcanic province. The volcanics rest disconformably on the Bhuj Foramtion (Early Cretaceous) and are overlain by the volcaniclastic sediments of the Late Paleocene Matanomadh Formation (Biswas, 1992). The volcanics occur in the southern and western part of the mainland and are absent in the central and northern parts as well as in the islands. They are present in a large strip from Lakhpat in the northwest to Anjar in the west and show an alternation of columnar and amygdaloidal basalts in general. The columnar flows form prominent ridges and hill while the amygdaloidal types are eroded to plain. Consequently, the intertrappean belt presents an alternation of ridges and valleys. The traps are thicker in the south (about 450 m) in comparison to the northwestern part where it is only 150 m thick (Biswas and Deshpande, 1973). Seven flows of pahoehoe type have been recognized by De (1981) in southern Kutch.

Recently, Crocket and Paul (2008) studied the platinum group elements in mafic igneous rocks from the Kutch region and found out that normalized profile of the PGE in tholeiitic flows of the southern Kutch are similar to those of the Western Ghats region.

Intertrappean beds separating the trap flows are relatively rare in Kutch. Wynne (1872) noticed some of these in western Kutch. Khanna and Mohan (1965), in a short note, described the intertrappean beds at Lakshmipur, Dayapar and Kora, in western Kutch. Bajpai *et al.* (1990) investigated these sections and also listed the recovered fossil assemblage. Four stratigraphic sections of intertrappean deposits have been studied for this dissertation. These are located near Anjar, Lakshmipur, Dayapar and Virani.

2.2.1 Anjar Intertrappeans

This Anjar intertrappean section originally came to light with the discovery of dinosaur fossils (Ghevariya, 1988). Subsequently, Bajpai *et al.* (1993) reported ornithoid eggshells of avian/theropod affinity from these beds. Bhandari *et al.* (1995, 1996) reported a major discovery of iridium enrichment from these beds between Flow III and Flow IV in the local stratigraphy. Since then, this section has attracted considerable attention. Shukla *et al.* (1997) claimed the presence of three well separated iridium rich horizons and suggested the possibility of multiple impacts. Ar/Ar dating and the magnetic stratigraphy of the lava flows at Anjar have been carried out by Venkatesan *et al.* (1996) and Courtillot *et al.* (2000). Courtillot *et al.* (2000) supported Bhandari *et al.*'s (1995) contention that the K/T bolide impact was recorded as an Ir deposit at Anjar. On the other hand, Hansen *et al.* (2001), based on their study of magnetic susceptibility and organic carbon isotope variation, ruled out the presence of K/T boundary at Anjar. They concluded that the clay layers associated closely with Ir enrichments are strongly leached, rhyolitic bentonites. Shrivastava *et al.* (2000) studied the clay mineralogy of the Anjar intertrappeans and opined that it is more compatible with the volcanic than extraterrestrial origin. According to them, smectite, derived from hydrothermal alteration of basalts, was the most probable carrier of iridium into the sediments. Sant et al. (2003) also favoured a volcanic origin of the iridium anomaly in Anjar intertrappeans. More recently, Shrivastava and Ahmad (2008) studyied variations in trace elemental concentrations and inter-element ratios of clay minerals from the Anjar intertrappeans, and suggested that Ir enrichment was not due to an extraterrestrial impact but was volcanically derived.

Micropaleontological investigations of the Anjar intertrappeans have been undertaken by several workers (Bajpai *et al.*, 1990, 1993; Bajpai, 1996; Bajpai and Prasad, 2000; Bhandari and colin, 1999; Whatley and Bajpai, 2000; Dogra *et al.* 2004; Khosla and Nagori, 2005). Significantly, Bajpai and Prasad (2000) reported the occurrence of dinosaur fossils (ornithoid and sauropod eggshell fragments, rare teeth) in levels above the iridium-rich layers at Anjar. According to these authors, lack of any Paleocene taxa above the iridium levels and the lack of evidence for reworking of dinosaur fossils above these layers suggest that the iridium levels at

Anjar predate the K/T boundary and they are possibly within Maastrichtian in the reversed magnetic chron 29R. Dogra *et al.* (2004) carried out palynological investigations of these beds and suggested an exclusively Maastrichtian age, with no evidence of any Paleocene elements. Ostracod faunas from Anjar intertrappeans were described by Bhandari and Colin (1999) who recorded 11 species. Whatley and Bajpai (2000) recorded two additional species from this section. More recently, Khosla and Nagori (2005) also studied the ostracod fauna from this section.

Khadkikar *et al.* (1999) concluded that these deposits are lacustrine in origin and that the local climate was semi-arid.

2.2.1.1 Location and Stratigraphy

The pits where the Ir anomalies were originally reported do not exist now, but a well- developed intertrappean succession, presumably in the same two flows (Flow III and IV in the local flow stratigraphy, Ghevariya, 1988) is now available in a railway-cutting near Viri village at N23°04'22.6"; E70°01'23.4" (Fig. 2.1). The Anjar volcano-sedimentary sequence comprises as many as seven basaltic flows enclosing four intertrappean beds (Ghevariya, 1988). The intertrappean section along the railway-cutting is exposed in a SW-NW direction for about 100 m. It is about 4 m thick in central part, tapering towards margins. It consists of an alternation of shale and limestone. Four main lithounits have been identified which is further divided into subunits. The succession (Fig. 2.2) rests with an irregular base on the Deccan Traps. The topmost part of the intertrappeans contains calcareous nodules that represent a paleosol.

Lithounit 1, *Shale*: This lithofacies essentially consists of shale with rare very thin carbonate bands. This lithofacies is well developed in the central part, occupying the basal part of the succession. This lithofacies yields molluscs, ostracods, rare fish and snakes as well as dinosaur eggshells. It is largely carbonaceous in character and is divided into 5 subunits as follows:

Subunit 1: 1-40 cm, greenish black soft mudstone unfossiliferous.

Subunit 2: 40-41 cm, 1 cm organic rich mudstone.

Subunit 3: 41-85 cm, dark mudstone, carbonate concretions and lenses with shell debris.

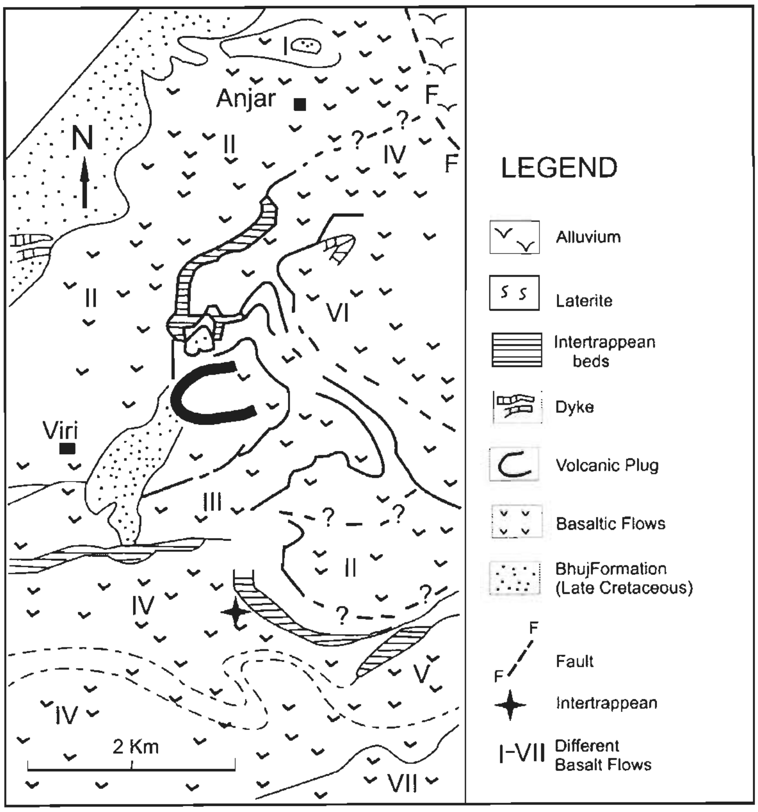

Figure 2.1 Geological map of the Anjar area, District Kutch, Gujarat (After Ghevariya, 1988)

Subunit 4: 75-120 cm black splintery shale.

Lithounit 2, *Bedded carbonate*: This 120-140 cm. lithofacies is most common in the succession. It consists of bedded granular carbonate with shell debris and other fossils. In the central part of the succession fossils are common. The lithofacies shows a number of features indicating wave and current activity.

(a) Ripple bedding- decimeter thick bands of ripple bedding where individual ripple beds are 0.5- 2.0cm thick.

(b) Ripple bed with mud drapes- centimeter thick bands of rippled layers are present draped by bud, preserving the ripple forms.

(c) Large scale cross bedding- 5-15 cm thick bands showing cross bedding are developed. Some of the cross beds are low angled. These channels are responsible for thinning and thickening of individual beds.

Lithounit 3, *Carbonate-Shale alternation*: This 140-240 cm lithofacies is made up of centimeter thick alternating layers of shale and carbonate making several decimeter thick packages. It can occur in two variants: (i) several centimeter thick shale alternating with 1-2 cm thick carbonates. (ii) several centimeter thick carbonate with 1-2 cm thick shale.

Significantly, no brown clay layers that were reported to contain iridium enrichment in the originally described pits (BG 1 to BG 3, see Bajpai, 1996) are noticeable in this interval. However, limonitic patches, without any significant lateral continuity, do occur in lhis unit. It will be of interest to see whether these limonitic patches are enriched in iridium. Microfauna recovered from this unit includes a large

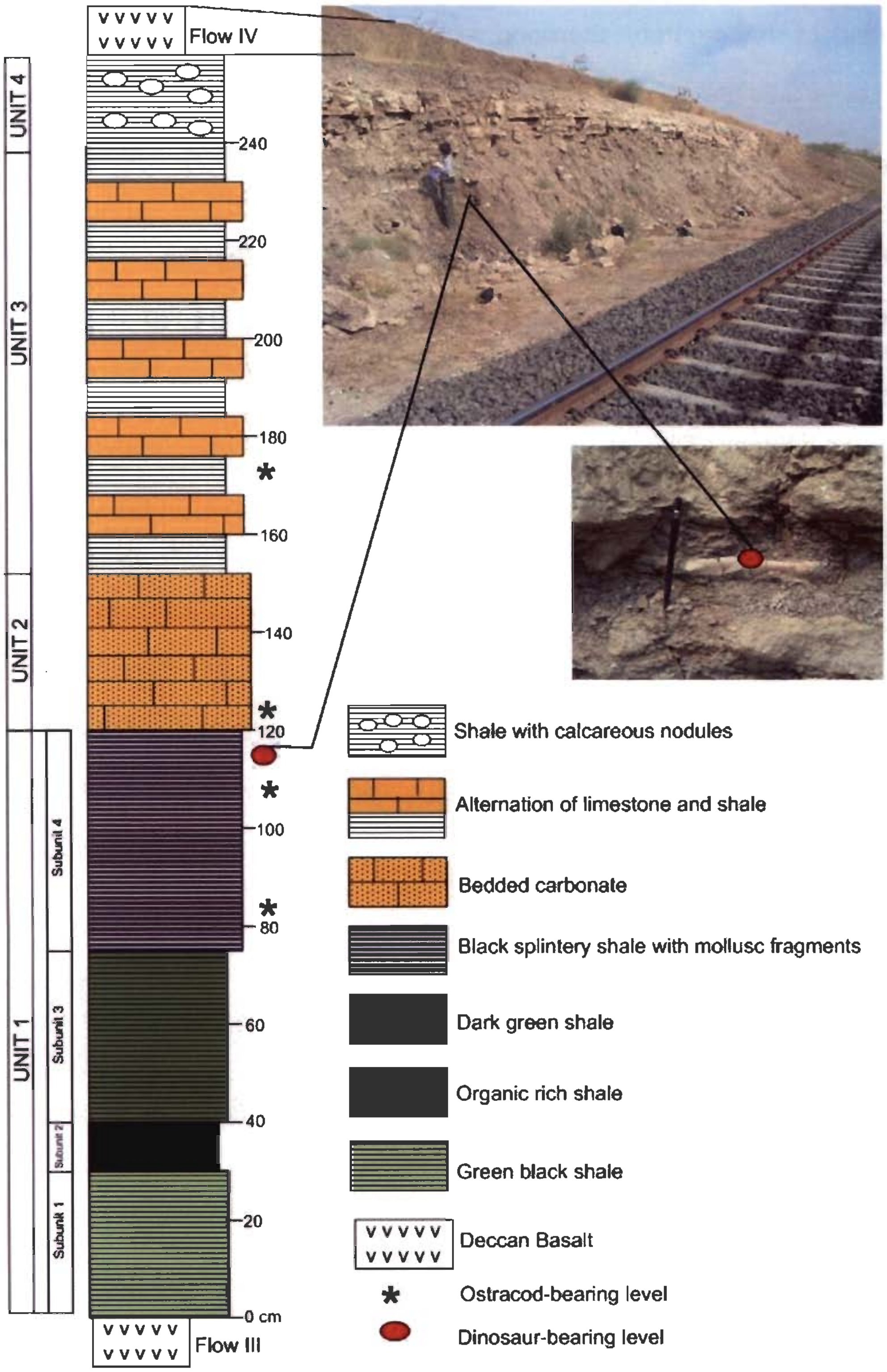

Figure 2.2 Stratigraphic section of the Anjar intertrappean beds, District Kutch, Gujarat

number of fragmentary theropod eggshells (ornithoid type) identical to those described by Bajpai *et al.* (1993). The eggshells are already published, so these have not been included in this dissertation.

Lithounit 4, *shale with calcareous nodules*: This lithofacies is 10 to 30 cm thick and is present more or less as a continuous layer marking the top of the intertrappean succession. It is essentially shale with dispersed carbonate nodules, which are irregular in shape. This lithofacies may be a palaeosol horizon developed on the top of the intertrappean sequence. It was formed on the dried out lake/pond, before the next lava flow.

The lithofacies characteristics of the Anjar intertrappeans suggest that these deposits were formed in a natural depression on a lava flow with about 4m relief. It was essentially a shallow alkaline pond. Initially, this pond received the terrigenous clastic material (clays) derived from weathered basalts in the adjoining areas. The pond was shallow but large enough to produce waves and currents which reworked the sediments of the pond. There were events of contraction and expansion of pond which controlled the facies association. At the end, when the pond was filled with sediments, the area was subareally exposed leading to development of paleosols with calcareous nodules.

2.2.2 Lakshmipur intertrappeans

The Lakshmipur intertrappean locality was first reported by Khanna and Mohan (1965) who recorded a few genera of ostracods and molluscs in their short note. Subsequent to this brief study, Bajpai *et al.*, (1990) studied this section and presented a faunal list of taxa recovered by them. They also figured a turtle shell which was attributed to *Shweboemys pisdurensis.* Later, Whatley and Bajpai (2000) described a diverse assemblage of freshwater ostracods from Lakshmipur. The assemblage included *Frambocythere tumiensis lakshmiae*, *Gomphocythere gomphiomatos*, *Pseudocypris ecphymatos, Centrocypris megalopos*, *Zonocypris spirula*, *Paracandona firmamentum*, *Cypria cyrtonidion*, *Cyprois rostellum*, *Cypridopsis wynnei*, *Cypridopsis hyperectyphos*, *Eucypris pelasgicos* and *Eucypris intervolcanus*, *Gomphocythere* sp., *Cyprois* sp., *Cypridopsis* sp.1.

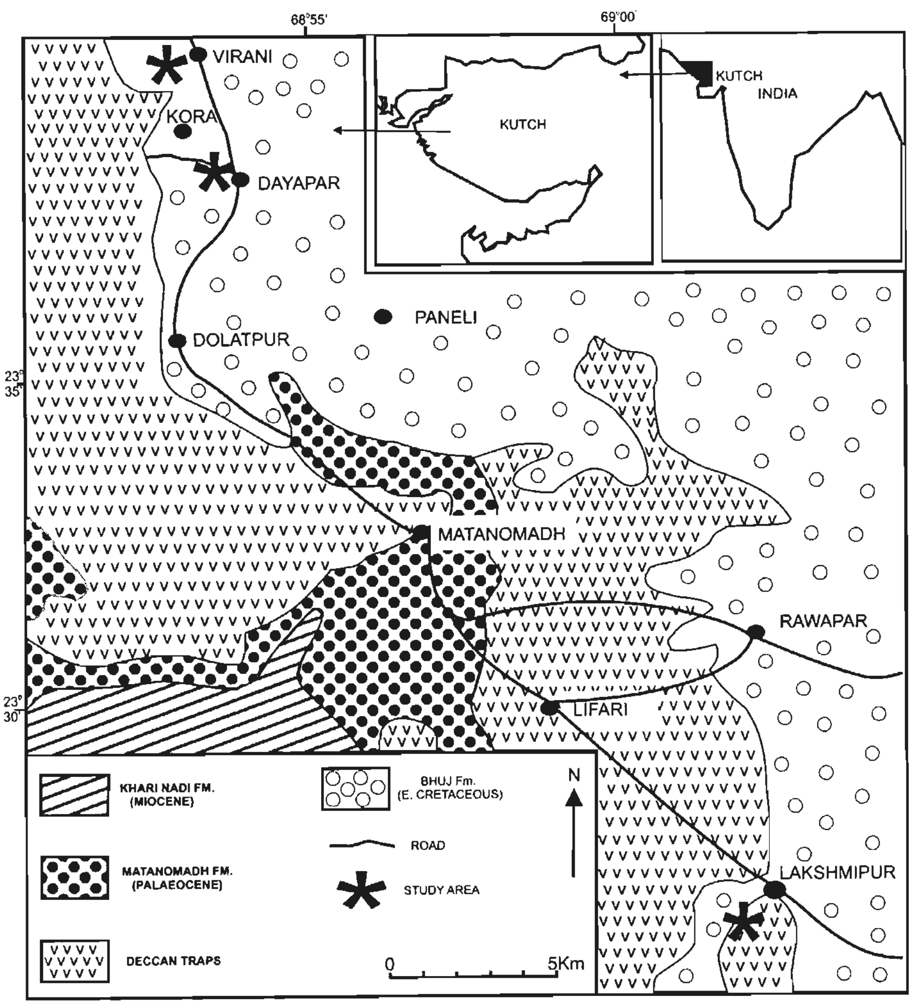

Figure 2.3 Geological map of part of western Kutch showing location of the present area of study (After Khanna and Mohan, 1965)

2.2.2.1 Location and stratigraphy

The Lakshmipur intertrappean locality N23°26'25.4": E69°01'17.7" (Fig. 2.3) is located about 1.5 km of the village Lakshmipur (N23°26'45" E69°2'50"). This section is exposed along a stream cutting and is about 2 m thick. Lithologically it consists of an alternation of limestone and mudstone. The basal two units of limestone which are light in weight (? ash-bearing) are full of ostracods. In the present study, carbon and oxygen isotopic composition of a few selected ostracod species was analysed (see Chapter 4).

The Lakshmipur intertrappean section is divided here into nine lithounits (Fig. 2.4).

Lithounit 1, 55 cm thick (ash-bearing) limestone full of ostracods. Light in weight, base not exposed.

Lithounit 2, 25 cm thick mudstone

Lithounit 3, 28 cm ostracod bearing limestone with small size *Physa*.

Lithounit 4, 12 cm mudstone

Lithounit 5, 30 cm *Physa*-bearing limestone

Lithounit 6, 5 cm mudstone.

Lithounit 7, 13 cm *Physa*-bearing limestone. This layer is not continuous and pinches out along the margins.

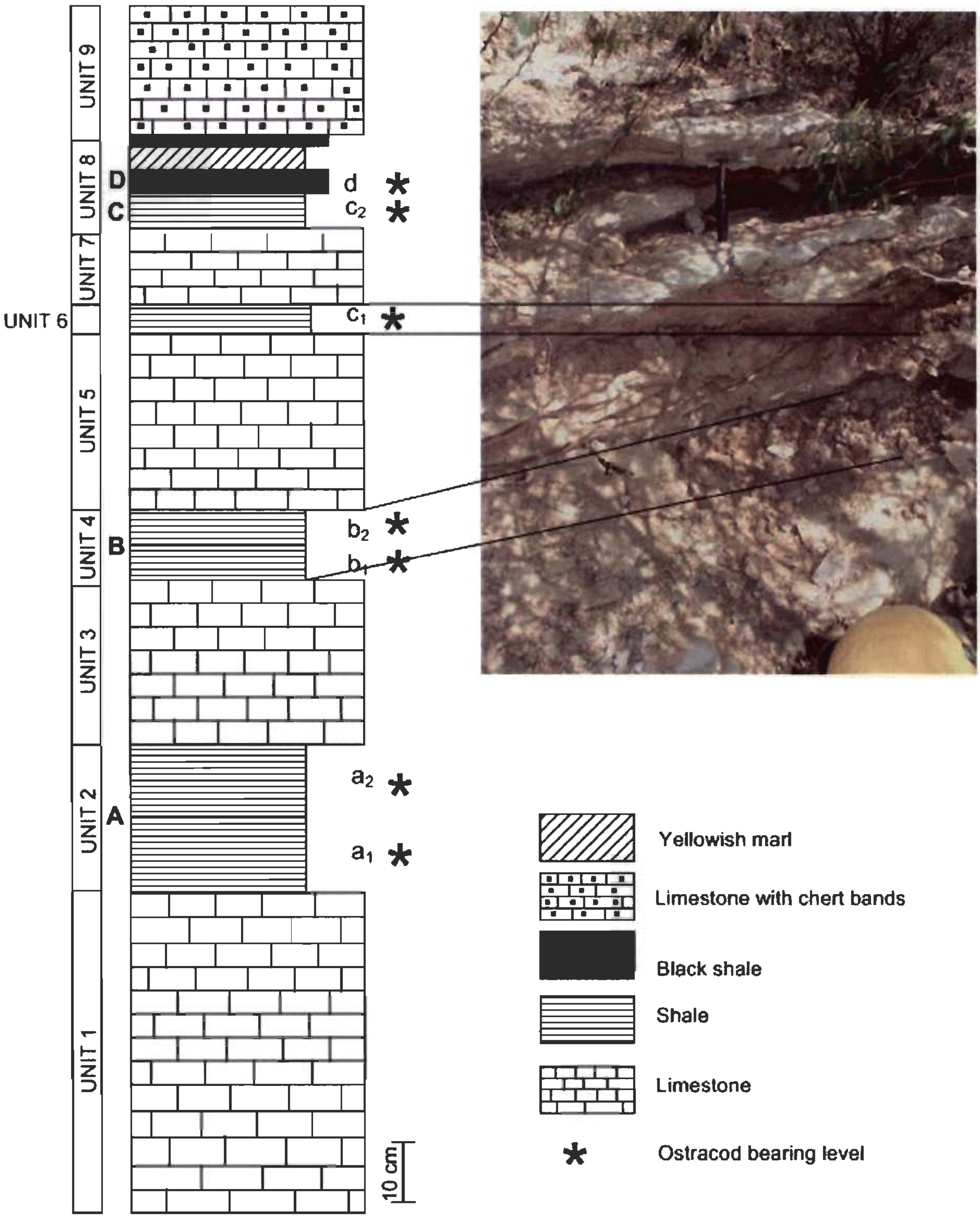

Figure 2.4 Stratigraphic section of Lakshmipur intertrappean beds, District Kutch, Gujarat

Lithounit 8, 6 cm black shale. This unit is further divided into 3 subunits. At the base is a 2 cm black shaly layer which is overlain by 3 cm yellow silty carbonate layer. The top of the unit is 1 cm black shaly layer.

Lithounit 9, 20-25 cm Alternation of *Physa*-bearing limestone and chert. Chertification of the limestone can be seen at this level. Large size *Physa* shells are common in this unit. Lenses of black chert also occur in this unit.

In the Lakshmipur section mudstone levels (unit 2, unit 4 and unit 6) are all fossil-bearing but the abundance of ostracods decreases upwards in the succession.

2.2.3 Dayapar Intertrappeans

This section was first reported by Khanna and mohan (1965) who recorded a few ostracod taxa as well as the gastropod *Physa.* Subsequently, Sahni and Bajpai (1988) and Bajpai (1990) reported the presence of dinosaur remains in this locality.

2.2.3.1 Location and Stratigraphy

The Dayapar intertrappean (Fig. 2.3) section occurs on an isolated hillock situated at N23° 38' 35.8" E 68° 53' 44.4", about 800 m NW of the village Dayapar (N23° 38' E 68° 54'). The section (Fig. 2.5) consists of 0.75 m of fossiliferous creamish marl overlain by 1.5 m red unfossiliferous clays. The latter are in turn covered by about 5 m thick weathered basalt. The lower flows are missing in this sectin and the intertrappean beds rest over a thin band of hard, brown gritty sandstones of the Bhuj Formation (early Cretaceous), which projects out in relief. Although the lower flows are missing, the facies (marl and clays) and fauna leave no doubt that this section is "intertrappean" in nature.The absence of lower trap flows is due to paleotopographic control.

2.2.3.2 Fossil assemblage

The creamish marl in this section has yielded abundant *Physa*, ostracods and teleost fishes. 15 species of ostracods have been identified, with particular abundance of *Paracypretta elizabethae*, *Cypridopsis hyperectyphos*, *Cypridopsis wynnei*, *Cypria cyrtonidion*, *Eucypris pelasgicos* and *Eucypris intervolcanus*.

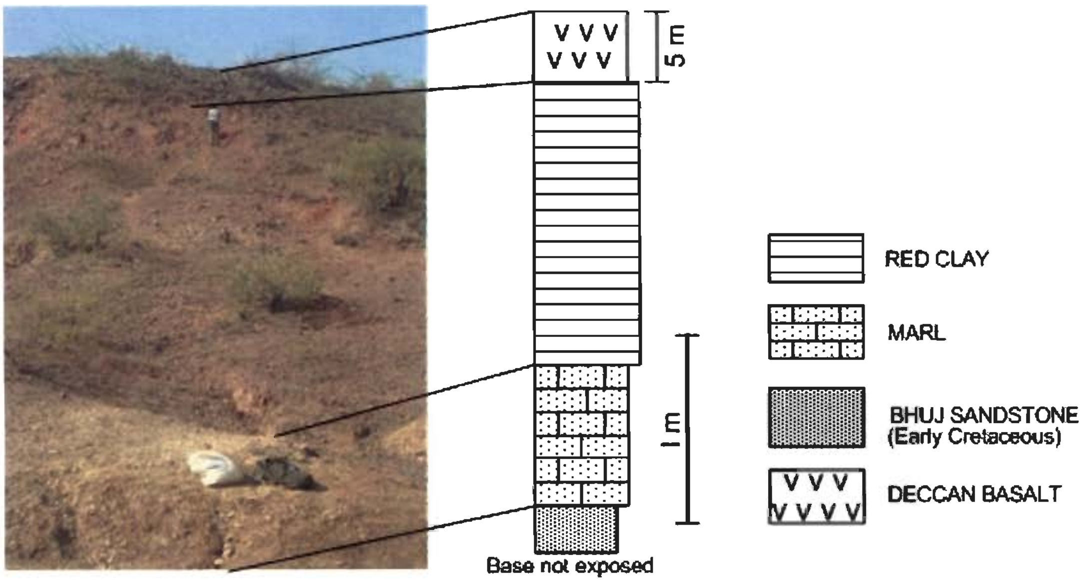

Figure 2.5 Stratigraphic section of Dayapar intertrappean beds, District Kutch, Gujarat

2.2.4 Virani intertrappeans

2.2.4.1 Location and stratigraphy

Approximately 2.5 km west of Dayapar, a new fossiliferous intertrappean locality (Fig.2.3) was encountered. This section (Fig. 2.6) is exposed along a stream-cutting and consists mainly of shale and marl.

2.2.4.2 Fossil assemblage

A small ostracod assemblage of 8 species has been recovered from this section along with fishes. The latter include *Lepisosteus* and osteoglossids.

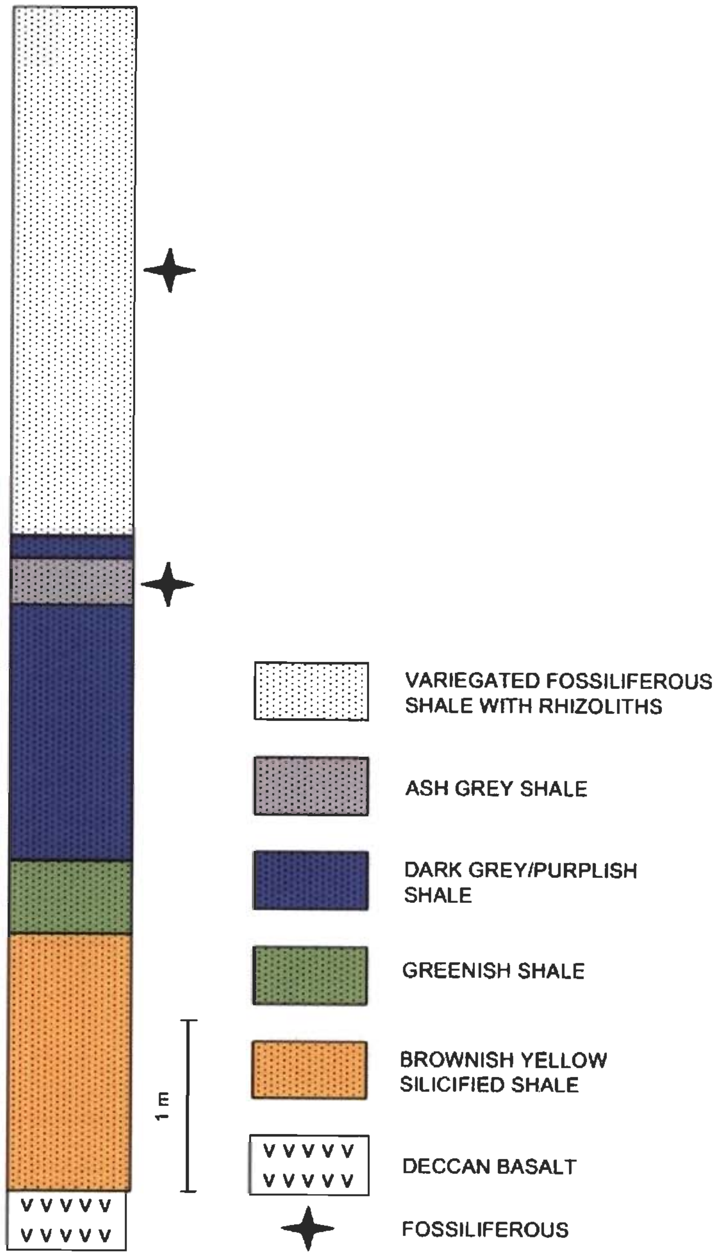

Figure 2.6 Stratigraphic section of Virani intertrappean beds, District Kutch, Gujarat

2.3 DISTRICT JHALAWAR, RAJASTHAN

The Deccan Traps exposed in parts of southeastern Rajasthan, represent the northernmost extensions of the Deccan volcanic province of peninsular India. Intertrappean beds have been reported to occur in this area (Sogani *et al.*, 1984; Sinha-Roy and Shukla, 1987; Mathur and Verma, 1988).

The thickness of Deccan Traps in SE Rajasthan is about 300 m (Sinha-Roy and Shukla, 1987). According to these authors the Deccan Traps of Jhalawar sections are mostly of *aa* type and are dominated by olivine basalts and are characteristic of continental rift volcanics. The basement of the Deccan Traps in this area is the Vindhyan Supergroup. The intertrappean beds of Rajasthan are extremely rare and amongst the most poorly studied in the Deccan volcanic province.

Until recently, these peripheral sections of the Deccan remained completely neglected. A supposed pterosaur was published over six decades ago from a locality near Mamoni (Dubey and Narein, 1947).Subsequently, Mathur and Verma (1988) described a few ostracod taxa from the intertrappean beds of Narli and Mamoni. The ostracod assemblage described by Mathur and Verma (1988) includes *Cyprois* sp., *Moenocypris sastryi*, *Moenocypris hunteri*, *Mongolianella* sp., *Pseudoeucypris* sp., *Paracypretta* sp. More recently, in a detailed work, Whatley *et al.* (2003) reported 8 species from Mamoni, namely *Frambocythere tumiensis anjarensis*, *Gomphocythere dasyderma*, *Paracypretta subglobosa*, *Cypridopsis hyperectyphos*, *Mongolianella* *cylindrica*, *Mongolianella subarcuata*, *Eucypris catantion* and *Cyclocypris amphybolos*.

2.3.1 Nahardi Intertrappeans

2.3.1.1 Location & Stratigraphy

This section is exposed near the village of Nahardi (24°26'35"N) (76° 11'49" E) about 10 km SE of Jhalarapatan, to the south of Jhalarapatan- Ujjain road, Jhalawar District of Rajasthan (Fig. 2.7). Lithologically this section (Fig. 2.8) comprises a 1.7 m thick bed of calcareous mudstone, overlain by the Deccan basalts. The Deccan basalts rest on Jhalarapatan Sandstone of Precambrian age.

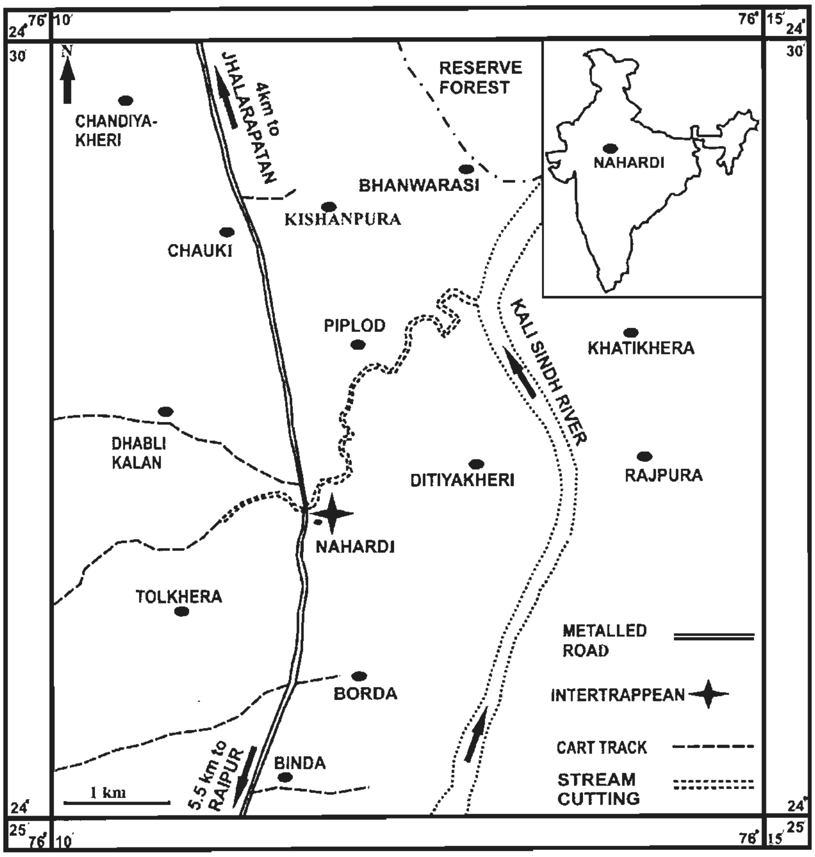

Figure 2.7 Location map of the Nahardi intertrappean locality, District Jhalawar, Rajasthan

2.3.1.2 Fossil assemblage

A fairly diverse assemblage of freshwater ostracods and fishes was recovered during the present investigation. Ostracods are represented by 13 species (*Cypridopsis wynnei*, *Cypridopsis hyperectyphos*, *Zonocypris spirula, Paracypretta subglobosa*, *Gomphocythere paucisulcatus*, *Eucandona kakamorpha, Eucypris pelasgicos, Mongolianella cylindrica, Mongolianella subarcuata, Limnocythere deccanensis, Candona amosi, Cypridea cavernosa* and *Cypria cyrtonidion* whereas fishes are known from two taxa (cf. *Igdabatis indicus* and *Lepisosteus indicus*). The ostracod assemblage consists essentially of taxa known from other intertrappean localities of peninsular India, with *Cypridopsis wynnei* being dominant.

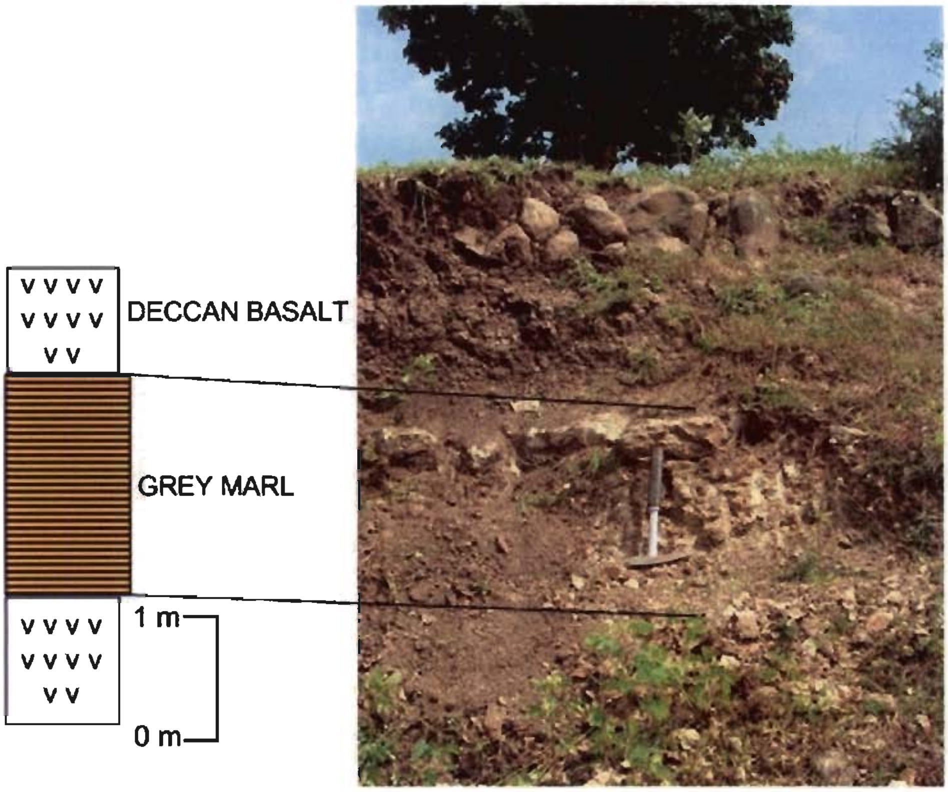

Figure 2.8 Stratigraphic section of Nahardi intertrappean beds, District Jhalawar, Rajasthan

2.4 DISTRICT LALITPUR, UTTAR PRADESH

The Deccan Traps in this area represent the northeasternmost extension of the main Deccan volcanic province. The intertrappeans in this are first came lo light with the description of charophytes from an intertrappean section near Papro (Singh, 1980; Singh and Mathur, 1980). In addition, freshwater molluscs, particularly *Physa* and *Lymnaea*, have also been recorded (but not described or illustrated). Geological setting of this section has been described in some detail by Kumar *et al.* (1980). The Deccan Traps in this area rest over the Kaimur Sandstone of the Vindhyan Supergroup (Late Precambrian), and the two are separated by a major unconformity represented by conglomerates (Kumar *et al.*, 1980).

2.4.1 Papro intertrappeans

2.4.1.1 Location and Stratigraphy

Intertrappean deposits of Lalitpur are exposed in a stream-cutting about 3 km north east of the Papro village ($24^0 48'20''$:$24^0 14'$) (Fig. 2.9). Intertrappeans in this section (Fig. 2.10) comprise about 1.5 m thick grey and black chert that yielded charophytes described previously by Singh (1980). Ongoing investigations by Joseph Hartman (University of North Dakota, USA, personal communication) have led to the recognition of a few more molluscan taxa in these cherts.

2.4.1.2 Fossil assemblage

During the present investigation, the Papro intertrappean locality yielded a small assemblage of ostracods. These ostracods were recovered from chert samples provided by Prof. M.P Singh, University of Lucknow, Lucknow.The recovered ostarcod assemblage consists of *Gomphocythere akalypton*, *Gomphocythere paucisulcatus*, *Mongolianella cylindrica*, *M. subarcuata*, *Cypridopsis hyperectyphos*, *Cypridopsis* sp. *Eucypris intervolcanus*, *E. pelasgicos*, *E. catantion*, *Eucypris* sp. *Paracypretta subglobosa*, *Paracypretta* sp. *Frambocythere tumiensis*, *Cypria cyrtonidion* and ?*Cyprois rostellum*.

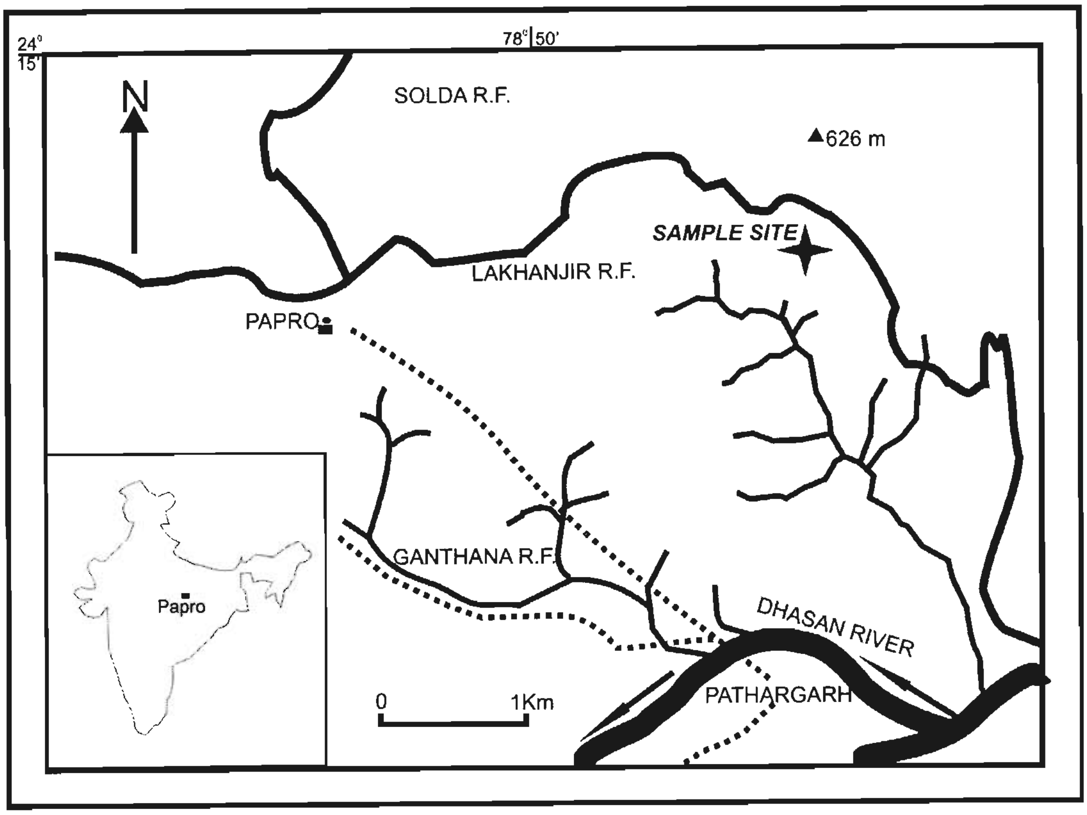

Figure 2.9 Location map of Papro intertrappean beds, District Lalitpur, Uttar Pradesh

2.5 DISTRICTS CHHINDWARA & MANDLA (MADHYA PRADESH) AND ADJOINING AREAS OF MAHARASHTRA

The intertrappean beds in and around Nagpur (Maharashtra) have been known since Hislop and Hunter's (1860) pioneering work on molluscan remains. At Takli, near Nagpur, these beds have produced mainly a terrestrial faunal assemblage comprising fishes, frogs, lizards, snakes, turtles, crocodiles, and rare dinosaurian elements including teeth and eggshell fragments (Lydekker, 1890; Sahni *et al.*, 1982; Rana, 1984; Gayet *et al.*, 1984; Vianey-Liaud *et al.*, 1987; Rana and Sahni, 1989). The fauna also includes associated microfossils include charophytes and ostraocds (Bhatia and Mannikeri, 1976; Bhatia and Rana, 1984; Bhatia *et al.*, 1990; Khosla and Nagori, 2007).

