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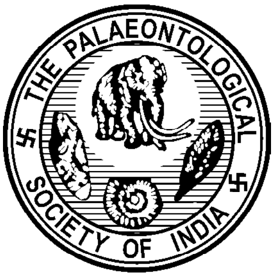

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INTEGRATED BIOSTRATIGRAPHY AND PALAEOENVIRONMENT OF THE MIDDLE JURASSIC SEDIMENTS AT KULDHAR (JAISALMER), WESTERN INDIA

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ABSTRACT

Stratigraphically controlled new ammonite collections from the Middle Jurassic sediments of Kuldhar (Jaisalmer, western India) indicate a Late Bathonian-early Late Callovian age. Previous records by different authors of *Dhosaites primus* and *Perisphinctes* (*Dichotomosphinctes*) aff. *subhelenae* from the top of the section suggest an age straddling Early to early Middle Oxfordian. The present study, besides documenting a rich ammonite fauna from Kuldhar (66 specimens), also identifies seventeen lithologic beds recording 7 ammonite zones and 2 subzones. These biozones are correlated with those of the adjoining Kachchh basin (western India) and the standard ammonite zones of the European and Submediterranean provinces. Additionally, based on an integrated multi-proxy approach using occurrences of benthic foraminifers, ostracods, nannofossils, belemnites, and trace fossils, the palaeoenvironment of the Kuldhar section is inferred.

Keywords: Middle Jurassic, Ammonite biostratigraphy, Palaeoenvironment, Jaisalmer, India

INTRODUCTION

The Mesozoic sediments of the Jaisalmer Basin (Fig. 1) are characterized by the deposition of carbonate rocks of the Jaisalmer Formation that unconformably overly the sandstones of the Lathi Formation (Das Gupta, 1975; Garg and Singh, 1983; Jain, 2007) (Table 1). The Jaisalmer Basin witnessed transgression sometime in Late Bajocian as indicated by the presence of coral *Isastrea bernardiana* (Orbigny) occurring "100 m below beds yielding Early Callovian ammonites" (Pandey and Fürsich, 1994). These "Early Callovian ammonites" were recorded from the Kuldhar section (Fig. 1), exposed along the Masurdi River, near the ruined village of Kuldhar (Fig. 2).

The present contribution, based on new ammonite collections from Kuldhar (Fig. 2), records 7 ammonite zones and 2 subzones (Fig. 3). These are correlated with the biozones of the adjoining Kachchh Basin (western India) and the standard ammonite zones of the European and Submediterranean provinces (Table 2). Additionally, based on previously recorded occurrences of benthic foraminifers, nannofossils, ostracods, trace fossils and belemnites, palaeoenvironment of the Kuldhar section is inferred.

PREVIOUS STUDIES

Body fossil evidences from Kuldhar, until recently, have produced conflicting ages for the same sediments (Jain, 2007, 2008) with no illustrated record either of the ammonite fauna (except for Subfamily Reineckeiinae; Cariou and Krishna, 1988) or of a detailed bed-by-bed stratigraphy. A comprehensive integrated faunal approach of co-occurring benthic foraminifers (Dave and Chatterjee, 1996), ostracods (Khosla *et al.*, 2006), nannofossils (Rai and Garg, 2007), trace fossils (Fürsich *et al.*, 1991) and ammonites is also lacking (Jain, 2007). Previous integrated approaches (foraminiferal-ammonite: Dave and Chatterjee, 1996; nannofossils-ammonite: Rai and Garg, 2007) are either anchored on alleged or misplaced age-diagnostic ammonite taxa or on sections that are studied only in part (for details see Jain, 2008) (Fig. 2). Even more, little consideration is given to the placement of important age-diagnostic ammonite taxa such as *Sivajiceras congener* [M] or *Macrocephalites triangularis* [M] (Dave and Chatterjee, 1996) which in the adjoining Kachchh Basin (Fig. 1) are zonal indices indicating precise age (Callomon, 1993; Jain *et al.*, 1996; Krishna and Ojha, 2000). Recently, Prasad (2006) studied the Kuldhar Member identifying 13 beds. However, except for his bottom 6 beds (beds 1-6), the remaining are hard to track. Additionally, Prasad's contribution has large problems with its taxonomic work (Callomon, 2008) and consequently with its biostratigraphy. A critical analysis is done here.

Thus, this contribution attempts to identify, describe and illustrate a bed-by-bed collection of ammonites, and presents the first comprehensive multi-proxy approach in inferring the palaeoenvironment of the sediments exposed at the Kuldhar section (Fig. 2). Additionally, the erected ammonite biozones are correlated with the established biozones of the adjoining Kachchh Basin and globally with the standard Submediterranean and Subboreal ammonite biozones (Table 2).

THE STUDY AREA

The Kuldhar section (26° 52" North 70° 47" East), situated near the ruined village of Kuldhar (Fig. 2), along the Masurdi River (18 Km south-west of the city of Jaisalmer), has exposed 17 beds for a sediment thickness of 12.7 m (Fig. 3). These beds are divided into three broad lithologic units. The lower calcareous unit comprises beds 1-6 (3.1 m thick); middle argillaceous unit of beds 7-16 (7 m thick) with thin calcareous inter-beds of oolitic limestone, capped by a fine-grained sandstone body, and an upper gypsiferous unit with two thin micritic inter-beds (beds 17b and d), capped by 2.6 m of loose sediments (Fig. 3; Table 3).

The lower 3.1 m thick unit has a 0.5 m clean sandstone body followed by a 2.6 m thick fine grained calcareous bed comprising beds 2-6 (Fig. 3). Beds 3-5 are hardgrounds, heavily bioturbated and bioclastic in nature, forming a prominent platform-like relief next to the river bed (Fig. 2; Locality I). Beds 3 and 6 lack bioclastic elements and the former is conspicuous for its low angle cross bedding. Numerous bivalve borings characterize the top of beds 3 to 5. A horizontal fault runs at the top of bed 6 and possibly accounts for a few metres of stratigraphic gap (Fig. 2; Locality I).

The middle unit (beds 7-16) is made up of a 7 m thick argillaceous unit with thin oolitic and moderately bioturbated

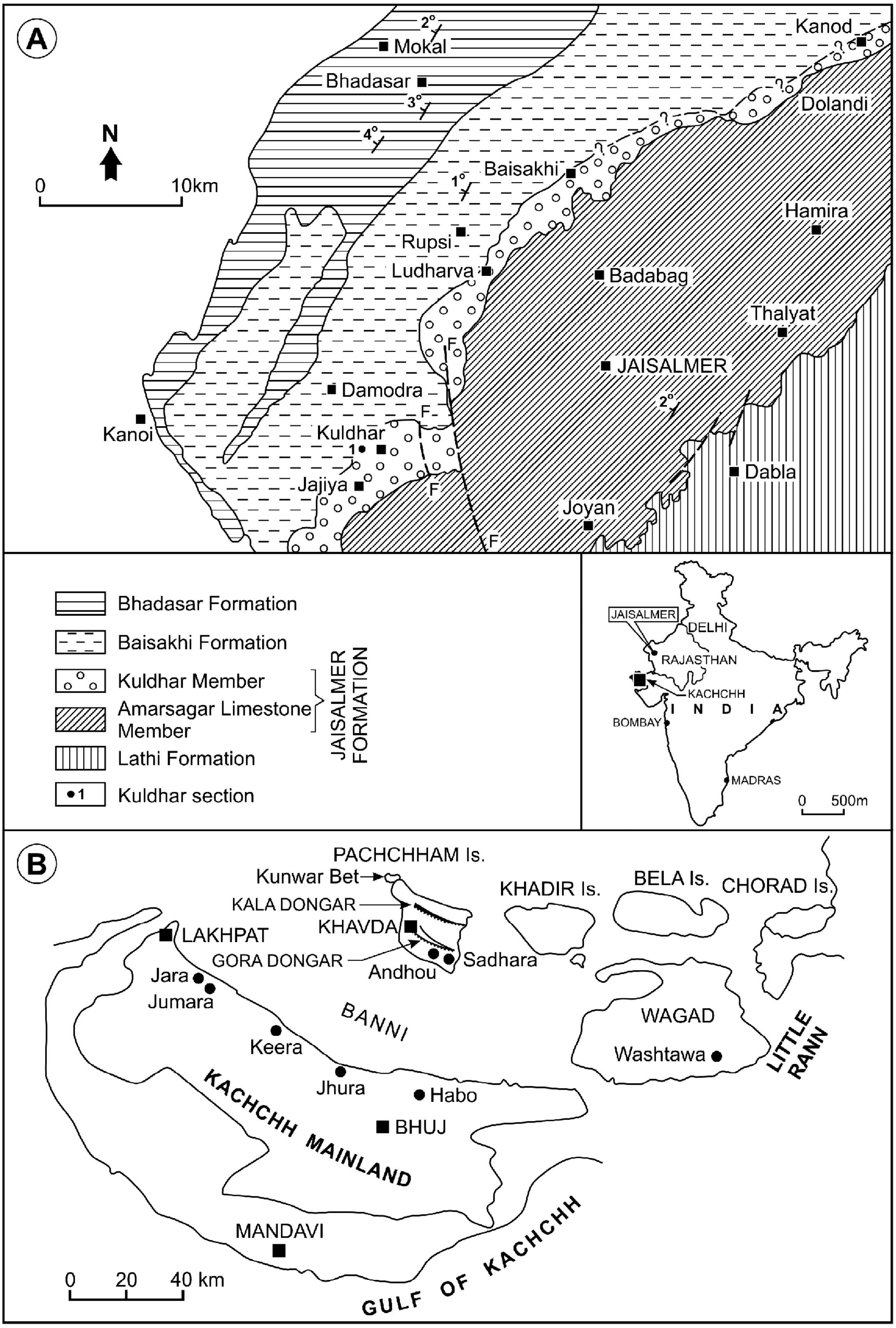


Fig. 1. Middle Jurassic outcrops of western India. Geological map of Jurassic sediments exposed in and around Jaisalmer (A) and localities from the Kachchh basin (B).

Table 1: Lithostratigraphy of the Jurassic sediments exposed in and around Jaisalmer area.

DAS GUPTA, 1975			GARG AND SINGH, 1983			JAIN, 2007	THIS STUDY	
Tithonian	BHADASAR FORMATION	Mokal Mb. Kala Dongar Mb.	BHADASAR FORMATION		Tithonian	Tithonian	Latest Tithonian	BHADASAR FORMATION
Kimmer-idgian	BAISAKHI FORMATION	Rupsi Mb. Ludharwa Mb.	JAISALMER FORMATION	Rupsi Shale Member	Earliest Tithonian-Latest Oxfordian	Earliest Tithonian-Latest Oxfordian	Late Tithonian - Kimmeridgian - Latest Oxfordian	BAISAKHI FORMATION
		Baisakhi Mb.		Baisakhi Member	Oxfordian	Oxfordian		
Callovo-Oxfordian	JAISALMER FORMATION	Kuldhar Mb.		Kuldhar Oolite Mb.	Middle-Early Callovian	Middle Callovian-Late Bathonain	Middle Callovian - Late Bathonain	JAISALMER FORMATION
		Badabag Mb. Fort Mb. Joyan Mb. Hamira Mb.		Amarsagar Limestone Member	Late - Middle Bathonian		Late - Middle Bathonian Bajocian*	
Lias-Bathonian	LATHI FORMATION	Thiat Mb. Odania Mb.	LATHI FORMATION	Early - Middle Jurassic (in part)				LATHI FORMATION

micritic bands representing beds 9, 11 and 13. Bed 16 is a medium-grained sandstone body with its lower part cross-bedded, upper surface ripple-bedded and the middle part is shelly in nature with several prominent *Zoophycos* traces. Together, they form a +7 m physiographic high at Locality III (Fig. 2).

The upper unit (2.6 m thick) is composed of gypsiferous shales with thin inter-beds of fine-grained limestone beds, constituting bed 17, and capped by loose sediments (Locality IV, Fig. 3). Dave and Chatterjee (1996) noted 6 m of shales over this bed that contained *Dhosaites primus* at its top (from the top beds at Locality IV; Fig. 3). This is a significant find and extends the age of the Kuldhar Member to at least earliest Oxfordian. Prasad (2006) from an unknown locality in Kuldhar recorded the association of *Perisphinctes* (*Dichotomosphinctes*) aff. *subhelenae*, *Mayaites* (*Mayaites*) aff. *maya* and *Dhosaites elephantoides* from the top of the section and dated the sediments as Late Oxfordian (Fig. 3). In Kachchh and elsewhere, this association is dated as Early to early Middle Oxfordian (Krishna *et al*., 1996). Interestingly, the present study recorded a stratigraphically loose example of early Late Callovian *Collotia fraasi* (Oppel) [M] (Plate 1) that has the same lithology and color (dirty yellow) as of the loose sediments overlying bed 17. However, due to its loose nature, its age reliability is low and based on previous studies mentioned above, an age straddling Early to early Middle Oxfordian is preferred for the top of the Kuldhar section. Pending, better constrained collections, a more refined age for these top sediments might be possible.