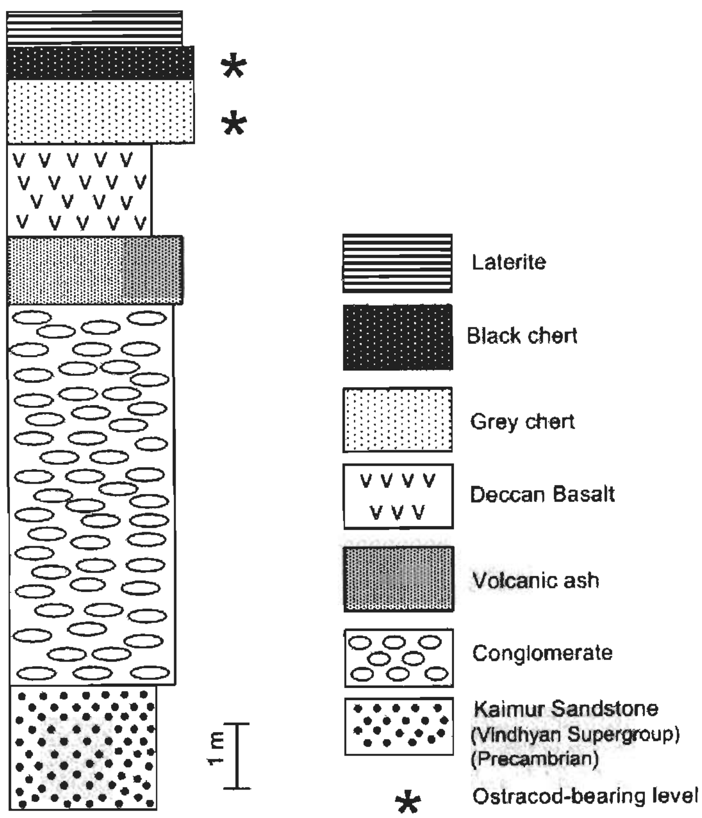

Figure 2.10 Stratigraphic section of Papro intertrappean locality, Lalitpur, Uttar Pradesh

In the past, a taxonomically diverse assemblage of megafloral remains (especially palm) has been reported from the Chhindwara, Mandla and Nagpur regions. Most of these studies assigned an early Tertiary (Paleocene/Eocene) age based on these floral remains (Bande *et al.*, 1981; Bande and Prakash, 1982; see review by Bande et al. 1988). On the other hand, the palynofloral (Kar and Srinivasan, 1998; Samanta and Mohabey, 2008) and faunal (Sahni and Bajpai, 1988; Srinivasan, 1996; Khosla *et al.*, 2004) remains have been interpreted as evidence of a Maastrichtian age.

In the Deccan intertrappeans of the Nagpur-Chhindwara and Mandla regions early workers interpreted a seashore paleoenvironment based on the presence of fossil palm fruits *Nypa, Cocos, Sonneratia* and the marine algae *Peyssonnelia* and *Solenopora* (Bande *et al.*, 1981, 1988; Bande and Prakash, 1982; Mehrotra, 1989). Based on these, Sahni (1984) proposed the existence of a marine seaway, the Trans-Deccan Strait, through the Godavari rift.

The Mohgaonkalan fossil forest is perhaps the best studied intertrappean beds in the Jhilmili area. The section contains a rich megaflora in black-brown variegated cherts, including palms (monocots, dicots), conifers and water fern representing terrestrial fresh water and marsh environments (Sahni and Rhode, 1937; Prakash, 1960). The reported fauna includes dinosaur eggshells, ostracods and molluscs (Srinivasan, 1996; Kumaran *et al.*, 1997; Whatley *et al.*, 2002, 2003; Khosla *et al.*, 2007; Kapgate, 2005). The age of this megaflora and fauna has been interpreted as Paleogene based on megaflora (e.g., Bande *et al.*, 1988; Bande and Chandra, 1990). Maastrichtian palynomorph assemblages and diatoms have been reported from the shales below the chert horizon (Kar and Srinivasan, 1998; Ambwani *et al.*, 2003). Singpur is another locality in the Jhilmili area with reported Maastrichtian age palynoflora (Samant *et al.*, 2008).

Phulsagar is another intertrappean section that has come to light. Bhattacharya and Fulmari (in Bajpai et al. 2004) while carrying out systematic geological mapping, first reported the presence of ostracods *Candoniella* sp. *Metacypris* sp., and *Darwinula* sp. from the Phulsagar intertrappeans. They also reported fossils of pelecypods (*Unio*), gatropods (*Physa*, *Lymnaea* and *Paludina*) and wood (*Ailantroxylon*, *Palmoxylon* and some seeds (Udhoji and Mohabey, 1991). The presence of foraminifers (*Melania* sp. *Hoegluda* sp. *Gavilenna* sp. *Spiroloulina* sp. and *Quinqueloquilina* sp.) was also claimed by these workers. However, the identification of these forams always remained doubtful and most of the purported foraminifers have since been considered to be the juvenile specimens of the various associated gastropod species that were cut in different views.

2.5.1 Jhilmili intertrappeans

2.5.1.1 Location and Stratigraphy

This Intertrappean section is exposed in a cutting by Pench River on the roadside near village Jhilmili (Fig. 2.11). The locality is located at Chhindwara-Mandla road at 22°02'41"N; 079°09'43"E in District Chhindwara. The Jhilmili intertrappean sediments were trenched to expose fresh rock, which were examined for lithological changes, described, measured and systematically sampled.

The Jhilmili intertrappean sediments are approx. 14 m thick. Lithologically, the section consists of claystones (paleosols), siltstones, clayey–silty marlstones to limestones, and can be subdivided into 4 different units. The monotonous red shale of the lower 6 m (Unit 1) and red and green shales of the upper 6.5 m (Unit 4 and 5) of the section were sampled at 20-50 cm intervals. The present study concentrates on the Unit 3 between 6 and 6.6 m, which consists of yellow to pink ostracod-rich shales and calcareous limestones with planktic foraminifera. This interval was sampled at 2-5 cm intervals across the laminated layers of the lower part and at 10-15 cm intervals in the thicker layers of the upper part. The Jhilmili section can be subdivided into six units, with units 1 and 6 representing lower and upper basalt traps, respectively (Fig. 2.12). Unit 2 marks the lower 6 m of intertrappean sediments consisting of red clayey siltstone with carbonate nodules and occasional quartz pebbles.

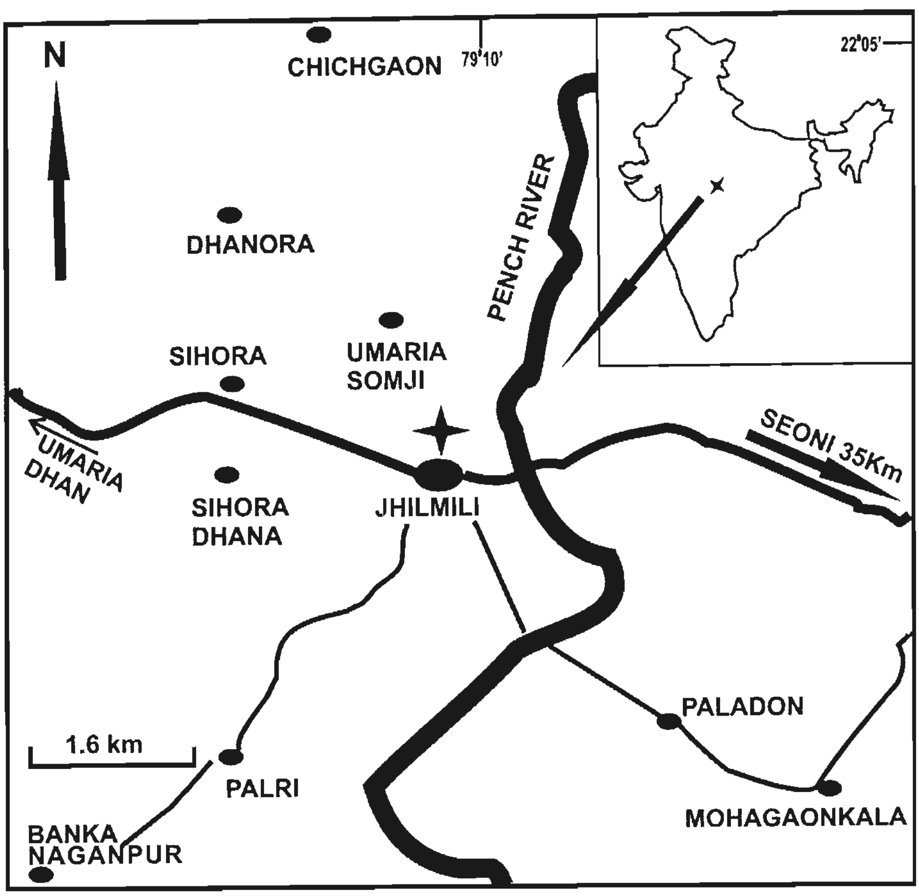

Figure 2.11 Location map of the Jhilmili intertrappean locality, District Chhindwara, Madhya Pradesh

Units 4 and 5 have similar lithologies, except for a colour change to grey-green in unit 5. Deposition occurred primarily in terrestrial environments, except near the top of unit 2 and unit 5 which indicate palustrine or flood plain deposition. Unit 3 marks a distinctly different environment during a relatively short time interval represented by just 70 cm. In the lower part of unit 3, sediments consist of alternating yellow to pink clays and marly limestones (JH16-JH22, Fig. 2.13). Freshwater algae (charophytes) and ostracods are common (JH17, JH19), and some clay layers contain early Danian planktic foraminifera, as well as clasts with Danian planktic foraminifer (JH16, JH18, JH20-22; Fig. 2.12). The upper part of unit 3 consist mainly of pink clays with intercalations of algal mats with freshwater ostracods and laminated claystones with rare brackish-marine ostracods and planktic foraminifera. This suggests repeated marine incursions into fresh water environments, periodically resulting in shallow marine to brackish-marine (e.g., estuarine) conditions. At the top of unit 3, a nodular limestone with abundant ostracod and shell fragments, charophytes, oncoids and quartz grains marks a storm deposit (JH26, tempestite).

2.5.1.2 Fossil assemblage

A diverse assemblage of ostracods and foraminifers has been recorded from Jhilmili. The ostracod assemblage comprises 16 species, which significantly include a brackish water species *Neocyprideis* cf. *N. raoi* previously known from the well known marine intertrappean deposits near Rajahmundry, Andhra Pradesh. Other ostracods are: *Gomphocythere strangulata*, *Frambocythere tumiensis lakshmiae*, *Cypridopsis hyperectyphos*, *Eucypris verruculosa*, *Limnocypridea ecphymatos*, *Candona ?amosi*, *Cypria cyrtonidion*, *Limnocythere deccanensis*, *Zonocypris spirula*, *Zonocypris viriensis*, *Darwinula torpedo*. The fish fauna recovered from this locality includes: *Lepisosteus* sp. and *Pycnodus*. Foraminiferal assemblage includes: *Hedbergella holmdelensis*, *Parasubbotina pseudobulloides*, *Subbotina triloculinoides*, *Globigerina pentagona*, *Globigerinelloides aspera* and *Guembelitria cretacea*.

2.5.2 Phulsagar intertrappeans

2.5.2.1 Location and Stratigraphy

The Phulsagar intertrappean (Fig. 2.13) section (N22°41'40" :E80°20'50") of District Mandla is exposed at 470 m elevation and has a thickness variable between less than 1 m and 2.5 m. The sediments consist of black and gray chert, variegated chert and red to buff coloured weathered chert in the basal part and brown and dirty white clays upwards in the sequence (Fig. 2.14).

2.5.2.2 Fossil assemblage

A small assemblage of 8 freshwater ostracod species was recovered as part of the present work on this section (Bajpai *et al.*, 2004). The assemblage includes: *Gomphocythere akalypton*, *Limnocythere deccanensis*, *?Cypridopsis whatleyi*, *Limnocypridea ecphymatos*, *Eucypris pelasgicos*, *E. intervolcanus*, *?Eucypris phulsagarensis* and *Mongolianella cylindrica*.

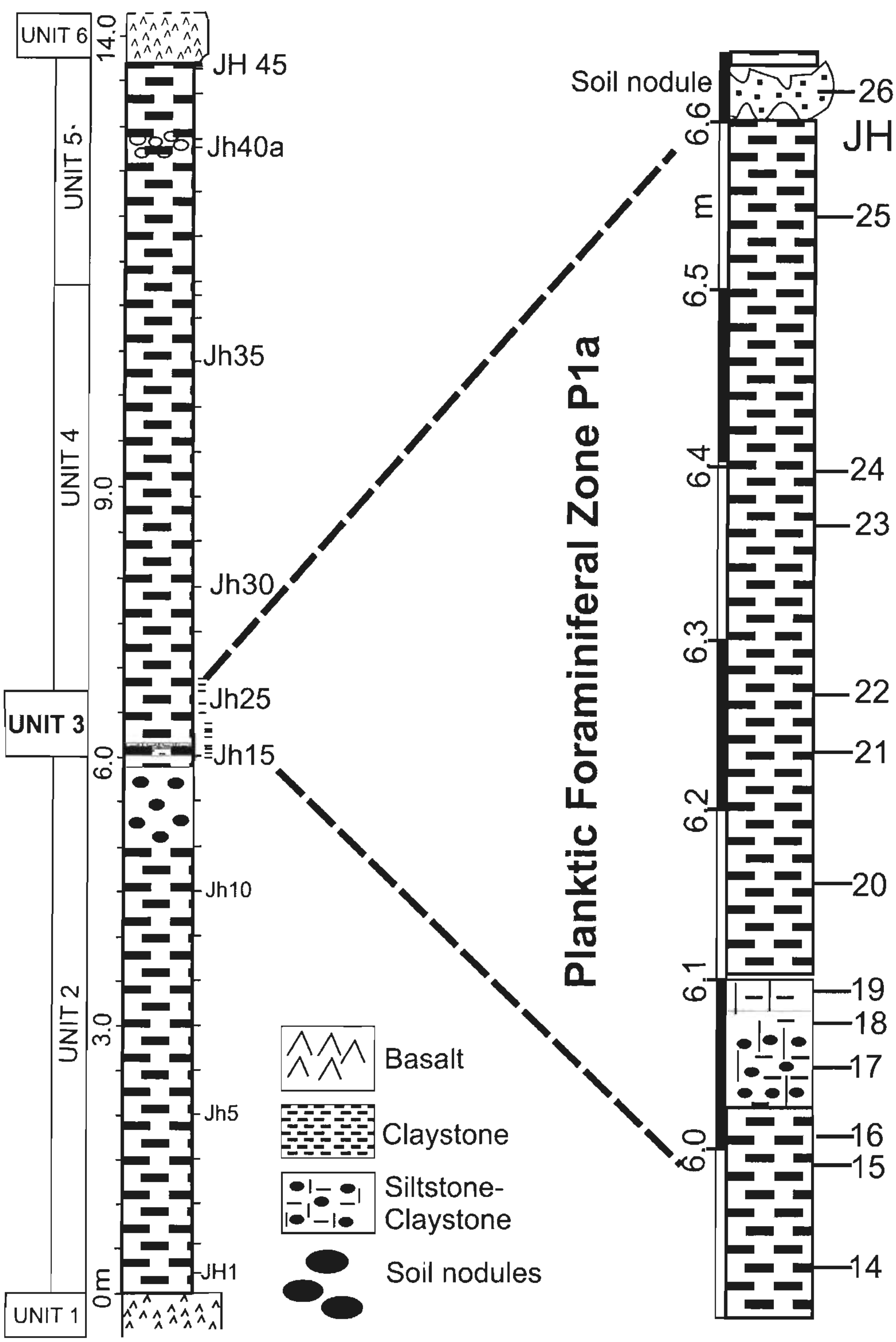

Figure 2.12 Stratigraphic section of Jhilmili intertrappean beds, District Chhindwara, Madhya Pradesh

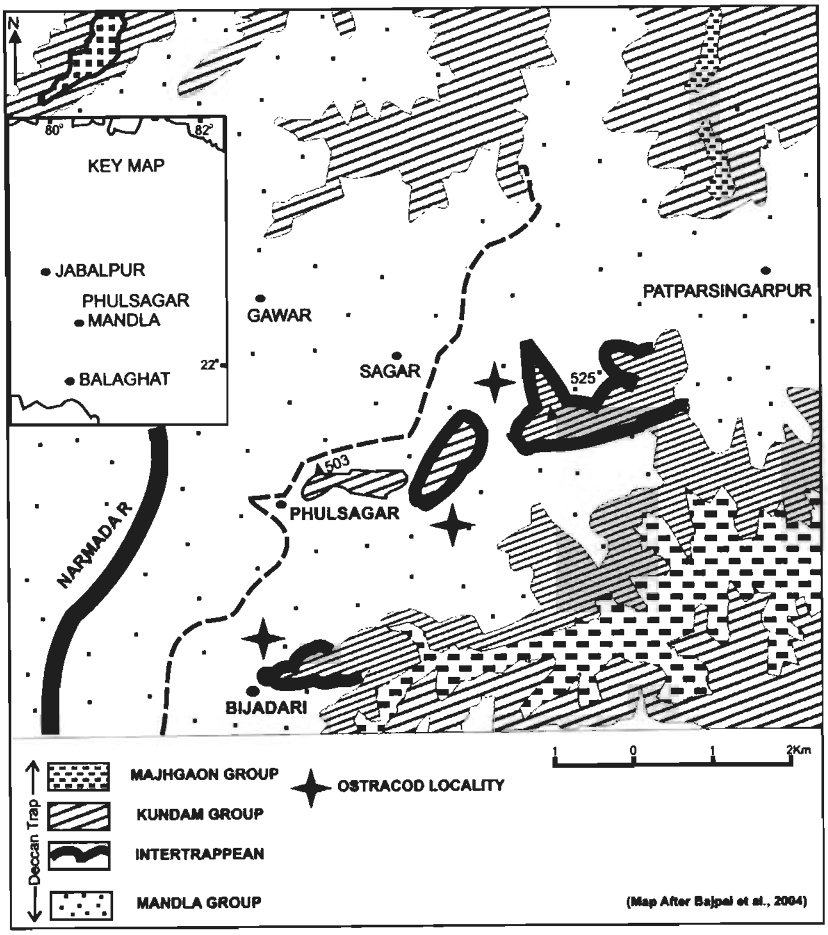

Figure 2.13 Location map of the phulsagar intertrappean locality District Mandla, Madhya Pradesh (After Bajpai et al. 2004)

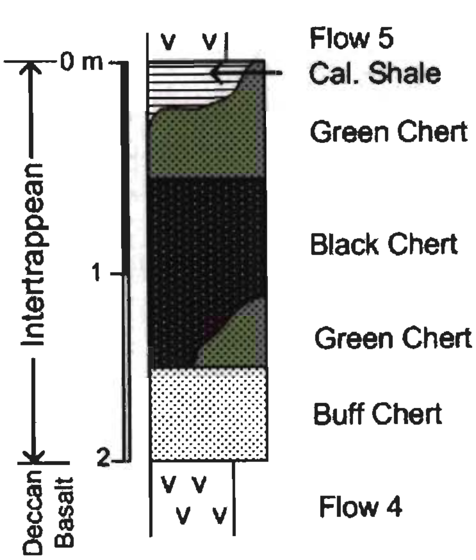

Figure 2.14 Stratigraphic section of Phulsagar intertrappean beds, District Mandla, Madhya Pradesh (Modified after Bajpai *et al.*, 2004)

2.6 EAST GODAVARI DISTRICT (RAJAHMUNDRY), ANDHRA PRADESH

In the Krishna-Godavari basin, about 1500 km to the southeast of the main Deccan volcanic province, a series of exposed lava flows with intercalated marine intertappean beds around the city of Rajahmundry near the southeastern coast of peninsular India has been historically considered as part of the original Deccan Traps province (Venkaya, 1949; Bhimasankaran, 1965). This is supported by their magnetostratigraphic and geochemical similarities to the main Deccan volcanic province to the west (Duncan and Pyle, 1988; Lightfoot *et al*., 1990; Subbarao and Pathak, 1993; Banerjee *et al*., 1996; Baksi, 2001; Knight et al. 2003; Jay and Widdowson, 2008; Self et al. 2008). Interestingly, the Rajahmundry lava flows are considered to be the longest (~1000 km long) flows on earth, belonging to the topmost part of the main Deccan Traps volcanic succession.

Due to their unique geographic position and brackish water/marine fossil assemblages the Rajahmundry intertrappean exposures, especially those around the Pangadi-Duddukuru and Kateru areas, have received considerable attention during the past about 70 years. Rao and Rao (1939) described thirteen species of *Chara* gyrogonites from the Kateru intertrappeans. They favoured a Paleocene age based on this charophyte assemblage.

Studies on ostracods have been been pioneered by Sastri (1963) who listed 9 species: *Cytherella* sp., *Cytherelloidea* sp. *Bairdia subdeltoidea*, *Cythere*? *ranikotiana*, *Cythereis bowerbanki*, *Cytheries* cf. *merosondaviesi*, Loxoconcha sp., *Cytheropteron* sp., *Eucytherura* sp. Later, Guha and Raju (1965) reported six ostracoda taxa, namely *Cythereis* cf. *tamulicus*, *Paracypris* sp., Protobuntonia sp., *Xestoleberis* sp., *Ovocythereidea* sp., and *Hermanites* cf. *pondicheriensis.*The first detailed paper on ostracods from this area was that by Jain (1978), who described and illustrated 12 taxa from these beds near Kateru. The assemblage included *Cytherella* sp. cf. *C. munsteri* (Roemer), *Cytherelloidea* sp. cf. *C. Keiji* Mckenzie, *Bairdia* sp. indet, *Bythocypris* sp., indet., *Cythereidea* sp. indet., *Ovocytheridea raoi*, *Quandracythere* (*H.*) *Subqadra Siddiqui*, *Ermanites* sp. cf. *H. cracens Siddiqui*, *Limnocythere* sp. indet, *Protobuntonia harmanni* and *Xestoleberis* sp. indet. An early Eocene age was assigned based on the ostracod assemblage. More recent studies on ostracods include those by Bhandari (1995) and Khosal and Nagori (2002).

Early studies on foraminifers from the Rajahmundry intertrappeans include Bhalla (1967) who favoured an Early Eocene age and alternating marine and brackish water conditions of deposition for these beds. Rao and Rao (1973) reported some foraminifers from the intertrappean beds at Kateru and described the following forms: *Sigmoilina* sp., *triloculina* aff. *Laevigata* d'orbigny, *robulus* sp. indet., *Nodosaria zippei reuss*, *Nonion* sp. indet., *Gambelina globifera* reuss, *orbulina* cf. *O. universa* d'Orbigny, *Spheroidinella* (sic) sp, *Globorotalia* cf. *G. menardii*, *Globotruncana* sp., and *Anomalina rudio* (sic) Reuss.

As part of its exploration programme, studies on microfauna from the subcrop of the the Krishna-Godavari basin have also been undertaken by the Oli and Natural Gas Corporation (ONGC) of India. Important contributions on ONGC wells include those by Govindan (1981), Jaiprakash et al. (1993), Raju et al., 1995, 1996). Planktic foraminifera from ONGC Palakollu-A well shows a latest Maastrichtian age for beds below the lower trap and a Danian (Plb to P2) age for the intertrappean beds. Similarly, the Narasapur well yielded an early Paleocene (Danian) age based on planktic foraminifera (Govindan, 1981; Jaiprakash *et al.*, 1993; Raju *et al.*, 1995, 1996), calcareous nanoplankton (Saxena and Misra, 1994), Dinoflagilates (Mehrotra and Sargeant, 1987) and palynology (Prasad and Pundeer, 2002).

The most comprehensive study on foraminifers to date is that by Keller et al. (2008). The most important result of this study is that the the lower Rajahmundry trap flows in C29R ended very near the K–T boundary, and that the intertrappean sediments are of early Danian zone P1a, which spans C29r above the KTB, or about 200 ky.

2.6.1 Duddukuru intertrappeans

2.6.1.1 Location & Stratigraphy

The Deccan Traps in the Rajahmundry area (Fig. 2.15) (Survey of India, Toposheet No. 65 G/12; $17^{o}\,1^{':}$ $18^{o}\,39^{'}\,02^{")}$, are intercalated with marine sedimentary strata, mainly limestone with some intercalated shales. The northern and northwestern part of the Duddukuru area is occupied by soft, coarse reddish Tirupati sandstones of the east coast Upper Gondwanas, some exposures of which are seen north of Gauripatnam and Devarapalli. Overlying the Tirupati sandstones are the infratrappean limestones and sandstones. The infratrappean sediments are exposed 1 km SE of the village Devarapalli and 1 km south of Duddukuru.

The infratrappean beds are unconformably overlain by the Deccan Traps which are widespread in this area and are constituted mainly by dark green or grey, hard basalt exhibiting spheroidal weathering on the surface. Intercalated with the volcanic flows are the intertrappean beds mainly found in a few limestone quarries being worked out on the eastern side of Linga Konda and about 1 km southeast of Duddukuru village. Similar exposures were also found 2.5 km north of Rajahmundry, near Kateru. These marine sedimentary strata are nearly horizontal with a maximum dip of only 4° to 6° towards the southeast. These low-dipping strata vary in thickness

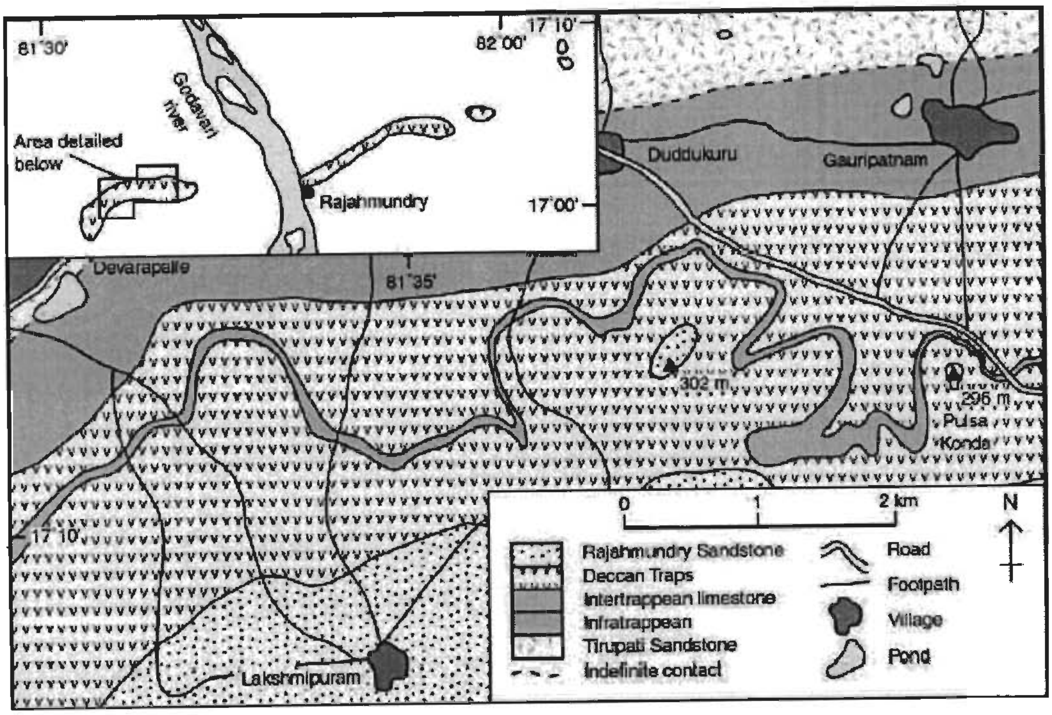

Figure 2.15 Map showing location of Duddukuru intertrappean beds, Rajahmundry area, District East Godavari (After Keller *et al.*, 2008)

from less than half a meter to 10 m. They are mainly composed of compact, very hard, massive, crystalline, and white to pinkish limestone in the lower half, while the upper part is generally composed of alternating impure limestone and shale bands. The intertrappean bands can be traced from the eastern side of Linga Konda, an approximately 80m hill, from where it follows around the northern and western sides of the same hill, crosses the Ellore-Kovvur road near milestone 351. Since the beds are low-dipping, the outcrops are widest in the valleys. The central portion of the intertrappean band is well developed, and a maximum thickness of 9 m has been recorded, whereas the eastern and the western ends are thin, not exceeding 4 m in thickness. However, there is a remarkable variation in the thickness of the limestone in the central portion. The junction between the intertrappeans and the overlying Trap is clearly seen at a number of places. There is a slight metamorphic effect of the traps on the immediately underlying limestone bands. There are approximately 30 to 50 m of trap rocks above the intertrappeans.

Figure 2.16 Government quarry, Duddukuru, near Rajahmundry, East Godavari District, Andhra Pradesh (After Keller et al. 2008)

2.6.1.2 Fossil assemblage

The microfauna recovered during this investigation comprises foraminifers, ostracods and microvertebrates. However, only the last named group i.e. microvertebrates has been included as part of this dissertation. The other two groups are already known through the works of the various authors as discussed above. The microvertebrates recovered during this investigation come from the Government quarry (Fig. 2.16) and Balaji quarry and comprise 3 fish taxa: *Chrysophrys sp., Eotrigonodon indicus* and *Pycnodus* sp. Foraminfers from these quarries have been described recently by Keller et al. (2008). Here the intertrappean sediments consist of limestone, shale and sandstone. The Deccan Traps in this area are unconformably overlain by the Rajahmundry Sandstones (Miocene).

CHAPTER 3

SYSTEMATIC PALEONTOLOGY

Faunal list from Nahardi intertrappean section, Jhalawar District, Rajasthan

OSTRACODA

Order PODOCOPIDA Muller, 1894

Superfamily CYTHERACEA Baird, 1850

Family LIMNOCYTHERIDAE Klie, 1938

Genus *Gomphocythere* Sars, 1924

Gomphocythere paucisulcatus Whatley *et al.*, 2002

Genus *Limnocythere* Klie, 1938

Limnocythere deccanensis Khosla and Nagori, 2005

Superfamily CYPRIDACEA Baird, 1845

Family CYPRIDIDAE Baird, 1845

Genus *Paracypretta* Sars, 1924

Paracypretta subglobosa (Soweby, 1840)

Genus *Cypridopsis* Brady, 1868

Cypridopsis Wynnei Whatley and Bajpai, 2000

Cypridopsis hyperectyphos Whatley and Bajpai, 2000

Genus *Eucypris* Vávra, 1891

Eucypris pelasgicos Whatley and Bajpai, 2000

Genus *Mongolianella* Mandelstam, 1955

Mongolianella cylindrica (Sowerby, 1840)

Mongolianella subarcuata (Sowerby, 1840)

Genus *Zonocypris* Müller, 1894

Zonocypris spirula Whatley and Bajpai, 2000

Family CANDONIDAE Kaufmann, 1900

Genus *Candona* Baird, 1845

Candona amosi Whatley *et al.*, 2002

Genus *Eucandona* Daday, 1900

Eucandona kakamorpha Whatley *et al.*, 2002

Family CYCLOCYPRIDINAE Kaufmann, 1900

Genus *Cypria* Zenker, 1854

Cypria cyrtonidion Whatley and Bajpai, 2000

Family HYOCYPRIDIDAE Kaufmann, 1900

Genus *Cypridea* Bosquet, 1852

Cypridea cavernosa Khosla *et al.*, 2005

PISCES

Class OSTEICHTHYES Huxley, 1880

Order LEPISOSTEIFORMES Berg, 1940

Family LEPISOSTEIDAE Cuvier, 1825

Genus *Lepisosteus* Lacepede, 1803

***Lepisosteus* sp.**

Order OSTEOBLOSSIFORMES Berg, 1940

Family OSTEOGLOSSIDAE Bonaparte, 1832

Gen. et sp. indet.

MOLLUSCA

Class GASTROPODA Cuvier, 1797

Order PULMONATA, Cuvier, 1814

Family PHYSIDAE Fitzinger, 1833

Genus *Physa* Draparnaud, 1801

Physa prinsepii Hislop, 1860

Family Lymnaeidae Rafinesque, 1815

Genus *Lymnaea* Sowerby, 1837

***Lymnaea* sp.**

Faunal list from Phulsagar intertrappean section, Mandla District, Madhya Pradesh

OSTRACODS

Order PODOCOPIDA Muller, 1894

Superfamily CYTHERACEA Baird, 1850

Family LIMNOCYTHERIDAE Klie, 1938

Genus *Gomphocythere* Sars, 1924

Gomphocythere akalypton Whatley and Bajpai, 2002

Genus *Limnocythere* Klie, 1938

Limnocythere deccanensis Khosla and Nagori, 2005

Superfamily CYPRIDACEA, Baird, 1845

Family CYPRIDIDAE Baird, 1845

Genus *Cypridopsis* Brady, 1868

Cypridopsis whatleyi Bajpai *et al.*, 2004

Genus *Eucypris* Vavra, 1891

Eucypris intervolcanus Whatley and Bajpai, 2000

Eucypris pelasgicos Whatley and Bajpai, 2000

Eucypris phulsagarensis Bajpai *et al.*, 2004

Genus *Mongolianella* Mandelstam, 1955

Mongolianella cylindrica (Sowerby, 1840)

Family HYOCYPRIDIDAE Kaufmann, 1900

Genus *Limnocypridea* Lyubimova, 1956

Limnocypridea ecphymatos Whatley and Bajpai, 2000

MOLLUSCA

Class GASTROPODA Cuvier, 1797

Order PULMONATA, Cuvier, 1814

Family PHYSIDAE Fitzinger, 1833

Genus *Physa* Draparnaud, 1801

Physa prinsepii Hislop, 1860

Family Lymnaeidae Rafinesque, 1815

Genus *Lymnaea* Sowerby, 1837

***Lymnaea* sp.**

Faunal/Floral list from Jhilmili intertrappean section, Chhindwara District, Madhya Pradesh

OSTRACODS

Order PODOCOPIDA Muller, 1894

Superfamily CYTHERACEA Baird, 1850

Family LIMNOCYTHERIDAE Klie, 1938

Genus *Gomphocythere* Sars, 1924

Gomphocythere strangulata (Jones, 1860)

Genus *Frambocythere* Colin, 1980

Frambocythere tumiensis anjarensis Bhandari and Colin, 1999

Superfamily CYPRIDACEA Baird, 1845

Family CYPRIDIDAE Baird, 1845

Genus *Cypridopsis* Brady, 1868

Cypridopsis hyperectyphos Whatley and Bajpai, 2000

Genus *Mongolianella* Mandelstam, 1955

Mongolianella cylindrica (Sowerby, 1840)

Family HYOCYPRIDIDAE Kaufmann, 1900

Genus *Limnocypridea* Lyubimova, 1956

Limnocypridea ecphymatos Whatley and Bajpai, 2000

Family CANDONIDAE Kaufmann, 1900

Genus *Cypria* Zenker, 1854

Cypria cyrtonidion Whatley and Bajpai, 2000

Superfamily CYTHERACEA Baird, 1845

Family CYTHERIDEIDAE Sars, 1925

Genus *Neocyprideis* Apostolescu, 1957

Neocyprideis* cf. *N. raoi (Jain, 1978)

Family LIMNOCYTHERIDAE Klie, 1938

Genus *Limnocythere* Klie, 1938

Limnocythere deccanensis Khosla *et al.*, 2005

***Limnocythere* sp.**

Superfamily CYPRIDACEA Baird, 1845

Family CYPRIDIDAE Baird, 1845

Genus *Paracypretta* Sars, 1924

Paracypretta subglobosa (Sowerby, 1840)

Paracypretta jonesi Bhatia and Rana, 1984

***Paracypretta* sp.**

Genus *Zonocypris* Muller, 1894

Zonocypris spirula Whatley and Bajpai, 2000

Zonocypris viriensis Khosla and Nagori, 2005

Superfamily DARWINULACEA Brady & Norman, 1889

Genus *Darwinula* Brady & Norman, 1885

Darwinula torpedo Whatley *et al.*, 2002

Genus *Paracandona* Hartwig, 1899

Paracandona firmamentum Whatley and Bajpai, 2000

FORAMINIFERA

Family HEDBERGELLIDAE Loeblich and Tappan, 1961

Genus *Hedbergella* Bronnimann and Brown, 1958

Hedbergella holmdelensis Olsson, 1964

Genus *Parasubbotina* Olsson, Hemleben, Berggren and Liu, 1992

Parasubbotina pseudobulloides (Plummer, 1926)

Family CATAPSYDRACIDAE Bolli, Loeblich and Tappan, 1957

Genus *Subbotina* Brotzen and Pozaryska, 1961

Subbotina triloculinoides (Plummer, 1926)

Family GLOBOGERINIDAE Carpenter, Parker and Jones, 1862

Genus *Globigerina (Eoglobigerina)* d'Orbigny, 1826

Globigerina pentagona (Morozova, 1961)

Family Globigerinelloididae Longoria, 1974

Genus *Globigerinelloides* Cushman and Ten Dam, 1948

Globigerinelloides aspera Koch, 1926

PISCES

Family LEPISOSTEIDAE Cuvier, 1825

Genus *Lepisosteus* Lacepede, 1803

***Lepisosteus* sp.**

Family PYCNODONTIDAE Agassiz, 1833

Genus *Pycnodus* Agassiz, 1833

***Pycnodus* sp.**

CHAROPHYTES

Family CHARACEAE

Genus *Platychara* Villant, 1719

Platychara perlata (Peck and Recker, 1947)

Genus *Chara*

***Chara* sp. indet.**

Faunal/Floral list from Papro section intertrappean locality, District Lalitpur, Uttar Pradesh

OSTRACODA

Superfamily CYTHERACEA Baird, 1850

Family LIMNOCYTHERIDAE Klie, 1938

Genus *Gomphocythere* Sars, 1924

Gomphocythere paucisulcatus Whatley *et al.*, 2002

Gomphocythere akalypton Whatley and Bajpai, 2002

Genus *Frambocythere* Colin, 1980

Frambocythere tumiensis lakshmiae Whatley and Bajpai, 2000

Superfamily CYPRIDACEA Baird, 1845

Family CYPRIDIDAE Baird, 1845

Genus *Cypridopsis* Brady, 1868

Cypridopsis hyperectyphos Whatley and Bajpai, 2000

***Cypridopsis* sp.**

Genus *Eucypris* Vávra, 1891

Eucypris intervolcanus Whatley and Bajpai, 2000

Eucypris catantion Whatley *et al.*, 2003

Genus *Mongolianella* Mandelstam, 1955

Mongolianella cylindrica (Sowerby, 1840)

Mongolianella subarcuata (Sowerby, 1840)

Genus *Zonocypris* Muller, 1894

Zonocypris spirula Whatley and Bajpai, 2000

Family CYCLOCYPRIDINAE Kaufmann, 1900

Genus *Cypria* Zenker, 1854

Cypria cyrtonidion Whatley and Bajpai, 2000

Family NOTODROMADIDAE Kaufmann, 1900

Genus *Cyprois* Zenker, 1854

Cyprois rostellum Whatley and Bajpai, 2000

MOLLUSCA

Class GASTROPODA Cuvier, 1797

Order PULMONATA, Cuvier, 1814

Family PHYSIDAE Fitzinger, 1833

Genus *Physa* Draparnaud, 1801

Physa prinsepii Hislop, 1860

Order CTENOBRANCHIATA Schweigger, 1820

Family VIVIPARIDAE Gray, 1847

Genus *Paludina* Lamarck, 1816

***Paludina* sp.**

Family Lymnaeidae Rafinesque, 1815

Genus *Lymnaea* Sowerby, 1837

***Lymnaea* sp.**

PISCES

Order OSTEOBLOSSIFORMES Berg, 1940

Family OSTEOGLOSSIDAE Bonaparte, 1832

Gen. et sp. indet.

Faunal List from Dayapar intertrappean section, District Kutch, Gujarat

OSTRACODA

Superfamily CYTHERACEA Baird, 1850

Family LIMNOCYTHERIDAE Klie, 1938

Genus *Frambocythere* Colin, 1980

Frambocythere tumiensis lakshmiae Whatley and Bajpai, 2000

Superfamily DARWINULACEA Brady and Norman, 1889

Genus *Darwinula* Brady and Norman, 1885

Darwinula sp.

Superfamily CYPRIDACEA Baird, 1845

Family CYPRIDIDAE Baird, 1845

Genus *Paracypretta* Sars, 1924

Paracypretta elizabethae Whatley *et al.*, 2002

Genus *Cypridopsis* Brady, 1868

Cypridopsis hyperectyphos Whatley and Bajpai, 2000

Cypridopsis wynnei Whatley and Bajpai, 2000

Genus *Eucypris* Vávra, 1891

Eucypris pelasgicos Whatley and Bajpai, 2000

Eucypris catantion Whatley *et al.,* 2003

Eucypris verruculosa Whatley *et al.*, 2002

Genus *Mongolianella* Mandelstam, 1955

Mongolianella cylindrica (Sowerby, 1840)

Mongolianella subarcuata (Sowerby, 1840)

Family CANDONIDAE Kaufmann, 1900

Genus *Candona* Baird, 1845

Candona amosi Whatley *et al.*, 2002

Genus *Paracandona* Hartwig, 1899

Paracandona sp.

Genus *Eucandona* Daday, 1900

Eucandona kakamorpha Whatley *et al.*, 2002

Family CYCLOCYPRIDINAE Kaufmann, 1900

Genus *Cypria* Zenker, 1854

Cypria cyrtonidion Whatley and Bajpai, 2000

Family NOTODROMADIDAE Kaufmann, 1900

Genus *Cyprois* Zenker, 1854

Cyprois rostellum Whatley and Bajpai, 2000

MOLLUSCA

Class GASTROPODA Cuvier, 1797

Order PULMONATA, Cuvier, 1814

Family PHYSIDAE Fitzinger, 1833

Genus *Physa* Draparnaud, 1801

Physa prinsepii Hislop, 1860

Order CTENOBRANCHIATA Schweigger, 1820

Family VIVIPARIDAE Gray, 1847

Genus *Paludina* Lamarck, 1816

***Paludina* sp.**

Family Lymnaeidae Rafinesque, 1815

Genus *Lymnaea* Sowerby, 1837

***Lymnaea* sp.**

VERTEBRATES

PISCES

Family LEPISOSTEIDAE Cuvier, 1825

Genus *Lepisosteus* Lacépède, 1803

***Lepisosteus* sp.**

Family PYCNODONTIDAE Agassiz, 1833

Genus *Pycnodus* Agassiz, 1833

***Pycnodus* sp.**

Order OSTEOBLOSSIFORMES Berg, 1940

Family OSTEOGLOSSIDAE Bonaparte, 1832

Gen. et sp. indet.

DINOSAURIA

Fragmentary dinosaur bones (indet.)

Faunal list from Virani intertrappean section, District Kutch, Gujarat

OSTRACODS

Superfamily CYPRIDACEA Baird, 1845

Family CYPRIDIDAE Baird, 1845

Genus *Eucypris* Vávra, 1891

Eucypris pelasgicos Whatley and Bajpai, 2000

Eucypris intervolcanus Whatley and Bajpai, 2000

Genus *Mongolianella* Mandelstam, 1955

Mongolianella cylindrica (Sowerby, 1840)

Genus *Cypridopsis* Brady, 1868

Cypridopsis hyperectyphos Whatley and Bajpai, 2000

Cypridopsis wynnei Whatley and Bajpai, 2000

***Cypridopsis* sp.**

Family CANDONIDAE Kaufmann, 1900

Genus *Eucandona* Daday, 1900

Eucandona kakamorpha Whatley *et al.*, 2002

Genus *Paracandona* Hartwig, 1899

Paracandona firmamentum Whatley and Bajpai, 2000

PISCES

Order OSTEOBLOSSIFORMES Berg, 1940

Family OSTEOGLOSSIDAE Bonaparte, 1832

Gen. et sp. indet.

Faunal list from Anjar intertrappean section, District Kutch, Gujarat

Superfamily CYPRIDACEA Baird, 1845

Family CANDONIDAE, Kaufmann, 1900

Genus *Candona* Baird, 1845

Candona amosi Whatley *et al.*, 2002

Family CYPRIDIDAE Baird, 1845

Genus *Paracypretta* Sars, 1924

Paracypretta jonesi Bhatia and Rana, 1984

Genus *Mongolianella* Mandelstam, 1955

Mongolianella cylindrica (Sowerby, 1840)

Genus *Cypridopsis* Brady, 1868

Cypridopsis hyperectyphos Whatley and Bajpai, 2000

Genus *Eucypris* Vávra, 1891

Eucypris pelasgicos Whatley and Bajpai, 2000

Family HYOCYPRIDIDAE Kaufmann, 1900

Genus *Limnocypridea* Lyubimova, 1956

Limnocypridea ecphymatos Whatley and Bajpai, 2000

Family NOTODROMADIDAE Kaufmann, 1900

Genus *Centrocypris* Vávra, 1895

Centrocypris megalopus Whatley and Bajpai, 2000

MOLLUSCA

Class GASTROPODA Cuvier, 1797

Order PULMONATA, Cuvier, 1814

Family PHYSIDAE Fitzinger, 1833

Genus *Physa* Draparnaud, 1801

Physa prinsepii Hislop, 1860

Order CTENOBRANCHIATA Schweigger, 1820

Family VIVIPARIDAE Gray, 1847

Genus *Paludina* Lamarck, 1816

***Paludina* sp.**

Family Lymnaeidae Rafinesque, 1815

Genus *Lymnaea* Sowerby, 1837

***Lymnaea* sp.**

VERTEBRATES

DINOSAURIA

Fragmentary dinosaur bones (? Sauropoda)

Fragmentary eggshells (Theropoda)

Faunal List from Early Paleocene Duddukuru intertrappean section, District East Godavari, Andhra Pradesh.

Order ACANTHOPTERYGII

Family SPARIDAE

Genus *Chrysophrys*

***Chrysophrys* sp.**

Order SALMONIFORMES

Family ENCHONDONTIDAE Lydekker, 1889

Eotrigonodon indicus (Lydekker, 1886)

Family PYCNODONTIDAE Agassiz, 1833

Genus *Pycnodus* Agassiz, 1833

***Pycnodus* sp.**

SYSTEMATIC DESCRIPTION

Class	Ostracoda Latreille, 1806
Order	Podocopida Müller, 1894
Suborder	Podocopina Müller, 1894
Superfamily	Cytheracea Baired, 1850
Family	Limnocytheridae Klie, 1938
Subfamily	Timiriaseviinae Mandelstam, 1960
Genus	*Gomphocythere* Sars, 1924

Gomphocythere akalypton Whatley and Bajpai, 2002

(Pl.1, fig. A-H)

Locality and horizon: Buff coloured chert from Phulsagar; grey chert from Papro.

Material: 30 carapaces from Phulsagar; 5 carapaces from Papro.

Description: Medium to large species of *Gomphocythere*. Subrectangular in lateral view; anterior margin broadly rounded with apex at mid height; posterior margin less broadly rounded than anterior margin; dorsal margin long and straight; median sulcus pronounced, sigmoidal in shape; A smaller, shorter sulcus is present anterio-dorsally of the main one; left valve larger than right valve; ornamentation reticulate and punctate.

Remarks: *G. akalypton* differs from *G. gomphotatos* of Lakshmipur, Kutch (Whatley and Bajpai, 2000a) in being notably smaller, more coarsely ornamented and in lacking the large number of secondary puncta within the reticulum. *Gomphocythere* sp. of Lakshmipur, Kutch (Whatley and Bajpai, 2000) is larger, punctate and has a very strong subponticulate ventro-lateral rib. *G. dasyderma* from Yanagundi, Karnataka (Whatley *et al.*, 2002), differs in being much less strongly inflated, much more acuminate posteriorly. *Gomphocythere paucisulcatus* (Whatley *et al.*, 2002) is a little smaller than the present species but has a reticulum of larger fossae. The present species from Lalitpur is slightly larger in size than the species from the Phulsagar locality. It may be due to presence of juvenile species in the Phulsagar. At Phulsagar, it constitutes a good assemblage and in Lalitpur locality it is one the more abundant species.

Gomphocythere paucisulcatus Whatley *et al.*, 2002

(Pl.1, fig. I-N)

1999 *Gomphocythere* ? sp. 1 Bhandari & Colin: 13, pl. 1, figs 11-13.

Locality and horizon: Creamish marl from Nahardi; grey chert from Papro.

Material: 4 carapaces from Papro; 30 carapaces from Nahardi

Description: A medium species of *Gomphocythere;* Slightly inflated; subovate to subrectangular in lateral view; anterior margin well rounded with apex below mid height; posterior margin more asymmetrically rounded with apex at mid height; dorsal margin long and straight; ventral margin with slight oral concavity; very slight median sulcus at mid length; left valve slightly larger than right valve; ornamentation reticulate.

Remarks: *G. akalypton* from Gulbarga, Karnataka (Whatley *et al.*, 2002b) is only slightly larger than the present species but differs in having a reticulum of smaller fossae, a very strongly developed median sulcus and in being strongly inflated and much more acumintate anteriorly than posteriorly. *G dasyderma* from Yanagundi, Karnataka (Whatley *et al.*, 2002b) is also rather larger, has a different ornament and a much stronger median sulcus. *G strangulata* (Jones, 1860) is much larger and has a much stronger median sulcus. *G. gomphotatos* from Lakshmipur, Kutch (Whatley and Bajpai 2000a) is considerably larger, has a much more delicate ornament and is strongly sulcate. *Gomphocythere* sp. of Lakshmipur, Kutch (Whatley and Bajpai, 2000) is also much larger, has a punctuate ornament, is sulcate and has a strong subponticulate ventro-lateral rib. This species is abundant in Nahardi and Papro intertrappean localites. Previously this species has also been reported earlier from Mohagaonkala, Chhindwara District (Whatley *et al.*, 2003b) and from the Lameta Formation at Dongargargaon, Maharashtra (Khosla *et al.*, 2005).

Gomphocythere strangulata (Jones, 1860)

(Pl.1, fig. O; Pl. 2, fig. A-B)

1860 *Cypria strangulata* spec. no. Jones, p. 187, Pl. 10, Fig. 73, a-d.
1984 *Metacypris strangulata* (Jones). Bhatia & Rana, (partim.) p. 33, Pl. 2, Figs. 8, 9; non Pl. 3, Figs 4-7 (4, 5= *Paracandona firmamentum* Whatley & Bajpai, p.339, Pl. 5, Figs. 1-6; 6,7=*Frambocythere tumiensis anjarensis* Bhandari & Colin, p. 12, pl. 1, Figs. 1-10).
1996 ? *Cytheridella strangulata* Jones (sic). Udhoji & Mohabey, p. 413, Pl. 2 Figs. 1-3.

Locality and horizon: Pink clays from Jhilmili (JH25).

Material: 10 carapaces.

Description: A large to very large species of *Gomphocythere* with ornamentation of polygonal and hexagonal reticulate; main median sulcus deep and sinuous, with smaller sulcus anteriorly; two tubercules occur dorsally between the two sulci and a flatter tublercle occurs just above the position of the adductor scars.

Remarks: The original material studied by Jones (1860) was collected by the Rev. Messrs. Hislop and Hunter from the neighbourhood of Nagpur. Bhatia and Rana (1984) also recovered the species from Gitti Khadan area near Nagpur, While Bhatia *et al.* (1990a) and Bhatia *et al.* (1996) record it fromTakli, also near Nagpur and also from Asifabad in Andhra Pradesh. Bhatia *et al.* (1990b) found the species at Mamoni in Kota District, Rajasthan. Udhoji and Mohabey (1996) encountered the species in the Upper Cretaceous Lameta formation of Maharashtra. Whatley *et al.* (2002b) recorded this species from Yahnagundi, Gulbarga District, Karnataka.

Genus *Frambocythere* Colin, 1980

Frambocythere tumiensis lakshmiae Whatley and Bajpai, 2000

(Pl. 3, fig. C-F)

Locality and horizon: Creamish marl from Dayapar; grey chert from Papro; mudstone from Lakshmipur; pink clays from Jhilmili (JH25).

Material: Single carapace from Papro; 4 carapaces from Dayapar; 10 specimens from Jhilmili; over 50 carapaces from Lakshmipur.

Description: A very small species with right valve larger than left valve; papillate ornamentation all over except on dorsal part of the anterio-marginal area; highly inflated; median sulcus pronounced; anterior margin broadly rounded; posterior margin less broadly rounded than the anterior.

Remarks: This species is different from *Frambocythere tumiensis anjarensis* (Bhandari and Colin, 1999) in its overlap which is normal in the latter (left valve>right valve) and is reverse in the fromer. Also, the anterior margin is more rounded and lacks the large papillate tubercles on the dorsal part of the anterior-marginal area. Further, in the present subspecies, the papillae paralleling the posterior part of the dorsal margin are much less pronounced. This species is one of the most abundant species in Lakshmipur locality but rare in Lalitpur and Dayapar species assermblage. This species has been previously reported from Lakshmipur, Gujarat (Whatley and Bajpai, 2000a) and Mohagaonkala, Chhindwara District (Whatley *et al.*, 2003b).

Frambocythere tumiensis anjarensis Bhandari and Colin, 1999

(Pl. 3, fig. A-B)

Locality and horizon: Yellow and pink clays from Jhilmili (JH16 to JH26).

Material: 20 carapaces.

Description: Very small species; left valve larger than right valve; the anterior margin is more rounded; papillate ornamentation; tubercles on the dorsal part of the anterior-marginal area; highly inflated; median sulcus pronounced.

Remarks: The species was initially recorded from the Late Cretaceous (Maastrichtian) beds of Anjar, Kutch District, Gujarat (Bhandari and Colin, 1999). The species has also been reported from the intertrappean beds of Yanagundi and Chandarki in Gulbarga District, Karnataka (Whatley *et al.*, 2002a) and Mamoni in

Kota District, Rajasthan (Whatley *et al.*, 2003a) and the Lameta Formation of Dongargaon, Maharashtra (Khosla *et al.*, 2005).

Limnocythere deccanensis Khosla *et al.*, 2005

(Pl. 2, fig. C-L)

Locaity and horizon: Buff coloured chert from Phulsagar; creamish marl from Nahardi; yellow and pink clays from Jhilmili (JH16 to JH26).

Material: Over 100 carapaces from Phulsagar; 3 carapaces from Nahardi; over 100 carapaces from Jhilmili.

Description: Carapace quadrate in lateral view; left valve larger than right valve; dorsal margin nearly straight sloping down posteriorly; ventral margin medially concave; anterior margin broad, obliquely rounded; posterior margin comparatively narrow, evenly rounded; somewhat flat sided, ends compressed, anterior being more than posterior. Valve marked by median vertical sulcus, broad upwards and narrowing downwardly; an arcuate anterior depression; characterized by antero ventral rib.

Remarks: This species was originally named as *L. bhatiai,* based on material from Phulsagar (Bajpai *et al.*, 2004). However, as pointed out by Khosla and Nagori (2007), this name is preoccupied by a species recorded from the Pliocene Tatrot Formation Upper Shivalik (Mathur, 1976). Khosla and Nagori, 2007 has retained *Limnocythere deccanensis* Khosla *et al.* (2005) as the valid name for *L. bhatiai.* This species occurs in good amount in Phulsagar and is rare in Nahardi and Jhilmili intertrappean localities. *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). It is the most abundant species in the present collection.

***Limnocythere* sp.**

(Pl. 2, fig. M-O)

Locaity and horizon: Yellow and pink clays from Jhilmili (JH16 to JH26).

Material: 5 carapaces.

Description: Carapace triangular in lateral view; reticullate ornamentation; left valve larger than right valve; dorsal margin slopes towards anterior margin at a high angle; ventral margin medially concave; anterior margin broad, obliquely rounded; very narrow posterior margin; ventral margin slightly concave towards posterior margin; slightly compressed anterior and posterior margins; sulcus towards anterior margins on the ventral side.

Remarks: *Limnocythere* sp. differs from *L. deccanensis* in being triangular in outline which is quadrate in 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.This is probably a new species but will be formally named when additional material becomes available.

Family	Cytherideidae
Subfamily	Cytherideinae
Genus	*Neocyprideis* Apostolescu, 1957

Neocyprideis* cf. *N. raoi (Jain, 1978)

(Pl. 14, fig. O; Pl. 15, fig. A-H)

Overcytheridea raoi Jain, 1978, p. 53, pl. 1, figs. 7-10; Bhandari, 1995, p. 95, 96, pl. 2, figs. 1,2.

Locality & Horizon: Pink clays from in Jhilmili (JH21 to JH25).

Material: 25 carapaces.

Description: 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 hight slightly anterior to the middle; dorsal margin arched.

Remarks: The species has been previously described as *Ovocytheridea raoi* by Jain (1978) from the intertrappean beds of Kateru, Rajahmundry and from Duddukuru, Godavari District, Andhra Pradesh (Bhandari, 1995). It is for the first time that a brackish water species is recorded from a continental intertrappean locality in the Deccan volcanic province. *Neocyprideis raoi* (Khosla and Nagori, 2002) was earlier described from the intertrappean beds (Early Paleocene) of Rajahmundry (east coast) of India. It occurs abundantly in the present collection.

Superfamily Darwinulacea Brady and Norman, 1889

Family Darwinulinidae Brady and Norman, 1889

Genus *Darwinula* Brady and Norman, 1885

***Darwinula* sp.**

(Pl. 3, fig. G-I)

Locality and horizon: Creamish marl from Dayapar.

Material: 4 carapaces from Dayapar.

Description: Small species of *Darwinula*. Triangular to subtriangular in shape; surface smooth; anterior margin narrowly rounded with apex above mid-height except in one specimen (pl. 3, fig. I) where apex is at or slightly below mid- height. Dorsal margin conspicuously high and much lower anteriorly; dorsal margin slopes towards anterior margin at a high angle; ventral margin straight in some specimens; right valve larger than left valve.

Remarks: The present species pertains to a new species but for nomenclature is deferred for want of additional material. It is smaller than *Darwinula torpedo* of Yanagundi, Karnataka (Whatley *et al*., 2002b). The dorsal margin of this species is very high posteriorly in comparison to *Darwinula torpedo*. The length is more than height in *Darwinula torpedo* but the present species is as long as high. The genus has been recorded from Gulbarga, Karnataka (Whatley *et al*., 2002b), Kora, Kutch (Bajpai and Whatley, 2001) and from Lameta formation of Jabalpur (Khosla and Sahni, 2000).

Darwinula torpedo Whatley *et al*., 2002

(Pl. 3, fig. J-K)

Locality and horizon: Pink clays from Jhilmili (JH24).

Material: Two carapaces.

Description: A medium, elongate and subcylindrical in lateral outline; anterior margin narrowly rounded; apex well below mid-height; posterior broadly rounded to subtrauncate; apex at or below mid height; dorsal margin straight to very gently convex; ventral margin without marked oral concavity; valve subequal or with right valve slightly larger than left valve.

Remarks: The species has been recorded from the intertrappean beds of Yanagundi section Gulbarga District, Karnataka (Whatley *et al.*, 2002b). The *Dawinula* sp. has also been recorded from the intertrappean beds of Kora, Kutch (Bajpai and Whatley, 2001) and from the Lameta formation of Jabalpur (Khosla and Sahni, 2000).

Superfamily	Cypridacea Baird, 1845
Family	Cyprididae Baird, 1845
Subfamily	Bradycypridinae Hratmann and Puri, 1974
Genus	Paracypretta Sars, 1924

Paracypretta subglobosa (Soweby, 1840)

(Pl. 3, fig. L-O; Pl. 4, fig. A)

1840 *Cypris subglobosa* J. de C. Sowerby, in Malcolmson, description in unpaginated explanation of Pl. 47, fig. 3

1988 *Paracypretta* sp. Mathur and Verma, p. 172, Pl. 1, fig. 7a-b.

1990b *Altanicypris szczechurae* (Stankevitch); Bhatia, Srinivasan, Bajpai and Jolli, p. 118, PL. 1, FIGS 9-10.

Locality and horizon: Creamish marl from Nahardi; yellow and pink clays from Jhilmili (JH17, JH19 and JH25).

Material: 2 carapaces from Nahardi; 20 carapaces from Jhilmili.

Description: Very large, highly inflated anterior margin strongly laterally compressed with apex below mid height; left valve larger than right valve; subovate to subtriangular in lateral view; greatest width centrally; posterior margin asymmetrically rounded with long gently convex posterior dorsal slope; apex below mid-height; dorsal margin strongly arched; with apex at about mid-length; papilatte ornamentation.

Remarks: This species differs from *P. elizabethae* from Kora in Kutch District (Bajpai and Whatley, 2001) in its papillate ornamentation which is punctate in the latter. *P. subglobosa* is more inflated than *P. elizabethae*. Also, in dorsal and ventral views, *P. subglobosa* is rounded posteriorly whereas *P. elizabethae* is pointed. The present species was first described from Sichel Hills, Andhra Pradesh (Sowerby, 1840) under the name *Cypris subglobosa*. Subsequently it was recorded from the intertrappean beds of Mamoni, Kota, Rajasthan (Whatley *et al*., 2003a).

Paracypretta jonesi Bhatia and Rana, 1984

(Pl. 4, fig. B-K)

1994 *Altanicypris* sp. Sahni and Khosla, p. 458, figs. n-p.

2000 *Paracypretta* sp. Bajpai and Prasad, p.258, fig. 2f.

2000 *Altanicypris bhatiai* Khosla and Sahni, p. 58, pl. 1, figs a-g.

2000b *Paracypretta Bhatiai* (Khosla and Sahni); Whatley and Bajpai, p. 174, pl. 1, figs 1-3.

2002 *Paracypretta bhatiai* (Khosla and Sahni); Whatley, Bajpai and Srinivasan, p. 3, figs 1-5.

Locality and horizon: Yellow and pink clays from Jhilmili (JH17, JH19 and JH25); Splintery shale from Anjar (Unit-3).

Material: 20 carapaces from Jhilmili; 15 valves from Anjar.

Description: Very large, inflated, subtriangular in lateral view; left valve larger than right valve; 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.

Remarks: *Paracypretta jonesi* is similar in dorsal and ventral view to *P. subglobosa* but in the latter species the ornament is papillate and not oriented parallel to the ventral margin. The present species 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. It 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, M.P (Sahni and Khosla, 1994; Khosla and Sahni, 2000) and Lameta Formation of Dongargaon area, Chandrapur District (Khosla *et al.*, 2005). This species is one of the most common species in the present collection.

Paracypretta elizabethae Bajpai and Whatley, 2003

(Pl. 4, fig. L-M)

1986 *Paracypretta jonesi* Bhatia and Rana; Prasad, p. 71, figs. 14-15

Locaity and horizon: Creamish marl from Dayapar.

Material: Over 50 carapaces.

Description: Very large, moderately inflated species of *Paracypretta.* Punctuate over entire surface; posterior end pointed; regularly fusiform in dorsal and ventral views; anterior margin broadly and only slightly assymetrically rounded, with anterio-dorsal slope gently convex to almost straight; left valve larger than right valve; dorsal margin strongly arched and almost umbonate; ventral margin with slight oral concavity.

Remarks: *P. elizabethae* is much less strongly inflated, its anterior margin is less laterally compressed and it posseses keel-like structures antero- and postero-ventrally which makes it different from *P. subglobosa*. So far, this species has been reported from Anjar and Kora in District Kutch (Whatley and Bajpai, 2000b; Bajpai *et al.*, 2001) and from Chandarki, District Gulbarga, Karnataka (Whatley *et al.*, 2002b). It is one of the most common species in the present collection.

***Paracypretta* sp. 1**

(Pl. 4, fig. N)

Locality and horizon: Grey chert from Papro.

Material: Single carapace.

Description: Large, smooth, inflated species of *Paracypretta.* Anterior margin well rounded but narrowly than the posterior margin with apex below mid height; umbonate dorsal margin; left valve larger than right valve; ventral margin slightly convex; long anterio-dorsal slope; anterior margin slightly compressed.

Remarks: This species is different from other species of *Paracypretta* in being smooth and in its slightly compressed anterior margin as compared to *P elizabethae* and *P subglobosa* in which the anterior margin is strongly compressed. It is possibly a new species.

***Paracypretta* sp. 2**

(Pl. 4, fig. O; Pl. 5, fig. A-C)

Locality and horizon: Pink clays from Jhilmili (JH25).

Material: 10 carapaces.

Description: 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; ornamentation is reticulate.

Remarks: This species differs from other species of *Paracypretta* in its reticulate ornatmentation. The ornamentation is punctate in *P. jonesi* and *P. elizabethae* papillate in subglobosa. This species is confined to the present locality.

Subfamily Cypridopsinae Kaufmann, 1900

Genus Cypridopsis Brady, 1868

Cypridopsis wynnei Whatley and Bajpai, 2000

(Pl. 5, fig. D-L)

1974 ?*Lycopterocypris buginstavicus* Stankevitch in Stankevitch & Sochava, p.281, pl. 2, fig. 9

1978 ?*Cypridopsis buginstavicis* (Stankevitch). Szczechura, p. 99, pl. 31, figs. 2,3.

1994 ? *Cypridopsis buginstavicus* (Stankevitch). Sahni and Khosla, figs. 2K,l.

Locality and horizon: Creamish marl from Nahardi and Dayapar; mudstone from Virani locality.

Material: Over 50 carapaces Nahardi; over 30 carapaces from Dayapar; 3 carapaces from Virani locality.

Description: Large, smooth, globular species of *Cypridopsis*. Subcircular in lateral view; strongly inflated; laterally compressed at anterior end with anterior margin broadly rounded; posterior margin more narrowly rounded; dorsal margin short straight and inclined towards the posterior; left valve larger than right valve.

Remarks: *C. wynnei* differs from *C. hyperectyphos* is being larger, less inflated and in being smooth. So far, *C. wynnei* Reported from Lakshmipur (Whatley and Bajpai, 2000a), Lameta formation, Jabalpur, M.P (Khosla and Sahni, 2000), Takli, Nagpur (Bhatia *et al.*, 1996), Chickni, Chandrapur, District Maharashtra (Whatley *et al.*, 2002, 2003 a,b), Chandarki and Yanagundi, Gulbarga Karnataka (Whatley *et al.*, 2002) and Bombay intertrappeans (Whatley *et al.*, 2003c). This species also occurs in Nahardi intertrappean locality and is common in the Dayapar intertrappean locality

Cypridopsis hyperectyphos Whatley and Bajpai, 2000

(Pl. 5, fig. M-O; Pl. 6, fig. A-K)

Locality and horizon: Creamish marl from Dayapar and Nahardi intertrappean; grey chert from Papro; splintery shale from Anjar (Unit-3); mudstone from Virani and Lakshmipur intertrappeans.

Material: Over 30 carapaces from Dayapar; 5 carapaces from Papro; 5 carapaces from Nahardi; 3 carapace from Virani; single carapace from Anjar.

Description: Medium sized; triangularly subovate in lateral view; strongly inflated and delicately punctate species of *Cypridopsis.* Almost circular in dorsal and ventral views; anterior margin very broadly rounded; posterior margin more narrowly rounded; dorsal margin umbonate; left larger than right valve with strong overlap in anterior half of carapace.

Remarks: *C. hyperectyphos* has been previously recorded from the intertrappean beds of Lakshmipur (Whatley and Bajpai, 2000a), Kora (Bajpai and Whatley, 2001) and Anjar (Khosla and Nagori, 2005) Kutch District 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). This is one of the common species in Dayapar intertrappean locality. At Papro also it occurs abundantly.

Cypridopsis whatleyi Bajpai *et al.*, 2004

(Pl. 6, fig. L; Pl. 7, fig. A-C)

2002 *Gomphocythere* sp. Whatley, Bajpai & Whittaker, p. 165, Pl. 1, figs. 2-3.

Locaity and horizon: Buff coloured chert from Phulsagar.

Material: Over 50 carapaces.

Description: Large to very large; fusiform in dorsal view with two distinct swellings in the posterior half; subcircular in lateral view; dorsal margin arched; ventral margin with shallow incurvature; carapace laterally compressed anteriorly; left valve larger than right valve, overlap particularly distinct anteriorly; delicately reticulate ornamentation; internal features not seen. It is commonly known from the present locality.

Remarks: This is a fairly common species in the present collection from Phulsagar. The first record of this species was based on a single specimen which was placed in the genus *Gomphocythere* (Whatley *et al.*, 2002). The present material confirms that it is referable to *Cypridopsis.*

Cypridopsis sp. 1

(Pl. 7, fig. D-E)

Locality and horizon: Grey chert from Papro.

Material: 2 carapaces.

Description: Small, smooth, slightly inflated species of *Cypridopsis.* Anterior angle narrowly rounded; posterior angle broadly rounded with apex of both the margins at mid height; left valve larger than right valve.

Remarks: This species is being recorded for the first time from the intertrappean beds of India. It will be formally named when additional material is recovered.

Cypridopsis sp.2

(Pl. 7, fig. F-H)

Locality & horizon: mudstone from Virani.

Material: 3 carapaces.

Description: Medium, subshperical species of *Cypridopsis*. Ornamentation is punctuate; left valve larger than right valve; anterior angle broadly rounded; posterior angle rounded narrowly than the anterior; dorsal margin umbonate; ventral margin slightly concave.

Remarks: The present species appears to be similar to *Cypridopsis* sp. reported from Lakshmipur, Kutch (Whatley and Bajpai, 2000a).

Genus *Zonocypris* Müller, 1894

Zonocypris spirula Whatley and Bajpai, 2000

(Pl. 7 fig. I-N)

Locality and horizon: Creamish marl from Nahardi; grey chert from Papro; pink clays (JH25) from Jhilmili.

Material: 3 carapaces from Nahardi; 2 carapaces from Papro; 20 carapaces from Jhilmili.

Description: A very small species of *Zonocypris*; tumid and strongly biconvex in dorsal view; anterior margin well rounded with apex at mid height; ventral margin straight; dorsal margin fusiform and short, straight and inclined towards the posterior; left valve larger than right valve; ornament of a single spiral helix comprising a single rib spirally coiled about mid-valve; initial coil is somewhat angular and the remainder more or less circular; Slightly inflated.

Remarks: This species differs from *Zonocypris gujarantensis* Bhandari & Colin (1999) in being somewhat larger, less circular in lateral view and in much more angularly tumid in dorsal view. Also, the latter species has much more angular intial coils and less convolutions overall in its spiral ornament. *Zonocypris spirula* has been widely recorded from the intertrappean beds of Lakshmipur (Whatley and Bajpai, 2000), Kora (Whatlley *et al.*, 2002c) and Anjar (Khosla and Nagori, 2005) in Kutch District, Gujarat and Yanagundi, Gulbarga District, Karnataka (Whatley *et al.*, 2002c); Mohagaonkalan, Chhindwara District (Khosla and Nagori, 2007) and from the Lameta Formation of Dongargaon, Chandrapur District, Maharashtra (Khosla *et al.*, 2005). This species occurs abundantly in the Jhilmili intertrappean section.

Zonocypris viriensis Khosla and Nagori, 2005

(Pl. 7, fig. O; Pl. 8, fig. A-C)

Locality and horizon: Yellow and pink clays (JH16-JH25) from Jhilmili.

Material: Over 100 carapaces.

Description: Carapace short and high, subovate in lateral outline. Greatest height ¾ of length slightly anterior to middle; left valve larger than right valve, overlapping disticlty around anterior and ventral margins; dorsal margin strongly convex, asymmetrical. ventral margin sinuate; anterior margin broadly rounded; posterior margin narrowly rounded in lower half; in dorsal view carapace very inflated; maximum width almost equal to length, behind middle. Valve surface ornamented by fine stiations concentrically arranged in the peripheral region and irregularly disposed in the middle.

Remarks: This species has been preiviously reported from the intertrappean beds of Anjar, District Kutch (Khosla and Nagori, 2005).

Subfamily Eucyprininae Bronsthein, 1947

Genus *Eucypris* Vávra, 1891

Eucypris intervolcanus Whatley and Bajpai, 2000

(Pl. 8, fig. D-K)

2000a *Eucypris intervolcanus* sp. nov. Whatley & Bajpai: 401,pl. 5, figs 16–19.

2001 *Eucypris intervolcanus* Whatley & Bajpai; Bajpai &Whatley: 103, pl. 3, figs 4, 7.

2002a *Eucypris intervolcanus* Whatley & Bajpai; Whatley *et al*.: pl. 4, fig. 11.

Locality and horizon: Buff coloured chert from Phulsagar; gray chert from Papro; mudstone from Virani.

Material: Over 20 carapace from Phulsagar; 4 carapace from Papro; single carapace from Virani.

Description: Medium to large species of *Eucypris*. Surface smooth. Greatest height at mid-length; subovate in lateral view; anterior margin well rounded but more narrowly than Posterio; apex below mid-height; anterio-dorsal slope long; posterior margin broadly rounded with apex at mid-height; dorsal margin sloping towards posterior; ventral margin concave; left valve larger than right valve.

Remarks: This species is smaller than *E. pelasgicos* and has much more rounded margins. It was previously recorded from Lakshmipur (Whatley and Bajpai, 2000), Kora, Kutch (Bajpai and Whately, 2001) and Yanagundi, Karnataka (Whatley *et al*., 2002b).

Eucypris pelasgicos Whatley and Bajpai, 2000

(Pl. 8, fig. L-O; Pl. 9, fig. A-L)

Non 1970 *Candona altanulaensis* Szczechura & Blaszyk, p.114, pl. 29, figs 2, 4.

?1965 *Eucypris* sp. Khanna & Mohan: fig 2, 1.

1990 *Candona altanulaensis* Szczechura & Blaszyk; Bhatia *et al.*, pl. 3, fig. 3.

1996 *Candona altanulaensis* Szczechura & Blaszyk; Bhatia *et* al., 297, pl. 3, fig. 3.

Locality and horizon: Creamish marl from Dayapar and Nahardi; mudstone from Virani; splintery shale from Anjar (Unit-3).

Material: Over 100 specimens from Phulsagar; 30 carapaces from Dayapar; 10 Carapaces from Nahardi; 2 carapaces from Virani; 10 carapaces from Anjar.

Description: Large, smooth species of *Eucypris*. Elongate to subovate in lateral view; umbonate dorsal margin; anterior margin well rounded with long anterio-dorsal slope with apex a little below mid-height; dorsal margin rounded in left valve and very bluntly pointed in right valve; dorsal margin distinctly umbonate at mid-length; ventral margin almost straight with slight oral incurvature; left valve larger than right valve.

Remarks: This species was reported previously from the intertrappean beds of Lakshmipur (Whatley and Bajpai, 2000a), Kora (Bajpai and Whatley, 2001), Mohagaonkalan Chhindwara District (Whatley *et al.*, 2002b) and from the Lameta Formation of Dongargaon, Chandrapur District, Maharashtra (Nagori and Mohabey, 2005). This is one of the dominant species at Phulsagar and in Dayapar.

Eucypris catantion Whatley *et al.*, 2003

(Pl. 9, fig. M-O; Pl. 10, fig. A)

2001 *Darwinula* sp. Bajpai & Whatley, p. 95, pl. 1, figs. 1, 3.

Locality and horizon: Creamish marl from Dayapar; grey chert from Papro.

Material: 10 carapaces from Dayapar; single carapace from Papro.

Description: Large species of *Eucypris* with a very narrowly pointed anterior margin; left valve larger than right valve but with right valve overlapping left valve mid-dorsally; posterior margin subtruncate in left valve and rounded in right valve; dorsal margin with distinct break of slope just behind mid-length behind which it is a straight and sloping gently towards posterior; ventral margin almost straight in left valve with slight median concavity; left valve larger than right valve; greatest height at about mid-length.

Remarks: *E. intervolcanus* (Whatley and Bajpai, 2000a) is considerably larger and has its posterior apex more rounded and higher. *E. pelasgicos* (Whatley and Bajpai, 2000a) is much larger, with adults exceeding 1mm in length and is different in shape than the present species. *E. verruculosa* (Whatley *et al.*, 2002b) is different in shape and has a delicately reticulate ornament. So far, this species has only been reported from Kora (Bajpai and Whatley, 2001) and Mamoni (Whatley *et al.*, 2003a).

Eucypris verruculosa Whatley *et al.*, 2002

(Pl. 10, fig. B-E)

Locality and horizon: Creamish marl from Dayapar.

Material: Over 10 carapaces.

Description: Large with well rounded anterior margin; posterior is more narrowly rounded; ornamentation reticulate with well scattered papillae; elongated irregularly; subovate in lateral view; anterior margin well rounded with apex at mid-height; dorsal margin straight, sloping posteriorly; left valve larger than right valve; known only from Chandarki, Gulbarga District, Karnataka (Whatley *et al.*, 2002).

Remarks: This species is different in shape from *E intervolcanus*, *E catantion* and *E. pelasgicos*. So far it has been described from Chandarki in Gulbarga (Whatley *et al.*, 2002b), Sichel Hills, Andhra Pradesh (Whatley *et al.*, 2003b) and from Takli intertrappean beds of Nagpur (Khosla and Nagori, 2007).

Eucypris phulsagarensis Bajpai *et al.*, 2004

(Pl. 10, figs. F-J)

Locality and horizon: Buff coloured chert from Phulsagar.

Material: Over 50 carapaces.

Description: Medium sized; regularly fusiform in dorsal view; anterior margin much broadly rounded than posterior; dorsal margin straight, oblique, sloping posteriorly; ventral margin with a pronounced posterior incurvature; left valve slightly larger than right valve; surface with scattered wart-like papillae; internal features not seen.

Remarks: The present generic assignment is tentative. No similar species are known to the authors from any other intertrappean deposits or from contemporary Chinese and Mongolian faunas. This species occurs abundantly in the present locality (Bajpai *et al.*, 2004).

***Eucypris* sp.**

(Pl.10, fig. K-L)

Locality and Horizon: Grey chert from Papro.

Material: 2 carapaces.

Description: Large, subovate with the anterior margin slightly more compressed than posterior margin; umbonate dorsal margin; anterio-dorsal slope steeper than posterior-dorsal slope; both the margin well rounded with apex little below mid-height in both; both the valves are of equal size.

Remarks: This species differs from *Eucypris pelasgicos* and *E. intervolcanus* from Lakshmipur, Kutch (Whatley and Bajpai, 2000a) in which the left valve is larger than right valve. In *Eucypris catantion* the anterior margin is more narrowly pointed. *Eucypris phulsagarensis* is different from the present species in having much more broadly rounded anterior angle and in its surface having wart like papillae.

Subfamily Herpetocypridinae Kaufmann, 1900

Genus *Mongolianella* Mandelstam, 1955

Mongolianella cylindrica (Sowerby, 1840)

(Pl. 10, fig. M-O; Pl. 11, fig.A-Q)

1840 *Cypris cylindrica* Sowerby (in Malcolmson). Unnumbered page plate discription, pl. 47, fig. 2.

Non 1955 *Mongolianella palmosa* Mandelstam in Galeeva, p. 46, pl. 11, fig. 2.

Non 1956 *Mongolianella palmosa* Mandelstam. Ljubinova, p. 86, pl. 18, figs. 2, 3.

Non 1978 *Mongolianella palmosa* Mandelstam. Szczechura, p. 103, pl. 32, figs. 3, 4.

Non 1990a *Mongolianella palmosa* (Mandelstam). Bhatia, Prasad & Rana, p. 47, pl. 2, Fig. 8.

1994 *Mongolianella palmosa* Mandelstam. Sahni & Khosla. p. 458, fig. 2 q, r.

Non 1996 *Mongolianella palmosa* (Mandelstam). Bhatia, Prasad & Rana, p. 306, pl. 2, fig. 8.

1999 *Mongolianella* sp. 2 Bhandari & Colin: 16, pl. 2, fig. 11.

2000 *Mongolianella palmosa* Mandelstam. Khosla & Sahni. p. 59, fig. 3 k, 1; 4 a-e.

Locality and horizon: Creamish marl from Dayapar and Nahardi; grey chert and Buff coloured chert from Papro and Phulsagar, respectively; pink clays (JH25) from Jhilmili; mudstone from Virani and Lakshmipur; spilintery shale from Anjar (Unit-3).

Material: 20 specimens from Phulsagar; 10 carapaces from Nahardi; 4 carapaces from Papro; 1 carapace from Virani; 2 carapaces from Jhilmili and Anjar; over 50 carapace from Lakshmipur.

Description: Large to very large, elongate, subrectangular to sub cylindrical, smooth species of *Mongolianella*. Fusiform in dorsal view; anterior end slightly more laterally compressed than posterior; left valve overlapping right valve strongly around the free margins; anterior margin narrowly rounded; posterior margin bluntly pointed; dorsal margin straight; ventral margin with shallow oral incurvature; greatest length through mid-height; greatest height at the anterior cardinal angle and greatest width medially.

Remarks: This species is widely known from peninsular India. It was originally reported from Nutnoor, Sichel hills, Andhra Pradesh (Sowerby, 1840), Narli (Mathur and Verma, 1988) and from the intertrappean beds of Asifabad, Andhra Pradesh (Bhatia *et al.*, 1996); Gitti Khadan,Nagpur (Bhatia and Rana, 1984), Takli (Bhatia *et al.*, 1996; Khosla and Nagori, 2007); Chandarki, Karnataka (Whatley *et al.*, 2002b), Lakshmipur (Whatley and Bajpai, 2000a) and Kora (Bajpai and Whatley, 2001) in

District Mamoni, Rajasthan (Whatley *et al.*, 2003a), Phulsagar, Mandla District (Bajpai et al., 2004). The species has also been described as *Mongolianella* sp. from the Lameta Formation, Jabalpur (Sahni and Khosla, 1994; Khosla and Sahni, 2000)

Mongolianella subarcuata Whatley *et al.*, 2003

(Pl. 11, fig. R; Pl. 12, fig. A-D)

2001 *Mongolianella* sp. B. Bajpai & Whatley, p. 104, pl. 3, figs. 11

Locality and horizon: Creamish marl from Dayapar and Nahardi; grey chert from Papro.

Material: 5 carapaces from Dayapar; 3 carapaces from Papro; 2 carapaces from Nahardi

Description: Small species of *Mongolianella subarcuate*, elongate subovate in lateral view; arched dorsal margin; medially concave ventral margin; anterior margin narrowly and asymmetrically rounded; posterior margin with downturned apex below mid-height; Dorsal margin narrow and bluntly pointed; LV larger than RV.

Remarks: This is half the size of *Mongolinella cylindrica*. It was previously recorded from the intertrappean beds of Kora District Kutch, Gujarat (Bajpai and Whatley, 2001), Mamoni District, Rajasthan (Whatley and Bajpai, 2003a) and Takli, District Nagpur, Maharashtra (Khosla and Nagori, 2007).

Family	Candonidae Kaufmann, 1900
Subfamily	Candoninae Kaufmann, 1900
Genus	*Candona* Baird, 1845

Candona amosi Whatley *et al.*, 2002

(Pl. 12, fig. E-I)

Non 1978 *Candona* (*Candona) sinensis* sp. n. Ho, in Hou et al., p. 160, pl. 7, fig. 34-54.

1999 *Candona* cf. *sinensis* Ho, 1978. Bhandari & Colin, p. 13, pl. 2, fig. 7.

2001 *Candona*?sp. Bhandari & Colin, 1999. Bajpai & Whatley, p. 102, pl. 2, fig. 13.

Locality and horizon: Creamish marl from Dayapar and Nahardi; grey chert from Papro. Splintery shale from Anjar (Unit-3).

Material: 5 carapaces from Dayapar; single carapace each from Nahardi and Anjar.

Description: Large, smooth species of *Candona* with well rounded end margins; anterior margin narrowly rounded with apex below mid-height; posterior margin with long convex posterior-dorsal slope and much shorter; more strongly convex, posterior ventral slope; ventral margin concave orally; left valve larger than right valve.

Remarks: This species differs from *Candona mysorephaseolus* from Yanagundi, Karnataka (Whatley *et al.*, 2002) in its considerably larger size and in its shape (very concave ventral margin). It recorded earlier from Kora (Bajpai and Whatley, 2001) and Yanagundi, Karnataka (Whatley, 2002) and Takli, Nagpur District (Khosla and Nagori, 2007).

Genus *Eucandona* Daday, 1900

Eucandona kakamorpha Whatley *et al.*, 2002

(Pl. 12, fig. J-R; Pl. 13, fig. A)

Locality and horizon: Creamish marl from Dayapar and Nahardi; mudstone Virani locality.

Material: 10 carapaces from Dayapar; 6 carapaces from Nahardi; single carapace from Virani.

Description: A median, smooth, high wedge-shaped species of *Eucandona*, with rounded anterior margin and strongly truncated posterior with long, almost straight posterior-dorsal slope; very high in proportion to length; dorsal margin short and slightly convex; ventral margin almost straight; left valve larger than right valve.

Remarks: This species has been reported previously only from Yanagundi, Karnataka (Whatley *et al.*, 2002b) and the Lameta Formation of Dongargaon, Chandrapaur District (Khosla *et al.*, 2005).

Genus *Paracandona* Hartwig, 1899

Paracandona firmamentum Whatley and Bajpai, 2000

(Pl. 13, fig. B-D)

2000 *Paracandona firmamentum* Whatley & Bajpai, p. 398-400, pl. 5, figs. 1-6.

Locality & horizon: Mudstone from Virani and Lakshmipur.

Material: Single carapace each from Virani and Lakshmipur.