EXISTING LITHO- AND BIOSTRATIGRAPHIC PROBLEMS

The sections measured for the Kuldhar Member are as wide-ranging in their lithology as they are in their inferred ages (Fig. 2). Hence, an attempt was recently made to streamline the age of the lower sediments of this Member (Jain, 2007, 2008). This contribution attempts to streamline both the litho- and biostratigraphy of the middle and upper parts of this member. The stratigraphic framework is modified after Jain (2007) (Table 1).

Kalia and Chowdhury (1983), while describing their foraminiferal fauna from Kuldhar, provided the most comprehensive and accurate stratigraphic column of the Kuldhar Member. They measured seven sections (A-G) along the Masurdi River (see top panel in Fig. 2 for their section localities). Section A is the only section that straddles the Bathonian-Callovian boundary beds (Jain, 2007, 2008; see top panel in Fig. 2) and at its lower part is overlain by non-fossiliferous coarse-grained calcareous sandstone bed of the Badabag Member (now part of the Jaisalmer Formation; Table 1). Later authors (Cariou and Krishna, 1988; Dave and Chatterjee, 1996; Khosla *et al*., 2006; Rai and Garg, 2007; Rai, 2009) only measured either one or a small combination of the sections given by Kalia and Chowdhury (1983; sections B-G; Fig. 2). Hence, their inferred ages remained Callovian (Cariou and Krishna, 1988; Dave and Chatterjee, 1996; Khosla *et al*., 2006; Rai and Garg, 2007). Fürsich *et al.* (1991), while describing the occurrence of hardgrounds in the Jurassic of Kachchh, were the only startigraphers who have accurately re-measured Section A (of Kalia and

Table 2: Correlation of Standard Callovian Zones , subzones and horizons of the Subboreal and the Submediterranean provinces with those of the biozones identified at Jumara (Kachchh) and Kuldhar (Jaisalmer). PW= Present work; RN = Rajnath's bed numbers (Rajnath 1932, 1942); C and K = Cariou and Krishna (1988).

SUBBOREAL PROVINCE					
		Zones	Subzones		Horizons
CALLOVIAN	LATE	Lamberti	Lamberti		Paucicostatum
					Lamberti
					Praelamberti
		Athleta	Henrici		Henrici
					Messiaeni
			Spinosum		Spinosum
			Proniae		Proniae
			Phlenum		Phlenum
	MIDDLE	Coronatum	Grossouvrie		Grossouvrie
					Obductum posterior
			Obductum		Obductum
		Jason	Jason		Jason b
					Jason a
			Medea		Medea
	EARLY	Calloviense	Enodatum		Enodatum c
					Enodatum b
					Enodatum a
			Calloviense	Calloviense	Micans
					Calloviense
		Koenigi	Galilaei		Galilaei
			Curtilobus		Subcostartus
				Koenigi	Tolybe
					Curtilobus
			Gowerianus		Gowerianus
				Kamptus	Metrochus
					?
		Herveyi	Kamptus		Kamptus c
				Macrocephalus	Kamptus b
					Kamptus a
			Terebratus		Terebratus b
					Terebratus a
			Keppleri		Verus
					Keppleri (Jacquoti)

SUBMEDITERRANEAN PROVINCE					
Horizons		Subzones		Zones	
Paucicostatum		Lamberti		Lamberti	LATE
Lamberti					
Praelamberti					
Athletoides		Poculum		Athleta	
Subtense					
Nodulosum					
Collotiformis		Collotiformis			
Piveteaui (Odyseus)					
Trezeense/Athleta		Trezeense (Nivernensis)			
Leckenbi					
Pseudopeltoceras		Rota (Gillardi)		Coronatum	MIDDLE
Rota/Regulare					
Waageni		Leuthardti (Waageni/Spathi)			
Leuthardti					
Baylei		Baylei (Gigantea)			
Villanyensis					
Richei		Tyranniformis (Multicostata)		Anceps	
Blyensis					
Turgidum		Stuebeli			
Bannense					
Kiliani		Patina (Oxyptycha/ Proximum)		Gracilis	EARLY
Boginense					
Michalski		Michalski			
Laugiere		Laugiere	Voultensis		
Tyranna (Pictava)		Pictava			
Grossouvrie		Grossouvrie			
Prahecquense		Prahecquense			
Moorei	Bullatus	Bullatus		Bullatus (Macrocephalus)	
Leptus					
Furculus					
Demariae					

JUMARA (KACHCHH)			
Zones	Subzones	Beds	
		PW	RN
Athleta	Ponderosum	D9-15	1a 2
	Athleta	D1-8	
Obtusicostites		C37-13	
			3
			4
Anceps	Kleidos	C12-4	5
			7-6
	Ramosa	C3	7a
Opis/Semilaevis		C2 B35-C1	8-11
Formosus		B29-34	12-13
Dimerus-Diadematus		B11-28	18-14
Madagascariensis		B1-10	21-19

KULDHAR (JAISALMER)			
Bed nos.		Zone	Subzone
C and K	PW		
	18	Fraasi	
5c	17	Paramorphum	
	14 - 16	Gigantea	
5b	13 12	Anceps	Eucyclum
	11		Anceps
5a	7-10	Dimerus - Transitorius - Opis	
4 - 2	5-6	Madagascariensis	

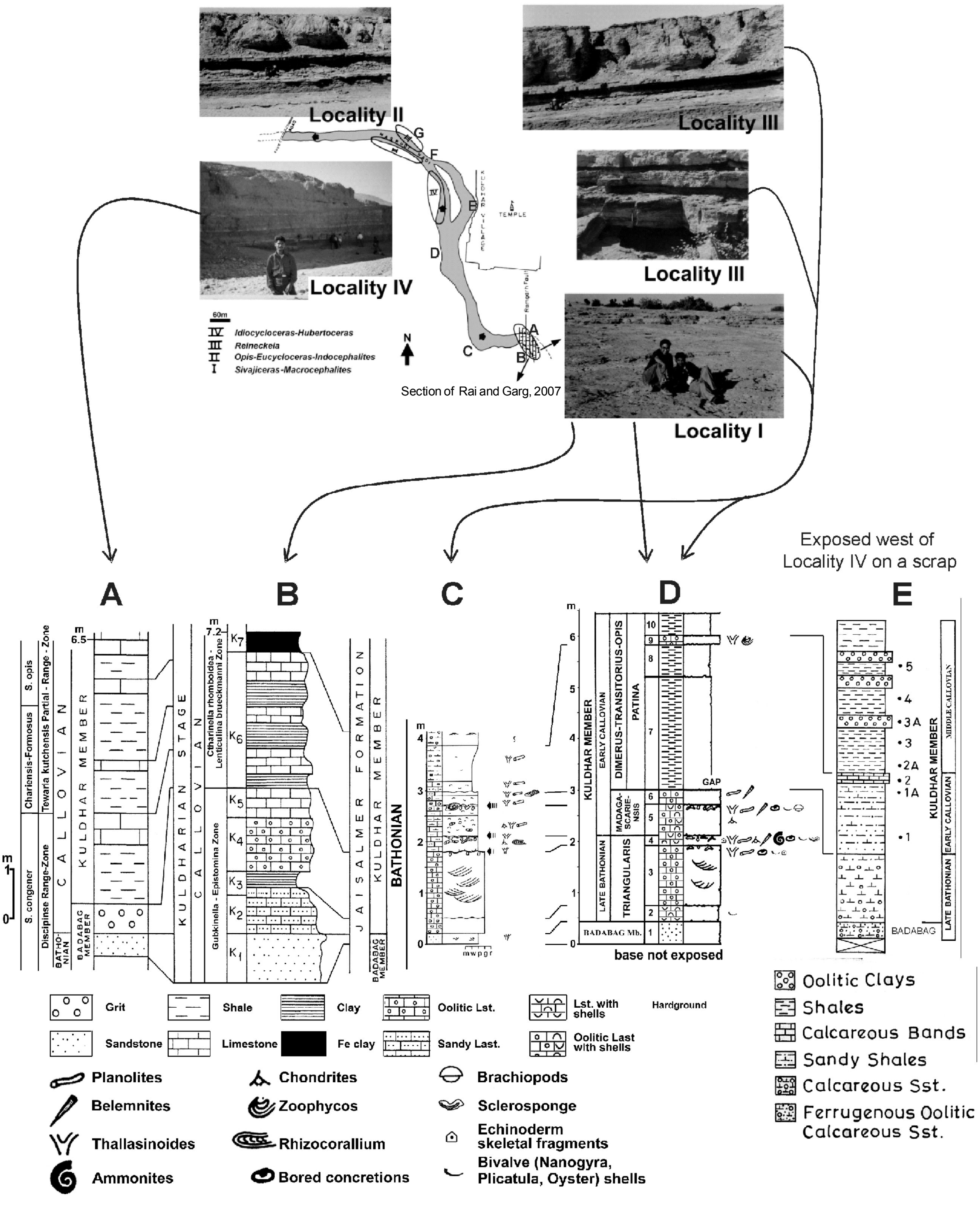


Fig. 2. Correlation of the Kuldhar Member beds. The upper part shows the locality map of beds exposed along the Masurdi River, Kuldhar village and the lower panel shows the correlation of sections identified by different authors from various localities. Kalia and Chowdhury (1981), along the Masurdi River, measured seven sections (A-G in bold). Also marked in the top panel are the present localities (I to IV) where ammonites were collected. Locality I is at A. All re-drawn sections in the lower panel have the same scale of 1m. A: is modified after Dave and Chatterjee (1996). B: composite section after Kalia and Chowdhury (1981). C: after Fürsich et al. (2001). D: after Jain, 2007 and 2008 and E: section by Rai and Garg (2007) with their nannofossil sampling levels. Note that they did not measure the entire Kuldhar Member, but measured a section only from a vertical scrap on the western flank of the river bed from Locality I at B (left side of the fault) that overlies beds 5-6 of present work. Part of this section is well exposed further north and west of present Locality IV. Note that for Section E the ages assigned on the right hand side are from present study. Bold arrows in 2C indicate hardgrounds. Note that this figure illustrates yet another aspect of complexity generated by partial sections measured by different workers from diverse locations (localities) but referred to as their "Kuldhar section" sensu stricto. Also note that section A is most likely a combination of sections from localities I and IV, B of I and III, C of I and D of I and III. The Bathonian-Callovian boundary sediments lie only at locality I and on the eastern flank of the river bed marked by an elliptical area with hatched symbols (limestone) (A at Locality I).