Description: Medium to large; subovate to subrectangular in lateral view; asymmetrically fusiform in dorsal view with anterior more pointed than posterior; anterior margin well rounded, posterior margin more bluntly than anterior; dorsal margin straight; ventral margin with slight oral concavity; greatest length through mid-height; left valve larger than right valve; small scattered spinose tubercles all over the surface.

Remarks: The present species resembles *Paracandona jabalpurensis* Khosla and Sahni (2000), described from the Lameta Formation of Jabalpur, Madhya Pradesh in overall outline. However, *P. jabalpurensis* (Sahni and Khosla, 1994) from the Maastrichtian Lameta Formation differs from *P. firmamentum* in being substantially larger (i.e length 0.90 mm; height 0.58 mm) more ovate and inflated and less laterally compressed anteriorly. *Paracandona* sp. from Chandarki, Gulbarga (Whatley *et al.*, 2002) is much larger (1.04 mm in length) and *Paracandona* ? sp. 1 (Bhandari and Colin, 1999) from Anjar is only half the size of the present species. It has been previously recorded only from the intertrappean beds of Lakshmipur, Kutch (Whatley and Bajpai, 2000a).

?*Paracandona* sp.

(Pl. 13, fig. E-F)

Locality and horizon: Creamish marl from Dayapar.

Material: 2 carapaces

Description: Small, smooth, Subrectangular in lateral view. Both the margins well rounded; anterior margin slightly narrower than the posterior margin; apex at mid height in both the margins; dorsal margin straight; left valve larger than right valve; carapace is slightly compressed towards anterior side.

Remarks: No species similar to present species is known from any other intertrappean locality in India.

Family Cyclocypridinae Kaufmann, 1900

Genus *Cypria* Zenker, 1854

Cypria crytonidion Whatley and Bajpai, 2000

(Pl. 13, fig. G-O)

1984 *Cyprois* sp. Bhatia & Rana, p. 33, pl. 2, figs. 12.

1988 *Cyprois* sp. Mathur & Verma, p. 173, pl. 1, figs. 1,2.

Locality and horizon: Creamish marl from Dayapar and Nahardi; grey chert from Papro; mudstone from Lakshmipur.

Material: 50 carapaces from Dayapar; 6 carapaces from Nahardi; single carapace from Papro; over 100 carapaces from Lakshmipur.

Description: Medium sized, smooth, subqadrate to sub-circular in lateral outline; left larger than right valve with overlap all round except dorsally where right valve overreaches left valve; anterior margin bluntly rounded with apex just above mid-height; posterior margin subtruncate with apex below mid-height and with long, gently convex postero-dorsal slope; dorsal margin short, straight and slightly inclined towards the posterior. Greatest length below mid-height and greatest height in just anterior of mid point and greatest width through the centre of carapace.

Remarks: The species has been widely recorded from the intertrappean beds of Lakshmipur (Whatley and Bajpai, 2000a), Kora (Bajpai and Whatley, 2001), Anjar in

District Kutch, Gujarat (Khosla and Nagori, 2005), Takli, District Nagpur Maharashtra (Khosla and Nagori, 2007), Mohagaonkalan in Chhindwara District, Madhya Pradesh (Whatley *et al.*, 2003b; Khosla and Nagori, 2007), Yanagundi and Chandarki, Gulbarga District , Karnataka (Whatley *et al.*, 2002b) and the Lameta Formation of Dongargaon, Chandrapur District, Maharashtra (Khosla *et al.*, 2005). This species occurs commonly at Dayapar and Lakshmipur locality.

Family	Hyocyprididae Kaufmann, 1900
Subfamily	Cyprideinae Martin, 1940
Genus	*Limnocypridea* Lyubimova, 1956

Limnocypridea ecphymatos Whatley and Bajpai, 2000

(Pl. 13, fig. P-R; Pl. 14, fig. A-F)

1990 *Cypridea(pseudocypridea) longa* Hou. Bhatia, Prasad and Rana pl.2, figs. 3, 4.

1996 Mongolocypris lonha (Hou). Bhatia, Prasad and Rana p. 304, pl.2, figs. 3, 4.

2000 *Limnocypridea* sp. Bajpai & Prasad, fig. 2g

Locality and horizon: Buff coloured chert from Phulsagar; pink clays from Jhilmili (JH25) (Unit-3); splintery shale (unit 1) from Anjar.

Material: Over 100 specimens from Phulsagar; 8 carapaces from Jhilmili; single specimen from Anjar.

Description: A very large, thick shelled densely papillate (ornamentation) species of *Limnocypridea* with rounded end margins; left valve larger than right valve with strong overlap; anterior margin well rounded with apex at mid height; posterior margin bluntly rounded to sub-truncate with apex above mid-height; dorsal margin gently convex; ventral margin with slight oral concavity. Greatest length is near mid-height.

Remarks: This species was recorded earlier from the intertrappean beds of Anjar (Whatley and Bajpai, 2000b) and Kora (Bajpai and Whatley, 2001), District Kutch, Gujarat.

Genus *Cypridea* Bosquet, 1852

Cypridea cavernosa Khosla *et al.*, 2005

(Pl. 14, fig. G-I)

Locality & Horizon: Creamish marl from Nahardi

Material: 2 carapaces

Description: Medium, elongate, subovate in lateral outline; Left valve larger than right valve; anterior margin broad; posterior margin much narrow; dorsal margin arched, ventral margin nearly straight; biconvex in dorsal view; Surface tuberculate.

Remarks: The present species differs from *Cypridea pavnaensis* (Khosla *et al.*, 2005) from the Lameta formation of Dongargaon area, District Chandrapur (Maharashtra) in having tuberculate surface which is smooth in the latter. *Cypridea pavnaensis* is larger than the present species. This species has been reported previously only from Asifabad, Andhra Pradesh (Bhatia *et al.*, 1996) and Takli, Nagpur (Bhatia and Rana, 1985).

Family	Notodromadidae Kaufmann, 1900
Subfamily	Cyproidinae Hartmann, 1963
Genus	*Cyprois* Zenker, 1854

Cyprois rostellum Whatley and Bajpai, 2000

(Pl. 14, fig. J-L)

Locality and horizon: Creamish marl from Dayapar; grey chert from Papro.

Material: Single carapace from Dayapar; 2 carapaces from Papro.

Description: Large, smooth species of *Cyprois.* Subrounded in lateral view; laterally inflated in dorsal view

Remarks: This species was previously recorded from the intertrappean beds of Lakshmipur (Whatley and Bajpai, 2000a), Kora, District Kutch, Gujarat (Bajpai and Whatley, 2001) and Mohagaonkalan, District Chhindwara, Madhya Pradesh (Khosla and Nagori, 2007).

Subfamily	Notodromatinae Kaufmann, 1900
Genus	*Centrocypris* Vavra, 1895

Centrocypris megalopus Whatley and Bajpai, 2000

(Pl. 14, fig. M-N)

Locality & horizon: splintery shale (unit 1) from Anjar

Material: 2 carapaces.

Description: Large, subovate in lateral view; inflated but more laterally compressed anteriorly in dorsal view; anterior margin broadly and symmetrically rounded;

posterior margin narrowly rounded than anterior; dorsal and ventral margins are gently convex; carapace surface densely covered with small spinose or papillae.

Remarks: This species has been previously reported only from the intertrappean beds of Lakshmipur (Whatley and Bajpai, 2000a) locality of Kutch.

Class Granuloreticulosea Lee, 1990

Order Foraminiferida Eichwald, 1830

Superfamily Planomalinacea Bolli, Loeblich and Tappan,1957

Family Globigerinelloididae Longoria, 1974

Genus Globigerinelloides Cushman and Ten Dam, 1948

Globigerinelloides aspera Koch, 1926

(Pl. 17, fig. E)

Horizon and Locality: Yellow and pink coloured clays from Jhilmili (JH25).

Description: A planispiral bilaterally symmetrical forams; 5-6 globular chambers with a slow rate of chamber increase; spinose wall texture; aperture centered in the coiling direction.

Order Foraminiferada Eichwald, 1830

Sub-order Globigerinina Delage and Herouard, 1896

Superfamily Gobigerninacea Carpenter, Parker and Jones, 1862

Family Globerigerinidae Carpenter, Parker and Jones, 1862

Subfamily Globergerininae Carpenter, Parker and Jones, 1862

Genus *Globigerina* d'Orbigny,1826

Globigerina pentagona *(*Morozova, 1961*)*

(Pl. 17, fig. F-H)

Horizon and Locality: Yellow and pink clays from Jhilmili (JH19 & JH22).

Description: A morphotype with 4.5 to 5 globular chambers with the last chamber covering the umbilicus area; rimed lip covering the aperture.

Genus *Parasubbotina* Olsson *et al.*, 1992

Parasubbotina pseudobulloides (Plummer, 1926)

(Pl. 17, fig. I-L)

Horizon and Locality: Yellow and pink clays from Jhilmili (JH19-JH20 & JH24-JH25).

Description: This species typically has 4.5 to 5 rapidly increasing globular to slightly compressed chambers; a nearly flat spiral side; a slight umbilical depression; aperture spans from the umbilicus to the margin (umbilical-extra-umbilical) and in some specimens extends upto the into the spiral side.

Family Catapsydracidae Bolli, Loeblich and Tappan, 1957

Genus *Subbotina* Brotzen and Pozaryska,1961

Subbotina triloculinoides (Plummer, 1926)

(Pl. 17, fig. A-D, A1, B1; Pl. 18, fig. H)

Horizon and Locality: Yellow and pink clays from Jhilmili (JH19 & JH25).

Description: A form with 3 to 3.5 globular chambers with the last chamber occupying upto half of the test size; an umblical depression; aperture covered by a wall developed broad flap or lip; cancellate spinose wall texture.

Superfamily Rotaliporacea Sigal, 1958

Family Hedbergellidae Loeblich and Tappan, 1961

Genus *Hedbergella* Bronnimann and Brown, 1958

Hedbergella holmdelensis Olsson (1964)

(Pl. 18, fig. A-G)

Horizon and Locality: Yellow and pink clays from Jhilmili (JH19).

Description: 4.5 to 5 chambers; differ from *pseudobulloides* by its slightly compressed, nearly planispiral coil and a smoother perforate wall; aperture umbilical-etra-umbilical and covered broad rim similar to pseudobulloides; typically twice the size of holmdelensis; chambers not ovate compressed; aperture always covered by a broad lip; axial periphery evenly perforate.

Remarks: The chamber test wall is perforate, similar to the specimens illustrated by Olsson *et al.*, (1999). Moreover the chamber test wall is perforate similar to specimens illustrated by Olsson *et al.* (1999, p. 167), rather than smooth and lightly covered with small pustules as they described; perforate wall texture weakly cancellate although the primary structure is covered by digenetic calcification. Because of these differences, it is not clear whether these specimens are morphotypes of pseudobulloides or holmdelensis. In this study we tentatively assign these specimens to *H.* cf. *holmdelensis*, while keeping in mind that further study of shallow marine intertrappean sediments may yield a more definite identification.

Class	Gastropoda Cuvier, 1797
Subclass	Euthyneura
Order	Pulmonata Cuvier, 1814
Suborder	Basommatophora Keferstein, 1864
Family	Physidae Fitzinger, 1833
Genus	*Physa* Draparnaud, 1801

Physa prinsepii Hislop, 1860

(Pl. 16, fig. D-E)

Locality & horizon: Grey chert from Papro; creamish marl from Dayapar.

Material: 5 specimens from each locality.

Description: Shell oval in shape; dextrally coiled; spire with two whorls, short upto one third of the height of the shell; coiling of the worls narrowing anteriorly; apex blunt; aperture oval or elongate; surface of the shell smooth; body whorl large and slightly convex.

Remarks: *Physa* was long considered as an index taxon for the intertrappean beds based on its widespread occurrence in almost all peninsular Indian localities. It is known from Takli, Nagpur (Hislop, 1860, Rana, 1984), Rajahmundry Hislop, 1860, Asifabad (Prasad, 1985) and from many other intertrappean localities. In recent years it has also been recorded from the Lameta formation exposed at several localities such as Pisdura, Jabalpur (Tripathi, 1986) and intertrappean beds of

Lalitpur (Singh, 1980). Outside India, this species is known from the Late Cretaceous of Iran (Eames, 1968).

Subclass	Streptoneura
Order	Ctenobranchiata Schweigger, 1820
Suborder	Platypoda
Superfamily	Taenioglossa
Family	Viviparidae J.E Gray, 1847
Genus	*Paludina* Lamarck, 1816

***Paludina* sp.**

(Pl. 16, fig. A-B, F & I)

Locality & horizon: Grey chert from Papro.

Material: 4 specimens.

Description: Conical in shape; apex rounded or blunt; spire with two whorls; body whorl large in and highly convex; whorls dextrally coiled; aperture trapezoidal or sub-rounded in shape, filled with matrix; body whorl large and conical/ cylindrical in shape.

Remarks: The genus *Paludina* is widely known from Deccan intertrappean including Nagpur and Kutch (Hislop, 1860; Rana, 1986; Bajpai, 1990). Sahni (1972) and Tripathi (1986) have also recorded it from Lameta beds at Jabalpur.

Family	Lymnaeidae Rafinesque, 1815
Genus	Lymnaea Sowerby, 1837

***Lymnaea* sp.**

(Pl. 16, fig. C, G & H)

Locality & horizon: Grey chert from Papro.

Material: 3 specimens.

Description: Shell sub-fusiform in shape; dextrally coiled; apical part sharp/ blunt; spiral with three whorls (Pl. 16, fig. C); body whorl large and convex; aperture not known due to poor preservation.

Remarks: The genus is also known from the intertrappean beds of Nagpur, Kutch and Gurmatkal (Rana, 1984; Khanna and Mohan, 1965; Kazim, 1945) as well as from the Lameta Formation at Jabalpur (Tripathi, 1986).

Class	Charophyta
Family	Characeae
Genus	*Chara* Villant, 1719

Platychara perlata (Peck and Reker, 1947)

(Pl. 15, fig. I-M)

Material: 20 carapaces from Jhilmili; 40 carapaces from Dayapar.

Horizon and Locality: Yellow to pink clays from in Jhilmili (JH17, JH19); creamish marl from Dayapar intertrappean locality.

Description: The species is characteristically subglobular or spherical in shape; wider than long with a rounded base; apex swallon and formes a distinct apical rosette.

Remarks: In India *Platychara perlata* was first reported from the Nagpur intertrappeans by Bhatia and Rana (1984). It is a cosmopolitan species ranging in age from Late Cretaceous to Paleocene. It is also the most abundant species in the Deccan intertrappean beds of peninsular India, having been recorded from as widely separates intertrappean localities as Gurmatkal (Distt. Gulbarga, Karnataka) and Kora (District Kutch, Gujarat) and Kora (District Kutch, Gujarat) (Srinivasan *et al.*, 1995).

Chara sp. Indet

(Pl. 15, fig. N-O)

Material: 20 carapaces from Jhilmili; 40 carapaces from Dayapar.

Horizon and Locality: Creamish marl from Dayapar intertrappean locality.

Description: 8-10 Cconcave line spiral visible in side view; elongated; length more than width.

Remarks: It is a cosmopolitan species and considered to be long ranging Genus.

Class	Osteichthyes Huxley, 1880
Subclass	Actinopterygii Cope, 1887
Infraclass	Neopterygii Regan, 1923
Division	Ginglymodi Cope, 1872
Order	Lepisosteiformes Berg, 1940
Family	Lepisosteidae Cuvier, 1825
Genus	Lepisosteus Lacepede, 1803

Lepisosteus sp.

(Pl.19, Fig. I-T)

Locality and horizon: Creamish marl from Dayapar and Nahardi.

Material: 4 specimens from Dayapar; 5 specimens from Nahardi

Description: Teeth conical slightly recurved; Crown smooth, slightly flattened; tip blunt covered with translucent enameloid; crown broadens gradually down to the base; basal part having parallel longitudinal striations.

Remarks: This species is widely known from the Late Cretaceous to intertrappean deposits of Madhya Pradesh (Hora 1938), Maharashtra (Jain and Sahni, 1983; Gayet *et al.*, 1984; Rana 1990), Andhra Pradesh (Prasad and Sahni, 1987; Prasad, 1989) and Eocene beds of Sub-Himalaya (Rana and Kumar, 1990). *Lepisosteus* is also widely known from Cretaceous-Eocene sequences of Madagascar, North America, South America and Europe (Astibia *et al.*, 1990); Bertinni *et al.*, 1993; Gottfried and Krause, 1998; Weems, 1990.

Division	Halecostomi Regan 1923
Order	Pycnodontiformes Berg, 1937
Suborder	Pycnodontoidei, Nursall, 1996
Superfamily	Pycnodontoidea Poyato-Ariza and Wenz, 2002
Family	Pycnodontidae Agassiz, 1833
Genus	*Pycnodus* Agassiz, 1833

***Pycnodus* sp.**

(Pl. 19, Fig. A-B; Pl. 20, fig. I-L)

Locality and horizon: Creamish marl from Dayapar; Greenish muddy shale from Balaji Quarry-18 and brownish grey sandy shale Gov. Quarry-17, 18, (Duddukuru).

Material: Single specimen Dayapar; 4 specimens from Duddukuru.

Description: Tooth elliptical in shape; occlusal surface bears two transverse ridges that meet each other laterally and separated by a well defined narrow, central depression; Base hollow. In the present collection teeth are circular, triangular and oval in shape.

Remarks: *Pycnodus* is known from the Eocene succession of the Subhatu Formation of NW Himalaya (Kumar and Loyal, 1897; Kumar, 1996) and from the Late Cretaceous of Nagpur area peninsular India (Woodward 1908; Gayet et al, 1984; Rana 1990); Andhra Pradesh (Prasad and Sahni 1987; Prasad 1989; Prasad and Khajuria 1990; Prasad and Singh, 1991). *Pycnodus* has also been recorded from the Eocene of Rajasthan (Rana *et al.*, 2005).

Order Salmoniformes

Family Enchondontidae Lydekker, 1889

Eotrigonodon indicus (Lydekker, 1886)

(Pl. 20, fig. A-F)

Locality and horizon: Creamish coloured marl from Dayapar; Greenish muddy shale from Balaji Quarry-18 and brownish grey sandy shale Gov. Quarry-17, 18, (Duddukuru).

Material: 15 specimens from Dayapar and Duddukuru.

Description: Pharyngeal teeth (Pl. 20, fig. K-L) has broader crown and a ridge connecting the terminal cusp and secondary cusp. Oral teeth (Pl. 20, fig. A-B, D & I) nearly rhombic in shape. Labial side flat; lingual side slightly concave; apex of the crown in the form of a smooth edge; anterior end extending upwards; cutting edge sharp and smooth; Root missing.

Remarks: This species is common in the Late Cretaceous-Early Tertiary successions of peninsular India as well as the subhimalaya (Lydekker, 1886; Jain and Sahni, 1983; Kumar, 1996 and Loyal, 1987; Prasad, 1889; Rana 1990; Bajpai *et al.* 1990; Kumar 1996; Rana *et al.*, 2004). It is known from the Kakra and Subathu formations of the northwestern Himalayas (Kumar and Loyal, 1987; Kumar, 1996), Cambay Shale of Gujarat (Rana *et al.*, 2004), Eocene Marh Formation of Rajasthan (Jolly and Loyal, 1985).

Order	Acanthopterygii
Family	Sparidae
Genus	*Chrysophrys* (Cuvier, 1833)

***Chrysophrys* sp.**

(Pl. 20, fig. G-H)

Locality & Horizon: Greenish muddy shale from Balaji Quarry-18 and brownish grey sandy shale Gov. Quarry-17, 18, (Duddukuru).

Material: 5 specimens.

Description: Small, circular or in the form of hemispherical cap, the coronal surface of the teeth is smooth; pulp cavity is large and concave.

Remarks: This species was also recovered from the intertrappean beds of Duddukuru, Andhra Pradesh (Prasad 1986). *Chrysophrys* is also common to Central Indian intertrappean and Early Subathu of Himachal Pradesh.

Superorder	Osteoglossomorpha Greenwood et al., 1966
Order	Osteoblossiformes Berg, 1940
Suborder	Osteoglossidae Greenwood et al., 1966
Family	Osteoglossidae Bonaparte, 1832

Gen. et sp. indet.

(Pl. 19, fig. C-F)

Locality and horizon: Creamish marl from Dayapar; grey chert from Papro; mudstone from Virani.

Material: 2 isolated teeth from Dayapar; single tooth each from Papro and Virani.

Description: Teeth conical; slightly curved to straight with distinct apical and basal parts; apical part smaller; conical; pointed and covered with transparent enamelloid; basal part much longer; sub-cylindrical slightly narrowing upwards; ornamented by fine longitudinal striations.

Remarks: Similar teeth are known from the intertrappean beds of Deothan and Kheri, Central India (Hora, 1938) and many other intertrappean localities. More recently, such teeth have been recorded from the Cambay Shale (Lower Eocene), Vastan Lignite mine, Gujarat (Rana *et al.*, 2004) and from Early Eocene Akli Formation, Giral lignite mine, Barmer District, Rajasthan (Rana *et al.*, 2005).

Superorder	Batomorphii Cappetta, 1980
Order	Myliobatiformes Compagno, 1973
Superfamily	Myliobatoidea Compagno, 1973
Family	Myliobatidae Bonaparte, 1938
Genus	*Igdabatis* Cappetta, 1972

Igdabatis indicus Prasad and Cappetta, 1993

(Pl. 19, fig. G-H)

Horizon and Locality: Creamish marl from Nahardi.

Material: 4 specimens.

Description: lateral teeth hexagonal or subtrapezoidal in outline; crown wider than long; crown surface with pitted ornamentation; root less high than crown.

Remarks: *Igdabatis indicus* has been recorded earlier from the Infratrappean beds of Merapalli (Andhra Pradesh), and the intertrappean beds of Asifabad (Andhra Pradesh) Kisalpuri and Lotkheri Madhya Pradesh (Khosla *et al.*, 2004).

CHAPTER 4

STABLE ISOTOPE ANALYSIS

4.1 INTRODUCTION

Ostracods are environmentally sensitive organisms which are readily preserved as fossils because of their calcitic shells. Over the past two decades or so, geochemical investigations (trace elements and stable isotopes) of ostracods have been shown to provide interesting insights into changes in paleoenvironmental conditions including temperature, effective precipitation and salinity (e.g. Chivas, 1985, 1986; Lister, 1988; De Deckker and Forester, 1988; Holmes and Chivas, 2002). In particular, oxygen- and carbon- stable isotope analyses of lacustrine ostracods are now being increasingly used in paleolimnology. Until now, however, such studies have been undertaken mainly in the Quaternary sediments. During the present investigation, a preliminary attempt was made to extend this approach for the first time in sediments as old as the terminal Cretaceous. The interpretation of the data is essentially tentative, based as it is on a limited sample, and also because of the possibilities of digenetic alteration of ostracod shells. However, as discussed below, this pilot study is a pointer of the potential importance of such investigations in understanding the environmental conditions that prevailed during the deposition of Deccan intertrappean beds. Freshwater ostracods as well as few samples of carbonate deposits from the intertrappean sections at Lakshmipur, District Kutch (Gujarat) were selected for this study. Ostracods from Lakshmipur were found to be reasonably well preserved. For taxonomic descriptions of ostracods, a reference may be made to Whatley and Bajpai (2000a). A very useful review of the application of stable isotopes in paleoenvironmental studies has been provided by Holmes and Chivas (2002).

4.2 OXYGEN ISOTOPE COMPOSITION OF OSTRACOD SHELLS

The $^{18}O/^{16}O$ ratio of carbonate precipitated from water depends on the oxygen isotope composition of ambient water and the temperature at which it precipitates. In case of calcite precipitated in isotopic equilibrium with the host water, there is a 0.23 per mil decrease in $\delta^{18}O$ for one degree Celsius rise in water temperature (Holmes and Chivas, 2002). In lakes, the effect due to temperature is generally masked by large temporal variations in the $^{18}O/^{16}O$ ratio of lake water, which may be caused by changes in the isotopic composition of rainfall due to air temperature changes or changes in the source of vapor. It has been shown that in deep freshwater lakes, the isotopic composition of benthic carbonates is mainly controlled by air-temperature related variations in the isotopic composition of rainfall. In lakes fed by the groundwater, the isotopic composition of groundwater is the main factor controlling the composition of lake water and the ostracods living there. Shallow, lakes subject to evaporation and dilution due to changes in precipitation, isotope analysis of freshwater ostracods provides a record of variations in precipitation/evaporation (P/E) ratios (Hodell *et al.*, 1995). In marginal marine environments, oxygen isotope data on ostracods may provide information on the mixing of water bodies with different isotopic composition. An important factor that needs to be considered in isotopic studies of ostracods is that their shell carbonate is generally not precipitated in isotopic equilibrium with the ambient water. There are positive vital offsets which are generally constant within individual genera (Xia *et al.*, 1997; Von Grafenstein *et al.*, 1999; Chivas, 2002). Thus, the magnitude of the vital effects needs to be taken into account when reconstructing paleoenvironmental changes based on more than one taxon. In case of lake, the oxygen isotope ratio of water depends on the balance between total input by direct precipitation and runoff from catchment area and loss during evaporation. If the evaporation exceeds input, the $d^{18}O$ value of residual water will be higher relative to local precipitation because of preferential loss of ^{16}O. If our assumption regarding ^{18}O value of lake water and temperature is correct, the enriched oxygen isotope ratio of ostracod samples implies that a dominantly evaporative condition prevailed in the lake. Though no evaporative mineral have yet been found in the exposed section, it is noted that the Lakshmipur intertrappean shows a rapid change in vertical facies association from impure limestone (often cherty) to mudstone. This change is obviously due to rapidly fluctuating lake shoreline and the lake may have been a closed basin that intermittently experienced evaporative conditions.

4.3 CARBON ISOTOPE COMPOSITION OF OSTRACOD SHELLS

Shell carbonate of an ostracod forms in equilibrium with the dissolved bicarbonate of the water in which the ostracod lives, and the $\delta^{18}C$ values of ostracod shells are broadly similar to those of inorganic calcite. The carbon isotope fractionation in both organic and inorganic calcite is nearly independent of temperature changes. Within the temperature range of 10-30^{0}C, calcite is enriched in $\delta^{18}C$ by 1.0 ± 0.2 compared to the dissolved inorganic carbonate or the DIC of the host water (Romanek *et al.*, 1992). In the case of ostracods, the vital effects are masked by variations in the isotopic composition of the DIC on the microscale (Von Grafenstein *et al.* 1999).

A number of factors have been found to control the geochemical signatures from ostracod shells (Chivas, 1986; Curtis and Hodell, 1993) and therefore interpretations may vary from relatively straightforward to increasingly complex. In lakes that are hydrologically closed, especially those in semi-arid to sub-humid regions, temporal changes in precipitation can lead to variations in salinity, solute composition and the $^{18}O/^{16}O$ of the water. Chivas (1985) successfully used the geochemical signatures of ostracod shells for the reconstruction of past salinity and evaporative evolution of Lake Keilambete, a small closed Crater Lake in Victoria, Australia. Since his pioneering studies, a number of similar investigations have successfully reconstructed salinity and/or effective precipitation using trace element and/or stable isotope determination of lacustrine ostracods (Lister, 1991; Curtis and Hodell, 1993; fritz *et al.* 1994; Holmes *et al.*, 1997, Bridgwater *et al.*, 1999; Ito, 2002).

4.4 PRESENT DATA

As part of the present investigation, carbon and oxygen isotope ratios of the ostracod and carbonate samples from Lakshmipur intertrappean deposits of Kutch (Gujarat) were independently analyzed at two laboratories: Physical research Laboratory (PRL), Ahmedabad, India; and the School of Earth and Environmental Sciences, Seoul National University, Seoul, South Korea (Prof. Yong Lee, personal communication).

The two most common freshwater ostracod species from Lakshmipur - *Cypria cyrtonidion* Whatley and Bajpai, 2000 and *Mongolianella cylindrica* (Sowerby, 1840) were selected for analysis at PRL. Both these species belong to the family Cyprididae. For comparison, the associated freshwater gastropod *Physa* and the sediment were also analyzed. The results are given in Table 4.1. Preliminary results from the PRL have already been published (Sanyal *et al.*, 2005). Ostracods from this section have been described in detail by Whatley and Bajpai (2000).

The carbon isotope ratios of the above ostracods are characterized by negative values, ranging from -5.7 to -7.4 per mil. These values indicate a fresh water origin of the ostracods and are consistent with the sedimentary facies and associated fossil biota that clearly indicate a freshwater origin for the Lakshmipur intertrappeans. As mentioned earlier, the associated fossil assemblage comprises freshwater molluscs, cyprinid fishes, charophytes and turtles. The $\delta^{13}C$ value of the mollusc shell fragments collected from the same stratigraphic level as the ostracod and that of the grayish limestone which underlies the ostracod-bearing horizon is -8.7 and -5.8 per mil (Table 4.1) respectively, again indicative of freshwater origin.

To interpret the oxygen isotope ratios, the lake water temperature was taken (as a first order approximation), to be the mean annual air temperature of the location. Paleogeographic investigation of the Indian subcontinent at the end of the Cretaceous (65 Ma) shows that the study area was at about 10^0S (Dietz and Holden, 1970) and the mean annual air surface temperature was probably not much different from today i.e. about 25^0C (Lamb, 1977). If direct precipitation and inflow from the catchment area (rain water) are assumed to be the main source of lake water, then the $\delta^{18}O$ value of ostracod lake water at 65 Ma can be estimated from the present-day rainwater data. The $\delta^{18}O$ value of present day at 10°S latitude varies from -2 per mil to -11 per mil with an average of about -5 per mill (relative to VSMOW) (from IAEA GNIP data from three stations of Indonesia). Using $\delta^{18}O$ $value_{shell}$ (PDB)= -0.47 + 0.97 $d^{18}O$ water (VSMOW) (Xia *et al.*, 1997) for precipitation at 25°C, the expected $d^{18}O$ value of ostracod is estimated to be -5.3 per mil.

Table 4.1: $\delta^{13}C$ $\delta^{18}O$ of ostracods, molluscs and limestone (relative to VPDB in per mil)

Sample Description	**$\delta^{13}C$**	**$\delta^{18}O$**
Ostracod (*Cypria cyrtonidion*)	-6.3	-3.4
Ostracod (*Cypria cyrtonidion)*	-7.4	-2.8
Ostracod (*Cypria cyrtonidion*	-5.2	-1.9
Ostracod (*Cypria cyrtonidion)*	-6.8	-3.7
Ostracod (*Mongolianella cylindrica)*	-5.7	-2.4
Mollusc (*Physa*)	-8.7	-2.8
Limestone	-5.8	-2.8

Oxygen isotope ratio of lacustrine water depends on the balance between total input by direct precipitation and runoff from catchment area and loss during evaporation. If the evaporation exceeds input, the $\delta^{18}O$ value of residual water will be higher relative to local precipitation because of preferential loss of ^{16}O. If our assumption regarding ^{18}O value of lake water and temperature is correct, then the enriched oxygen isotope ratio of ostracod samples implies that a dominantly evaporative condition prevailed in the lake. Though no evaporative mineral has yet been found in the exposed section, it is noted that the Lakshmipur intertrappean shows a rapid change in vertical facies association from impure limestone (often cherty) to mudstone (Fig. 2.4). This change is obviously due to rapidly fluctuating lake shoreline and the lake may have been a closed basin that intermittently experienced evaporative conditions

Table 4.2: Oxygen and Carbon isotopic compositions of Deccan intertrappean lacustrine carbonates

Locality-horizon	$\delta^{13}C$	$\delta^{18}O$	**At**	**25^{0}C**	**20^{0}C**
			$\delta^{18}O$ SMOW	$\delta^{18}O$ water	$\delta^{18}O$ water
Lakshmipur-a	-5.7	-3.1	27.7	-1.1	-2.2
Lakshmipur-b	-5.2	-3.3	27.5	-1.3	-2.4
Lakshmipur-c	-6.7	-3.4	27.4	-1.4	-2.5
Lakshmipur-d	-6.7	-3.0	27.8	-1.0	-2.1

In addition to freshwater ostracods, 4 samples of carbonate sediments from Lakshmipur intertrappean deposits were analyzed by Prof. Yong Lee, (South Korea). The values of oxygen isotopic composition were found to be heavy, ranging from -3.0 to -3.4 per mil PDB, reflecting isotopically more evolved waters. This can be attributed to a reduction in river water influence which in turn may reflect lowering of lake level as a result of increased aridity. This interpretation reflects a relatively longer residence time of the palaeolake waters associated with evaporation under the closed lake system, which is supported by relatively heavy oxygen isotopic compositions estimated at 20 degree and 25^0C (Table 4.2). The estimated oxygen isotopic compositions of lake water are much heavier then the inferred oxygen isotopic compositions of meteoric water in central India (approx. 8 per mil) during the deposition of the intertrappean Upper Cretaceous Lameta Formation (Ghosh *et al.*, 1995).

The carbon isotope composition of these carbonates (-5.2 to -6.7 per mil) records the input of light CO_2 produced by the decay of organic matter. Carbon isotopic fractionation between dissolved and CO_2 is 8 per mil to 10 per mil at 25^0C. Under isotopic equilibrium with the atmosphere CO_2 which normally has a δ^{13}C of -7 per mil, the lacustrine carbonate would precipitate with a δ^{13}C of +1 to +3per mil (Ramnek *et al.*, 1992).

The sediment samples from Lakshmipur contain ostracods and molluscs. Thus, the δ^{18}O and δ^{3}C values of these samples may represent a mixture of unknown proportions of inorganic matrix of micrite and ostracod and mollusc carbonate. Van Grafenstein *et al.* (1999) reported that the isotopic compositions of modern limnic ostracod and mollusc carbonate shows vital offsets of +0.7 to +2.4 per mil and -1.5 to +1.4 per mil for d^{18}O and d^{13}C, respectively. Even taking considerations of these vital offsets, the isotopic compositions of samples Lakshmipur (a-d) are still heavy compared to the incoming freshwater runoff, suggesting that some evaporation has occurred in the lake. Thus, it is concluded that the deposition of Lakshmipur intertrappeans took place mostly in ephemeral, very shallow areas. It is important to note that culturing experiments and studies of living ostracods and modern lake water have shown that ostracod species calcify out of equilibrium with water (Xia *et al.*, 1997; Von Grafenstein *et al.*, 1999; Keatings, 2000). Also, benthic ostracods and molluscs reflect the isotopic compositions and the temperature of the surface water. Samples from Lakshmipur (a-d) contain mixture of ostracod and micrite, but do not show difference in oxygen and carbon isotopic compositions compared to Lakshmipur (a) ostracod, suggesting that the lake water was well homogenized and thus little difference in chemistry between surface and bottom waters.

CHAPTER 5

DISCUSSION

5.1 INTRODUCTION

The Deccan volcano-sedimentary province of peninsular India represents one of the largest occurrences of continental flood basalt volcanism in the world. During the past two decades or so, there has been a dramatic revival of interest in this volcanic activity primarily because of its close time correspondence to the age of the Cretaceous-Tertiary (K-T) boundary at 65 Ma, as revealed by a wealth of radiometric and paleomagnetic data (e.g. Courtillot *et al.* 1986, 1988, 2000; Duncan and Pyle 1988; Vandamme et al., 1991; Baksi, 2001; Knight *et al.*, 2003; Chenet *et al.*, 2007, 2008). Significantly, Chenet et al. (2008) have shown, based mainly on flow-by-flow reanalysis of paleomagnetic directions in the Mahabaleshwar sections, that Deccan volcanism lasted spanned a much shorter time than previously realized and that very large single eruptive events (SEEs) probably occurred in a few decades.

In a major recent study, Keller *et al.* (2008), based on biostratigraphic data from the outlying Deccan intertrappean deposits of Rajahmundry area near the southeast coast of India in the state of Andhra Pradesh, have found convincing evidence that the K-T boundary occurred at or near the end of the Deccan volcanic activity, indicating a cause and effect relationship between the two events.

However, biostratigraphic age determination of intertrappean sediments for the main part of the Deccan volcanic province has been difficult because these sediments mostly yield terrestrial fossils, though with considerable diversity (e.g. Khosla and Sahni, 2003). This assemblage includes fragmentary dinosaur fossils (eggshells, teeth and rare bones) and a remarkably diverse endemic freshwater ostracod fauna (Bajpai and Whatley, 2001; Whatley and Bajpai, 2005, 2006). Significantly, the occurrence of dinosaur fossils in several intertrappean localities has led to the general acceptance of a Maastrichtian age for these deposits (e.g. Sahni and Bajpai, 1988; Ghevariya, 1988; Srinivasan, 1996; Bajpai and Prasad, 2000). Prior to this age determination, the Deccan intertrappeans were generally considered to be early Tertiary (Paleocene) in age based mainly on paleobotanical data, especially plant megafossils and charophytes (see Bande et al. 1988 for a review).

Apart from its relevance to the K/T boundary debate, there is much current interest in the biogeographic relations of the latest Cretaceous intertrappean/Lameta terrestrial biota (e.g. Sahni and Prasad, 2008). In a geodynamic context, this fauna spans the terminal phase of India's northward drift preceding the India-Asia collision at ca. 55 Ma. Significantly, until a few years ago, this Maastrichtian fauna was widely considered to lack endemic elements, and hence inconsistent with the geophysical models that show the Indian subcontinent as an isolated, northward drifting landmass (e.g. Sahni, 1984). The presence of both Gondwanan and some Laurasian elements has been noted (e.g. Sahni and Bajpai, 1991; Prasad and Sahni, 1999; Rage, 2003; Sahni and Prasad, 2008). Explanations for the presence of Laurasian elements range from an early India-Asia contact (Jaeger *et al.*, 1989) to sweepstakes (trans-oceanic) dispersals, possibly aided by the Dras-Kohistan island arc system (Ali and Aitchison, 2008; Sahni and Prasad, 2008). On the other hand, the Gondwanan affinities have have been interpreted as evidence that physical links existed between the Indo-Madagascar-Schelles block and South America probably as late as 80 Ma, although opinion is divided as to the exact dispersal route (Kerguelen Plateau or Gunnerus Ridge) (see Hay *et al.*, 1999; Case, 2002).

More recently, a new biogeographic perspective has come to light with the recognition of a remarkably diverse, endemic freshwater ostracod fauna from the Deccan intertrappeans (Whatley and Bajpai, 2006). The extensive ostracod endemism, as evident from the presence of over 75 new species, has been interpreted by these workers as evidence of India's geographical isolation around the K/T boundary, consistent with the geophysical models for this interval.

Overall, these three biogeographic domains present major biogeographic puzzles that basically underscore the fact that the distribution of terrestrial fossil biota, when considered in a rigorous phylogenetic and geodynamic context, can be a powerful tool for reconstructing past geographic relationships between landmasses.

Another important issue is the influence of Deccan volcanism on contemporary communities and the survival of freshwater aquatic communities across the K-T boundary (Prasad and Khajuria, 1995; Tandon, 2002; Cripps *et al.*, 2005; Khosla *et al.*, 2005). However, efforts to understand the faunal response to Deccan volcanism have been hamered because of the scarcity of any documented occurrences of continental Paleocene horizons in the Deccan volcanic province.

One of the most important current issues is the paleoenvironmental setting of the Deccan volcano-sedimentary sequence of peninsular India around the K/T boundary. This issue bears on the Cretaceous-Tertiary paleogeography of peninsular India, including the marine incursions. The idea of a marine incursion was advanced over 25 years ago based on limited paleobotanical evidence from the Deccan intertrappeans (e.g. Bande and Prakash, 1982) and sedimentological data on the late Cretaceous Lameta Formation, underlying the Deccan Traps of Jabalpur, central India (Singh, 1981). However, subsequent sedimentological investigations favoured a non-marine origin of the Lameta Formation (e.g. Brookfield and Sahni, 1987; Tandon *et al.*, 1995) and this idea found widespread acceptance during the past two decades. More recently, however, the dinosaur-bearing Lameta sediments of Jabalpur have been interpreted as a lagoonal deposit, implying a marine shore line in the proximity (Shukla and Srivastava, 2008). It is important to note that there was no faunal evidence until now for the presence of marine depositional conditions during the Deccan eruptive phase except in the well known Rajahmundry sections.

Against this background, the present investigation was carried out in a few selected intertrappean sections in the Deccan volcanic province of peninsular India. As discussed below, the microfaunas recovered during this investigation has provided significant insight in to the above issues.

5.2 PALEOENVIRONMENTS AND PALEOGEOGRAPHY

5.2.1 Implications of present data from the Jhilmili section

During the present investigation a diverse ostracod and foraminifer assemblage was recovered from the Jhilmili intertrappean section of District Chhindwara of Madhya Pradesh, central India. The assemblage includes not only a number of freshwater taxa (*Limnocythere deccanensis*, *Limnocythere* sp., *Limnocypridea ecphymatos*, *Mongolianella cylindrica*, *Zonocypris viriensis*, *Zonocypris spirula*, *Cypridopsis hyperectyphos*, *Paracypretta subglobosa*, *Paracypretta* sp. 1, *Paracypretta* sp.2, *Gomphocythere strangulata*, *Darwinula torpedo*), but also a brackish water species *Neocyprideis* cf. *N. raoi* (samples JH21-JH26). In addition, freshwater algae (charophytes) was also found at Jhilmili. The relative abundance of ostracods, planktic foraminifers and charophytes through the main fossiliferous interval (Unit 3) at Jhilmili is depicted in Fig. 5.1. It is to be noted that the brackish water ostracod species (*Neocyprideis raoi*) has been previously recorded in the well known shallow marine intertrappean beds of the Rajahmundry area near the east coast of India (Khosla and Nagori, 2002).

The discovery of planktic foraminifers in Jhilmili has very important implications for the K-T paleoenvironments in the Deccan volcanic province. Their occurrence in India over 800 km from the present coast is intriguing and raises questions of their provenance and survival. The first obvious question is whether the foraminifera or brackish water ostracod species could be contaminants in the Jhilmili samples. This possibility is easily ruled out because there are no sediments with foraminifera or ostracods in the Jhilmili section apart from the 60 cm thick interval. The intertrappeans are both underlain and overlain by the Deccan basalts, so there is no possibility of reworking from older horizons or leaking from younger ones. Also, no marine deposits are known from the area.