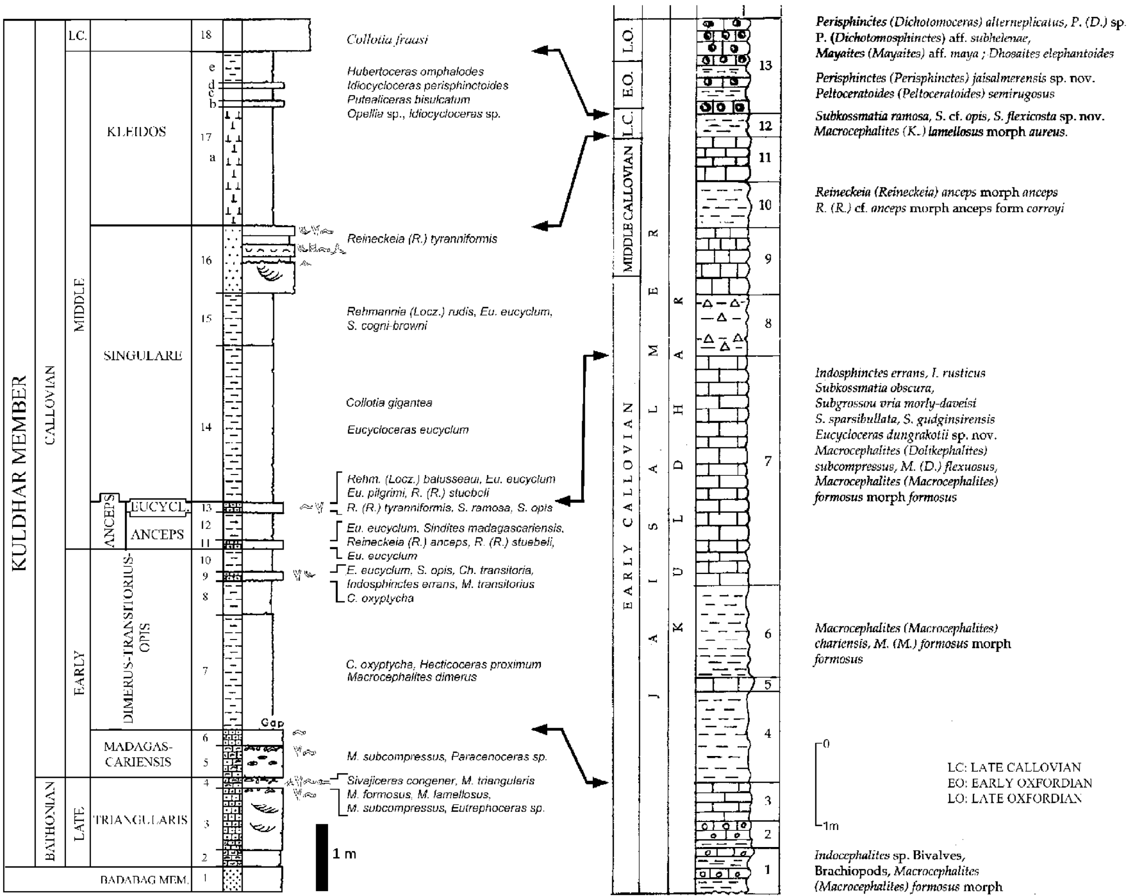


Fig. 3. Correlation of the present biozones with those of Prasad (2006) identified at Kuldhar, Jaisalmer.

Chowdhury, 1983) where the actual Bathonian-Callovian boundary lies (as demonstrated by Jain, 2007, 2008).

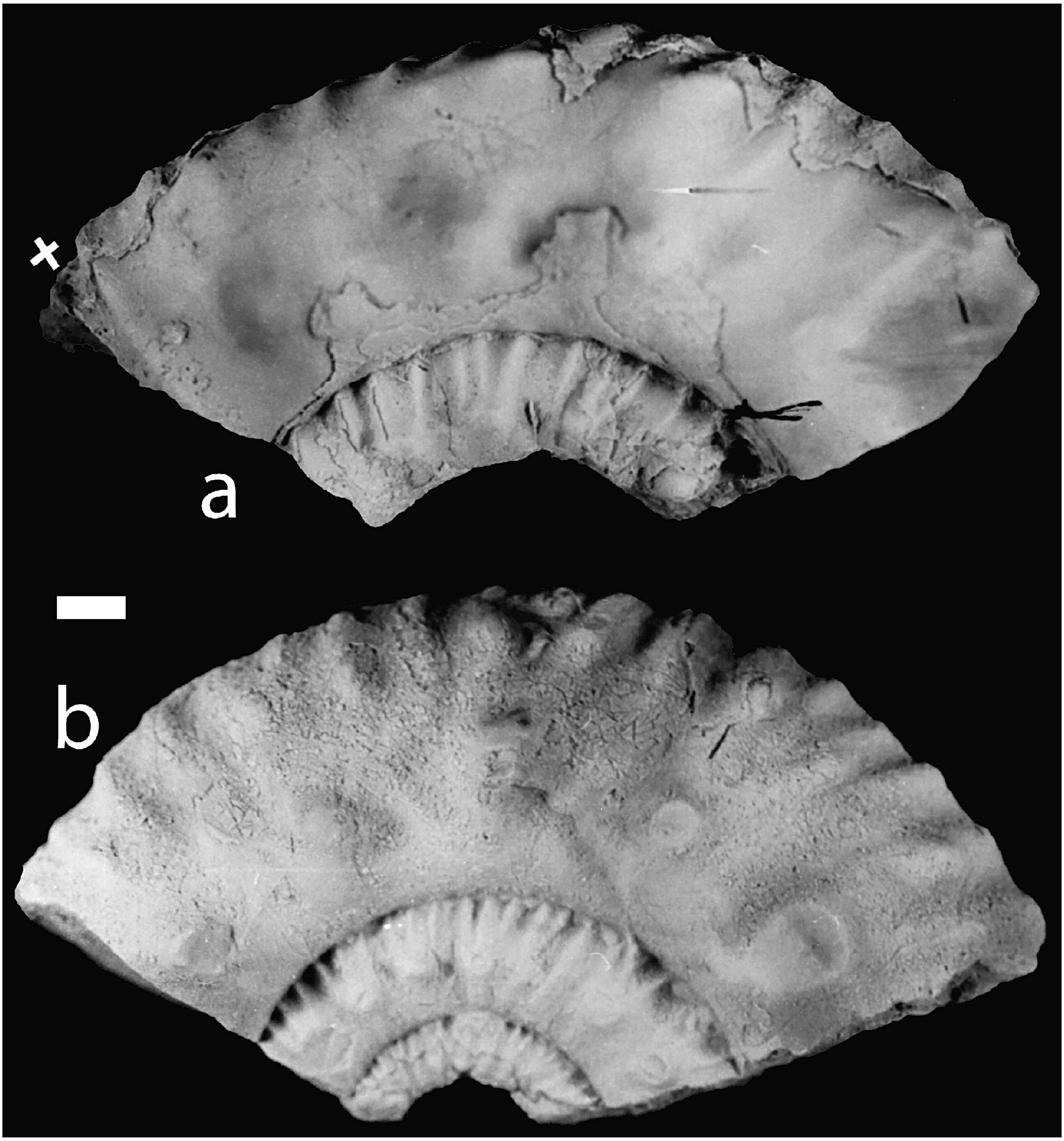
A more generalized and largely hard to trace (though often cited) lithosection is given by Cariou and Krishna (1988) documenting an important fauna of subfamily Reineckeiinae Hyatt. This section could not be traced or correlated with any of the sections discussed here. It will not be discussed henceforth, though the importance of the fossil finds cannot be negated. Ephemeral floods could have wiped out these low-lying beds that were possibly once exposed at Localities II and III (Fig. 2). However, an attempt is made to correlate their (Cariou and Krishna, 1988) beds based on the contained fauna with those of the present work (Table 2). The lithosection by Dave and Chatterjee (1996) used for describing their foraminiferal fauna is based on a combination of sections B and C of Kalia and Chowdhury (exposed along the western flank of the river from Locality IV in Fig. 2). Although they measured only a part of the section, they inferred a Callovian age for the entire Kuldhar Member (Fig. 2). Similarly, Khosla *et al.* (2006), who only measured Section C, and Rai and Garg (2007) and Rai (2009) who measured only the sediments exposed on a vertical scrap south-west of Locality IV (Fig. 2E), erroneously considered the entire Kuldhar Member as Callovian resulting in large age discrepancy (Jain, 2008).

Recently, Prasad (2006) studied the Kuldhar Member in somewhat more detail and identified 13 beds spanning Early Callovian to Late Oxfordian (Fig. 3). Except for the bottom 6 beds (beds 1-6), the remaining beds are hard to track. Additionally, there are serious problems with his biostratigraphic and taxonomic work (Callamon, 2008). Overall,

Table 3: Thickness distribution of beds identified in the Kuldhar section, (Jaisalmer).

Bed		Lithology	Thick (m)
		Debris	1.40
		Conglomerate	0.40
17	e	Yellowish white shale	0.60
	d	Micritic limestone	0.10
	c	Shale	0.25
	b	Micritic limestone	0.15
	a	Silty clays with thin gypsum bands	2.00
16		Brown oolitic limestone	1.50
15		Purple shale	0.60
14		Yellowish white shale	2.40
13		Golden brown oolitic limestone	0.20
12		Whitish yellow shale	0.40
11		Golden brown oolitic limestone	0.15
10		Sandy clay	0.40
9		Oolitic marlstone	0.15
8		Light yellow sandy clay	0.70
7		Grey shales with thin oolitic bands	1.00
		GAP	
6		Oolitic limestone	0.30
5		Oolitic limestone, heavily bioturbated	0.60
4		Bioclastic limestone	0.20
3		Oolitic bioclastic limestone	1.20
2		Yellow limestone	0.30
1		Fine grained yellow sandstone	0.50

Plate I



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EXPLANATION OF PLATE I

a-b. ***Collotia fraasi*** (Oppel) [M], bed 18, Locality IV, Fraasi Zone.
a. sample no. SJK/18/1, Lateral view;
b. sample no. SJK/18/2, lateral view. Bar represents 1 cm. Specimens belong to the Kuldhar section.

this contribution (Prasad, 2006) lacks (a) a proper arrangement of the taxonomic description of species, (b) identification of phragmocone and body chamber stages, that are otherwise quite clear at places, and more importantly (c) most newly erected species are based on fragmented and moderate to poorly preserved specimens that lack comprehensive and updated taxonomic comparisons with co-occurring and coeval species from within (India) and outside the basin (global). A case in point is the total absence of comparison with coeval and similar species extensively described by Jana *et al.* (2005) from the adjoining Kachchh basin. The problems with taxonomic identification and subsequent age assignment for the fauna from beds 7 and 12 (Prasad, 2006) are particularly acute and are briefly discussed.

Prasad's (2006) bed 7 (Fig. 3), dated as mid Early Callovian, has otherwise yielded a mixed fauna of late Early to early Middle Callovian age including *Macrocephalites formosus*, *M. subcompressus*, *M. flexuosus*, *Indosphinctes errans*, *I. rusticus*, *Subkossmatia obscura*, *Subgrossouvria morley-daviesi*, *S. sparsibullata*, *S. gudginsirensis* (= *S. gudjinsiriensis*) and a new species of *Eucycloceras*, *E. dungrakotti*.

The *M. formosus* specimen illustrated by Prasad (2006, p. 17, pl. 1, fig. 3; whorl section in pl. 19, fig. 5) from his bed 3 (= present beds 5-6) as mentioned in the text, is shown to have come from his bed 1 in his Fig. 3, and is quite intriguing also. Besides being poorly preserved, it shows negative allometry (U/D = 0.18 at 34 mm to 0.11 at 107 mm) whereas "typical" *M. formosus* displays the reverse; strong uncoiling of the umbilical seam with increasing shell diameter (Bhaumik *et al.*, 1993, p. 170, fig. 5d). Prasad's specimen may well be an intermediate form closely resembling the "inflated (so called *chariensis*) variant" of *M. formosus* (see Bhaumik *et al.*, 1993, pl. 1, fig. 5). Such morphological variability in the *formosus* - *chariensis* group is well documented from the adjoining Kachchh basin (Bhaumik *et al.*, 1993).

The *Macrocephalites* (*Dolikephalites*) *flexuosus* Spath (Prasad, 2006, p. 20, pl. 1, fig. 5) (= *M. flexuosus* Spath) is most likely a variant of the late Early Callovian Indonesian *Macrocephalites keeuwensis* Boehm [m] (Westermann and Callomon, 1988, pl. 12, figs. 1-5, non fig. 4). This Kuldhar specimen, on one hand, is an intermediate form between the sparsely ribbed Madagascan *M. flexuosus* (Collignon, 1958, pl. 18, fig. 77) and, on the other hand, with Spath's (1928, pl. 32, fig. 4) densely ribbed *M. flexuosus*. All these are now considered as junior synonyms of the late Early Callovian *M. keeuwensis* [m] (Westermann and Callomon, 1988, p. 63). Bathonian Indonesian forms have already been recorded from the adjoining Kachchh basin (Jain, 2002; Roy *et al.*, 2006) and also from the Bathonian sediments of Central Nepal (Enay and Cariou, 1999).

Prasad's *Indosphinctes errans* Spath (Prasad, 2006, pl. 8, fig. 6; pl. 20, fig. 1) matches with the earliest *Indosphinctes* recorded from the Madagascariensis Zone of the adjoining Kachchh basin from Jumara (Jain and Pandey, 2000). Prasad's specimen (pl. 20, fig. 1) is poorly preserved and can at best be assigned as a species of *Indosphinctes*.

Eucycloceras dungrakotti (Prasad, 2006, pl. 5, fig. 4) is possibly a variant of *Subkossmatia opis* [m] (compare with *Eucycloceras opis* var. *opis* [m] of Jana *et al.*, 2005, pl. 3, fig. 8). Similar variants are illustrated here and the genus is also discussed in somewhat more detail below.