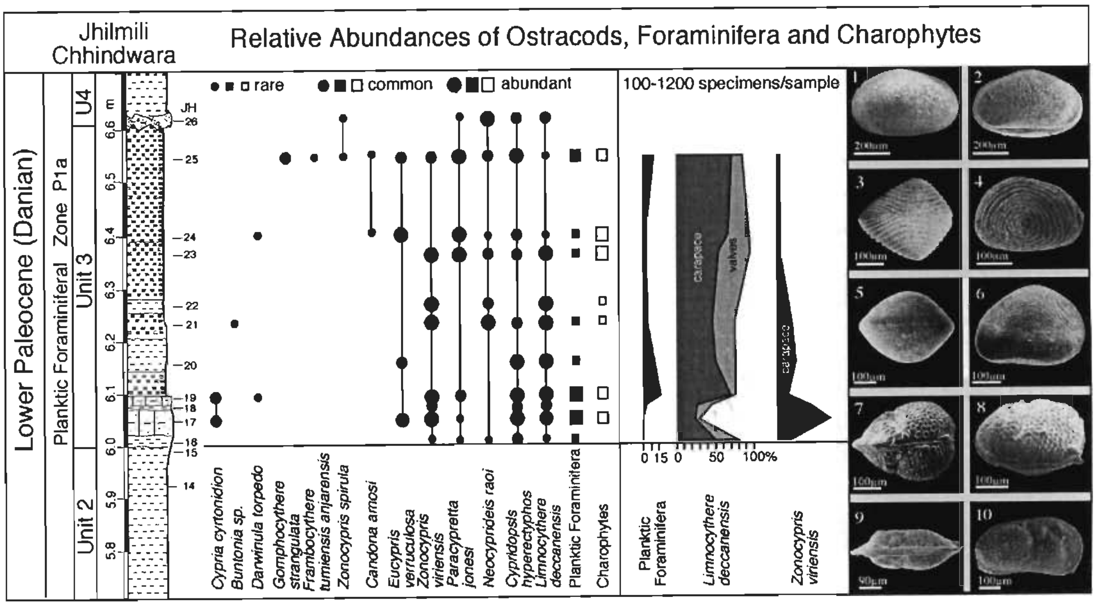

Figure 5.1 Relative abundance of ostracods, charophytes and planktic foraminifera in unit 3 of Jhilmili intertrappean sediments (After Keller *et al., in press*)

The second possibility is that the foraminifera could have been blown in by winds or storms. This possibility is also ruled out because there are no known occurrences of early Danian or Maastrichtian deposits in central India from which they could have derived. Furthermore, the Jhilmili foraminifera consist of uniform early Danian assemblages without any exotic species (e.g., older Cretaceous) or benthic foraminifera. In case of wind or storm transportation of microfossils, an exotic assemblage of species from various ages, including benthics is expected, rather than a narrow zone P1a assemblage.

A third question is whether the stratigraphy could explain the mixture of freshwater ostracods and planktic foraminifera. This question arises because In the Jhilmili section, foram-bearing layers also contain abundant freshwater ostracods (Fig. 2.12). Although thin beds were sampled carefully, it is not entirely ruled out that some overlap sampling took place because of larger samples collected for ostracods, resulting in the mixing of freshwater and brackish- marine layers.

Another pertinent question is whether the paleoecological affinities of ostracods have been misinterpreted. This possibility is highly unlikely because of the wealth of data available on ostracod ecology (e.g. Whatley and Bajpai 2005) as well as the preliminary stable isotope data that indicate both freshwater and brackish-marine environments (Keller *et al.* in review).

Another important question concerns the absence of benthic foraminifera in the present assemblage. Because planktic and benthic foraminifera tend to coexist, even in high stress environments (e.g., low oxygen, salinity variations), the absence of the benthic forms is intriguing. It appears that the absence of benthic foraminifers at Jhilmili is due to very unusual, or very temporary (e.g., seasonal) marine conditions that prevented the establishment of a benthic foraminiferal fauna. In contrast, they are very common in shallow marine intertrappean sediments of Rajahmundry (Keller *et al.*, 2008).

The above discussion suggests that seasonal currents could have transported planktic foraminifera into Central India from a nearby marine seaway. These currents could have brought offshore planktics inshore temporarily creating brackish-marine or estuarine conditions. The absence of benthic foraminifera at Jhilmili suggests that marine conditions could not be established long enough for benthics to invade the substrate.

5.2.1.1 Existence of a marine seaway in central India

The present discovery of early Danian planktic foraminifers in predominantly terrestrial intertrappean sediments at Jhilmili clearly reveals marine incursions into central India during the K-T transition. Although the idea of a marine seaway was originally proposed over decades ago on the basis of paleobotanical data (Sahni and Mehrotra, 1974; Lakhanpal, 1974; Bande *et al.*, 1981; Sahni, 1983), no conclusive evidence has been available until now to confirm this hypothesis. Jhilmili is situated in central India about 1000 km from the present seacoast to the west and an equal distance from the eastern coast. The only way to explain the presence of planktic foraminifera in Jhilmili is a marine source. This seaway would likely have been from the west along the Narmada and Tapti rift valleys as Jhilmili is situated almost at the eastern extension of the Tapti rift valley (Keller *et al.*, under revision). Sahni (1983) called this seaway the "Trans-Deccan Strait' which according to him extended northwards from the Godavari basin. However, fossil evidence is currently lacking for a seaway along the Godavari valley. An alternative source (preferred here) for the planktic foraminifera at Jhilmili was a major seaway that extended into central India along the Narmada and Tapti rift zones during the late Cretaceous-early Paleocene (Fig. 5.2). It is important to note that evidence of a marine seaway along the Narmada rift zone during the late Cretaceous (Cenomanian-Turonian and possibly into the Maastrichtian) has long been known from the Bagh Beds based on marine invertebrates, including ostracods, planktic foraminifera and algae (Chiplonkar and Badve, 1968; Sharma, 1976; Badve and Ghare, 1977; Rajshekhar, 1996). However, evidence for the existence of this seaway during the Maastrichtian is highly controversial and based largely on sedimentological data (e.g. Singh, 1981, but see Tandon *et al.*, 1995 for an opposing viewpoint). Most recently, the Lameta beds at Jabalpur have been interpreted as lagoonal deposits (Shukla and Srivastava, 2008).

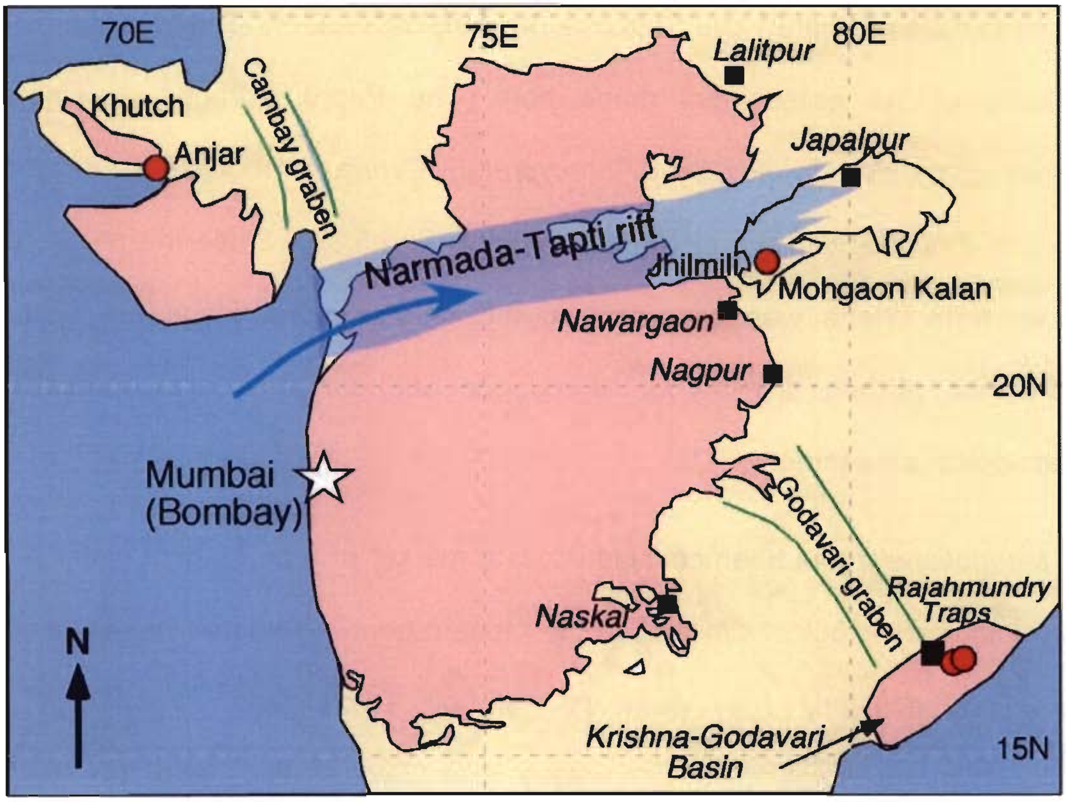

FIGURE 5.2 Map showing the marine seaway along the Narmada-Tapti valleys (after Keller *et al.*, in press)

The discovery of planktic foraminifers at Jhilmili should be followed by similar finds along the Narmada and Tapti zones. The challenge is to find and document additional evidence of this trans-India seaway, since such evidence would provide high-resolution age control and correlation with the marine record, define the K-T boundary within the Deccan Trap and provide crucial information of the climatic, biotic and environmental effect of the Deccan eruptions and their mass extinction at KT (Keller. et al. under revision)

5.2.2 Paleoecological implications of intertrappean ostracods

The paleoecological implications of the intertrappean ostracod faunas have been discussed recently in some detail by Whatley and Bajpai (2005), particularly in reference to Kutch (Gujarat) and Gulbarga (Karnataka) sections. This work forms the main basis of the assessment made here. The Papro ostracod assemblage comprises *Eucypris*, *Cypridopsis, Paracypretta, Cypria, Mongolianella, Cyprois, Zonocypris*, *Frambocythere* and *Gomphocythere* (Fig. 5.3B). Since the recovery of ostracods from cherts was very difficult, the present assemblage may not be representative of true diversity or abundance and can only allow preliminary paleoecological assessment.

Mongolianella has been considered as a marker of a permanent water body, based on its morphological similarity to the modern genus *Herpetocypris* Brady and Norman. In addition, the presence of of *Cypridopsis*, *Frambocythere*, *Gomphocythere*, *Paracypretta*, *Zonocypris* and *Cypria* also tend to suggest permanent waters. However, *Eucypris*, which belongs to the subfamily Eucypridinae, is considered to be a good guide to temporary waters, as is *Cyprois*. This admixed ostracod assemblage from Papro is thus suggestive of a lacustrine system that comprised a core of permanent water and a periphery that was subject to dessication during the dry season.

A paleoecological reconstruction similar to Papro section is proposed here for the Nahardi (Jhalawar, Rajasthan), Dayapar, Kora, Virani and Anjar (Kutch, Gujarat) and Phulsagar (Mandla, MP) intertrappean sections. All these sections yielded an admixture of ostracod taxa with preferences for permanent and temporary water bodies, although they do differ in detail, both in terms of diversity and relative abundance. For example, the Nahardi ostracods are dominated by markers for permanent waters (*Cypridopsis*, *Gomphocythere* and *Mongolianella*) as compared to those suggesting temporary conditions such as *Eucypris* (Fig. 5.3C).

In the Phulsagar section, which lies on the eastern margin of the Deccan volcanic province around Jabalpur-Mandla, the presence of two new species points to the fact that there is significant difference in the inter-trap faunas from different localities, not only in terms of the relative abundance of the various taxa but also in overall composition. In addition, the temporary water genus *Eucypris* is seen to dominate the Phulsagar assemblage (Fig. 5.3D). On the other hand, the genus *Limnocypridea*, a swimmer, also occurs in abundance in this section, pointing to permanent conditions. In the case of the Dayapar section (Fig. 5.3A), several hundered ostraocods were recovered during the present investigation and the assemblage comprises 14 species: *Frambocythere tumiensis lakshmiae, Darwinula kutchensis, Paracypretta elizabethae, Cypridopsis wynnei, Cypridopsis hyperectyphos, Eucypris pelasgicos, Eucypris catantion, Eucypris verruculosa, Mongolianella subarcuata, Candona amosi, Eucandona kakamorpha, Paracandona* sp. *Cypria cyrtonidion and cyprois rostellum.*

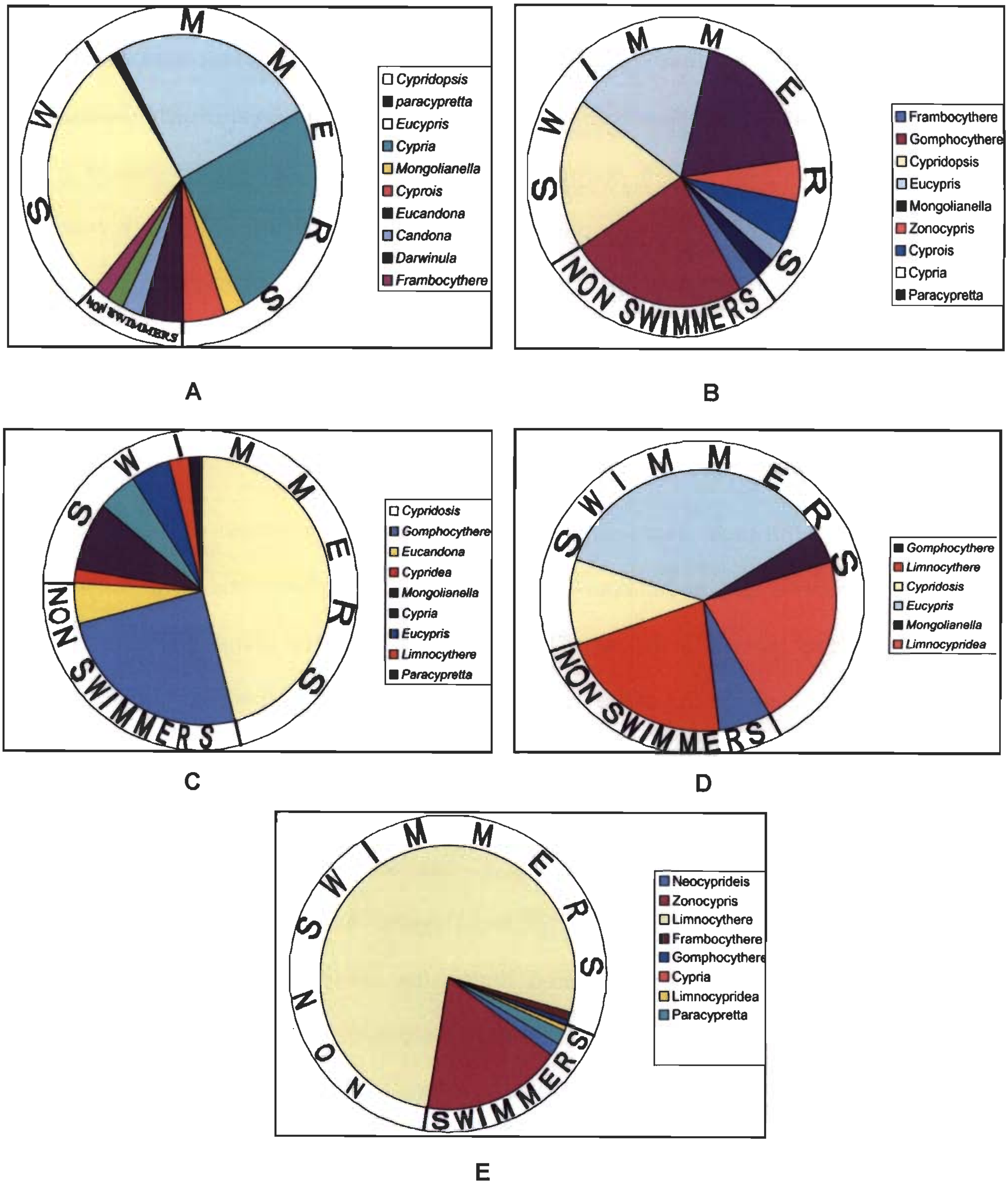

FIGURE 5.3 Relative abundance of intertrappean ostracod taxa in terms of their probable requirements for temporary/permanent water bodies (based on data from Whatley and Bajpai, 2008). A-Dayapar intertrappeans, B-Papro intertrappeans, C-Nahardi intertrappeans, D-Phulsagar intertrappeans, E-Jhilmili intertrappeans.

Paleoecologically, this ostracod assemblage again shows an admixture of swimmers (*Paracypretta, Cypridopsis and Cypria*) and non-swimmers (*Eucypris, Darwinula and Frambocythere*). Taxa with preferences for both permanent water (*Cypridopsis and Cypria*) and temporary water (*Eucypris*) occurs in this locality with the dominance of the former. The presence of *Candona amosi, Paracandona* sp. and *Eucandona kakamorpha* at Dayapar indicates soft muddy bottom conditions to allow these species to burrow.

Another aspect of the intertrappean ostracod faunas that merits some discussion is the diversity and the degree of commonality between the various intertrappean sections (Table 5; Fig. 5.4). It has been noted that a number of species occur in almost all the localities but there are some that are restricted to one locality. For instance, a number of species were found to be confined to individual localities under the present investigation: *Limnocypridea ecphymatos* (Phulsagar), *Eucypris phulsagarensis* (Phulsagar), *Darwinula kutchensis* n. sp. (Dayapar), *Cypridopsis whatleyi* (Phulsagar) and *Limnocythere jhilmiliensis* n. sp. (Fig. 5.4). The occurrence of species confined to single localities is probably a measure of the enhanced rate of evolutionary activity taking place in the non-marine intertrappean ecosystems (Whatley and Bajpai, 2005). As is well known, the entire Deccan volcanic interval lasted for a relatively short geological interval close to Cretaceous-Tertiary boundary (e.g. Chenet *et al.* 2008). During the volcanic episode, ecosystems including the contained faunas and floras were wiped out by lava flows and ash falls, followed by intervals of quiescence when the newly formed landscapes were gradually recolonized by plant and animal communities. This instability may have been one of the major factors responsible for the rapid evolutionary activity that took place over this relatively short interval in pools that were probably geographically isolated.

In general, there is a high level of commonality between the individual intertrappean ostracod faunas, as shown by Whatley and Bajpai (2005). Fig 5.4 is an updated tie-line diagram that shows this pattern. However, it is to be noted that in some cases there are low levels of commonality between geographically close sections, such as Mamoni and Nahardi in Rajasthan and Dayapur, Kora and Lakshmipur in the Kutch District of Gujarat. Other examples are seen in Fig. 5.4.

Table 5. Updated list of ostracod species recorded from the various Deccan intertrappean localities of peninsular India (Abbreviations: KOR= Kora; LKP= Lakshmipur; ANJ= Anjar; MAM= Mamoni; NAH= Nahardi; DAY= Dayapar; PHUL= Phulsagar; MOH= Mohagaonkala; JHL= Jhilmili; NAG= Nagpur; ASIF= Asifabad; CHAN= Chandarki; YAN= Yanagundi; BOM= Bombay; LAL= Lalitpur; VIR= Virani)

S. No.	OSTRACOD SPECIES	DECCAN INTERTRAPPEAN LOCALITIES															
		KOR	LKP	ANJ	MAM	NAH	DAY	PHUL	MOH	JHL	NAG	ASIF	CHAN	YAN	BOM	LAL	VIR
1.	*Gomphocythere akalypton*							x									
2.	*Gomphocythere paucisulcatus*					x			x		x				x	x	
3.	*Gomphocyhthere akalypton*												X			x	
4.	*Gomphocythere strangulate*			x	x					x	x	x		x			
5.	*Gomphocythere dasyderma*				x						x		X	x			
6.	*Gomphocythere gomphotatos*		x														
7.	*Gomphocythere* sp.		x														

8.	*Frambocythere tumiensis lakshmiae*		X				X		X	X						X	
9.	*Frambocythere tumiensis anjarensis*			X	X				X		X	X	X	X			
10.	*Limnocythere bhatiai*							X									
11.	*Limnocythere deccanensis*					X		X	X	X	X						
12.	*Limnocythere falsicarinata*		X	X							X						
13.	*Limnocythere bajpaii*								X								
14.	*Limnocythere* sp.																
15.	*Darwinula torpedo*								X	X	X			X			
16.	*Darwinula kutchensis*						X										
17.	*Paracypretta subglobosa*				X	X				X							
18.	*Paracypretta jonesi*			X					X		X	X	X	X			
19.	*Paracypretta elizabethae*	X					X										
20.	*Paracypretta anjarensis*			X													
21.	*Paracypretta sp.*	X									X						
22.	*Altanicypris deccanensis*		X														
23.	*Altanicypris szcsechurae*				X						X						
24.	*Cypridopsis elechistos*								X		X						
25.	*Cypridopsis hyperectyphos*		X		X	X	X			X	X			X		X	X
26.	*Cypridopsis palaichthonos*	X													X		
27.	*?Cypridopsis whatleyi*							X									
28.	*Cypridopsis wynnei*		X			X	X				X		X	X	X		X
29.	*Cypridopsis alphospilotos*																
30.	*Cypridopsis astralos*												X	X			
31.	*Cypridopsis legitima*		X														
32.	*Cypridopsis dongargaonensis*																

33.	*Cypridopsis mohagaonensis*								x								
34.	*Cypridopsis sahni*																
35.	*Cypridopsis* sp.								x							X	x
36.	*Cypridopsis* sp.1	x															
37.	*Cypridopsis* sp.2	x															
38.	*Sarscypridosis* sp.	x															
39.	*Cetacella* sp.	x															
40.	*Zonocypris gujaratensis*			x					x		x						
41.	*Zonocypris labyrinthicus*								x		x						
42.	*Zonocypris spirula*	x	x			x			x	x	x			x		X	
43.	*Zonocypris virensis*			x						x							
44.	*Potamocypris?* sp.			x													
45.	*Eucypris pelasgicos*	x				x	x	x	x		x						x
46.	*Eucypris intervolcanus*	x	x					x	x		x			x		x	x
47.	*Eucypris catantion*	x			x		x									x	
48.	*Eucypris verruculosa*						x				?		X				
49.	?*Eucypris phulsagarensis*							x									
50.	*Eucypris* sp. A								x								
51.	*Eucypris* sp. B								x								
52.	*Eucypris* sp. C								x								
53.	*Eucypris* sp.										x						
54.	*Eucypris* sp.1																
55.	*Mongolianella cylindrical*	x	x		x	x	x	x		x	x	x	X	x		x	x
56.	*Mongolianella subarcuata*				x	x	x				x					x	
57.	*Mongolianella hislopi*										x	x					

58.	*Mongolianella khamarinensis*			X													
59.	*Mongolianella ashui*																
60.	*Mongolianella* sp.								X		X						
61.	*Mongolianella*? sp.1			X													
62.	*Moenocypris hunteri*					X					X	X					
63.	*Moenocypris sastryi*				X	X											
64.	*Valdoniella* ?sp.			X													
65.	*Candona amosi*	X		X		X	X				X			X			
66.	*Candona mysorephaseolus*													X			
67.	*Candona altanulaensis*										X						
68.	*Candona bagmodica*										X						
69.	*Candona henaensis*										X						
70.	*Typhlocypris* sp.			X													
71.	*Eucandona kakamorpha*					X	X							X			X
72.	*Paracandona* sp.						X						X				
73.	*Paracandona firmamentum*		X						X	X					X		X
74.	*Paracandona* sp.1			X													
75.	*Cyclocypris amphibolos*	X			X				X		X			X			
76.	*Cyclocypris sahni*																
77.	*Cypria cyrtonidion*	X	X		X	X	X		X	X	X		X	X		X	
78.	*Cypria intertrappeana*	X													X		
79.	*Cypria* sp.	X															
80.	*Pseudocypris ectopos*		X														
81.	*Pseudoeucypris* sp.				X												
82.	*Mongoliocypris*																

83.	*Mongolocypris* sp.																
84.	*Cypridea cavernosa*					x					x	x					
85.	*Cypridea pavnaensis*																
86.	*Cypridea* sp.																
87.	*Limnocypridea ecphymatos*	x		x				x		x	x	x					
88.	*Limnocypridea jabalpurensis*			x													
89.	*Talicypridea biformata*	x									x	x					
90.	*Talicypridea* ? sp.										x						
91.	*Talicypridea* sp.	x															
92.	*Centrocypris Megalopus*		x														
93.	*Cyprois rostellum*	x	x				x		x		x				x	X	
94.	*Cyprois polygonum*	x															
95.	*Cyprois sp.*		x														
96.	?*Cyprois* sp.											x					
97.	*Trapezoidella* sp.																
98.	*Cetacella* sp.	x															
99.	*Valdoniella* sp.			x													
100.	*Neocyprideis raoi*									x							
101.	*Cypris semmimarginata*														x		
102.	*Cypris* sp.														x		

In such cases, although there is no doubt about the lacustrine environments represented by each section, it is unlikely that these lakes were united by a single river system. One of the possible factors to account for the differences in ostracod faunas between close-by sections is the chemistry of water bodies, as has already been demonstrated convincingly in a number of cases (De Deckker, 1988; De Deckker and Forester, 1988; Smith, 1993; Curry, 1998; Holmes and Chivas, 2002). It is suggested that the observed differences in the taxonomic composition and relative abundances of ostracods at the various intertrappean localities are possibly the result of differing water chemistry and/or environmental energy levels. This possibility needs to be investigated in detail in future studies.

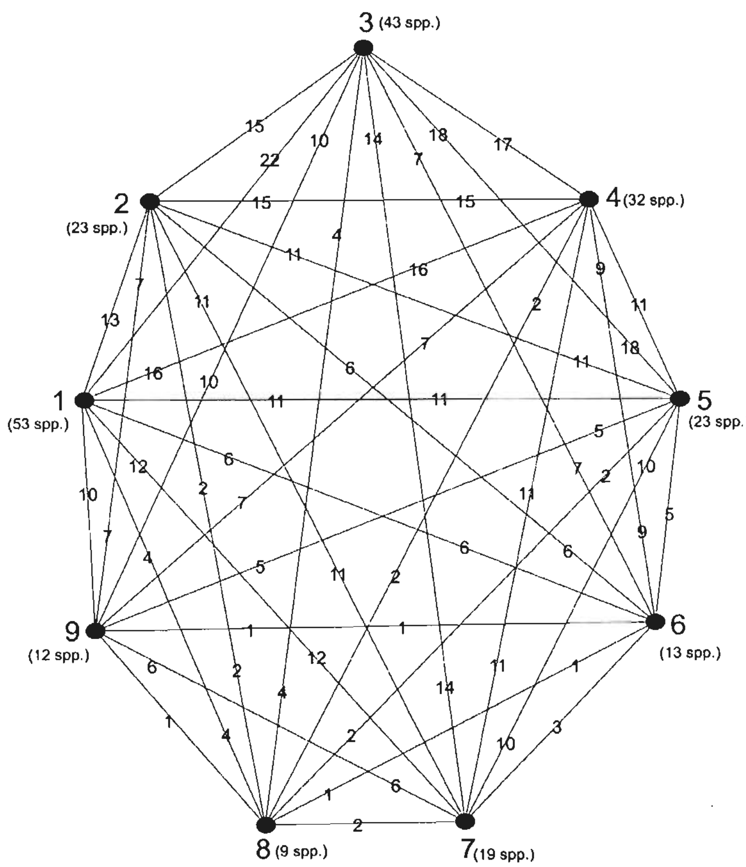

Figure 5.4 Tie-line diagram showing the degree of commonality of freshwater ostracods between the various intertrappean sections. Key to the localities is as follows:1. Gujarat (Lakshmipur, Kora, Anjar, Dayapar, Virani); 2. SE Rajasthan (Mamoni, Nahardi); 3. Madhya Pradesh; Maharashtra 1 (Nagpur); 5. Maharashtra II (Chandrapur; 6. Andhra Pradesh; 7. Karnataka; 8. Maharashtra III (Bombay); 8 Uttar Pradesh. (Modified after Whatley and Bajpai, 2006).

Another interesting observation with regard to the intertrappean ostracods is that, in nearly all cases, a large majority of ostracods were recovered with the two valves still attached. A number of possibilities may be invoked to explain this observation (De Deckker, 2002). First, it is possible that interstitial ostracods became trapped among sediment particles, and the valves could not be separated after death. Second, a high sedimentation rate may have trapped the ostracod carapace and the sediment surrounding the carapace may have prevented separation of the valves after the death of the ostracod. The third possibility is that unfavourable conditions arising from the onset of volcanic activity in the vicinity may have caused the death of ostracods but rapid sedimentation may have led to their quick burial, preventing disarticulation of valves. Anoxic conditions probably prevented other organisms from disrupting the accumulated ostracod carapaces and disarticulating their valves.

5.2.3 Implications of stable isotope data

It is important to recall that the stable isotope data (Chapter 4) on freshwater ostracods and associated sediments in one of the investigated sections (Lakshmipur intertrappeans, Kutch) suggest evaporative conditions during depositions. This implies deposition from more saline residues than those that deposit limestone, such as gypsum or halite (Whatley and Bajpai, 2005). Paleoecologically, however, the fossil evidence suggests a taxonomically diverse, thriving fauna of ostracods living in a well established water body, a scenario one would not expect in an evaporative regime which typically supports a low diversity fauna (e.g. Whatley and Cusminsky, 1999). Although the fossil data does not rule out intermittent dessication, the apparent absence of evaporatic minerals (such as gypsum, halite) in the Lakshmipur section needs to be investigated in detail in order to reconcile the the fossil and isotope evidence. Significantly, the occurrence of evaporative minerals (gypsum) has already been noted in the Anjar intertrappean locality, also in Kutch (Shrivastava and Ahmad, 2008).

5.3 INFLUENCE OF DECCAN VOLCANISM ON CONTEMPORARY BIOTA

The sheer magnitude of the Deccan volcanism, the short time span over which the volcanic activity occurred, and the recent estimates of flood basalt emissions of SO_2 as the main agent of environmental change (Self *et al.*, 2008), raises major questions regarding volcanically-induced ecological crisis and its influence on contemporary ecosystems (e.g. Prasad and Khajuria, 1995; Tandon, 2002; Cripps *et al.*, 2005; Khosla *et al.* 2005). However, efforts to establish the cause and effect relationship between the K-T extinctions and Deccan volcanism have been previously hampered by our lack of knowledge regarding the precise position of the extinction level in the Deccan volcanic pile. Most recently, Keller et al. (2008), based on biostratigraphic data from the outlying Deccan intertrappean deposits of Rajahmundry area (Andhra Pradesh) on the southeast coast of India, have found convincing evidence that the K-T boundary occurred at or near the end of the main phase of Deccan volcanic activity, demonstrating for the first time a causative relationship between the two events. This study of planktic foraminifera from shallow marine intertrappean quarry sections at Duddukuru near Rajahmundry has revealed an early Danian zone P1a assemblages between lower and upper traps of C29R and C29N magnetic polarity zones, respectively (Knight *et al.*, 2003, 2005; Baksi, 2005; Keller *et al.*, 2008). A similar result has been obtained from the present study of intertrappean deposits at Jhilmili (District Chhindwara, MP) where a planktic foraminifer assemblage of early Dainian (P1a) age occurs above the lower Deccan basaltic flow, which correlates with the end of the main phase of Deccan volcanism (e.g., top of the Ambenali Formation) consistent with recent results from Rajahmundry (Keller *et al.*, 2008; Jay and Widdowson, 2008).

The continental Papro section of Lalitpur District (UP) investigated 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 already pointed out elsewhere, this section occupies a special place in the main Deccan province because of recent palynological data suggesting a Paleocene age, in contrast to all other continental intertrappean sections that are considered to be end-Cretaceous (Maastrichtian) in age. The recorded Paleocene ostracod assemblage from Lalitpur significantly shows a striking similarity to ostracod faunas previously documented from a number of Maastrichtian intertrappean localities in the Deccan volcanic province (Table 5). A similar picture emerges from the freshwater ostracods from the Jhilmili section which occur in association with early Danian planktic foraminifers (see section 5.2.1). A large majority of these ostracod taxa (at the species level) have already been recorded from other sections (Table 5). Some of these ostracods (e.g. *Cypridopsis wynnei*) also occur in the Danian-aged intertrappean sections of Bombay (Whatley *et al.*, 2003). A possible explanation for this striking overall similarity is that the intertrappean freshwater ostracods were one of the least affected communities, 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 and the Deccan intertrappeans. This situation is reminiscent of other intertrappean freshwater organisms such as molluscs which are currently under study (Hartman *et al.*, 2007). Initial observations show that the Papro molluscs comprise 4 taxa: *Physa, Lymnaea* and 2 species of *Viviparus.* These taxa can be compared to similarly sized molluscs from Maastrichtian intertrappean beds of central India. Although better sampling at the Papro Locality is required to get a better idea of the diversity, it is apparent that atleast some of the freshwater taxa were not influenced by the volcanic activity events in this region. The present ostracod data from Papro supports Hartman's *et al.* (2007) interpretations. The fact that these taxa were able to repopulate during periods of quiescence between basaltic flows, also suggests that refugia were relatively close. 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 Paparo and Jhilmili data, combined together, do suggest that the indirect impact of volcanic activity on adjacent freshwater ecosystems was limited in aquatic settings.

The most important question, however, concerns the last stratigraphic occurrence of dinosaurs in the Deccan volcanic province. Significantly, the Papro and Jhilmili intertrappeans sections have not yielded any dinosaur fossils, consistent with their early Paleocene age. However, the presence of dinosaur fossils in several other intertrappean localities in the Deccan province such as Anjar, Dayapar (Gujarat), Asifabad (Andhra Pradesh), Hathni River section near Jabalpur and Mohagaonkalan in Chhindwara District (MP), clearly shows that dinosaurs (both theropods and sauropods) thrived in the Deccan province even after the initiation of volcanic activity. It is very important to note that dinosaur fossils (eggshells) occur in the Mohagaonkalan section of Chhindwara area. This section lies stratigraphically below the early Paleocene intertrappeans at Jhilmili being reported here. Evidently, dinosaurs survived the initial volcanic pulses in the Deccan as suggested by their fragmentary fossils, particularly eggshell fragments such as those at Mohagaonkalan. However, the magnetic polarity of the dinosaur-bearing intertrappeans at Mohagaonkalan is not known, so it it is not possible to ascertain whether or not they persisted into C29R. In another instance (Anjar), dinosaur fossils occur in beds associated with iridium-enriched levels between the third and fourth flows in the local flow stratigraphy (Bhandari *et al.*, 1996). However, paleontological investigations of intertrappeans between the same two flows have revealed the presence of dinosaur fossils (eggshells, rare teeth) even above the iridium levels, suggesting that the iridium interval predates the K-T boundary Maastrichtian, and is possibly within Maastrichtian, in the early part of magnetic chron 29R (Bajpai and Prasad, 2000). A similar viewpoint was put forward by Hansen *et al.* (2001) who described the iridium-bearing clay layers at Anjar as "strongly leached, rhyolitic bentonites", and unrelated to the K-T boundary. It will be of considerable interest to work out, using geochemical criteria and the magnetic stratigraphy, the relative stratigraphic position of the dinosaur-yielding intertrappean horizons at Anjar and other intertrappean localities with respect to the well known Western Ghats stratigraphy. Such data will help to determine whether the dinosaurs persisted upto the Cretaceous-Tertiary boundary, in the Deccan province, as suggested here, or whether they died out a few hundred thousand years before the K-T boundary.

5.4 BIOSTRATIGRAPHIC CONSIDERATIONS

In general, biostratigraphic age determination of intertrappean deposits, which represent periods of volcanic quiescence, has been rather difficult because these sediments consist mainly of terrestrial deposits, though with a diverse non-marine biota (see summary in Khosla and Sahni, 2003). The assemblage includes fragmentary dinosaur fossils (eggshells, teeth and rare bones) and a remarkably diverse endemic freshwater ostracod fauna (Bajpai and Whatley, 2001; Whatley and Bajpai, 2005, 2006; Khosla and Nagori, 2007). The presence of dinosaur fossils in several intertrappean localities across the Deccan province led to the general acceptance of a Maastrichtian age for these deposits (Sahni and Bajpai, 1988; Ghevariya, 1988; Srinivasan, 1996; Bajpai and Prasad, 2000).

A more precise age control is available in marine intertrappean sequences in the subsurface and outcrops in the Krishna-Godavari Basin (Govindan, 1981; Jaiprakash *et al.*, 1993; Keller *et al.*, 2008). The most recent study of planktic foraminifera from a shallow marine intertrappean quarry sections at Duddukuru near Rajahmundry quarries has revealed an early Danian zone P1a assemblages between lower and upper traps of C29R and C29N magnetic polarity zones, respectively (Knight *et al.*, 2003, 2005; Baksi, 2005; Keller *et al.*, 2008).

Biostratigraphic dating of the K-T transition in marine sediments have thus provided a significantly higher resolution than was possible with radiometric methods.

However, identification of K-T boundary within the main Deccan volcanic province has remained problematic because of the absence of marine fauna. For example, in the central India part of the volcanic province (Nagpur, Chhindwara and Mandla regions), biostratigraphy based on terrestrial macrofauna and flora has resulted in age assignments of Paleocene-Eocene (Bande *et al.*, 1981; Bande and Prakash, 1982; Mehrotra, 1989) or Maastrichtian ages (Sahni and Bajpai, 1988; Srinivasan *et al.*, 1994; Kar and Srinivasan, 1998; Khosla and Sahni, 2000, 2003; Khosla *et al.*, 2004; Prasad *et al.*, 2007; Samant and Mohabey, 2005). Palynological investigations of the Jhilmili intertrappeans (Cripps, 2002) revealed three samples rich in pollen, but no age diagnostic species.

The best-studied intertrappean beds in the Jhilmili area (but not the presently investigated section) occur in the Mohgaonkalan fossil forest located about 15 km to the southeast of the present section. The Mohgaonkalan section contains a rich megaflora in black-brown variegated cherts, including palms (monocots, dicots), conifers and water fern representing terrestrial freshwater and marshy environments (Sahni and Rhode, 1937; Prakash, 1960). Reported fauna includes dinosaur eggshells, ostracods and molluscs (Srinivasan, 1996; Kumaran *et al.*, 1997; Whatley *et al.*, 2002, 2003; Khosla and Nagori, 2007; Kapgate, 2005). The age of this megaflora and fauna has been interpreted as Paleogene based on megaflora (e.g., Bande *et al.*, 1988; Bande and Chandra, 1990). On the other hand, Maastrichtian palynomorph assemblages and diatoms have been reported from the shales below the chert horizon (Kar and Srinivasan, 1998; Ambwani *et al.*, 2003). Singpur is another locality in the Jhilmili area with reported Maastrichtian age palynoflora (Samant *et al.*, 2008). The presently investigated Jhilmili section differs from both Mohgaonkalan and Singpur in that neither of these palynoflora, megaflora or megafauna is present (Cripps, 2002). The Jhilmili intertrappean sediments thus represent a different age and paleoenvironment.

The present investigations have led to a more precise age dating and a link to the marine record due to the fortuitous discovery of foraminifera, in association with freshwater to brackish-marine ostracod assemblages, in an intertrappean section at Jhilmili, in central India. Planktic foraminifera in the Jhilmili intertrappean sediments were first discovered in washed residues. However, these specimens are mostly large (>150µm) and include early Danian species *Parasubbotina pseudobulloides, Subbotina triloculinoides, Praemurica taurica and Globigerina (E.) pentagona*. Smaller species were rarely observed in washed residues of the 100-150µm, 63-100µm and 36-63µm size fractions. This is probably due to dissolution effects and destruction of small fragile Danian species during laboratory processing. Thus, for further foraminiferal recovery, efforts (ongoing collaboration with G. Keller) were concentrated on thin section analysis. This led to the recovery of small planktic foraminiferal species (<100µm) which include *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* (Keller *et al.*, in press). In association with the Danian species, a number of K-T survivors such as *Hedbergella cf. holmdelensis, Globigerinelloides aspera* and the disaster opportunist *Guembelitria cretacea* (MacLeod and Keller, 1991; Paul, 2005) were also found.

The Jhilmili foraminifer assemblage, present in unit 3 (6.0-6.6 m) (Fig. 5.5), is typical of the early Danian *P. eugubina* zone P1a, similar to the assemblage recorded at the intertrappean beds of the Rajahamundry quarries (Keller *et al.*, 2008). Together with the short basal Danian zone P0, the zone P1a spans the interval of C29R above the K-T boundary, or about 280 ky (Cande and Kent, 1991; Gradstein and Ogg, 2004). Zone P1a is characterized by the range of *P. eugubina* and can be subdivided into subzones Pla(1) and P1a(2) based on the first appearances of *P. pseudobulloides* and *S. triloculinoides*, which generally appear about half way through zone P1a (Keller *et al.* (1995, 2002), or about 100-150 ky after the K-T boundary. In the unit 3 of Jhilmili intertrappeans (Keller *et al.*, in press), the presence of these index species together with *P. eugubina,* indicate that the foraminifera-bearing interval was deposited about 100-150 ky after the K-T boundary in subzone P1a (2). The underlying 6 m of red shale in unit 2 consist mainly of paleosols and were likely deposited during the early Danian P0-P1a(1) interval. The upper red and green shales of units 4 and 5 represent paleosols and palustrine conditions and were likely deposited during subzone P1a(2), as suggested by magnetostratigraphy (Keller *et al.*, under revision). Thus, the discovery of planktic foraminifers in the Jhilmili intertrappeans provides the first definite age evidence and identifies this intertrappean as early Danian zone P1a age (Fig. 5.6). Moreover, it permits correlation of this intertrappean sequence to the shallow marine intertrappean sediments in the Rajahmundry quarries where similar zone P1a assemblages have been identified between the lower trap of C29R and the upper trap of C29R-C29N transition age (Knight *et al.*, 2003, 2005; Baksi, 2005; Keller *et al.*, 2008), correlative with Ambenali and Mahalabeshwar Formations, respectively (Chenet *et al.*, 2007; Jay and Widdowson, 2008; Self *et al.*, 2008)

This identifies the Jhilmili and Rajahmundry lower trap basalt flows as marking the end of the main Deccan volcanic phase (Chenet *et al.*, 2007) at or near the K-T boundary and the intertrappean sediments as early Danian immediately following the K-T mass extinction. It is important to note that geographic extent (Fig. 5.6) of the Ambenali and Mahabaleshwar Formations of Western Ghats lava flows covers the Jhimili section (Self *et al.*, 2008).