Prasad's *Subgrossouvria sparsibullata* (Prasad, 2006, p. 31, pl. 7, fig. 4; pl. 8, fig. 5) is most likely an inflated variant of *S. gudjinsiriensis* Spath (Prasad, 2006, p. 30, pl. 7, fig. 2 and 7; pl. 8, fig. 3) and *Subkossmatia obscura* Spath (=*Eucycleceras opis* var. *obscura* of Jana *et al.*, 2005) illustrated by Prasad (2006, pl. 2, fig. 3), in the adjoining Kachchh basin (Spath, 1928-33; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000) occurs with "typical" early Middle Callovian *Sivajiceras kleidos* (Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000).

Subgrossouvria morly-daveisi Spath is a "typical" early Middle Callovian form that succeeds both *Reineckeia* (*Reineckeia*) *anceps* [M] and *Sivajiceras kleidos* [M] in the adjoining Kachchh basin and does not co-occur with any of the Macrocephalitids, known so far; the latter had already disappeared by this time (Spath, 1928-33; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000).

Thus, based on the occurrence of several taxa and common faunal elements with the adjoining Kachchh basin and elsewhere (Westermann and Callomon, 1988; Bhaumik *et al.*, 1993; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000; Jana *et al.*, 2006), it is safe to conclude that Prasad's (2006) bed 7 yields a mixed assemblage of late Early to early Middle Callovian age and not of Early Callovian age as suggested (Prasad, 2006).

The next bed (bed 12 of Prasad, 2006) is similarly problematic. The bed is marked by the co-occurrence of otherwise "typical" Early Callovian *Macrocephalites lamellosus* morph *aureus* (Sowerby), "typical" early Middle Callovian *Subkossmatia ramosa* Spath, a late Early-Middle Callovian *Subkossmatia* cf. *opis* Sowerby and *Subkossmatia flexicosta*, a new species. However, Prasad (2006), assigned this bed a Late Callovian age. Interestingly, Macrocephalitids do not reach even the middle part of Middle Callovian and *Subkossmatia* has yet to be recorded from the later parts of

EXPLANATION OF PLATE II

Specimens a-f, i are from the latest Bathonian bed 4, Locality I, Triangularis Zone.

a-c. ***Macrocephalites triangularis*** Spath [M], sample no. SJK/4/1,

a. Lateral view;

b. Apertural view;

c. Lateral view (sample no. SJK/4/2);

d-f. ***Macrocephalites formosus*** (Sowerby) [M], sample no. SJK/4/3;

d. Lateral view;

e. Opposite Lateral view;

f. Apertural view;

i. ***Sivajiceras congener*** (Waagen) [M], sample no. SJK/4/6, Lateral view and

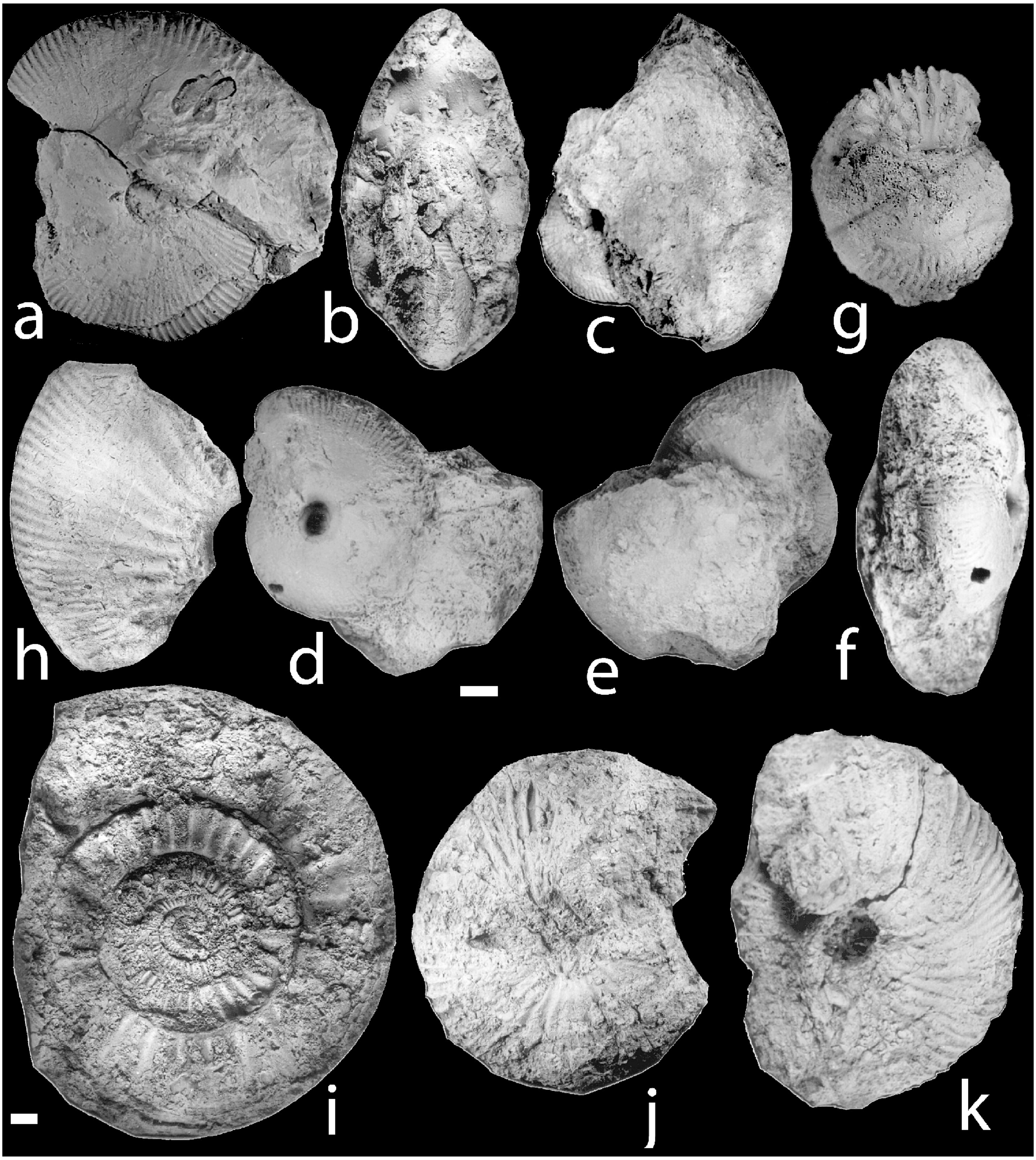
k. ***Macrocephalites lamellosus*** (Waagen) [m], sample no. SJK/4/4, Lateral view.

h and j are from bed 5, Locality I, Madagascariensis Zone.

h. ***Macrocephalites* cf. *madagascariensis*** (Sowerby) [M], sample no. SJK/5/1, Lateral view;

j. ***Macrocephalites subcompressus*** (Waagen) [m], sample no. SJK/5/2, Lateral view;

g. ***Macrocephalites dimerus*** (Waagen) [m], sample no. SJK/7/1, bed 7, slightly north (~70 m) Locality III, Dimerus-Transitorius-Opis Zone. Lateral view. Bar represents 1 cm. All specimens unless mentioned belong to the Kuldhar section.


a
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Middle Callovian (Waagen, 1875; Spath, 1927-1933; Krishna and Westermann, 1985, 1987; Westermann and Callomon, 1988; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000; Roy *et al.*, 2006; Jain *et al.*, 1996; Jain, 2007, 2008), let alone Late Callovian, as suggested by Prasad (2006). This suggests that similar to bed 7, the assemblage from bed 12 is also mixed up.

Thus, based on the above discussion, it becomes imperative that an updated biostratigraphic and taxonomic work is urgently needed for the rich ammonite fauna yielded by the Kuldhar sediments. It is also equally important to address the implications of excessive splitting of species based on old taxonomic comparisons and subsequent erection of new ones on incomplete or badly preserved specimens (Prasad, 2006). These not only pose immense problems for evolutionary systematics but renders the otherwise well constrained and often age-diagnostic ammonite species and its distribution (used for global correlation) useless.

THIS STUDY

The present contribution is divided into 3 sections:

Section 1 erects biozones based on the present distribution of the ammonite fauna recorded from the Kuldhar section and correlates these with those of the adjoining Kachchh basin and the standard zones of the European and Submediterranean provinces.

Section 2 attempts to put forward the likely depositional paleoenvironment for the Kuldhar sediments based on previous and present observations of the recorded macro- and microfauna including that of benthic foraminifers, ostracods, nannofossils, belemnites, and trace fossils.

Section 3 deals with a brief taxonomy of the present recorded specimens. Some common species that were also recorded by Prasad (2006) are reviewed.

Additionally, marker intervals in both the Jaisalmer and Kachchh basins are briefly mentioned to get a sense of the depositional realm of these two Jurassic basins within the western part of the Indian Subcontinent. Furthermore, this contribution also attempts to demonstrate that large morphological variability exists within a species (best demonstrated by the Jana *et al.*, 2005 study based on Kachchh samples) and that such variability does not necessarily require the erection of new species. Excessive splitting can undermine the otherwise excellent quality of the ammonite fauna and thus, complicate any meaningful biostratigraphic inter- and intra-basinal and provincial correlation.

SECTION 1

Biostratigraphic Correlation

The present study identifies 7 Zones and 2 subzones for the 17 beds (bed 2-18) exposed at the Kuldhar section, along the Masurdi River (Fig. 3). Bed 1 is unfossiliferous and belongs to the lower Badabag Member, now part of the Amarsagar Limestone Member of the Jaisalmer Formation (Table 1). This unit has already been dated as Late Bathonian based on the characteristic presence of genus *Clydoniceras* (Prasad *et al.*, 2007). The succeeding beds (2-17) belong to the Kuldhar Member discussed herein. Beds 2-4 form the Triangularis Zone of Late Bathonian age and beds 5-6 belong to the Early Callovian Madagascariensis Zone. Both these zones, their fauna and the placement of the Bathonian-Callovian boundary have previously been discussed in detail (Jain, 2007, 2008) and will not be discussed here any further. For sake of brevity, the fauna is illustrated in Plate 2. Beds 7-10 constitute the Dimerus-Transitorius-Opis Zone of mid-to-late Early Callovian age and beds 11-13 form the larger Anceps Zone that includes the lower Anceps subzone (beds 10-12) and the upper Eucyclum subzone (bed 13) of early Middle Callovian age. This is succeeded by the Gigantea Zone (beds 14-16) of mid Middle Callovian age and the topmost Paramorphum Zone of latest Middle Callovian age. A loose sample of *Collotia fraasi* (Plate 1) from the top of the section indicates early Late Callovian age. Based on the presence of this form from this bed, it is tentatively assigned to represent the informal Fraasi Zone (Fig. 3).

Triangularis Zone

Beds 2-3 are devoid of ammonites and bed 4 has yielded *Sivajiceras congener* [M], *Macrocephalites triangularis* [M], *M. formosus* [M], *M. lamellosus* [m], *M. subcompressus* [m] and *Eutrephoceras* sp. (Locality I in Fig. 2; for details see Jain, 2007, 2008).

The association of *S. congener* [M] and *M. triangularis* [M] in the adjoining Kachchh basin indicates Latest Bathonian age (Callomon, 1993). *Sivajiceras* as a genus in Kachchh has a long range spanning from latest Middle Bathonian (Jain, 1998; Jain and Pandey, 2000; Jain, 2002; Jain, 2007) to late Middle Callovian (Krishna and Ojha, 1996; Prasad, 1998; Jain and Pandey, 2000) with a hiatus during Early Callovian.

Recently, the presence of *M. formosus* [M] from the same beds was reaffirmed by Prasad (2006) suggesting that this species is also long ranging as previously indicated by Prasad (1998; Jara; Fig. 1B) and Jain and Pandey (2000; Jumara; Fig. 1B) from Kachchh. Interestingly, *M. formosus* [M] has also been recorded from the late Early Callovian Gracilis Zone in France (Krishna and Cariou, 1990) (Table 2).

Prasad (2006) from his bed 1 (beds 1-3 of present work; Fig. 2) recorded three fragmentary and poorly preserved specimens of *Macrocephalites* aff. *transitorius* Spath (his *Indocephalites* aff. *transitorius*; 2006, p. 24, pl. 3, fig. 7 and pl. 4, figs. 2-3). However, these forms are considerably more compressed and evolute than the species they are assigned to; their fragmentary nature can at best merit their identification as a depressed species of *Macrocephalites* only. Similar forms are quite common in the Late Bathonian Patcham Formation of Jumara (Kachchh; Krishna and Westermann, 1987; Callomon, 1993; Jain and Pandey, 2000). Hence, pending more complete specimens, any species identification and subsequent reliable age assignment based on these fragmentary specimens should be considered with caution.

Madagascariensis Zone

Bed 5 has yielded *Paracenoceras* sp., *Macrocephalites* cf. *madagascariensis* [M] and *M. subcompressus* [m]. Cariou and Krishna (1988) recorded *M. madagascariensis* [M] and *M. transitorius* [M] from the same sediments. The succeeding bed 6, a thin 0.30 m thick oolitic limestone, is devoid of ammonites.

M. madagascariensis is widespread in the adjoining Kachchh basin occurring both in the Mainland (Jumara, Jara, Keera and Habo Domes; Fig. 1) as well as in the Island belt (Pachchham Island) and assumes a zonal status within the Indo-Madagascan province (Krishna and Westermann, 1987; Krishna and Cariou, 1990; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000). In Kachchh, *M. madagascariensis* ranges from the subjacent Triangularis Zone to the succeeding Dimerus-Diadematus Zone at Jumara (Jain and Pandey, 2000 = Chrysoolithicus Zone of Krishna and Ojha, 1996 at Keera), but its acme is within the intermediate Madagascariensis Zone (Krishna and Westermann 1985, 1987) of earliest Early Callovian age. *M. madagascariensis* has also been recorded from the Early Callovian sediments of Central Nepal (Gradstein *et al.*, 1989) and France (Cariou 1980, 1984, Krishna and Cariou 1990, 1993). In England (Callomon 1988), *M. verus* Buckman (= *M. macrocephalus* Zittel non Schlotheim), a form morphologically close to *M. madagascariensis* [M], ranges from the Verus Horizon (Keppleri subzone) to the Terebratus Horizon (Terebratus subzone) of the Herveyi Zone of Early Callovian age also (Table 2). Solitary Late Bathonian records of *M. madagascariensis* are also noted from Indonesia (Westermann and Callomon, 1988) and from the Triangularis Zone of Madagascar (Collignon, 1958).

Thus, in the present study, both beds 5-6 are included within the Madagascariensis Zone and dated as earliest Early Callovian (Jain, 2007, 2008). The strata above bed 6 are horizontally displaced and the contact between beds 6 and 7 is not clear and is depicted by a "Gap" (Fig. 3). Incidentally, a similar hiatus is also noted at Jumara (Kachchh) that represents the most expanded Callovian section in western India (Biswas, 1991; Jain and Pandey, 2000).

Dimerus-Transitorius-Opis Zone

This zone spans from beds 7 to 9 (Fig. 3) and is equivalent to beds 4 to 6 of Prasad (2006). The lower part of the calcareous shale facies of bed 7 has yielded *Macrocephalites dimerus*, *Hecticoceras proximum*, *Collotia oxyptycha* and *Hecticoceratoides* cf. *suborientalis* and in the upper part *Subkossmatia opis*, *Eucycloceras eucyclum* and *Choffatia transitoria* (Locality II; Fig. 2).

M. dimerus [m] in Kachchh has a long range from Late Bathonian to mid-Early Callovian and hence, is stratigraphically not very valuable (Krishna and Ojha, 1996; Jain and Pandey, 2000). However, the association of *C. oxyptycha* [m] and *H. proximum* [M] is well-constrained and indicates a latest Early Callovian age (Krishna and Ojha, 1996; Jain and Pandey, 2000).

In Kachchh (at both Keera and Jumara Domes; Fig. 1) *Subkossmatia opis* [m] transgresses the Early/Middle Callovian boundary (Krishna and Ojha, 1996; Jain and Pandey, 2000). At Jara (Fig. 1), *S. opis* occurs in early Middle Callovian sediments and ranges the entire Anceps Zone of Middle Callovian age (from the Anceps to the Singulare subzones of the Anceps Zone; Prasad, 1998). Kanjilal (1974) from the Habo Dome (Kachchh; Fig. 1) recorded *S.* cf. *opis* from his bed 7 (Anceps Zone) of the Jhikhadi Member in association with *Idiocycloceras* sp., *Reineckeia* sp., *Choffatia* sp. and *Eucycloceras eucyclum* [M] and dated the assemblage as Middle Callovian. *S. opis* has yet to be recorded from the Island belt outcrops of the Kachchh basin and beyond the mid of Middle Callovian time period.

In Keera, *E. eucyclum*, *S. opis* and *C. oxyptycha* occur together in the latest Early Callovian subzones (Opis / Eucyclum; SIII Horizon; beds 120-131; Krishna and Ojha, 1996). This horizon (SIII) has also yielded *Hecticoceras proximum* and based on it, the subzone was correlated with the Proximum Horizon of the Submediterranean province (Table 2). *H. proximum* is an index of the Patina (Oxyptyca / Proximum) subzone of the Gracilis Zone of the Submediterranean province (Cariou, 1984; Krishna and Ojha, 1996; Table 2).

At Kuldhar, *C. oxyptycha* is restricted to bed 9 and is also associated with the first appearance of genus *Indosphinctes* (*I. errans*). In the Submediterranean province and in Kachchh (Cariou and Krishna, 1988), *Indosphinctes* occurs slightly early in the Laugieri subzone of the Gracilis Zone (Cariou and Krishna, 1988) (Table 2).

Thus, in Europe (Austrian Alps and France) as in Kachchh, *Collotia oxyptycha* is strictly localized at the top of Early Callovian sediments (Cariou, 1984; Cariou and Krishna, 1988; Jain and Pandey, 2000). The association of *C. oxyptycha* with *H. proximum* at Kuldhar, Jaisalmer further attests its localized nature. Hence, beds 7 to 9 are dated as latest Early Callovian.

The beds 7 to 9 of present work are equivalent to beds 4 to 6 of Prasad (2006) that have also yielded *Macrocephalites chariensis* and *M. formosus*. Both species in Kachchh span from the earliest Callovian Madagascariensis Zone to its nominal Formosus Zone of mid Early Callovian age (Bhaumik *et al.*, 1993; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000).

Anceps Zone

This zone includes beds 10 to13 (Fig. 3). Two subzones are identified within these beds, the lower Anceps (beds 10-12) and the upper Eucyclum (bed 13). Bed 10 is devoid of ammonites. Bed no. 11 has yielded *Reineckeia* (*R.*) *anceps* [M] in association with *R.* (*R.*) *stuebeli* [m], *Subkossmatia opis* [m], *Indosphinctes urbanus* [M] and *Eucycloceras eucyclum* [M] (Locality III; Fig. 2). In bed 12 *Sindeites madagascariensis* [M], *E. eucyclum* [M], *Subkossmatia opis* [m], *S. cogni-browni* [m], *S. obscura* [m] and *S. ramosa* [m] are recorded. Bed 13 has yielded *Rehmannia* (*Loczyceras*) *balusseaui* [M], *R.* (*R.*) *stuebeli* [m and M], *R.* (*R.*) *tyranniformis* [M], *S. opis* [m], *E. eucyclum* [M], *Idiocycloceras perisphinctoides* [M] and *I. dubium* [m] (Locality III; Fig. 2).

Anceps subzone

This subzone spans from beds 10-12. *Reineckeia* (*Reineckeia*) *stuebeli* [M] is restricted to the base of Middle Callovian and *Reineckeia* (*R.*) *anceps* [M] is an index of the Anceps Zone in the Submediterranean province (Cariou, 1984; Cariou and Krishna, 1988). Hence, beds 11-12 are correlated with the Stuebeli subzone, Anceps Zone of the Submediterranean province (Table 2). In Kachchh, at Jumara, *R.* (*R.*) *stuebeli* [M] also marks the base of Middle Callovian (Jain and Pandey, 2000) and at Keera, the Ramosa subzone (AI horizon; beds 131 - 163), the lowest subzone of the Anceps Zone, is also defined by the first occurrence of *R.* (*R.*) *anceps* [M] occurring in association with *Subkossmatia ramosa* [m] and *Chanasia hartmanni* (Krishna and Ojha, 1996).

Eucyclum subzone

Rehmannia (*L.*) *balusseaui* [M] in Europe is common in the upper part of the Anceps Zone as also *Reineckeia* (*R.*) *tyranniformis* [M] and hence, bed 13 has been correlated with the Tyranniformis subzone of the Anceps Zone of the Submediterranean province (Fig. 3; Table 2). *Sindeites madagascariensis* [M] is recorded for the first time from the Indian subcontinent. This species has also been recorded from Middle Callovian sediments of Madagascar (Collignon, 1958). Owning to the dominance of *E. eucyclum* [M] from this bed, it is assigned a subzonal status here.

Gigantea Zone

This Zone spans from beds 14 to 16 (Fig. 3). Bed 14 has yielded *Collotia gigantea* [M], *E. eucyclum* [M], *Hecticoceras* cf. *hecticum* Reinecke [M] and *Idiocycloceras singulare* [M] (Locality III; Fig. 3). *C. gigantea* is restricted to the upper part of the Coronatum Zone of the Submediterranean province (Cariou, 1984; Cariou and Krishna, 1988) (Table 2). *Rehmannia* (*Loczyceras*) *rudis* [M] which succeeds *C. gigantea* at the

Kuldhar section has also been recorded from bed 15. Bed 16 has yielded *R.* (*R.*) *tyranniformis* [M]. Thus, the pair of *Collotia gigantea* [M] and *Rehmannia* (*L.*) *rudis* [M] helps in correlating beds 14-16 with the Baylei subzone, upper part of the Coronatum Zone of the Submediterranean province (Table 2). Bed 16 records the last appearance of *R.* (*R.*) *tyranniformis* [M]. However, this species, in Europe, disappears at the base of the Coronatum Zone. Its absence further up attests its similar European and Kachchh occurrences (Jain and Pandey, 2000).

Paramorphum Zone

Bed 17a has yielded *Paralcidia* sp.; bed 17c - *Hecticoceras* sp. and *Hecticoceras ignobile* Waagen [M]; bed 17d - *Sivajiceras paramorphum* [M] and *Putealiceras bisulcatum* [M] and bed 17e has yielded *Hubertoceras omphalodes* [M] and *Subgrossouvria* sp. [M] from Locality IV (Fig. 2).

At Keera (Krishna and Ojha, 1996) *Idiocycloceras* is also succeeded by *Sivajiceras* (*S. paramorphum* and *S. kleidos*). In the present work, bed 17, which follows after the *Collotia gigantea* - *Rehmannia* (*L.*) *rudis* pair favors correlation of these beds with the Leuthardti subzone (Coronatum Zone) of the Submediterranean province (Table 2). This pair in Europe typifies the base of the Coronatum Zone (Cariou, 1980; Cariou and Krishna, 1988).

Fraasi Zone

A loose sample of *Collotia fraasi* [M] from the top of the Kuldhar section indicates early Late Callovian age. Based on the presence of this form from this bed, it is tentatively assigned to represent the informal Fraasi Zone here (Fig. 3).

Interestingly, in Kachchh (Jumara), *C. fraasi* [M] occurs with *Peltoceras* (*P.*) *athleta* [M] and is correlated with the Collotiformis subzone, Athleta Zone of the Submediterranean province (Jain and Pandey, 2000; see Table 2). *C. fraasi* also persists at the same level in the adjoining Jara Dome (personal observation; Fig. 1) and is associated with *C.* aff. *kachchhense* and *C.* aff. *decora* (Prasad 1998). In the Keera Dome (Fig. 1) also, *C. fraasi* co-occurs with *Peltoceras* (*P. metamorphicum* and *P. vijaya*) and species of *Binatisphinctes* and *Paralcidia* (Krishna and Ojha, 1996, 2000). In the Habo Dome (Fig. 1), bed 4 of the Athleta beds (Kanjilal, 1974) has also yielded *Reineckeia* (*R.*) *kachchhense*, a possible synonymy for *C. fraasi*.

In fact, genus *Collotia* in Kachchh is widespread in the Athleta Subzone, Athleta Zone (Krishna and Ojha, 1996, 2000; Prasad 1998; Jain and Pandey, 2000). Thus, within the Kachchh basin, the common occurrence of genus *Collotia*, along *Peltoceras* (*P.*) *athleta* helps in correlating the Athleta Zone of these domes (Table 2).