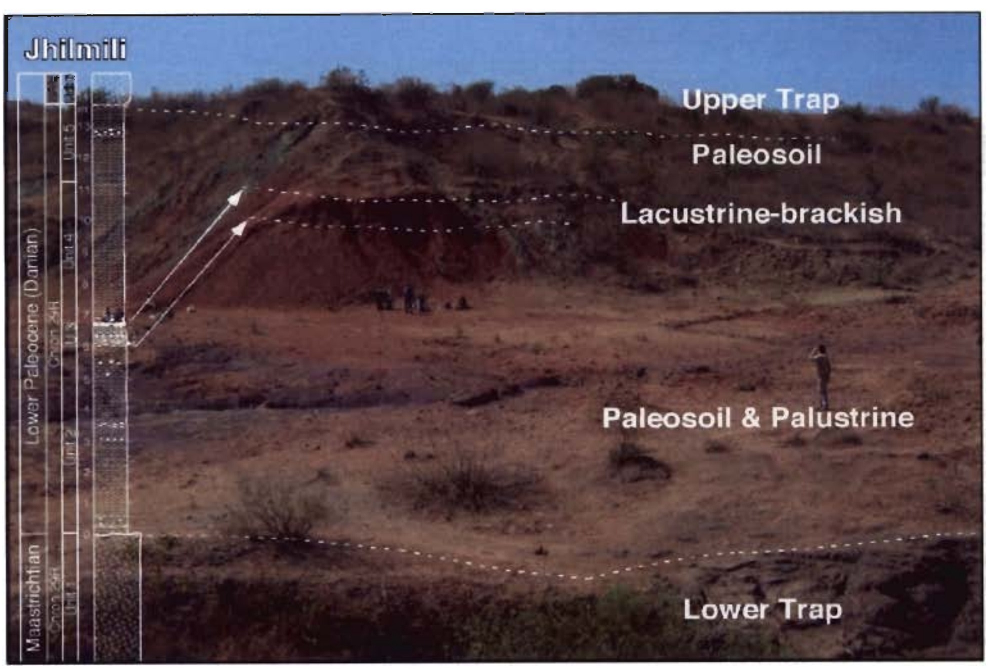

Figure 5.5 Jhilmili outcrop showing lower trap basalt flow (unit 1) at the base followed by intertrappean sediments consisting of paleosoil and palustrine sediments (unit 2), a narrow interval of lacustrine to brackish marine (unit 3) and return to paleosoils (units 4-5) underlying the upper trap (unit 6) (from Keller *et al.*, in review)

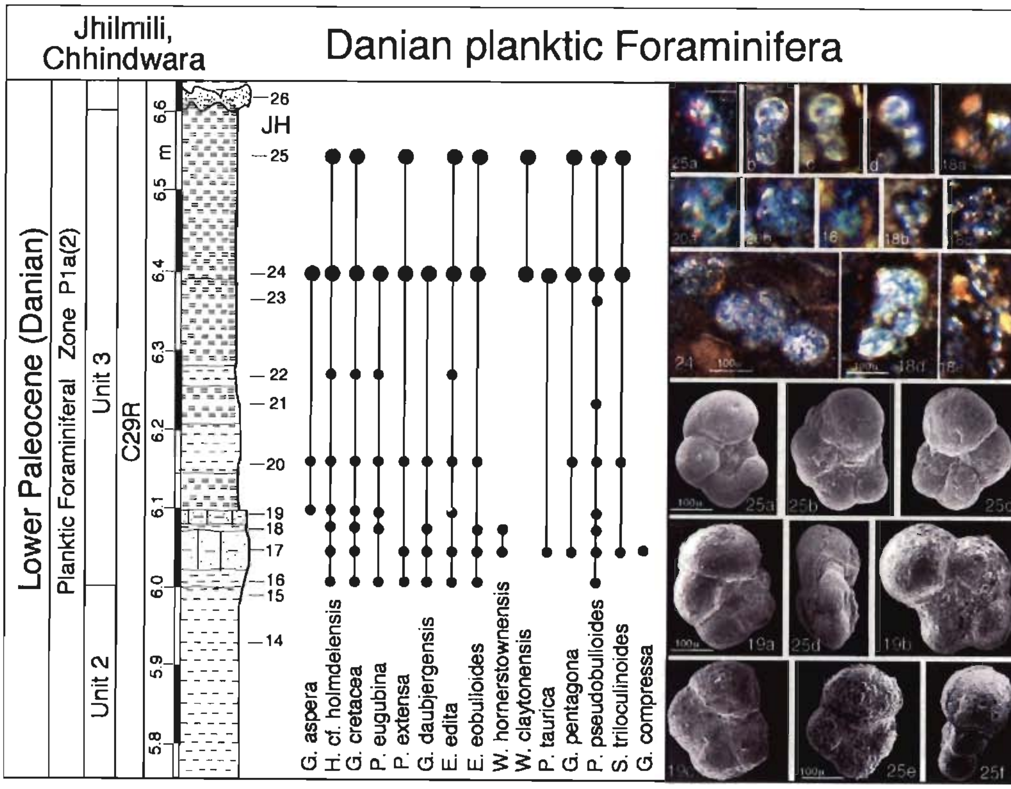

Figure 5.6 Planktic foraminiferal biostratigraphiy and species ranges of Jhilmili intertrappean sediments (Keller *et al.*, in press)

5.5 BIOGEOGRAPHIC CONSIDERATIONS

The physical and biotic links of India following its separation from the Gondwanaland continue to attract considerable attention in the context of geodynamic plate tectonic model (Ali and Aitchison, 2008). In particular, biogeographic affinities of the terrestrial fossil biota spanning the interval from the terminal phase of India's northward drift until its collision with Asia (approximately between 65 to 45 Ma) have evoked much interest. (e.g. Briggs 2003; Sahni, 2006; Sahni and Prasad, 2008; Bajpai, 2008). Traditional plate tectonic models show India as an island continent during the end-Cretaceous as the Indian plate drifted northwards through the middle of the Neotethys until the India-Asia collision around

55 Ma (Fig. 5.8, e.g. Ali and Aitchison, 2008). However, the 'island continent' hypothesis has been disputed by several workers on the grounds that the Maastrichtian terrestrial fossils, found in the Deccan intertrappean beds and the Lameta Formation of peninsular India, do not provide any evidence of an endemic biota that should have resulted if India remained in physical isolation before its contact with Asia (e.g. Sahni, 1983).

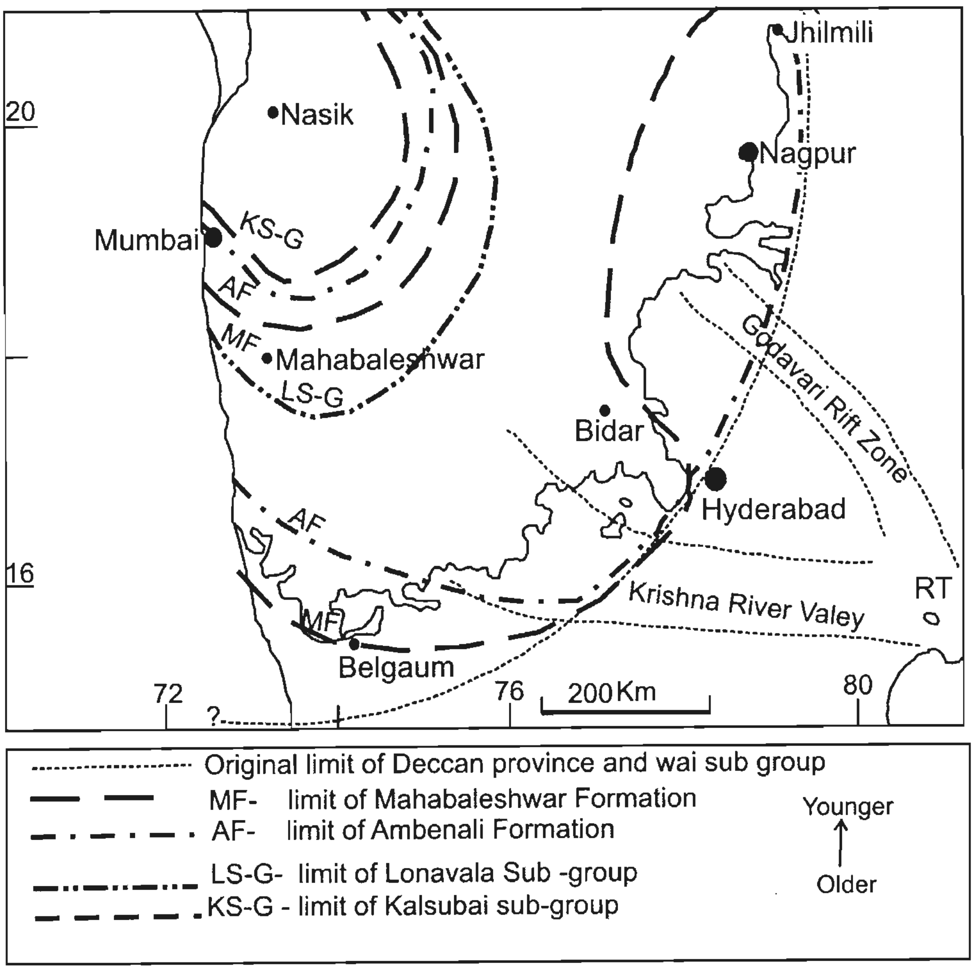

FIGURE 5.7 Map showing the southern part of the Deccan volcanic province with the inferred limits of the various lava flows formations. Note that the Ambenali Formations cover the presently investigated Jhilmili section (Modified after Self *et al.*, 2008)

5.5.1 The issue of Laurasian connection

During the past over two decades, the Deccan intertrappean biota of peninsular India has been argued to include several Laurasian elements. The Laurasian biota includes pelobatid and discoglossid frogs, anguid lizards, and eutherian mammals (Sahni and Bajpai, 1991; see also Sahni and Prasad, 2008 and references therein). Of particular siginficance are the discoglossid (Gobiatinae) frogs and the eutherian mammals such as *Deccanolestes*. The presence of these Eurasian elements in the latest Cretaceous of India has been interpreted variously, and the proposals put forward include

i) dispersals through a direct contact between India and Asia as early as the K/T boundary at ca. 65 Ma (Fig. 5.8c) (Jaeger *et al.*, 1989)

ii) dispersals through NE Africa with India tracking close to Africa during its northward movement (Fig. 5.8d) (Briggs, 2003) or via an extended northeastern Africa ('Greater Somalia', Chatterjee and Scotese, 1999).

iii) dispersals through filter bridges via Dras-Kohistan island arc (Prasad and Sahni, 1999)

iv) dispersals through sweepstakes mechanism involving, for instance, transportation on vegetation rafts (Ali and Aitchison, 2008).

Although no Eurasian elements including mammals or frogs were recovered during the present investigation, it is relevant to note the objections that have been raised in the past regarding the biogeographic significance of such fossils. According to Thewissen and McKenna (1992), the Discoglossidae is a paraphyletic assemblage of primitive frogs, which casts doubts on the Eurasian affinities of these forms. Thewissen and McKenna (1992) doubted the familial attribution of the "Eurasian" mammal *Deccanolestes* (Palaeoryctidae) found in the Deccan intertrappeans on account of the fragmentary material on which this taxon is based. Furthermore, Rana and Wilson (2003) proposed a number of alternative hypotheses to explain the presence of eutherian mammals in the latest Cetaceous of India.

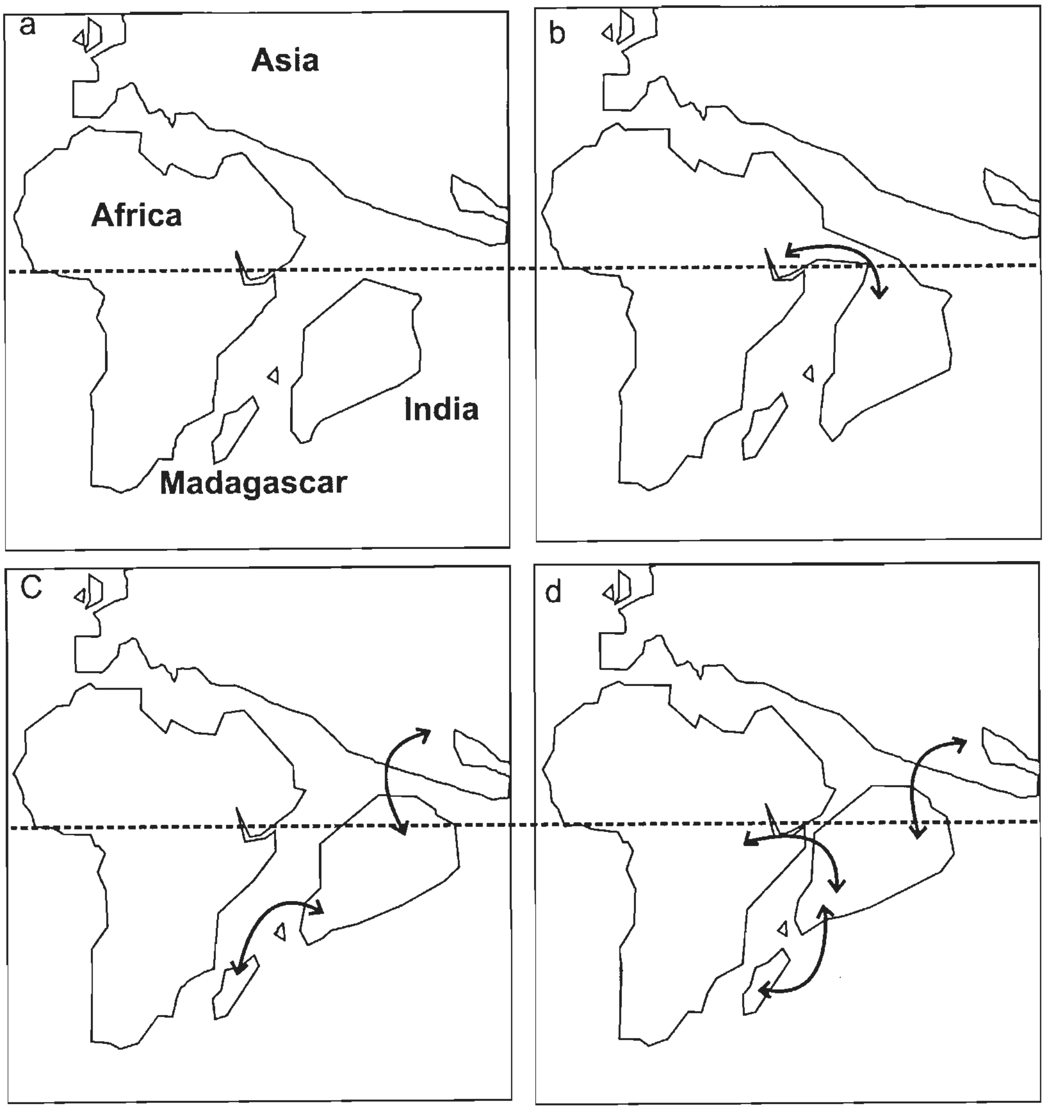

FIGURE 5.8 Various proposals for India's paleogeographic relations during Late Cretaceous. A- Island continent hypothesis, B- hypothesis for North Africa (Greater Somalia) connections, C-hypothesis for Madagascar-India-Asia connections, D-hypothesis for Madagascar-india-Africa-Asia connections. (After Ali and Aitchison, 2008).

These authors do not rule out the possibilities of i) Gondwana vicariance i.e. more widespread (southern) distribution of eutherian mammals prior to the break-up of the Gondwanaland or, alternatively ii) North America-South America dispersal route.

More recently, Sahni and Prasad (2008) again cited *Deccanolestes* and the discoglossid frogs as evidence of India's biological connectivity with Asia during Maastrichtian, but favoured a sweepstakes mode of dispersal to explain its presence in India, an idea earlier proposed by Ali and Aitchison (2008). Also important to cite here is a recent phylogenetic study (Wible *et al.* 2007) in which *Deccanolestes* has been shown as a sister taxon to a Eurasian mammal. This work reiterates the presence of some Eurasian mammals in the Maastrichtian non-marine biota of peninsular India. The present work supports the idea of dispersal of Eurasian elements into India by mechanism of sweepstakes, and not through a continuous terrestrial route as proposed by Jaeger *et al.* (1989). Similar sweepstake dispersal has been proposed recently to explain the puzzling presence of several African elements in Madagascar (e.g. Vences *et al.* 2003).

5.5.2 The issue of Gondwanan connection

Apart from the Laurasian elements, a number of Gondwanan taxa have also been described from the Maastrichtian Deccan intertrappean biota of India. Of particular importance are three groups: sudamericid (Gondwanathere), abelisaurid dinosaurs that are believed to exhibit close affinities to South American and Madagascar forms. In addition, haramyid mammals, *Indobatrachus*

(Myobatrachinae), leptodactylid, hylid and ranid frogs, nigerophiid and madtsoiid snakes, pelomedusoid turtles and baurusuchid crocodiles have also been cited in support of the Gondwanan connection (Sahni and Prasad, 2008).

Initially, Sahni (1984) proposed that some aseismic structures in the Indian Ocean such as the Mascarene Plateau and the Chagos-Laccadive ridges may possibly have served as a terrestrial route to allow faunal exchanges between India, Madagascar and South America. More recent proposals, however, suggest that physical links existed between Indo-Madagascar and South America (via Antarctica or Africa) during the late Cretaceous, probably no later than 85-90 Ma (Krause *et al.*, 1997; Prasad and Sahni, 1999; Sereno et al. 1994). It must be noted that of the several Gondwanan elements in the Maastrichtian of the Indian subcontinent, the dinosaur and the crocodile data, in particular, provide compelling evidence in favour of terrestrial links between the Gondwanan continents during the late Cretaceous. The other Gondwanan elements were small-sized and their dispersal may alternatively be explained by the sweepstakes (rafting) mode and not by actual physical connections. This picture will be clearer when the continental fauna spanning the interval between about 85 and 65 Ma is discovered. Going by the current geophysical data, significant amount of endemism should have developed during this 20 million year interval because of India's oceanic isolation. The present ostracod data strongly supports the idea of such isolation, as discussed below.

5.5.3 The issue of endemism

As mentioned earlier, evidence for endemism among the Maastrichtian-Paleocene terrestrial faunas of India was lacking until recently, and this led to notions of india's biological (and physical) connectivity with the surrounding landmasses in the Indian Ocean during this interval. More recently, in a series of publications, extensive endemism has been recognized among Maastrichitian freshwater ostracod faunas of the Deccan intertrappean deposits (Whatley and Bajpai 2006 *et seq*). The ostracod assemblage is remarkably diverse comprises over 75 freshwater ostracod species which are endemic at species level. These authors attribute this endemism to India's geographic isolation around the K/T boundary, consistent with the traditional geophysical models for this interval (Fig. 5.9).

In the context of studies on the intertrappean ostracods, it is now becoming increasingly clear that there has been the tendency in the past to attribute their genera to Mongolian and Chinese taxa. This resulted in a series of mis-identifications leading to a false overall resemblance being advocated between the Indian and the Mongolo-Chinese faunas. Further, this error was further compounded by the assignment of Indian taxa to Mongolian and Chinese species although they are quite unrelated. Many of the intertrappean species encountered in a series of publications (see Whatley and Bajpai, 2005 and references therein) had not been previously described, and many were attributed to genera so far not recorded from the intertrappeans. It is thus clear, as shown by Whatley & Bajpai (2000c) that the Indian late Cretaceous intertrappean ostracods do not indicate close Asian affinities. Actually, at the specific level they are clearly endemic to India. At the generic level, the intertrappean ostracods are cosmopolitan and show nearly as much affinity with European and North American Cretaceous ostracods as they do with other Asian faunas, with the exception of Mongolia where, although only one species occurs in common, there is a 39% communality of genera (Whatley and Bajpai, 2005). However, it is surprising that in spite of the erstwhile relations in the former Gondwanaland, the degree of similarity of intertrappean faunas to their African counterparts is extremely low, both at specific and generic level. A low degree of similarity is also seen between the Indian intertrappean and South American ostracod faunas.

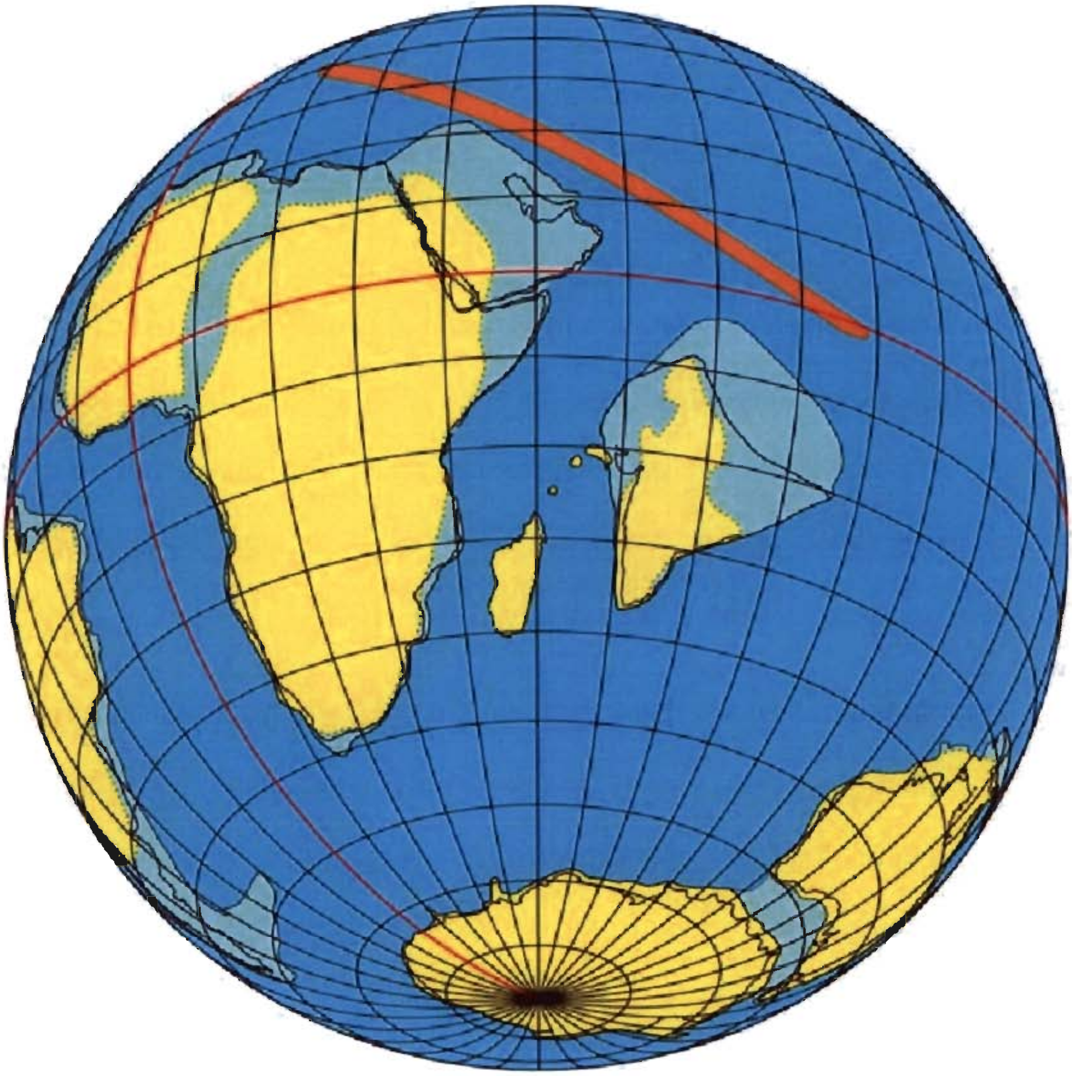

Figure 5.9 Paleogeographic position of India at 65.7 Ma. Note the wide separation between India's leading northern edge and the Dras-Kohistan island arc and its strike equivalents (in red) (After Ali and Aitchison, 2008).

5.5.4 The Out-of India hypothesis

The past few years have seen the emergence of an interesting 'Out-of-India' hypothesis, which advocates a Gondwanan origin for several groups of modern Asian biota (Karanth, 2006). Based on molecular phylogeny and divergence timings, this hypothesis holds that a number of Gondwanan forms were rafted on the northward drifting Indian plate and arrived in Asia as a result of India-Asia collision. Biota supporting this hypothesis includes diverse modern groups such as ranids and caecilians (Amphibia), agamid lizards, cichlid fishes, ratite birds, and crypteroniaceae plants.

Fossil evidence is critical to test the hypothesis of Out-of-India dispersal. So far, however, fossil data bearing on this hypothesis are scarce and there are only a few groups that apparently support the Gondwanan origin and Out-of-India dispersal. Important among these are the ranid frogs (Prasad and Rage, 2004; Bajpai and Kapur, 2008) and agamid lizards (Prasad and Bajpai, 2008).

Intertrappean freshwater ostracod faunas provide interesting insights into the issue of Out-of-India dispersal (Whatley and Bajpai, 2006). A number of intertrappean ostracod genera appear to be restricted to India in the Maastrichtian-Danian, becoming subsequently more widely distributed. These include: *Paracypretta* Sars, *Moenocypris* Triebel, *Centrocypris* Vavra and *Pseudocypris* Daday. The widespread genus *Paracypretta* is typical of the Indian intertrappeans and gives them their unique character. It probably originated in India and subsequently migrated from India to become diverse, for example in Africa at the present day (Whatley and Bajpai, 2006). However, there are some other genera that do not replicate this pattern. For instance, *Zonocypris* G. W. Muller, with 4 species in India and 1 in Africa in the Maastrichtian, appears to suggest migration out of India. However, a literature survey shows that *Zonocypris* has been described from the Aptian/Albian of Brasil (Colin and Depeche, 1997), possibly its oldest record. Another noteworthy example is *Frambocythere* Colin, which too is first recorded from the Albian of equatorial Africa (Colin, 1993) although at the generic level it occurs as 2 different subspecies of the same species in India and other subspecies in China, France and Spain during the Maastrichtian.

It is of much current interest to see if the Out-of-India dispersal is supported by additional taxa among plants, vertebrates and invertebrates. Ongoing studies of the Vastan mammals are expected to provide significant insights into the Out-of-India (or Into-India) hypothesis, and the origins and dispersal pattern of many terrestrial mammalian orders that appeared almost simultaneously across the northern continents during the intense warming interval around 55 Ma.

Following the Deccan Traps volcanism, the next major tectonic event to take place was the early Tertiary (ca. 55 Ma) initiation of India-Asia collision (e.g. Sahni, 2006). The colision led to major biotic changes driven by shallowing of the Tethys Sea between the two landmasses. These changes include the origin and radiation of new mammalian communities in the Indian subcontinent, documented in recent years from the Eocene sedimentary sequences of Kutch and Surat (Gujarat) and the Subathu Formation of NW Himalaya in Himachal Pradesh and Jammu & Kashmir. Data from Kutch and Himalaya have clearly established the Indian landmass as the centre of origin and early evolution of marine mammals, particularly whales (Thewissen *et al.*, 2007). More recently, a highly diverse terrestrial mammal fauna and associated lower vertebrates of basal Eocene age (approximately 55 Ma) has come to light from the Vastan lignite mine of District Surat, Gujarat. The assemblage is not only the oldest known Cenozoic terrestrial vertebrate fauna from South Asia but possibly includes the globally oldest records of several modern groups, including anthropoids and lagomorphs (Bajpai *et al.*, 2005, 2006, 2007, 2008; Rana *et al.*, 2008; Rose *et al.*, 2008). The Vastan fauna shows links with Laurasian early Eocene faunas and suggests early Cenozoic exchanges with Eaurasia in the context of tectonic collision between India and Asia. Ongoing studies of this remarkable mammal fauna are expected to a better understanding of the importance of India as an important center for the mammalian radiation.

CHAPTER 6

SUMMARY AND CONCLUSIONS

- This investigation was undertaken with the objectives of determining the biogeographic affinities of the end Cretaceous/early Paleocene faunas of the Deccan volcanic province in a geodynamic context; working out paleoenvironments/ paleogeography as well as paleoecoloical conditions based on the recovered intertrappean microbiota (including stable isotopic constraints from selected sections) and working out biostratigraphic implications of the recovered intertrappean biota for constraining temporal relationships between individual sections of the Deccan volcanic province. Nine sections of the Deccan intertrappean deposits of peninsular India were selected for the present dissertation. These sections are: Dayapar, Virani, Lakshmipur, Anjar (District Kutch, Gujarat); Jhilmili, District Chhindwara and Phulsagar, District Mandla (Madhya Pradesh); Nahardi, District Jhalawar (Rajasthan); Papro, District Lalitpur (Uttar Pradesh) and Duddukuru, East Godavari District (Andhra Pradesh).
- The discovery of planktic foraminifers in the Deccan intertrappean deposits at Jhilmili (District Chhindwara, Madhya Pradesh) is one of the most important highlights of this dissertation. The recovered foraminifer taxa include early Danian species *Parasubbotina pseudobulloides, Subbotina triloculinoides, Praemurica taurica and Globigerina (E.) pentagona*. Prior to this discovery,

foraminifers were not known from any intertrappean section in the main part of the Deccan volcanic province. The discovery of 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 presence of early Danian zone P1a planktic foraminiferal assemblages along with brackish water ostracods in the Jhilmili intertrappean sediments is important for two main reasons. First, it indicates that a seaway existed in central India during the Maastrichtian-early Paleocene. Secondly, it indicates that the K-T boundary is at or near the end of the lower trap basalt eruption, which correlates with the end of the main phase of Deccan volcanism (e.g., top of the Ambenali Formation) consistent with recent results from Rajahmundry (Keller *et al.*, 2008; Jay and Widdowson, 2008).
- The proposed marine incursions during the K/T transition may have followed the Narmada and Tapti rift zones where a seaway is already known to have existed during the Cenomanian-Turonian (Bagh Beds).
- Along the proposed seaway a rich and diverse fauna of dinosaurs and associated vertebrates flourished during the Maastrichtian. Their diversity decline and eventual extinction may now be evaluated within the context of this major trans-India seaway and the killing effects of the main phase of Deccan volcanism near the end of the Maastrichtian.

- In addition to foraminifers, a diverse assemblage of ostracods has been also discovered in the Jhilmili intertrappeans. The ostracod assemblage comprises 16 species including at least three new species that will be named when additional material is forthcoming. Significantly, the assemblage includes a brackish water species *Neocyprideis* cf. *N. raoi* which was previously known from the well known marine Deccan intertrappean deposits near Rajahmundry (Andhra Pradesh), outside of the main Deccan province.
- The present investigations have led to the recovery of a freshwater ostracod assemblage (12 spp.) for the first time from the Paleocene-aged Deccan intertrappean deposits of Papro (District Lalitpur, Uttar Pradesh).The assemblage, currently under publication (Sharma *et al.*, *in press*) is strikingly similar to those documented from Deccan intertrappean deposits dated as Maastrichtian. A likely explanation for this similarity is that the intertrappean freshwater ostracods were one of the least affected communities, at least qualitatively, across the Cretaceous-Tertiary transition, a situation similar to freshwater molluscs.
- A fairy diverse assemblage of freshwater ostracods (13 spp.) and fishes (2 species) has been recovered from the Deccan intertrappean deposits at Nahardi, in District Jhalawar of Rajasthan, NW India. Intertrappeans in this area, representing one of the northern most extensions of the Deccan volcano-sedimentary sequences, were amongst the most poorly known in the entire Deccan province. The ostracod assemblage is correlatable to corresponding assemblages from other sections in the Deccan. The presence

of an age diagnostic ray fish (*Igdabatis*) suggests a Maastrictian age for this section.

- Two new, potentially important fossiliferous intertrappean setions have come to light as a result of this investigation. One of these is at Virani, District Kutch, Gujarat where a small ostracod assemblage comprising 8 species, in association with few fishes, has been recovered. The other is at Phulsagar, District Mandla (Madhya Pradesh) from where 8 ostracod species (including 2 new) have been recorded from grey and black chert bands (in Bajpai *et al.*, 2004).
- A poorly known intertrappean section near the village Dayapar, District Kutch (Gujarat), was also studied for the present dissertation. An assemblage of 15 ostraocd species has been recorded for the first time from this section in association with charophytes and fishes.
- The Deccan intertrappean ostracods of peninsular India are strongly endemic at species level and do not indicate close Asian affinities as originally claimed. At the generic level, the intertrappean ostracods are cosmopolitan and show nearly as much affinity with European and North American Cretaceous ostracods as they do with other Asian faunas. Furthermore, in spite of the erstwhile relations with the former Gondwana continents, the degree of similarity of intertrappean faunas to their African counterparts is extremely low, both at specific and generic level. A similarly low similarity is seen between the Indian intertrappean and South American ostracod faunas. The extensive ostracod endemism suggests India's geographic isolation around

the K-T boundary time, consistent with the traditional geophysical data that show India as northward moving island continent during this interval. The intertrappean ostracod data thus helps to reconcile a long standing apparent conflict between the geophysical and paleontological data.

- Several Deccan intertrappean ostracod taxa (*Limnocythere, Eucypris, Cyprois, Cyridopods* perhaps *Candona*) appear to support the Out of India" hypothesis.
- Paleoecological analysis of Deccan intertrappean ostracods from different localities reveals an admixed ostracod assemblage suggestive of a lacustrine system that comprised a core of permanent water and a periphery that was subject to dessication during the dry season.
- A preliminary attempt was made to analyze the carbon and oxygen stable isotopes of ostracod shells recovered from the Lakshmipur intertrappean deposits of Kutch. This is the first time that this approach has been extended to sediments older than the Quaternary. Although essentially tentative, the present data does point to the potential of extending this approach to older deposits. The study (Sanyal *et al*. 2005) suggests that evaporative conditions prevailed intermittently during the deposition of Lakshmipur intertrappeans. However, this tentative conclusion does need supportive evidence from the presence of evaporative minerals. Significantly, such evaporative minerals have already been found in another intertrappean section (Anjar) in Kutch.

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EXPLANATION OF PLATE 1

(Scale bar equals 60μm for A-D, I–N; 200μm for E-F, H, O; 300μm for G)

A-H. ***Gomphocythere akalypton*** Whatley and Bajpai, 2002

A. Carapace, dorsal view (IITR/SB/PI/1)

B. Carapace, right lateral view (IITR/SB/PI/2)

C. Carapace, dorsal view (IITR/SB/PI/4)

D. Carapace, right lateral view (IITR/SB/PI/7)

E. Carapace, dorsal view (IITR/SB/LI/9)

F. Carapace, right lateral view (IITR/SB/LI/11)

G. Carapace, left lateral view IITR/SB/LI/17)

H. Carapace, dorsal view (IITR/SB/LI /11)

I-N. ***Gomphocythere paucisulcatus*** Whatley *et al.*, 2002

I. Carapace, right lateral view, (IITR /SB/LI/23)

J. Carapace, left lateral view, (IITR /SB/LI/52)

K. Carapace, dorsal view, (IITR /SB/LI/21)

L. Carapace left lateral view (IITR/SB/NI/30)

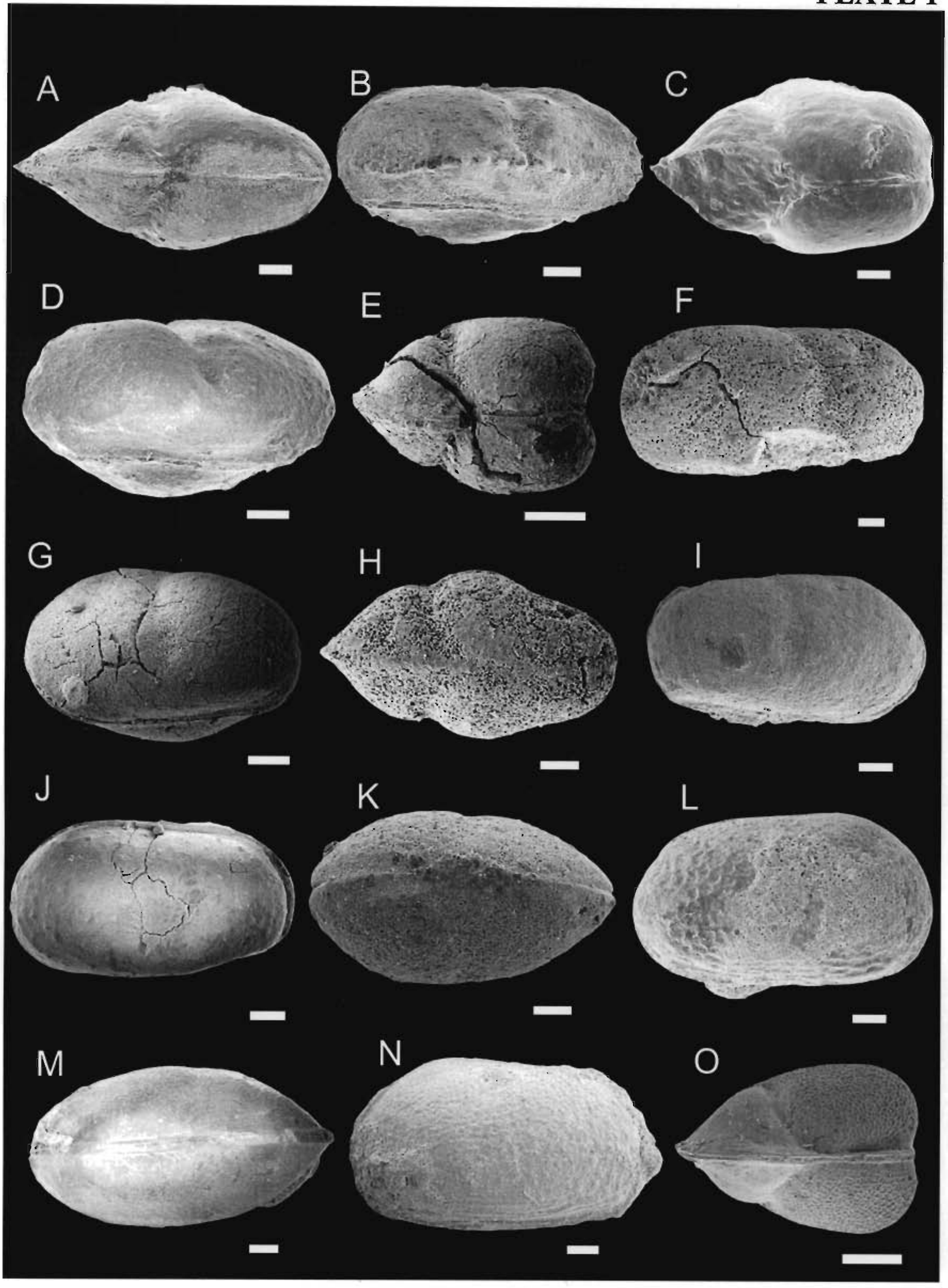
M. Carapace, dorsal view (IITR/SB/NI/28)

N. Carapace, right lateral view (IITR/SB/NI/29)

O. ***Gomphocythere strangulata*** (Jones, 1860)

O. Carapace dorsal view (IITR/SB/JH/1)

PLATE 1



EXPLANATION OF PLATE 2

(Scale bar equals 200µm for A-B, H, M-O; 90µm for C-E, G, J; 60µm for F, K, L)

A- B. ***Gomphocythere strangulata*** (Jones, 1860)

A. Carapace, right lateral view (IITR/SB/JH/2)

B. Carapace, dorsal view (IITR/SB/JH/3)

C-L. ***Lymnocythere deccanensis*** Khosla and Nagori, 2005

C. Carapace, dorsal view. (IITR/SB/PI/20)

D. Carapace, right lateral view (IITR/SB/PI/18)

E. Carapace, left lateral view (IITR/SB/PI/16)

F. Carapace, right lateral view (IITR/SB/PI/5)

G. Carapace, right lateral view (IITR/SB/NI/43)

H. Carapace, left lateral view (ITR/SB/JH/4)

I. Carapace, right lateral view (IITR/SB/JH/5)

J. Carapace, right lateral view (IITR/SB/JH/6)

K. Carapace, left lateral view (ITR/SB/JH/7)

L. Carapace, dorsal view (IITR/SB/JH/8)

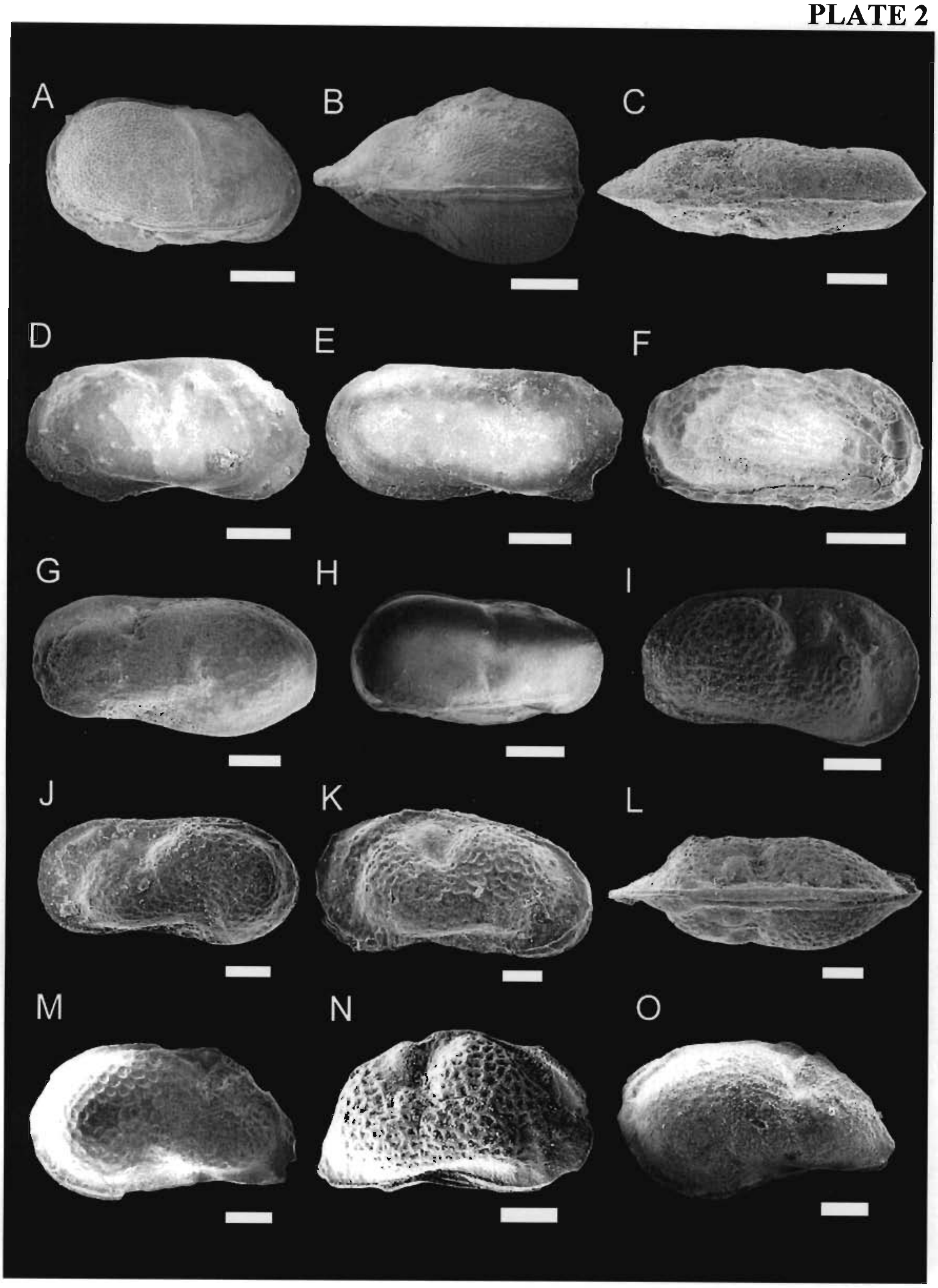
M-O. ***Lymnocythere*** **sp**.