Thus, the presence of *C. fraasi* (bed 18) and of *Paralcidia* from bed 17a at Kuldhar above the Middle Callovian fauna favors correlation of bed 18 with the Collotiformis Subzone, Athleta Zone of the Submediterranean province (Table 2). However, further up, a previous record of *Dhosaites primus*, 6 m above bed 17 (Chatterjee, 1990) suggests an Early Oxfordian age. But, a more recent record of *Perisphinctes* (*Dichotomosphinctes*) aff. *subhelenae* from the top of the section has been assigned an early Middle Oxfordian age (Prasad, 2006). Here, pending precise finds, an age straddling between Early to early Middle Oxfordian is favored for the top of the section.

A distribution chart of the ammonite fauna (66 specimens) recorded from Kuldhar is given in Table 4.

SECTION II

Palaeoenvironment of the Kuldhar Section

Nannofossils

Early Callovian low diversity nannofossil assemblage has recently been reported from the Kuldhar section (Rai and Garg, 2007; see Fig. 2 Section E for their sampling distance). The palaeoecological potential of this assemblage has not been inferred. It is done so here. This Callovian nannofossil assemblage of 21 species (Rai and Garg, 2007) is dominated by long-ranging taxa such as *Watznaueria barnesae*, *W. britannica*, *W. ovate*, *Cyclagelosphaera margerelii* and marked by variable-sized species of *Watznaueria*.

The placolith *Watznaueria barnesae* is generally regarded as a dissolution-resistant cosmopolitan taxon abundant in oligotrophic surface water settings (Roth and Krumbach, 1986; Premoli-Silva *et al.*, 1989; Williams and Bralower, 1995; Burns and Bralower, 1998; Herrle, 2003; Ebra and Tremolada, 2004). However, blooms of this taxon are also considered to indicate eutrophic environments (Lees *et al.*, 2004). This species is also considered to have an opportunist mode of life, able to thrive under extreme conditions and is better adapted than any of its counterparts (Thomsen, 1989; Mutterlose, 1991). High abundances of *W. barnesae* have also been observed in other restricted, shallow-water settings where samples show a high abundance/low diversity nannoflora (Mutterlose, 1989), as noted at Kuldhar (Rai and Garg, 2007).

Watznaueria manivitae is prolific in low-latitude nannofloral assemblages and its distribution is controlled by temperature. Pittet and Mattioli (2002) and Olivier *et al.* (2004) proposed that this species proliferates under oligotrophic conditions. However, *W. britannica* has been suggested both as a mesotrophic (Lees *et al.*, 2004) or a eutrophic taxon (Busson *et al.*, 1992; 1993).

The ecological affinities of *Cyclagelosphaera margerelii*, another cosmopolitan species, is still unclear. Pittet and Mattioli (2002) and Olivier *et al.* (2004) suggest that it occupies an intermediate position within the trophic continuum between *W. manivitae* (more oligotrophic) and small-sized *W. britannica* (more eutrophic). Several authors (Busson *et al.*, 1992; 1993; Tribovillard *et al.*, 1992) described extremely high abundance of *C. margerelii* in lagoonal environments characterized by low-diversity nannofloral assemblages with marked salinity variations. Interestingly, this taxon also survived the Cretaceous/Tertiary boundary extinction and hence, has been interpreted as a neritic species (Street and Bown, 2000; Bown *et al.*, 2004). However, it is unclear if the small fluctuations in abundance of this taxon are driven by increases and decreases of other taxa or by salinity variations.

Thus, overall, a warm, humid and moderately oligotrophic condition at shallow shelf depths (<50 m) is inferred for the entire Early Callovian section studied at Kuldhar.

Benthic foraminifers

Thick-walled lenticulinids dominate between beds 2-~7 (samples nos. R-34/3-13 of Dave and Chatterjee, 1996) and deep-dwelling epistominids between beds 9-13 (samples nos. R-34/15-19 of Dave and Chatterjee, 1996). *Epistomina mosquensis* dominates within the Epistominids and *Lenticulina muensteri* and *L. bulla* for Lenticulinids (Dave and Chatterjee, 1996). *E. mosquensis* (and in general species of *Epistomina*) prefer relatively deep waters from ~200 to 250 m, whereas *L. muensteri* (and in general species of *Lenticulina*, *Nodosaria*

Table 4: Distribution of species and genera identified from Kuldhar (Jaisalmer).

STAGE	SUBSTAGE	ZONES		Bed nos.		SPECIES																																									
						Macrocephalites dimerus [m]	Macrocephalites formosus [M]	Macrocephalites lamellosus [m]	Macrocephalites cf. madagascariensis [M]	Macrocephalites subcompressus [m]	Macrocephalites transitorius [M]	Macrocephalites triangularis [M]	Subkossmatia cogni-browni [m]	Subkossmatia discoidea [mm]	Subkossmatia opis [m]	Subkossmatia ramosa [m]	Subkossmatia obscura [m]	Eucycloceras eucyclum [M]	Idiocycloceras dubium [m]	Idiocycloceras dubium [M]	Idiocycloceras perisphinctoides [M]	Idiocycloceras singulare [M]	Collotia gigantea [M]	Collotia oxtptycha [M]	Collotia fraasi	Reinekeia (R.) anceps [M]	Reinekeia (R.) stuebeli [m]	Reinekeia (R.) stuebeli [M]	Reinekeia (R.) tyranniformis [M]	Rehmannia (Loczyceras) balusseaui [M]	Rehmannia (L.) rudis [M]	Sivajiceras congener [M]	Sivajiceras paramorphum [M]	Subgrossouvria sp.	Indosphinctes peregrinus [M]	Indosphinctes urbanus [M]	Choffatia transitoria [M]	Hecticoceras ignobile [M]	Hecticoceras sp. [M]	Hecticoceras cf. suborientalis [M]	Hecticoceras proximum [M]	Hecticoceras cf. hecticum [M]	Paranoceras sp. [M]	Eutrephoceras sp. [M]	Putealiceras bisulcatum [M]	Siendietes madagascariensis [M]	Hubertoceras omphalodes [M]
CALLOVIAN	LATE	Fraasi		18																					2																						
	MIDDLE	Paramorphum		17	e																													1													1
					d																												1												1		
					c																																	1	1								
					b																																										
					a																																										
		Gigantea		16																									1																		
				15																											1																
				14														1				1	2																			1					
		Anceps	Eucyclum	13											1			2	1		1						1	1	1	2																	
			Anceps	12									1		1	1	1	1		1	1																									1	
				11										1	1			1								4	1									1											
				10																																											
	EARLY	Dimerus-Transitorius-Opis		9							1				2			1						2											1		1										
				8																																											
				7		1																		3																1	1						
		Madagascariensis		6																																											
				5					1	1																																	1				
BATHONAIN	LATE	Triangularis		4			1	1		1		2																				1												1			
				3																																											
				2																																											
				1																																											

STAGE	SUBSTAGE	ZONES		Bed nos.		GENUS																	
						Macrocephalites	Subkossmatia	Eucycloceras	Idiocycloceras	Collotia	Reinekeia	Rehmannia	Sivajiceras	Hecticoceras	Paranoceras	Eutrephoceras	Indosphinctes	Choffatia	Grossouvria	Siendietes	Putealiceras	Subgrossouvria	Hubertoceras
CALLOVIAN	LATE	Fraasi		18						▨													
	MIDDLE	Paramorphum		17	e					▨												▨	▨
					d					▨			▨								▨		
					c					▨			▨	▨									
					b					▨			▨	▨									
					a					▨			▨	▨									
		Gigantea		16						▨	▨		▨	▨									
				15						▨	▨	▨	▨	▨									
				14				▨	▨	▨	▨	▨	▨	▨									
		Anceps	Eucyclum	13			▨	▨	▨	▨	▨	▨	▨	▨									
			Anceps	12			▨	▨	▨	▨	▨		▨	▨						▨			
				11			▨	▨		▨	▨		▨	▨					▨				
				10			▨	▨		▨			▨	▨									
	EARLY	Dimerus-Transitorius-Opis		9		▨	▨	▨		▨			▨	▨			▨	▨					
				8		▨				▨			▨	▨									
				7		▨				▨			▨	▨									
		Madagascariensis		6		▨							▨										
				5		▨							▨		▨								
BATHONAIN	LATE	Triangularis		4		▨							▨			▨							
				3																			
				2																			
				1																			

or *Dentalina*) fill the depth niche between ~50 to 150 m (Murray, 2001). Low diversity of benthic foraminifers (maximum species diversity is 8; and a range of 6-8 is noted for beds 2-4; data of Dave and Chatterjee, 1996) may also indicate a somewhat stressed environment.

However, Kalia and Chowdhury (1983) from the same section recorded a rich benthic foraminiferal fauna of 47 species indicating a healthy bottom environment with well-oxygenated conditions. Additionally, in this study (Kalia and Chowdhury, 1983), the placement of dominant taxa are also opposite in occurrence as compared to that by Dave and Chatterjee (1996).

Kalia and Chowdhury (1983), for the same sediments, identified three foraminiferal assemblages:

a. The *Gubkinella-Epistomina ghoshi* assemblage marked by the abundance of epistominids, planktonic foraminifers and arenaceous benthic forms. This assemblage extends from sandy limestone to oolitic beds (beds 1-6 of present work; Fig. 3).
b. The *Citharinella rhomboidea-Lenticulina brueckmanni* assemblage is characterized by the abundance of nodosariids (especially lenticulinids). This assemblage extends from clay limestone intercalations to grayish clay beds (beds 7-13 of present work; Fig. 3) and
c. The Barren zone includes the top gypsiferous clay horizon, devoid of microfossils (beds 14-17 of present work; Figs. 3).

Thus, interestingly, according to Dave and Chatterjee (1996) lenticulinids dominate between beds 2-~7 (their samples nos. R-34/3-13), whereas according to Kalia and Chowdhury (1983), Epistominids dominate. Additionally, up section, according to Dave and Chatterjee (1996), the Epistominids have an abundant but restricted occurrence (their samples nos. R-34/15-19) but according to Kalia and Chowdhury (1983), Nodosariids (especially lenticulinids) dominate at this level.

Thus, if the data of Dave and Chatterjee (1996) are considered, the Kuldhar section experienced a stressed environment marked by low abundances and low species diversity. Additionally, beds 2-7 experienced less deep settings (50 to 150 m) as compared to beds 9-13 (200 to 250 m). This depth estimation, species diversity and paleoenvironment are reversed if the dataset of Kalia and Chowdhury (1983) is considered.

Although benthic foraminifers are excellent indicators of the marine environment, the dataset from the Kuldhar section due to their contrasting distribution are surprisingly of little use in interpreting the prevailing environment, except for suggesting that the depth of deposition was less than 100 m (van Morkhoven *et al.*, 1986) and the high diversity of ammonites would suggest some open marine connection. A more comprehensive and well-constrained benthic foraminiferal data is urgently needed for these excellently preserved beds at Kuldhar to infer its palaeoenvironment.

Ostracods

Khosla *et al.* (2006) described the ostracod assemblage from Kuldhar (Fig. 3). Their section includes beds 5-17 of present work with possible omissions of beds 9-13 (Fig. 3). They (Khosla *et al.*, 2006) identified three ostracod assemblages (= concurrent range zones) dominated by genus *Majungaella*. *Majungaella* in the Mesozoic was widely distributed in shallow, warm seas and but in the Jurassic was restricted to the southern Hemisphere (India, Africa and Madagascar). Thus, only broad conclusions can be arrived at for the Kuldhar section and the available data indicate that for bed 4 upwards, a shallow (<30 m) warm water environment was present.

Trace fossils

The presence of *Rhizocorallium* in bed 4 along with *Chondrites* and *Thalassinoides* (Fig. 3; see also Fürsich, 1998; Jain, 2007) in association with oolites and shell debris indicates deposition of the bed in a storm-influenced ramp setting. Higher up, bed 5 has yielded abundant traces of *Thalassinoides* and *Planolites* (Fig. 3), suggesting relatively calmer conditions. However, presence of bored concretions, hardgrounds, and shell debris also indicates long periods of non-deposition (hiatus) and intermittent episodes of storm influenced below fair-weather wave base. Up section, the presence of well-preserved and large traces of *Zoophycos* and *Thalassinoides* in beds 9 and 16 (Fig. 3) suggests ramp environments of low to intermediate energy (Fürsich, 1998).

Fürsich (1998) noted that high energy/near shore areas and submarine shoals are represented by members of the Skolithos ichnofacies such as *Ophiomorpha* and *Rhizocorallium* and that the storm-influenced ramp contains both members of the Cruziana ichnofacies (*Rhizocorallium*, *Thalassinoides* and *Chondrites*) and the Skolithos ichnofacies (in particular *Ophiomorpha*). The Cruziana ichnofacies were produced during interstorm phases, the Skolithos ichnofacies are of post-storm origin. Carbonate ramp environments of low to intermediate energy also contain members of the Cruziana ichnofacies, whilst equivalent siliciclastic environments are characterized by a low-diversity *Zoophycos* ichnofacies. Low energy basinal environments of fine-grained substrates contain an impoverished Cruziana ichnofacies consisting of *Chondrites* and *Thalassinoides*.

Though, a much more detailed analysis and close bed-by-bed examination of trace fossils distribution is needed for any accurate inference for the Kuldhar Member, the preliminary data indicate that bathymetrically, bed 3 is deposited at a shallow ramp setting (*Thalassinoides* and *Planolites*), followed by sudden deepening (*Chondrites* with *Thalassinoides* and *Planolites*) for bed 4 and again shallowing to bed 3 levels for beds 5-6. However, beds 4-6 had much lower energy levels marked by the absence of cross-bedded ripple marks present at the top of bed 3.

Bored concretions and growth of serpulids over oyster shells in beds 3-6 suggest periods of break in sedimentation. Presence of hardgrounds at this level has already been well documented by Fürsich *et al.* (1991). Presence of well-preserved and large traces of *Zoophycos* and *Thalassinoides* in bed 9 and of *Thalassinoides* and *Planolites* in bed 13 suggests calmer and deeper conditions for beds 9-13.

Presence of cross bedding in the lower part of bed 16 (sandstone) indicates shallowing and high energy conditions of deposition. The upper part of this bed has however well-preserved and large traces of *Zoophycos* suggesting calmer and slightly deeper conditions which prevailed thereafter until bed 17, which is indicatively marked by thick calcareous marls (Fig. 3).

Belemnites

Abundant belemnites have been noted in beds 3-6 (Fig. 3). The construction of the belemnite phragmocone imposes a habitat depth limit due to the possibility of implosion from hydrostatic pressure. For two species of *Hibolithes* (that proliferate the Kuldhar section and in the adjoining Kachchh basin), the habitat depth limit is calculated at around 215 m

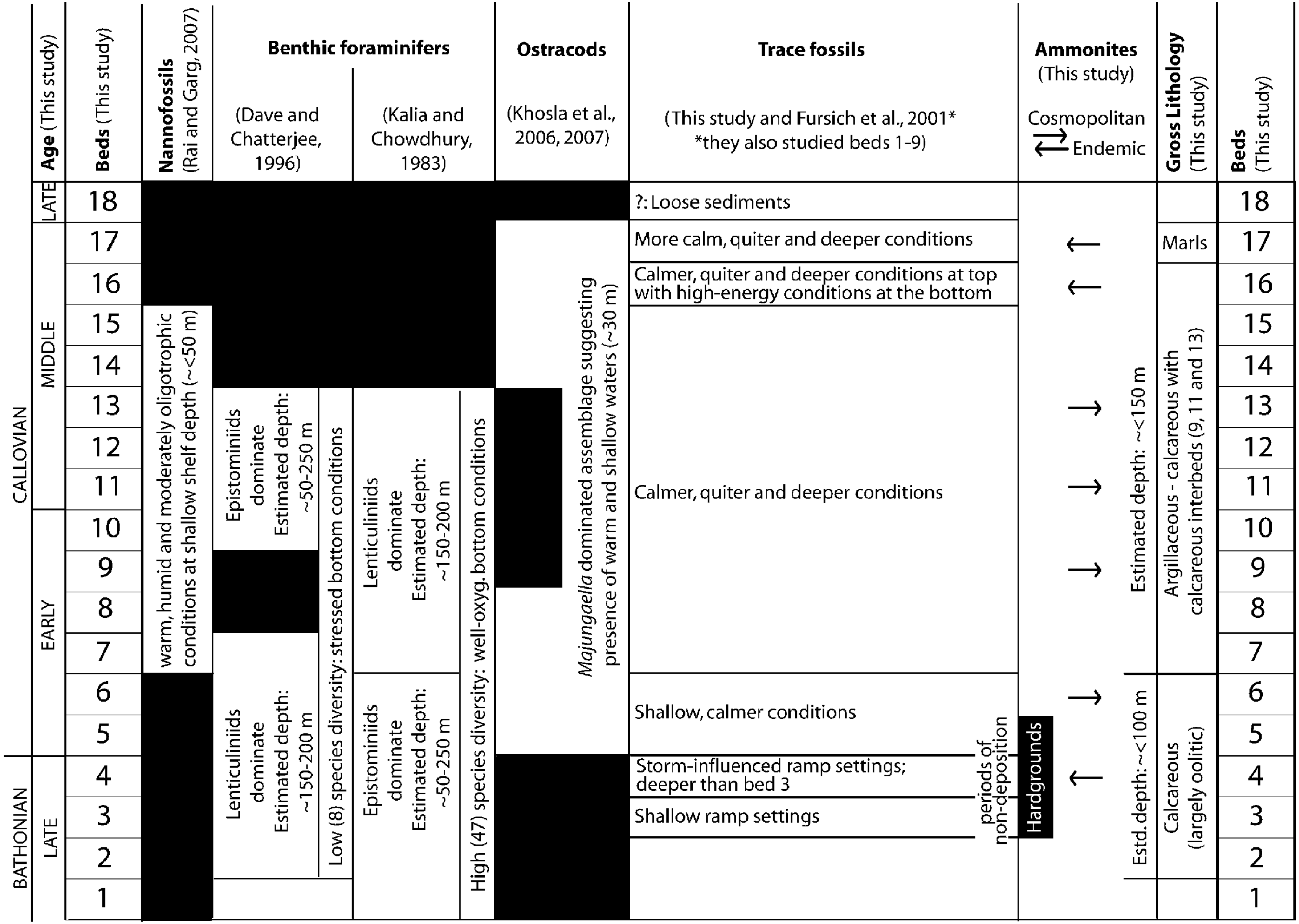


Fig. 4. A summary of paleoenvironmental conditions inferred from various micro- and macrofauna identified from Kuldhar (Jaisalmer). The cosmopolitan and endemic species of ammonites recorded at Kuldhar are also marked along with the gross lithology of co-occurring beds.

(Wierzbowski, 2004). According to him, other belemnites should have had a lower depth limit averaging 150 m, similar to the depth limit of a majority of ammonites. A differentiation of depth limit is, however, possibly recognized within the Middle Jurassic genus *Cylindroteuthis* (Westermann, 1973). Similarly, the large differentiation of depth limit is also observed for modern *Sepia*; particular *Sepia* species differing in shell size and septal thickness inhabit either shallow or deep waters, but rarely exceeding depths of 200 mts (Rexfort and Mutterlose, 2006). For these reasons the calculations of the depth habitat of belemnites seem not to be very exact but based on the above discussion, a lower depth limit of 150-200 mts would be safe to assume, confirming their necto-benthic mode of life in the Jurassic. Thus, the presence of belemnites indicates a conservative depth not exceeding 150 mts.

In summary, the sediments at Kuldhar indicate deposition in a warm, humid and moderately oligotrophic condition at shallow shelf depths (<100 m) with an intermittent open marine connection. The distribution of trace fossils better indicates the fluctuations both in sea and energy levels. The beds are deposited at shallow ramp settings, a sudden deepening for bed 4, shallowing for beds 5-6, with calmer and deeper conditions until bed 13. Cross-bedding in the lower part of bed 16 indicates shallowing and high energy conditions of deposition followed by calmer and slightly deeper conditions until bed 17. Sudden deepening possibly brought in Suboreal and Submediterranean ammonites as exemplified by numerous common species of Family Reineckeiidae Hyatt, Grossouvrianae Spath and Hecticoceratinae Spath. A summary of the palaeoenvironment discussed above in given in Fig. 4.

Interbasinal marker intervals

Pandey *et al.* (2009a, b) identified four marker intervals in both Jaisalmer and Kachchh basins:

1. the pebbly rudstone unit with *Isastrea bernardiana* and *Leptosphinctes* of the Kaladongar Formation (Kachchh Basin) and the *Isastrea bernardiana*-bearing rudstone of the Jaisalmer Formation (Jaisalmer Basin) both represent transgressive systems tract (TST) deposits dated as Late Bajocian;
2. bioturbated micrites with anomalodesmatan bivalves within the Goradongar Yellow Flagstone Member (Kachchh Basin) and bioturbated units in the Fort Member (Jaisalmer Basin) represent maximum flooding zone (MFZ) deposits of the Middle to Late Bathonian;
3. trough-crossbedded, sandy pack- to grainstones of the Raimalro Limestone Member (Kachchh Basin) and the basal limestone-sandstone unit of the Kuldhar section of the Jaisalmer Formation (Jaisalmer Basin) correspond to Late Bathonain TST deposits; and
4. ferruginous ooid-bearing carbonates with hardgrounds of the Dhosa Oolite member (Kachchh Basin) and the middle part of the Jajiya Member (Jaisalmer Basin) are Oxfordian TST deposits.

Pandey *et al.* (2009a, b) further noted that the fact that in both basins similar biofacies prevailed during certain time intervals, a common control of their depositional history is plausible. However, as the two basins represent different tectonic settings, the most likely controlling factors are likely to be (a) relative sea-level changes produced by eustatic processes, (b) common subsidence history of the northwestern margin of the Indian craton, and (c) similar paleoclimate.

SECTION III

Systematic Palaeontology

In this section only those specimens are described in detail that have stratigraphic relevance or form an important element of an assemblage. Dimorphism in *Rehmannia* (*Loczyceras*) *rudis* (Bourquin), *Reineckeia* (*Reineckeia*) *stuebeli* Steinmann, *R.* (*R.*) *anceps* (Reinecke) and *Idiocycloceras dubium* Spath are documented. Microconchs (male) of *Rehmannia* (*L.*) *reissi* (Steinmann) and *R.* (*L.*) *rudis* (Bourquin) and macroconchs (female) of *Collotia oxyptycha* (Neumayr) [M] and *C. gigantea* (Bourquin) are also described.

Both microconchs of *R.* (*L.*) *rudis* (Bourquin) [m] and *R.* (*R.*) *anceps* (Reinecke) are described from Jumara (Kachchh) and *R.* (*L.*) *reissi* (Steinmann) [m], *R.* (*R.*) *stuebeli* Steinmann [M and m] are common to Kuldhar (Jaisalmer) and Jumara (Kachchh) sections. A comparitive age-range chart for these species is provided (Fig. 5).

Both Spath's genus *Eucycloceras* and *Subkossmatia* from Kachchh have recently been investigated and integrated into one genus *Eucycloceras* Spath (Jana *et al.*, 2005). However, in the present study (based on both morphological and statistical data), the traditional taxonomic classification of Spath (1924-1928) and Callomon (in Donovan *et al.*, 1981) is preferred. Brief comparison with the new classification of Jana *et al.* (2005) is also done (Table 5).

Additionally, only new data on species description with an emphasis on family Reineckeiidae is given, since, much of the species description is well documented by works of Waagen (1875), Spath (1927-33) and Jana *et al.* (2005). Other specimens are, thus, only recorded and illustrated for future species comparisons.

All measurements are given in Appendix-1. D, shell diameter; U, umbilical diameter; T, thickness of the shell; H, height of the shell; all measurements are in millimetres; M, macroconch; m, microconch. The notation SJK used for Kuldhar specimens is based on Sreepat Jain Kuldhar and is followed by bed number and specimen number. So, for example a specimen from bed 9 will have the notation as SJK/9/1. Those from Jumara (Kachchh) have the first initials as Ju. All specimens are reposited at the Invertebrate Paleontology Laboratory of the Geology Department, University of Rajasthan, Jaipur, India. At places, the old inventory numbers (like the one illustrated on Plate 6, fig. c: Ju/12/7) is now replaced by the newer one (Ju/B35/10). Collections for 1993-1994 were broad based and were later refined in 1999. Hence, the two numbering systems.