M. Carapace, left lateral view (IITR/SB/JH/9)

N. Carapace, right lateral view (IITR/SB/JH/10)

O. Carapace, left lateral view (IITR/SB/JH/11)

PLATE 2



EXPLANATION OF PLATE 3

(Scale bar equals 100µm for A, K; 200µm for B, J, O; 90µm for C, H, I; 60µm for D-G; 300µm for L; 400µm for M; 250 µm for N)

A-B. ***Frambocythere tumiensis anjarensis*** Bhandari and Colin, 1999

A. Carapace, dorsal view (IITR/SB/AN/57)

B. Carapace, dorsal view (IITR/SB/A /58)

C-F. ***Frambocythere tumiensis lakshmiae*** Whatley and Bajpai, 2000

C. Carapace, dorsal view (IITR/SB/DI/42)

D. Carapace, dorsal view (IITR/SB/LKP/11)

E. Carapace, dorsal view (IITR/SB/LKP/10)

F. Carapace, dorsal view (IITR/SB/LI/46)

G-I. ***Darwinula* sp.**

G. Carapace, left lateral view (IITR/SB/DI/67)

H. Carapace, right lateral view (IITR/SB/DI/59)

I. Carapace, left lateral view (IITR/SB/DI/60)

J- K. ***Darwinula torpedo*** Whatley *et al.*, 2002

J. Carapace, right lateral view (IITR/SB/JH/12)

K. Carapace, right lateral view (IITR/SB/JH/13)

L-O. ***Paracypretta subglobosa*** (Soweby, 1840)

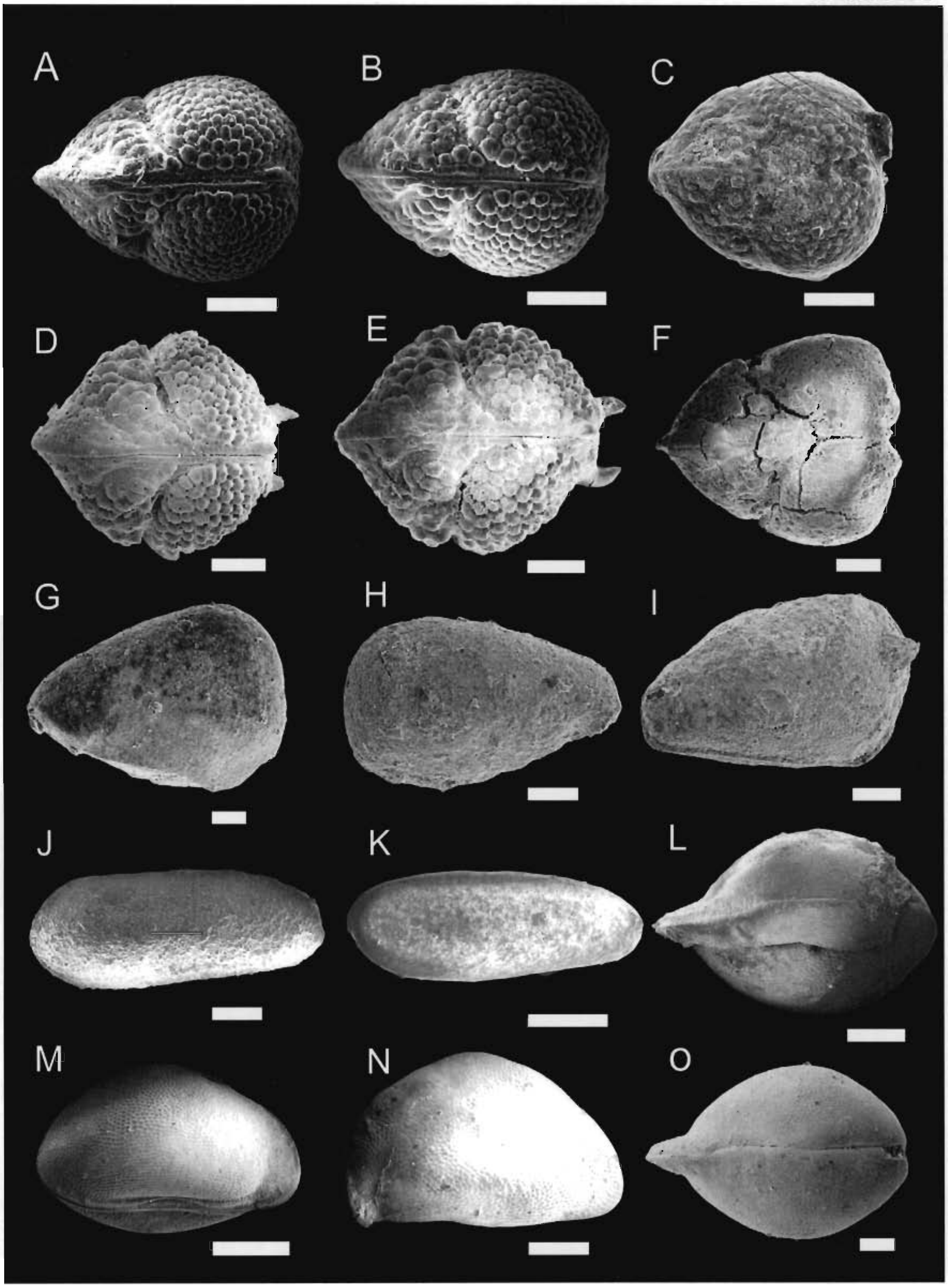
L. Carapace, dorsal view (IITR/SB/JH/14)

M. Carapace, right lateral view (IITR/SB/JH/15)

N. Carapace, left lateral view (IITR/SB/JH/16)

O. Carapace, dorsal view (IITR/SB/NI/11)

PLATE 3



EXPLANATION OF PLATE 4

(Scale bar equals 100μm for A; 200μm for B, F, J, M, O; 250μm for C-D, G, K; 500μm for E; 300μm for H, I, L; 80μm for N)

A. ***Paracypretta subglobosa*** (Sowerby, 1840)

A. Carapace, left lateral view (IITR/SB/NI/24)

B-K. ***Paracypretta jonesi*** Bhatia and Rana, 1984

B. Carapace, dorsal view (IITR/SB/JH/17)

C. Carapace, dorsal view (IITR/SB/JH/18)

D. Carapace, left lateral view (IITR/SB/JH/19)

E. Carapace, dorsal view (ITR/SB/JH/20)

F. Carapace, dorsal view (IITR/SB/JH/21)

G. Carapace, left lateral view (IITR/SB/JH/22)

H. Carapace, left lateral view (IITR/SB/AN/5)

I. Carapace, left lateral view (IITR/SB/AN/6)

J. Carapace, left lateral view (IITR/SB/AN/7)

K. Carapace, right lateral view (IITR/SB/AN /4)

L-M. ***Paracypretta elizabethae*** Whatley *et al.*, 2002

L. Carapace, dorsal, lateral view (IITR/SB/DI/9)

M. Carapace, left view (IITR/SB/DI/10)

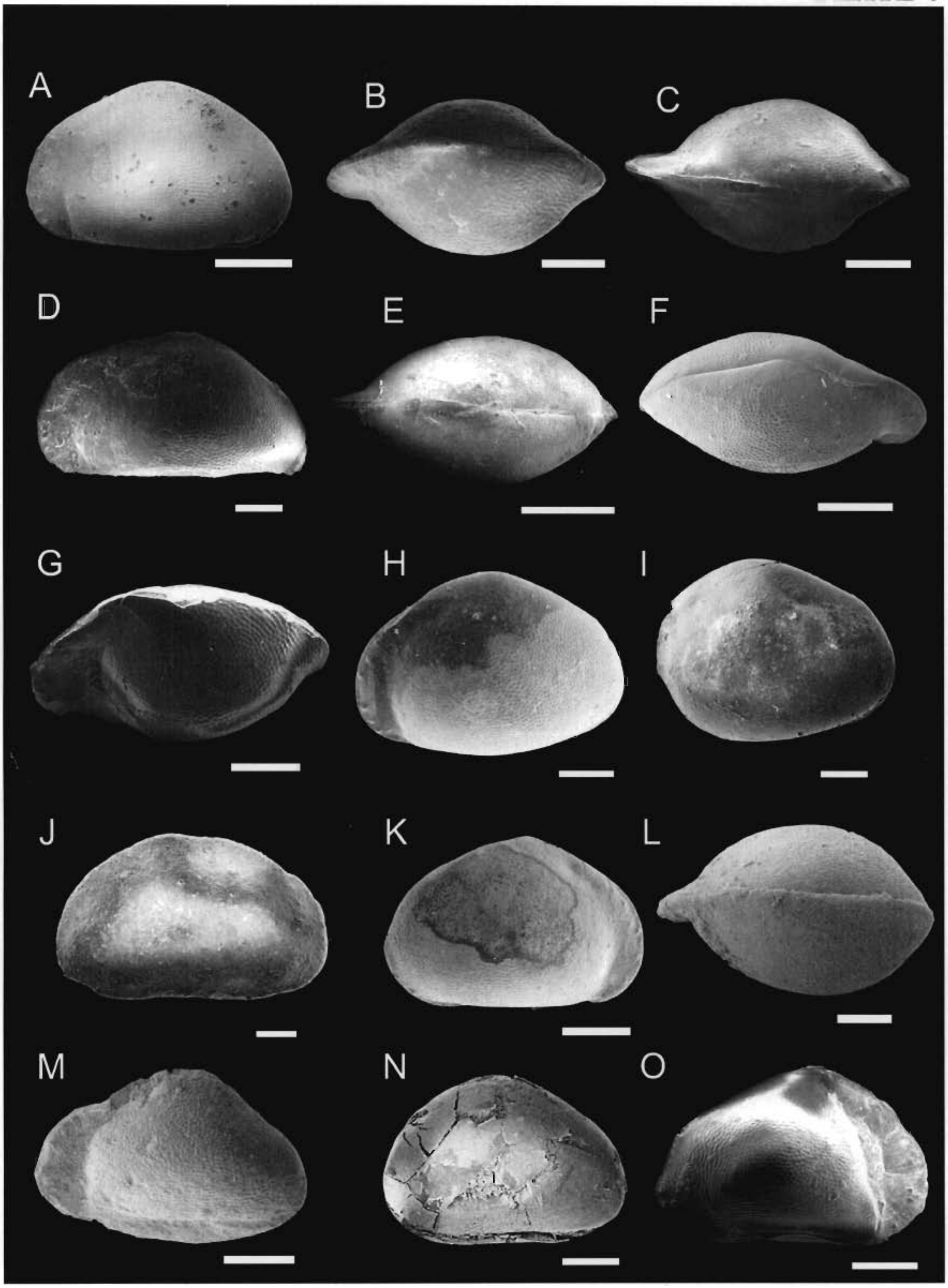
N. ***Paracypretta*** **sp.1**

N. Carapace, right lateral view (IITR/SB/LI/36)

O. ***Paracypretta*** **sp. 2**

O. Carapace, right lateral view (IITR/SB/JH/23)

PLATE 4



EXPLANATION OF PLATE 5

(Scale bar equals 200µm A-B, D-L; 90µm for M-O; 100µm for C)

A-C. *Paracypretta* sp. 2

A. Carapace, left lateral view (IITR/SB/JH/24)

B. Carapace, right lateral view (IITR/SB/JH/25)

C. Carapace, left lateral view (IITR/SB/JH/26)

D-L. *Cypridopsis wynnei* Whatley and Bajpai, 2000

D. Carapace, dorsal view (IITR/SB/DI/31)

E. Carapace, left lateral view (IITR/SB/DI/29)

F. Carapace, right lateral view (IITR/SB/DI/30)

G. Carapace, right lateral view (IITR/SB/NI/21)

H. Carapace, dorsal view (IITR/SB/NI/22)

I. Carapace, right lateral view (IITR/SB/NI/20)

J. Carapace, dorsal view (IITR/SB/VI/8)

K. Carapace, right lateral view (IITR/SB/VI/9)

L. Carapace, left lateral view (IITR/SB/VI/8)

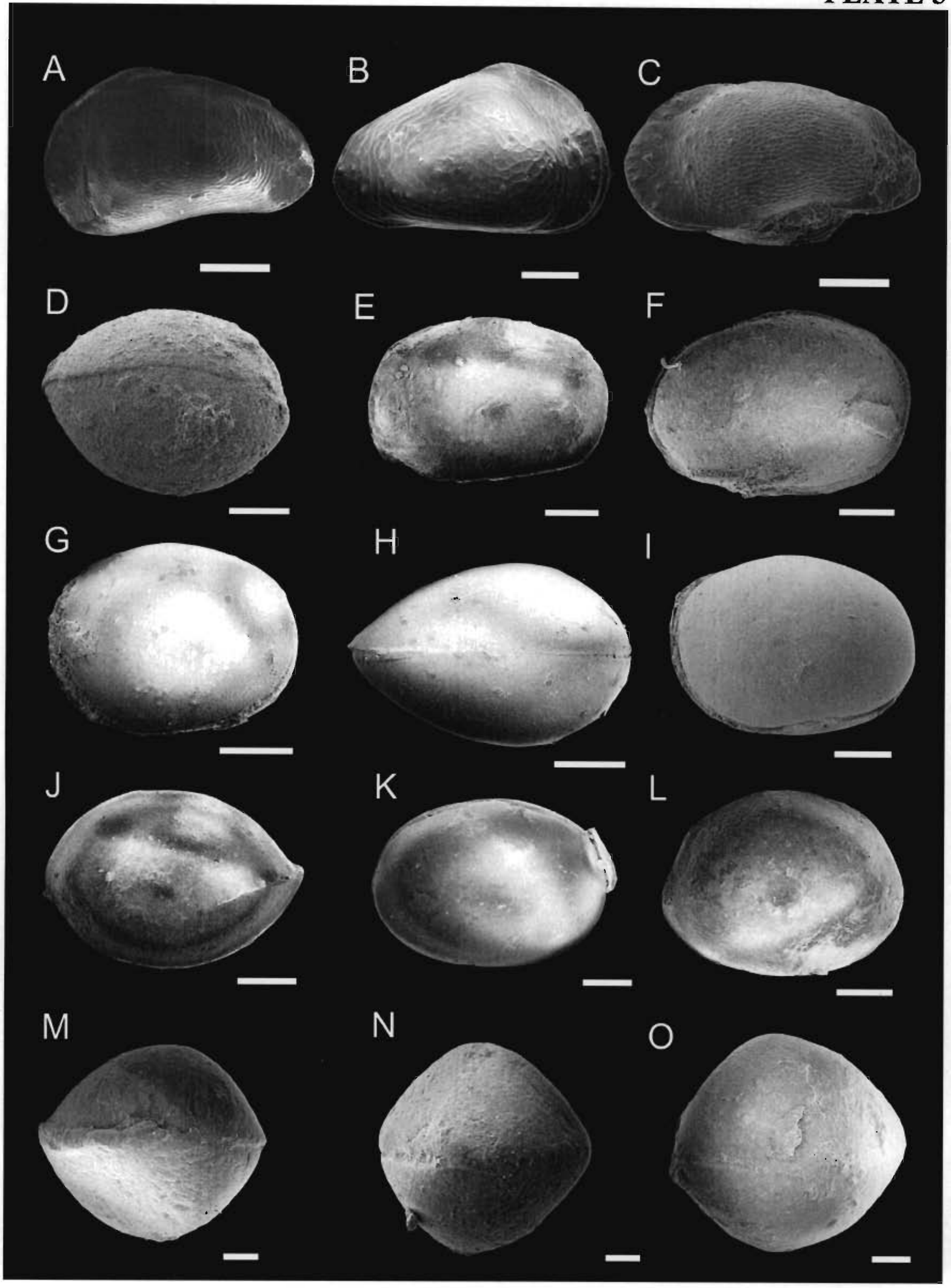
M-O. *Cypridopsis hyperectyphos* Whatley and Bajpai, 2000

M. Carapace, dorsal view (IITR/SB/VI/5)

N. Carapace, dorsal view (IITR/SB/VI/6)

O. Carapace, dorsal view (IITR/SB/NI/32)

PLATE 5



EXPLANATION OF PLATE 6

(Scale bar equals 200µm for A, B, L; 90µm for C-K)

A-K. ***Cypridopsis hyperectyphos*** Whatley and Bajpai, 2000

A. Carapace, dorsal view (IITR/SB/JH/27)

B. Carapace, dorsal view (IITR/SB/AN/12)

C. Carapace, dorsal view (IITR/SB/LKP/7)

D. Carapace, left lateral view (IITR/SB/LKP/8)

E. Carapace, dorsal view (IITR/SB/LKP/9)

F. Carapace, dorsal view (IITR/SB/DI/24)

G. Carapace, dorsal view (IITR/SB/DI/26)

H. Carapace, right lateral view (IITR/SB/DI/24)

I. Carapace, dorsal view (IITR /SB/LI/15)

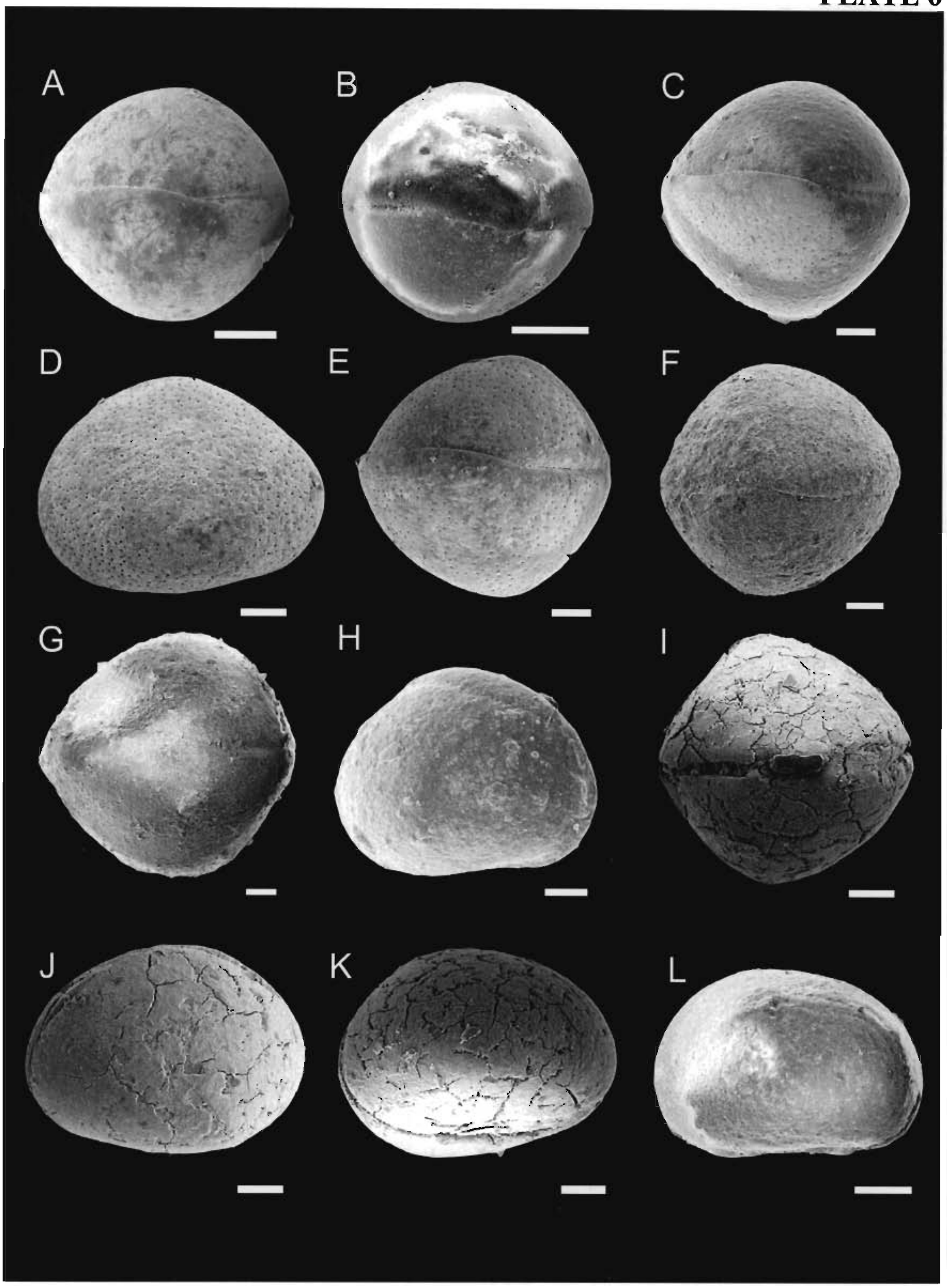
J. Carapace, right lateral view (IITR /SB/LI/14)

K. Carapace, left lateral view (IITR /SB/LI/14)

L. ***Cypridopsis whatleyi*** Bajpai *et al.*, 2004

L.. Carapace, right lateral view (IITR/SB/PI/37)

PLATE 6



EXPLANATION OF PLATE 7

(Scale bar equals 200µm for A-C, F, M; 60µm for D-E, I-L; 100µm for G-H, N-O)

A-C. ***Cypridopsis whatleyi*** Bajpai *et al*., 2004

A. Carapace, right lateral view (IITR/SB/PI/38)

B. Carapace, left lateral view (IITR/SB/PI/39)

C. Carapace, dorsal view (IITR/SB/PI/35)

D-E. ***Cypridopsis* sp. 1**

D. Carapace, left lateral view (IITR/SB/LI/49)

E. Carapace, dorsal view (IITR/SB/LI/48)

F-H. ***Cypridopsis* sp. 2**

F. Carapace, left lateral view (IITR/SB/VI/14)

G. Carapace, dorsal lateral view (IITR/SB/VI/15)

H. Carapace, dorsal lateral view (IITR/SB/VI/16)

I-N. ***Zonocypris spirula*** Whatley and Bajpai, 2000

I. Carapace, dorsal view (IITR/SB/LI/60)

J. Carapace, right lateral view (IITR/SB/LI/59)

K. Carapace, left lateral view (IITR/SB/NI/38)

L. Carapace, dorsal view (IITR/SB/JH/28)

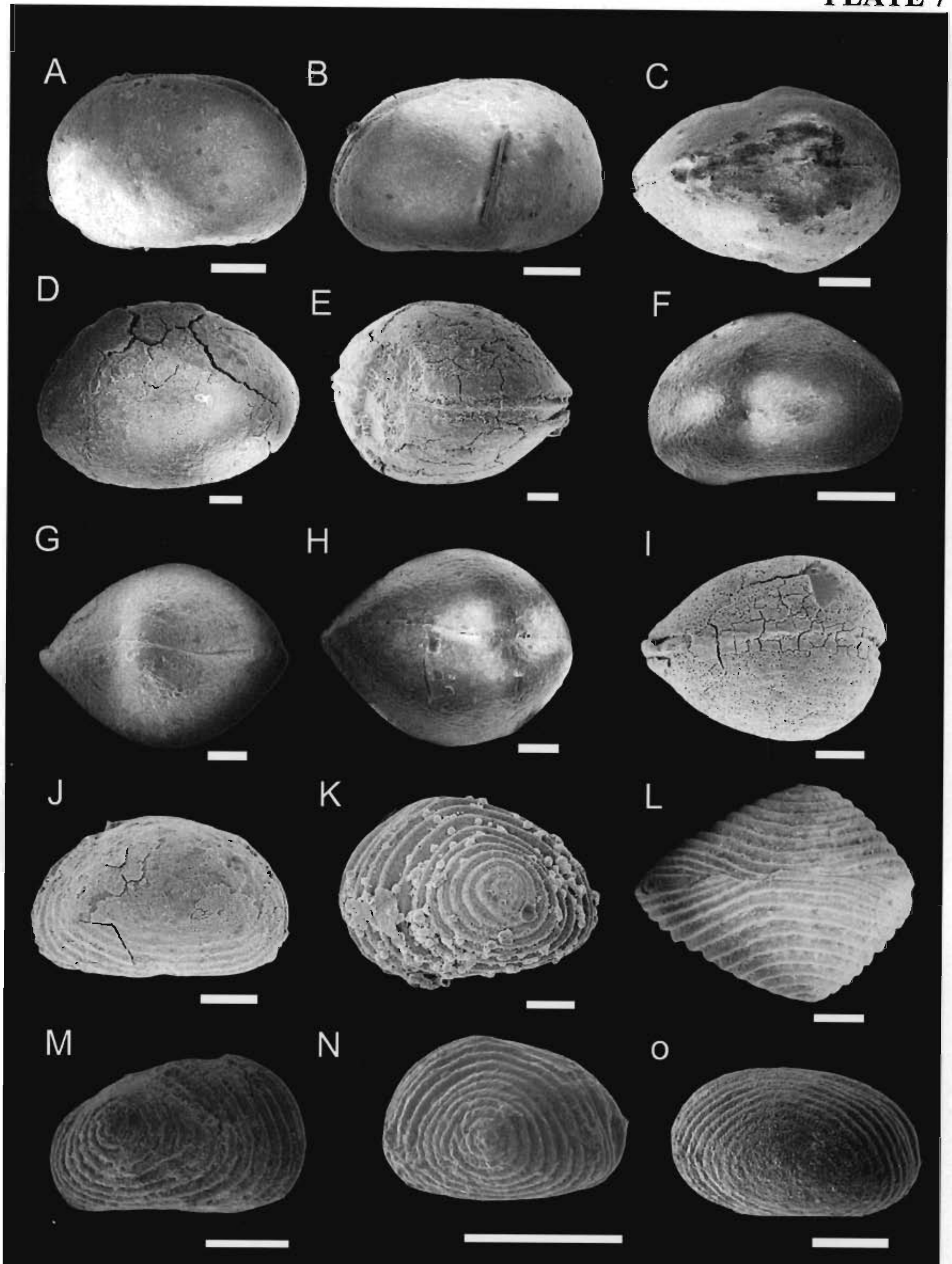
M. Carapace, right lateral view (IITR/SB/JH/29)

N. Carapace, left lateral view (IITR/SB/JH/30)

O. ***Zonocypris viriensis*** Khosla and Nagori, 2005

O. Carapace, right lateral view (IITR/SB/JH/31)

PLATE 7



EXPLANATION OF PLATE 8

(Scale bar equals 100µm for A-B, I-J; 60µm for C; 90µm for D-G; 30 µm for H; 300µm for K; 180µm for L; 200µm for M-O)

A-C. ***Zonocypris viriensis*** Khosla and Nagori, 2005

A. Carapace, left lateral view (IITR/SB/JH/32)

B. Carapace, dorsal view (IITR/SB/JH/33)

C. Carapace, right lateral view (IITR/SB/JH/34)

D-K. ***Eucypris intervolcanus*** Whatley and Bajpai, 2000

D. Carapace, dorsal view (IITR/SB/LI/55)

E. Carapace, right lateral view (IITR/SB/LI/54)

F. Carapace, left lateral view (IITR/SB/LI/39)

G. Carapace, left lateral view (IITR/SB/LI/8)

H. Carapace, right lateral view (IITR/SB/VI/13)

I. Carapace, right lateral view (IITR/SB/PI/78)

J. Carapace, left lateral view (IITR/SB/PI/77)

K. Carapace, dorsal lateral view (IITR/SB/PI/80)

L-O. ***Eucypris pelasgicos*** Whatley and Bajpai, 2000

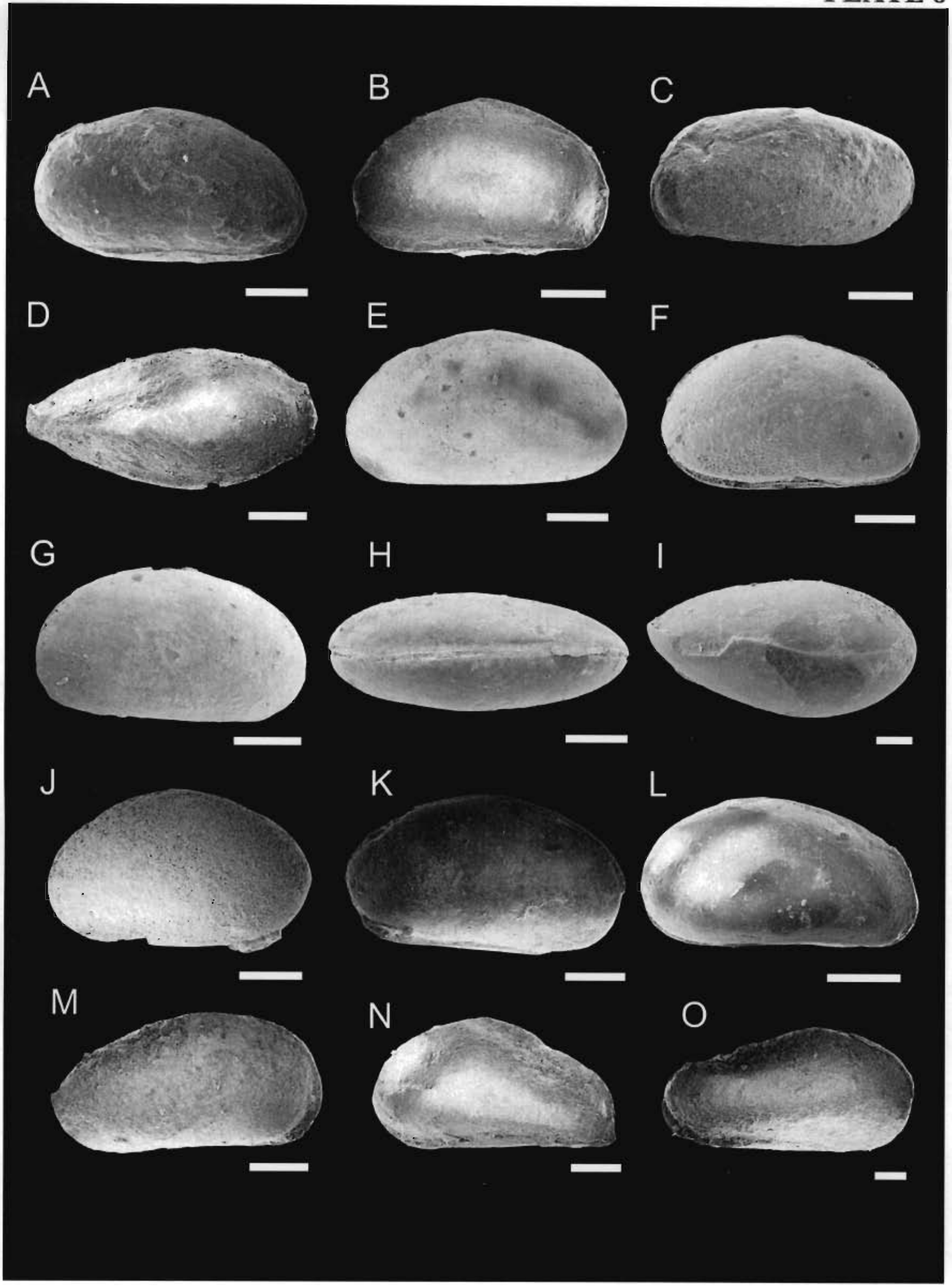
L. Carapace, left lateral view (IITR/SB/LKP/5)

M. Carapace, dorsal view (IITR/SB/LKP/6)

N. Carapace, left lateral view (IITR/SB/ AN/9)

O. Carapace, left lateral view (IITR/SB/DI/46)

PLATE 8



EXPLANATION OF PLATE 9

(Scale bar equals 200µm for A-H, J-N; 120µm for I, O)

A-L. ***Eucypris pelasgicos*** Whatley and Bajpai, 2000

A. Carapace, right lateral view (IITR/SB/DI/50)

B. Carapace, right lateral view (IITR/SB/DI/47)

C. Carapace, left lateral view (IITR/SB/DI/49)

D. Carapace, dorsal view (IITR/SB/DI/126)

E. Carapace, left lateral view (IITR/SB/PI/10)

F. Carapace, right lateral view (IITR/SB/PI/11)

G. Carapace, right lateral view (IITR/SB/PI/12)

H. Carapace, dorsal view (IITR/SB/PI/9)

I. Carapace, dorsal view (IITR/SB/NI/44)

J. Carapace, left lateral view (IITR/SB/NI/53)

K. Carapace, left lateral view (IITR/SB/VI/1)

L. Carapace, right lateral view (IITR/SB/VI/2)

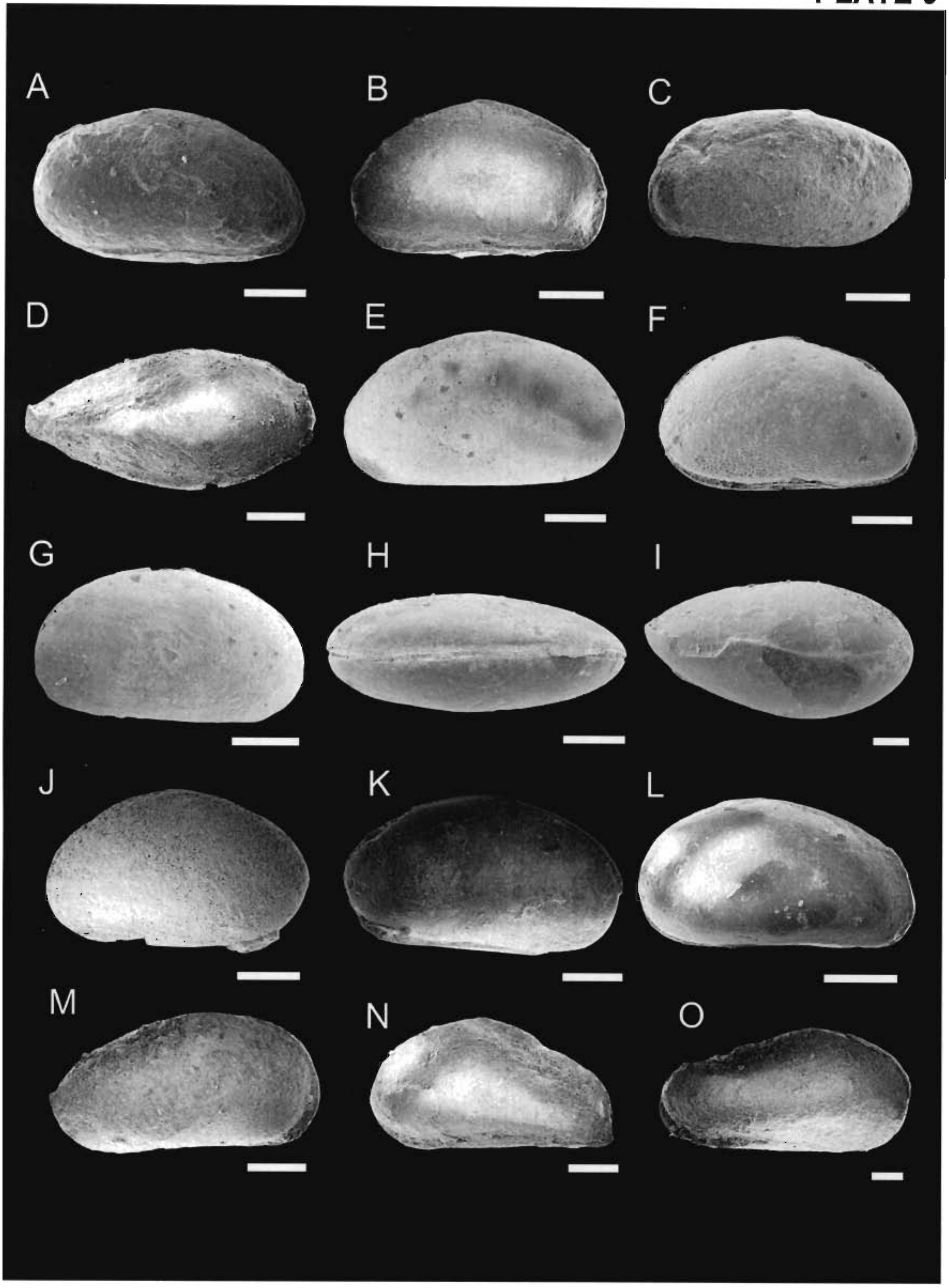
M-N. ***Eucypris catantion*** Whatley *et al.*, 2003

M. Carapace, left lateral view (IITR/SB/DI/19)

N. Carapace, right lateral view (IITR/SB/DI/21)

O. Carapace, left lateral view (IITR/SB/DI/23)

PLATE 9



EXPLANATION OF PLATE 10

(Scale bar equals 90µm for A, H-I; 200µm B-F, J-M; 180µm for N-O)

A. ***Eucypris catantion*** Whatley *et al.,* 2003

A. Carapace, right lateral view (IITR/SB/LI/53)

B-E. ***Eucypris verruculosa*** Whatley *et al*., 2002

B. Carapace, right lateral view (IITR/SB/DI/87)

C. Carapace, left lateral view (IITR/SB/DI/8)

D. Carapace, dorsal view (IITR/SB/DI/133)

E. Carapace, right lateral view (IITR/SB/DI/88)

F-J. ***Eucypris phulsagarensis*** Bajpai *et al*., 2004

F. Carapace, dorsal view (IITR/SB/PI/22,)

G. Carapace, right lateral view (IITR/SB/PI/25)

H. Carapace, left lateral view (IITR/SB/PI/23)

I. Carapace right lateral view (IITR/SB/PI/24)

J. Carapace, dorsal view (IITR/SB/PI/26)

K-L. ***Eucypris* sp.**

K. Carapace, left lateral view (IITR/SB/LI/44)

L. carapace, left lateral view (IITR/SB/LI/33)

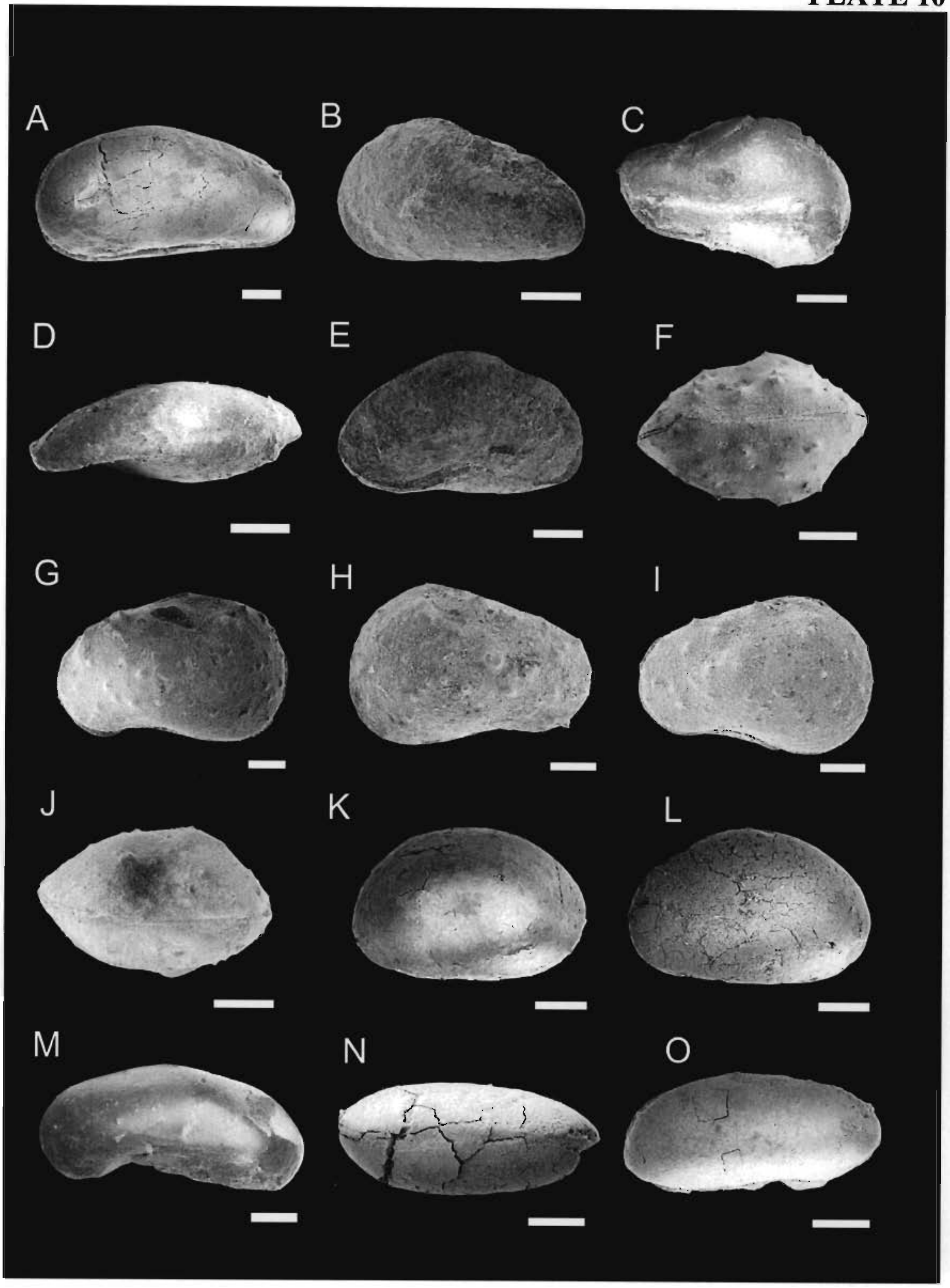
M-O. ***Mongolianella cylindrica*** (Sowerby, 1840)

M. Carapace, right lateral view (IITR/SB/VI/18)

N. Carapace, dorsal view (IITR/SB/LI/5)

O. Carapace, left lateral view (IITR/SB/LI/30)

PLATE 10



EXPLANATION OF PLATE 11

(Scale bar equals 90μm for A, F; 240μm B, Q; 200μm C-D, G-K, M, O, R; 180μm for E, L, P; 100μm for N)

A-Q. ***Mongolianella cylindrica*** (Sowerby, 1840)

A. Carapace, right lateral view (IITR/SB/LI/30)

B. Carapace, left lateral view (IITR/SB/NI/12)

C. Carapace, right lateral view (IITR/SB/NI/24)

D. Carapace, right lateral view (IITR/SB/DI/17)

E. Carapace, left lateral view (IITR/SB/DI/15)

F. Carapace, right lateral view (IITR/SB/DI/16)

G. Carapace, right lateral view (IITR/SB/ AN/2)

H. Carapace, right lateral (IITR/SB/ AN/3)

I. Carapace, right lateral view (IITR/SB/JH/35)

J. Carapace, right lateral view (IITR/SB/JH/36)

K. Carapace, dorsal lateral view (IITR/SB/PI/43)

L. Carapace, left lateral view (IITR/SB/PI/45)

M. Carapace, right lateral view (IITR/SB/PI/48)

N. Carapace, left view (IITR/SB/PI/47)

O. Carapace, left lateral view (IITR/SB/PI/49)

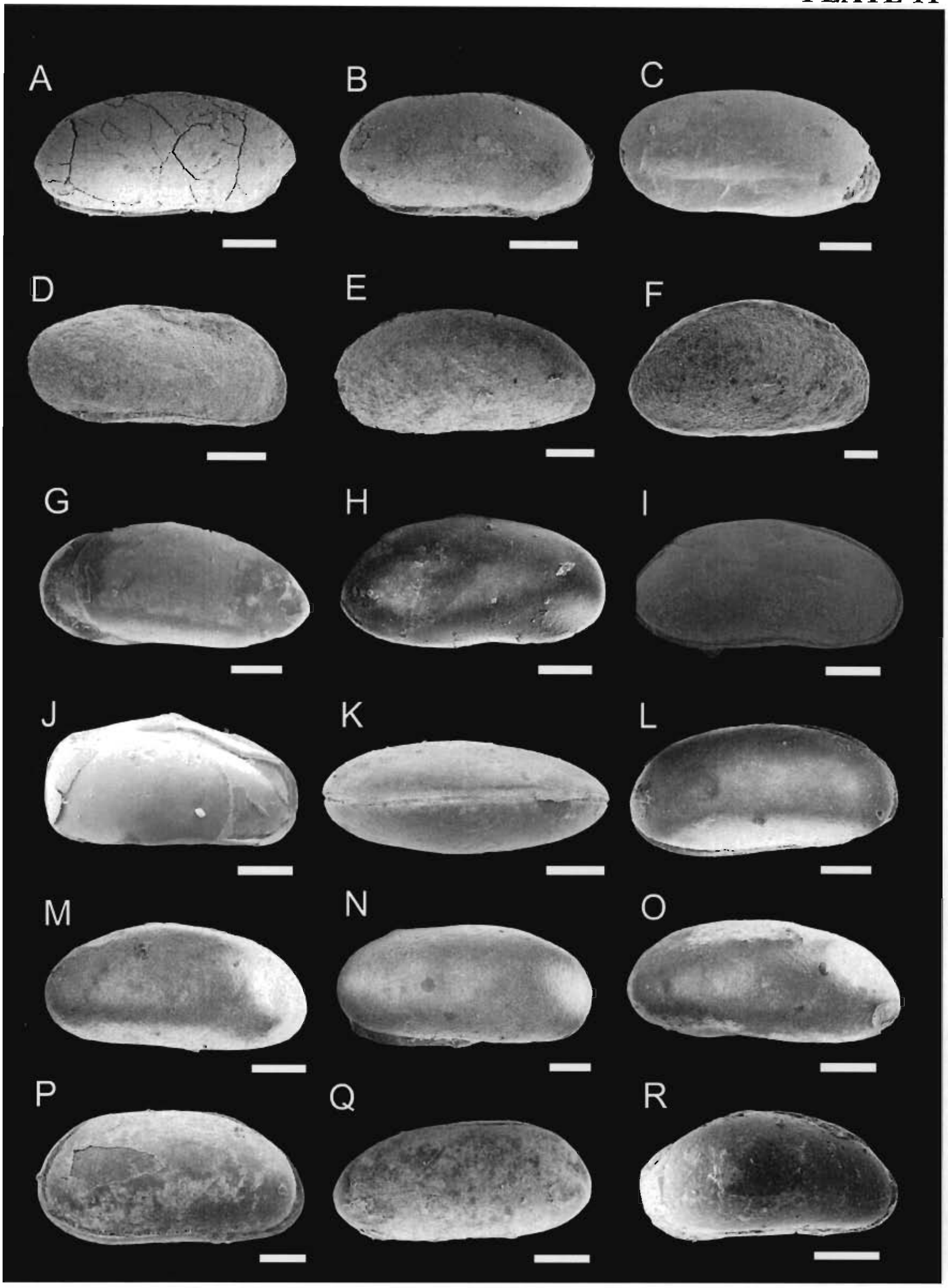
P. Carapace, right lateral view (IITR/SB/LKP/1)

Q. Carapace, left lateral view (IITR/SB/LKP/2)

R. ***Mongolianella subarcuata*** (Sowerby, 1840)

Carapace, left lateral view (IITR/SB/NI/82)

PLATE 11



EXPLANATION OF PLATE 12

(Scale bar equals 400µm for A; 120µm B-D, M, Q; 200µm E, G, K, N-P; 180µm for H-I, R; 90µm for J, L)

A-D. ***Mongolianella subarcuata*** (Sowerby, 1840)

A. Carapace, right lateral view (IITR/SB/NI/82)

B. Carapace, right lateral view (IITR/SB/LI/58)

C. Carapace, left lateral view (IITR/SB/LI/57)

D. Carapace, dorsal view (IITR/SB/LI/27)

E-I. ***Candona amosi*** Whatley *et al*., 2002

E. Carapace, right lateral view (IITR/SB/DI/80)

F. Carapace, right lateral view (IITR/SB/DI/79)

G. Carapace, left lateral view (IITR/SB/DI/78)

H. Carapace, left lateral view (IITR/SB/NI/40)

I. Carapace, left lateral view (IITR/SB/ AN/1)

J-R. ***Eucandona kakamorpha*** Whatley *et al*., 2002

J. Carapace, left lateral view (IITR/SB/NI/34)

K. Carapace, right lateral view (IITR/SB/NI/13)

L. Carapace, right lateral view (IITR/SB/NI/68)

M. Carapace, right lateral view (IITR/SB/DI/58)

N. Carapace, left lateral view (IITR/SB/DI/54)

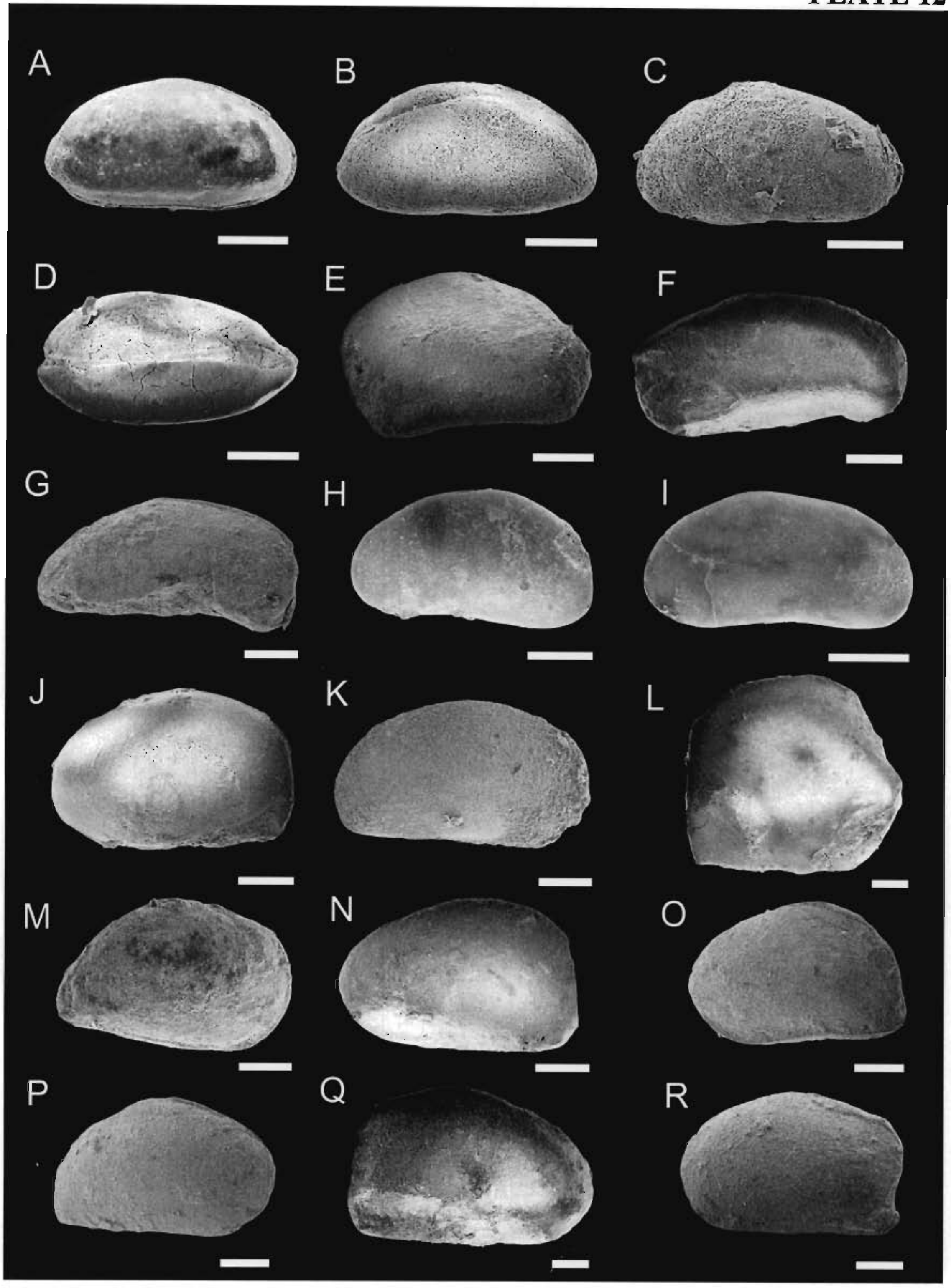
O. Carapace, left lateral view (IITR/SB/DI/57)

P. Carapace, right lateral view (IITR/SB/DI/53)

Q. Carapace, right lateral view (IITR/SB/DI/52)

R. Carapace, left lateral view (IITR/SB/DI/55)

PLATE 12



EXPLANATION OF PLATE 13

(Scale bar equals 90µm for A-C, E-F, H-M; 60µm G; 200µm for D, N; 150µm for O; 400µm for P-R)

A. ***Eucandona kakamorpha*** Whatley *et al.*, 2002

Carapace, right lateral view (IITR/SB/VI/11)

B-D. ***Paracandona firmamentum*** Whatley and Bajpai, 2000

B. Carapace, right lateral view (IITR/SB/LKP/12)

C. Carapace, right lateral view (IITR/SB/VI/12)

D. Carapace, right lateral view (IITR/SB/JH/37)

E-F. ***Paracandona*** **sp.**

E. Carapace, right lateral view (IITR/SB/DI/90)

F. Carapace, right lateral view (IITR/SB/DI/91)

G-O. ***Cypria cyrtonidion*** Whatley and Bajpai, 2000

G. Carapace, right lateral view (IITR/SB/DI/39)

H. Carapace, left lateral view IITR/SB/DI/37)

I. Carapace, left lateral view (IITR/SB/DI/35)

J. Carapace, right lateral view (IITR/SB/LKP/3)

K. Carapace, left lateral view (IITR/SB/NI/36)

L. Carapace, right lateral view (IITR/SB/NI/35)

M. Carapace, left lateral view (IITR/SB/LI/45)

N. Carapace, left lateral (IITR/SB/JH/38)

O. Carapace, right lateral (IITR/SB/JH/39)

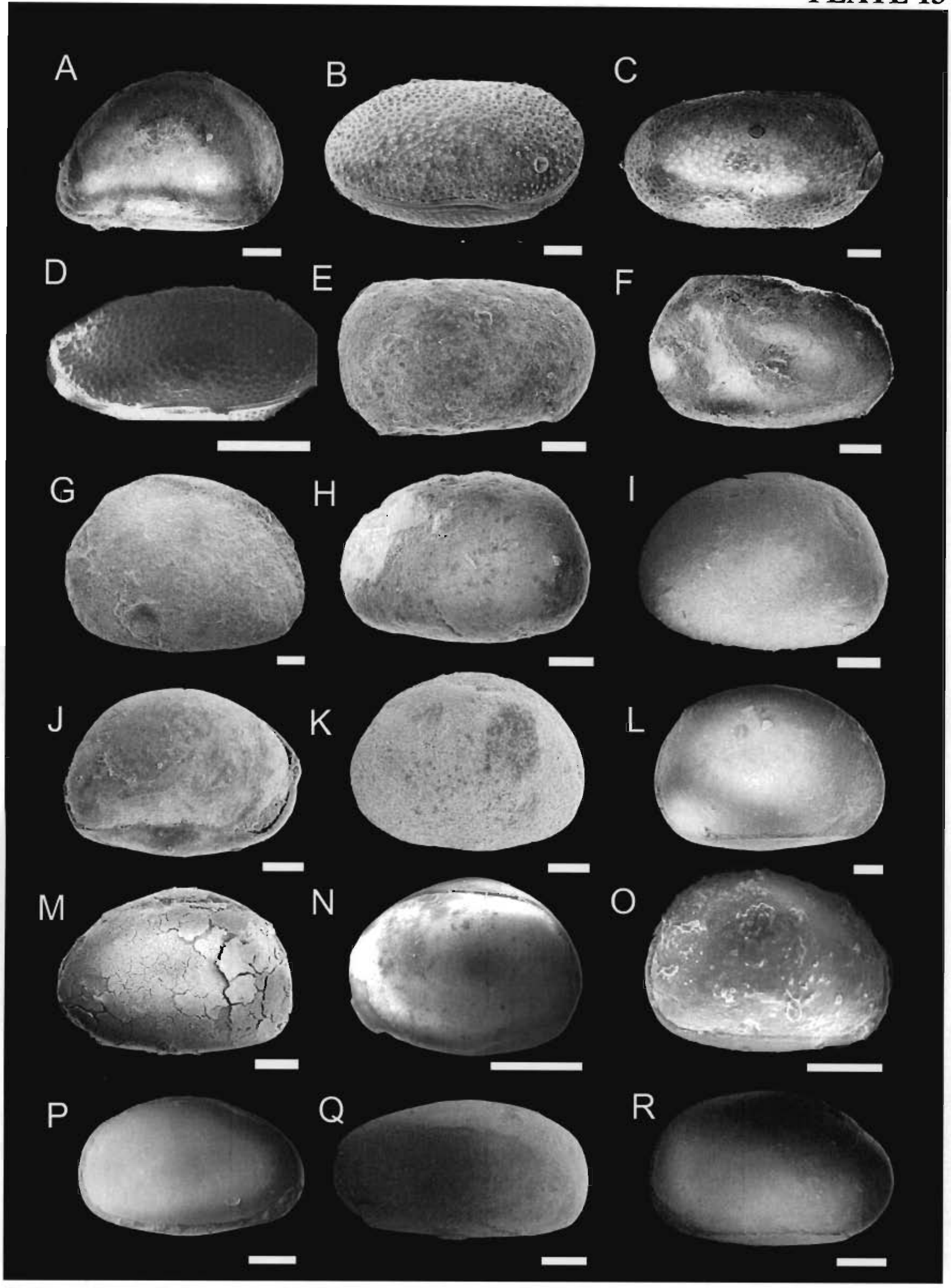
P-R. ***Limnocypridea ecphymatos*** Whatley and Bajpai, 2000

P. Carapace, left lateral view (IITR/SB/JH/40)

Q. Carapace, right lateral view (IITR/SB/JH/41)

R. Carapace, left lateral view (IITR/SB/JH/42)

PLATE 13



EXPLANATION OF PLATE 14

(Scale bar equals 400µm for A, E; 300µm B-D; 200µm for F, K-N; 60µm for G; 120µm for H-I; 90µm for J; 100µm for O)

A-F. ***Limnocypridea ecphymatos*** Whatley and Bajpai, 2000

A. Carapace, right lateral view (IITR/SB/ AN/8)

B. Carapace, right lateral view (IITR/SB/PI/59)

C. Carapace, left lateral view (IITR/SB/PI/58)

D. Carapace, left lateral view (IITR/SB/PI/41)

E. Carapace, dorsal view (IITR/SB/PI/50)

F. Carapace, dorsal view (IITR/SB/PI/54)

G-I. ***Cypridea cavernosa*** Khosla *et al*., 2005

G. Carapace, dorsal view (IITR/SB/NI/119)

H. Carapace, right lateral view (IITR/SB/NI/63)

I. Carapace, left lateral view (IITR/SB/NI/83)

J-L. ***Cyprois rostellum*** Whatley and Bajpai, 2000

J. Carapace, left lateral view (IITR/SB/LI/50)

K. Carapace, left lateral view (IITR/SB/LI/61)

L. Carapace, right lateral view (IITR/SB/DI/95)

M-N. ***Centrocypris megalopus*** Whatley and Bajpai, 2000

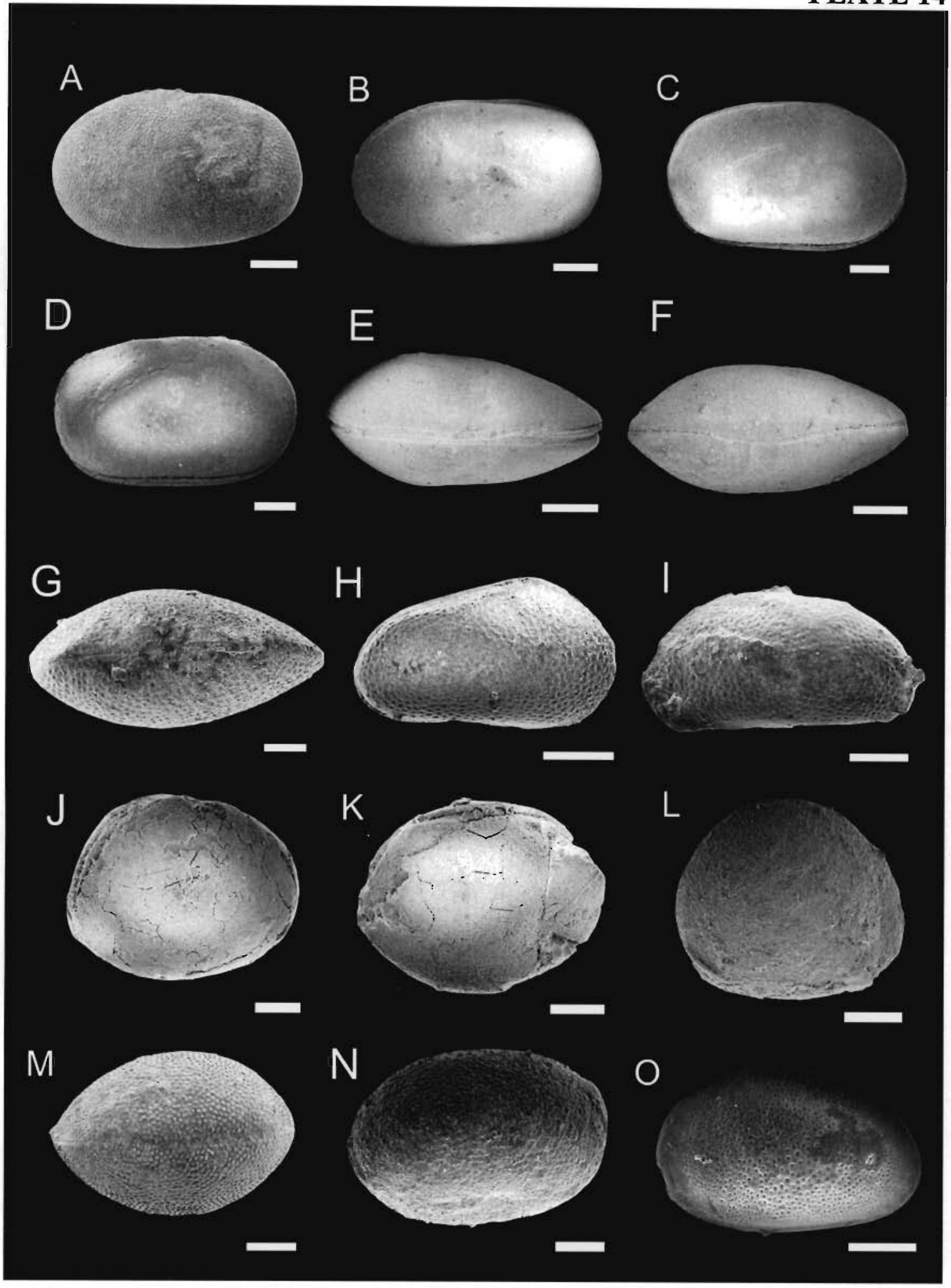
M. Carapace, dorsal view (IITR/SB/ AN/9)

N. Carapace, right lateral view (IITR/SB/ AN/10)

O. ***Neocyprideis* cf. *N. raoi*** (Jain, 1978)

O. Carapace, left lateral view (IITR/SB/JH/43)

PLATE 14



EXPLANATION OF PLATE 15

(Scale bar equals 150µm for A-B, M; 200µm for C-D, H-J, L; 600µm for E, G; 800µm for F; 100µm K, N, O)

A-H. ***Neocyprideis* cf. *N. raoi*** (Jain, 1978)

A. Carapace, right lateral view (IITR/SB/JH/44)

B. Valve, inner view (IITR/SB/JH/45)

C. Carapace, right lateral view (IITR/SB/JH/46)

D. Carapace, left lateral view (IITR/SB/JH/47)

E. Carapace, left lateral view (IITR/SB/JH/48)

F. Carapace, right lateral view (ITR/SB/JH/49)

G. Carapace, dorsal view (IITR/SB/JH/50)

H. Carapace, left lateral view (ITR/SB/JH/51)

I-M. ***Platychara perlata*** (Peck & Reker, 1947)

I. Lateral view IITR/SB/JH/53

J. Basal view IITR/SB/JH/54

K. Apical view IITR/SB/DI/58

L. Lateral view IITR/SB/DI/61

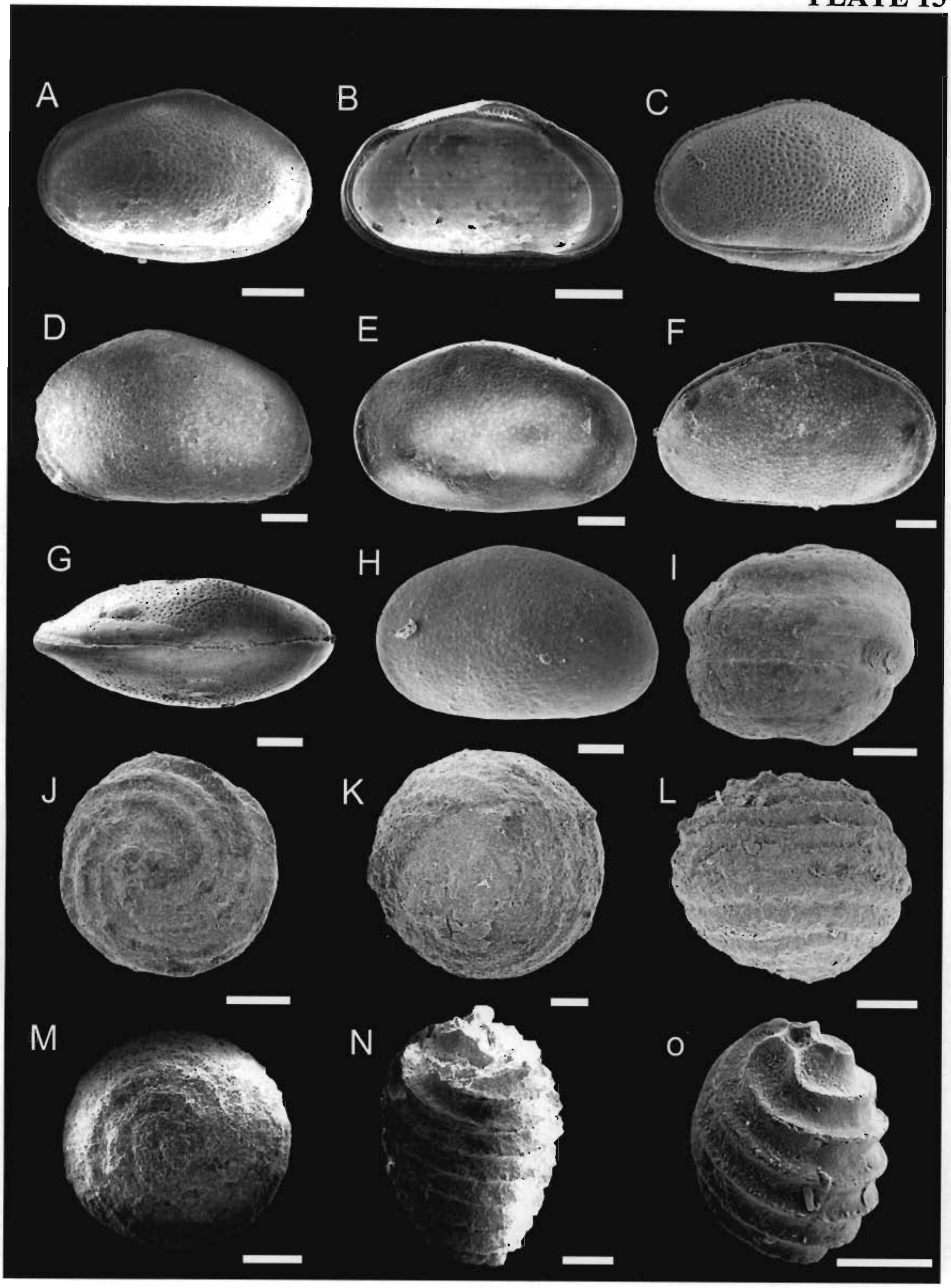
M. Basal view IITR/SB/DI/6

N-O ***Chara* sp. Indet**

N. Lateral view IITR/SB/DI/11

O. Lateral view IITR/SB/DI/12

PLATE 15



EXPLANATION OF PLATE 16

(Scale bar equals 200μm for A-B, G, E; 300μm for C, F; 100μm for D, H, I)

A-B, F, I. ***Paludina*** **sp.**

A. Lateral view (IITR/SB/LI/65)

B. Lateral view (IITR/SB/LI/66)

F. Lateral view (IITR/SB/LI/70)

I. Lateral/ occlusal view (IITR/SB/LI/73)

C, H, G. ***Lymnaea*** **sp.**

C. Left lateral view (IITR/SB/LI/67)

H. Right lateral view (IITR/SB/LI/72)

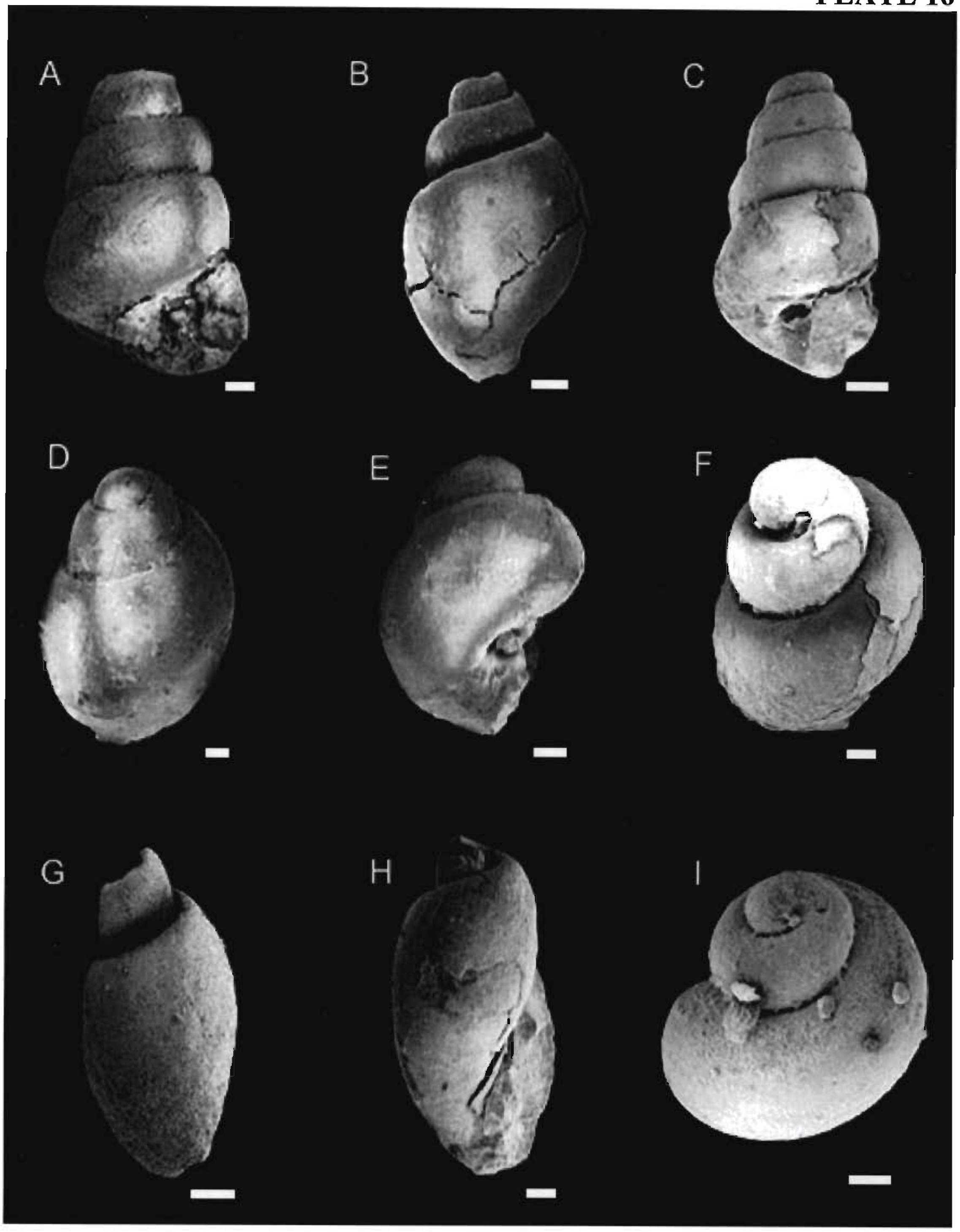
G. Right lateral view (IITR/SB/LI/710)

D, E. ***Physa principii*** Hislop 1860

D. Dorsal view (IITR/SB/LI/68)

E. Left lateral view (IITR/SB/LI/69)

PLATE 16



EXPLANATION OF PLATE 17

(Scale bar equals 100µm for A-D, E; 200µm for F-L; 5µm for A1, B, E1)

A-D. ***Subbotina triloculinoides*** (Plummer, 1926) (Samples JH19, JH25)

A1-B1. Cancellate spinose wall texture with calcite overgrowth of chambers in fig. A and B

E. ***Globigerinelloides aspera*** (Cushman, 1933) (sample JH25)

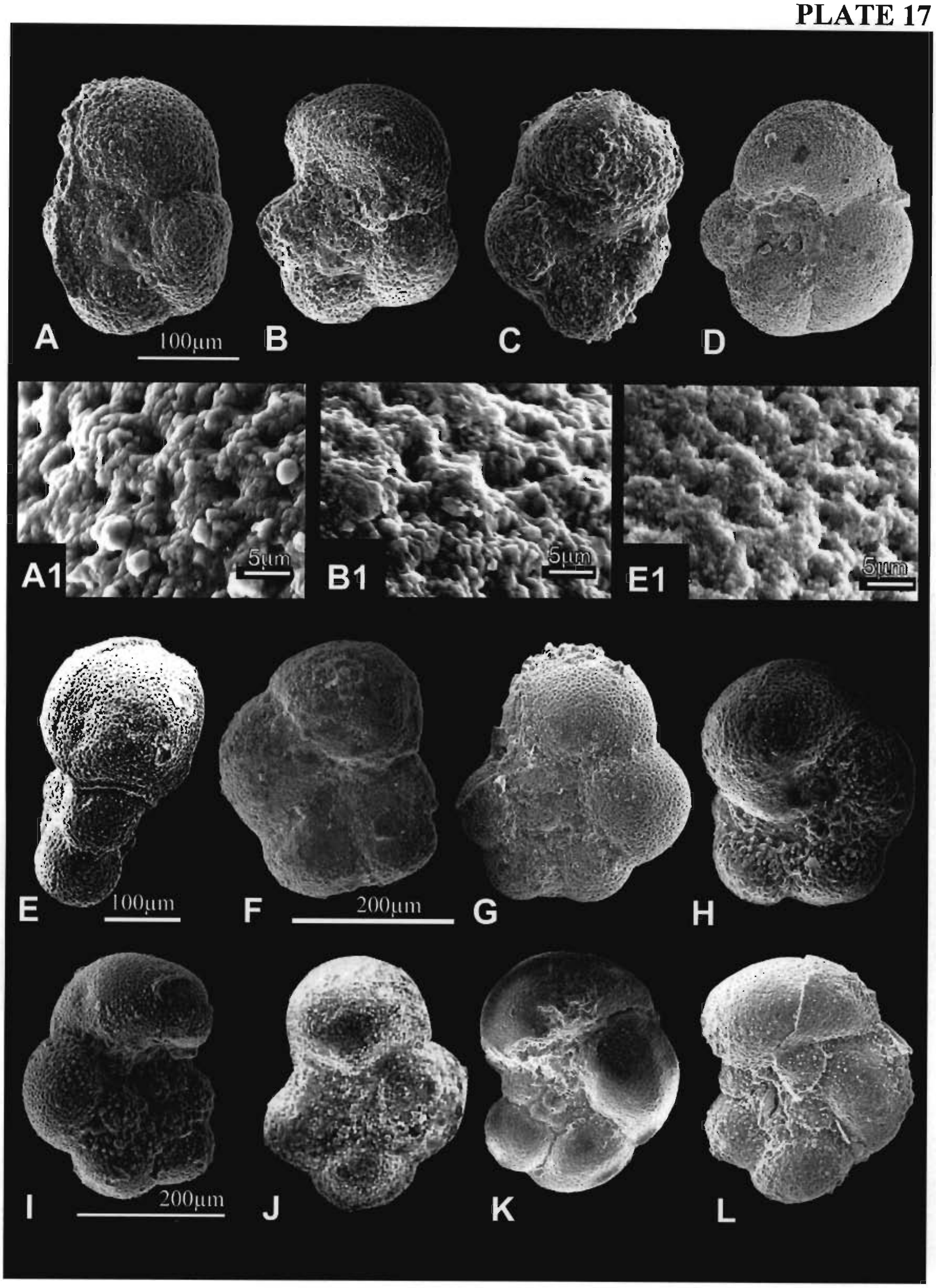
E. Side view

E1. Spinose wall texture

F-H. ***Globigerina (Eoglobigerina) pentagona*** (Morozova, 1961), spiral and umbilical views (samples JH19, JH24).

I-L. ***Parasubbotina pseudobulloides*** (Plummer, 1926) (samples JH 19-20, JH24-25)

PLATE 17



EXPLANATION OF PLATE 18

(Scale bar equals 100µm for A-C, F-H; 500µm for D; 5µm for E)

A-G. ***Hedbergella holmdelensis*** (Olsson, 1964)

A-C sample JH19

D. Close-up of last chamber below aperture showing perforate wall texture

E. Cancellate spinose wall with calcite overgrowth

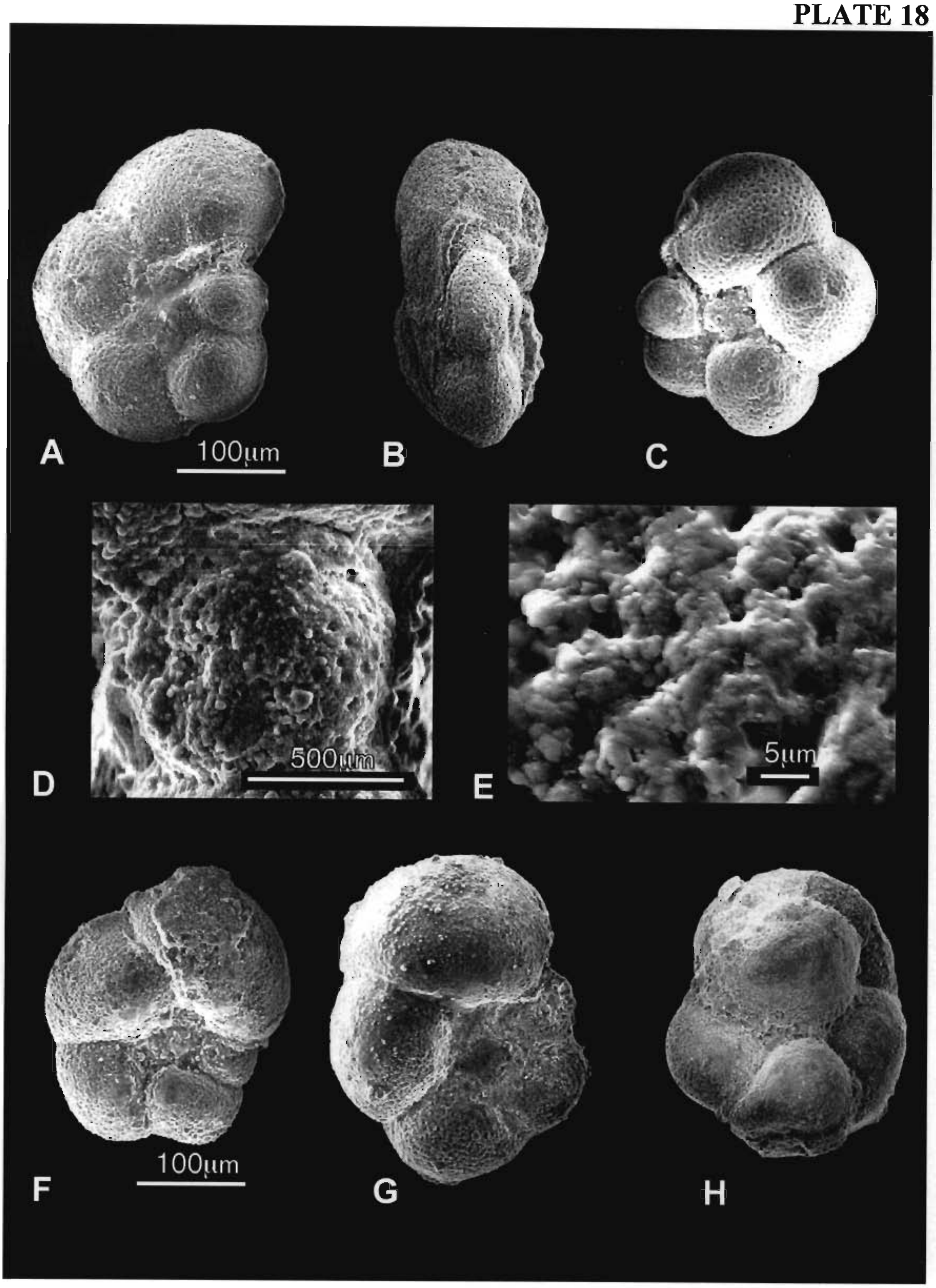
F. Spiral view

G. Spiral view

H. ***Subbotina triloculionoides*** (Plummer, 1926)

Aberrant last chamber view (sample JH25)

PLATE 18



EXPLANATION OF PLATE 19

(Scale bar equals 200µm for A-B, G-H; 60µm for C, I; 100µm for D-F, J-T)

A-B. ***Pynodus* sp.**

A. Isolated tooth, occlusal view (IITR/SB/DI/106)

B. Isolated tooth, occlusal view (IITR/SB/JH/72)

C-F. ***Osteoglossidae* gen. et. sp. indet.**

C. Isolated tooth, lateral view (IITR/SB/DI/108)

D. Isolated tooth, lateral view (IITR/SB/DI/101)

E. Isolated tooth, lateral view (IITR/SB/LI/80)

F. Isolated tooth, lateral view (IITR/SB/VI/23)

G-H. ***Igdabatis indicus*** Prasad and Cappetta, 1993

G. Isolated tooth, lateral view (IITR/SB/NI/17)

H. Isolated tooth, occclusal view (IITR/SB/NI/18)

I-T. ***Lepisosteus* sp.**

I. Isolated tooth, lateral view (IITR/SB/DI/107)

J. Isolated tooth, lateral view (IITR/SB/DI/115)

K. Isolated tooth, lateral view (IITR/SB/NI/51)

L. Isolated tooth, lateral view (IITR/SB/NI/48)

M. Isolated tooth, lateral view (IITR/SB/NI/47)

N. Isolated tooth, lateral view (IITR/SB/NI/49)

O. Isolated tooth, lateral view (IITR/SB/VI/17)

P. Isolated tooth, lateral view (IITR/SB/VI/20)

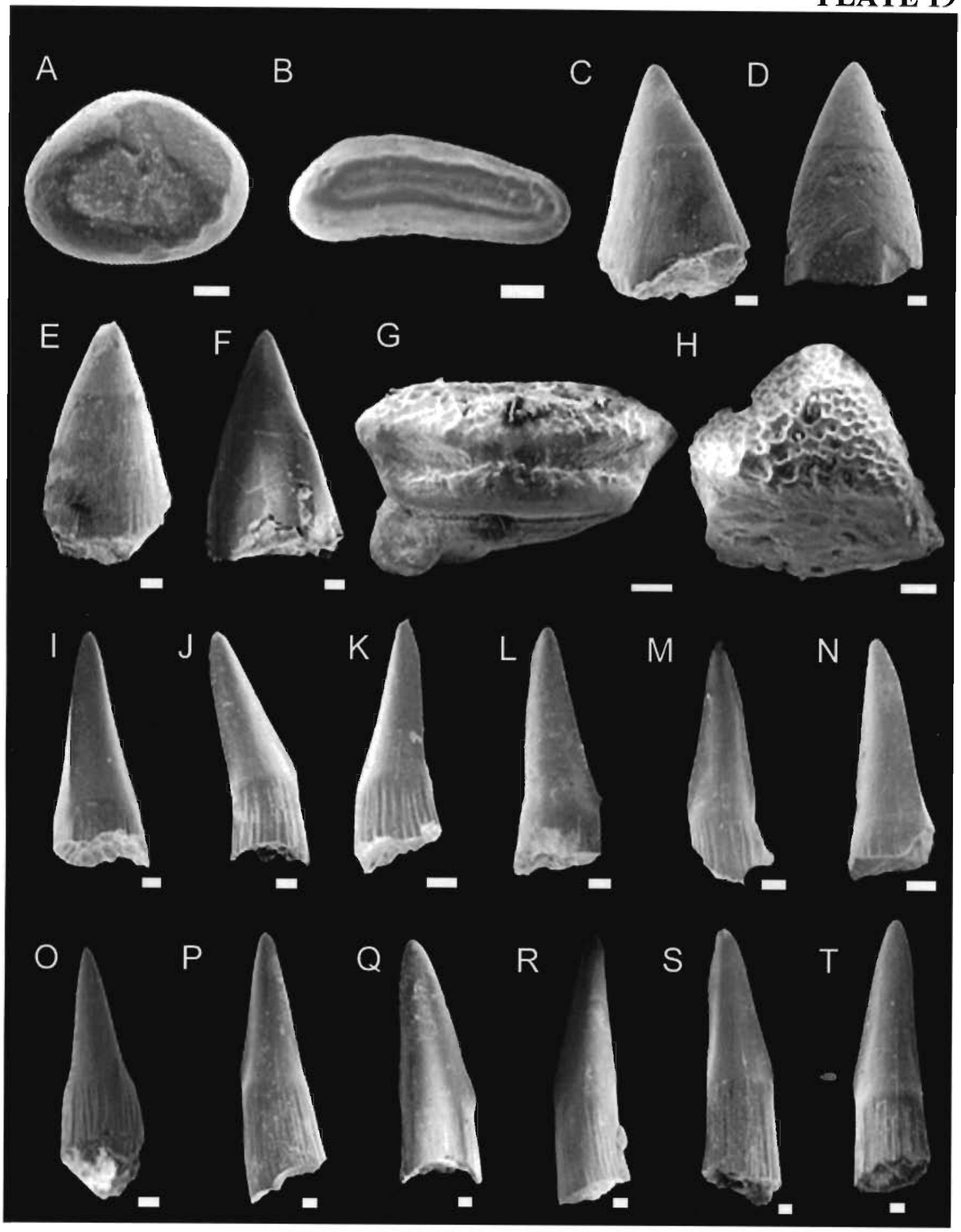
Q. Isolated tooth, lateral view (IITR/SB/VI/30)

R. Isolated tooth, lateral view (IITR/SB/VI/19)

S. Isolated tooth, lateral view (IITR/SB/VI/21)

T. Isolated tooth, lateral view (IITR/SB/VI/28)

PLATE 19



EXPLANATION OF PLATE 20

(Scale bar equals 200µm for A-D, G, J; 100µm for E-F, I, K; 300µm for H, L)

A-F. ***Eotrigonodon indicus*** (Lydekker, 1886)

A. Isolated oral tooth, lateral view (IITR/SB/RI/1)

B. Isolated oral tooth, lateral view (IITR/SB/RI/2)

C. Isolated oral tooth, lateral view (IITR/SB/RI/8)

D. Isolated pharyngeal tooth, lateral view (IITR/SB/RI/6)

E. Isolated pharyngeal tooth, lateral view (IITR/SB/RI/11)

F. Isolated pharyngeal tooth, lateral view (IITR/SB/RI/13)

G-H. ***Chrysophrys* sp.**

G. Isolated tooth, occlusal view (IITR/SB/RI/9)

H. Isolated oral tooth, occlusal view (IITR/SB/RI/18)

I- L. ***Pycnodus* sp.**

I. Isolated tooth, occlusal view (IITR/SB/RI/3)

J. Isolated tooth, occlusal view (IITR/SB/RI/4)

K. Isolated tooth, occlusal view (IITR/SB/RI/7)

L. Isolated tooth, occlusal view (IITR/SB/RI/19)

PLATE 20