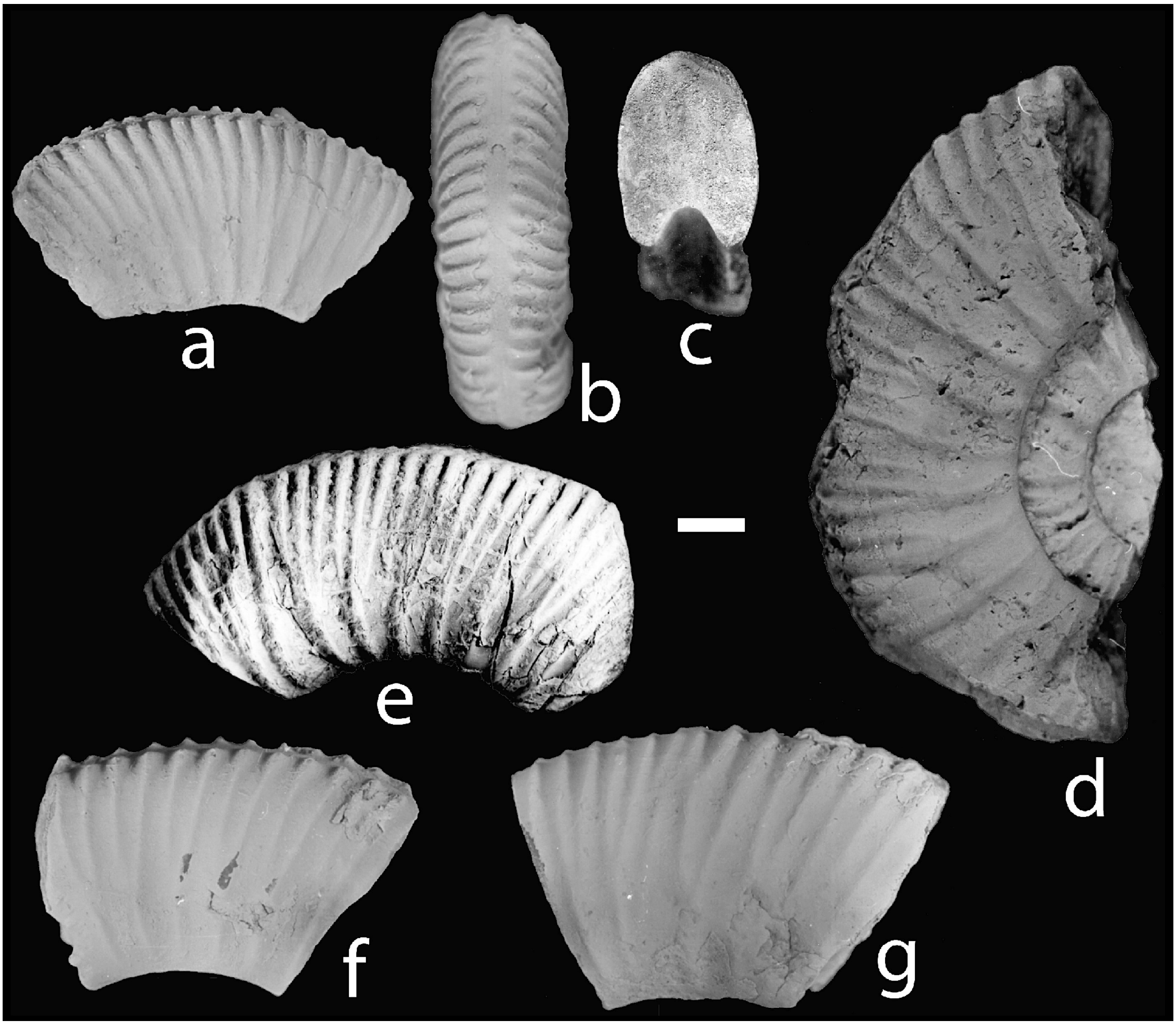
The principle for differentiation of dimorphism is the co-occurrence of two groups of ammonites differing in shell size, ornamentation of outer whorl(s), type of peristomal modifications and displaying identical or practically indistinguishable inner whorls (Makowski, 1962; Callomon, 1963, 1969). Dimorphism was interpreted as sexual in nature. Smaller forms with more complex peristome as males, and larger - as females (Makowski, 1962). Thus, in general, the microconchs are smaller, lappeted and strongly ornamented, with strong primary ribs. However, it must also be pointed out that "the question of which of a dimorphic pair should be identified with a particular sex...can never rise above speculation" (Callomon, 1963, p. 47).

Family ***Reineckeiidae*** Hyatt, 1900

Subfamily ***Reneckeiinae*** Hyatt, 1900

Cariou (1980, p. 35) recognized two distinct subfamilies -

Plate III



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EXPLANATION OF PLATE III

a-g. ***Collotia oxyptycha*** (Neumayr) [M] from beds 8 and 9, Dimerus-Transitorius-Opis Zone, Locality III, a-c, f and g are from bed 8, sample nos. SJK/7/2-4 respectively; d-e from bed 9, sample nos. SJK/9/1-2 respectively. All are septate specimens with lateral views except for b (ventral view) c (apertural view). Bar represent 1 cm. All specimens unless mentioned belong to the Kuldhar section.

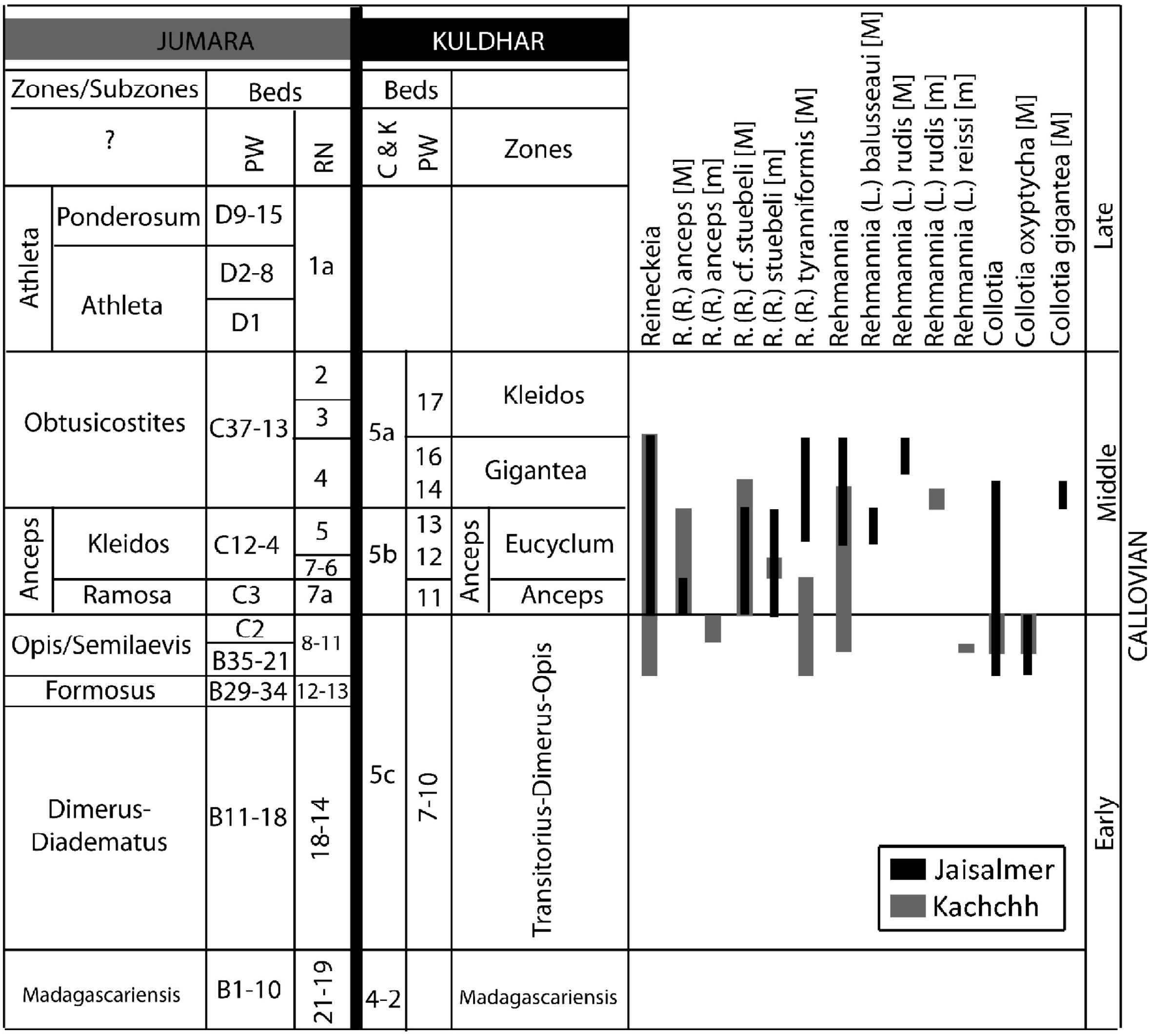


Fig. 5. A comparative range-chart summary of Subfamily Reineckeiinae identified from Kuldhar (Jaisalmer) and Jumara (Kachchh). Note that most species occurrence are well-constrained by coeval time.

the Late Bathonian-Early Callovian East Pacific Neuqueniceratinae recorded from the Andes (Riccardi and Westermann, 1991) with rare occurrences from Japan (Westermann and Callomon, 1988). The Japanese specimens have now been assigned to a new genus - *Pesedoneuquenicera*s (Riccardi and Westermann, 1991). The other subfamily - the cosmopolitan late Early Callovian - early Middle Callovian western Tethyan Reineckeiinae is widely distributed in the Mediterranean, Submediterranean, Subboreal, Indo-Malgache as well as in the Andes, Mexico (Cariou and Krishna, 1988).

Recently, the age of the western Tethyan Reineckeiinae was revised and lowered down to an age bracketed to lie between latest Late Bathonian and Middle Bathonian (Jain *et al.*, 1996; Jain, 2000) which incidentally, also coincides with the extension of the upper age limit of this family in the Andes into the Early Oxfordian (Gröschke, 1994). In Kachchh, Spath (1932, p. 252), on purely nomenclatural grounds, had earlier assigned Bathonian age to the earliest Reineckeiid (*Epimorphoceras decorus*), recorded by Waagen (1875, p. 208, pl. 57, figs. 3a-c) from the "highest beds of the Putchum group of Jumara" (Sponge beds; Jain *et al.*, 1996). The recent Bathonian discovery of *Reineckeia* sp. indet. A and B [M] from the Yellow bed of the Jumara Dome (bed A4) has made "the supposed centre of evolution...to be moved eastwards...into the Pacific" (Jain *et al.*, 1996). This Bathonian discovery from the same level at Jumara as also the strong resemblance of the asymmetrical lateral lobe of *Reineckeia* sp. A (Jain *et al.*, 1996) with that of *E. decorum* (Waagen), favors the much debated placement of the latter in the Reineckeiidae firmly.

Genus ***Collotia*** (De Grossouvre, 1917)
Type species: *Ammonites fraasi* (Oppel 1857)
Collotia oxyptycha (Neumayr, 1870) [M]
(Pl. III, figs. a-g, Text-fig. 6a)

Collotia oxyptycha (Neumayr) - Cariou, 1980, p. 503, pl. 43, figs. 1-4, pl. 44, figs, 1,4-5, pl. 45, figs. 1-2, text-figs. 162-163, 168, 175-177 and 201. - Cariou and Krishna, 1988, p. 164, pl. 4, figs. 2, 3a-b and 4a-b; Text-fig. 4.

Material: 5 specimens (SJK/9/2-4 and SJK/9/1-2).

Horizon: Bed 7, Patina subzone and bed 9, Anceps Zone, Locality II (Fig. 2), Kuldhar.

Description: All specimens are fragmentary but preserved well enough to enable correct identification at the species level. Shell is large, evolute and compressed with missing inner

Table 5: A comparative morphological categorization based on the classification given by Spath (1928), followed by Callomon in Donovan et al. (1981) and used here with the one given by Jana *et al.* (2005).

Classification followed here is of Spath (1927-33) and Donovan *et al.* (1981)	**Modern classification after Jana *et al.* (2005)**
Eucycloceras eucyclum (Waagen) [M]	*Eucycloceras opis* (Sowerby) [M]
Subkossmatia opis (Sowerby) [m]	*Eucycloceras opis* (Sowerby) [m]
Subkossmatia cogni-browni Spath [m]	
Subkossmatia discoidea Spath [m]	
Subkossmatia ramosa Spath [M]	*Idiocycloceras perisphinctoides* Spath [M]
Idiocycloceras dubium Spath [m]	*Idiocycloceras perisphinctoides* Spath [m]
Idiocycloceras perisphinctoides Spath [M]	*Idiocycloceras perisphinctoides* Spath [M]
Idiocycloceras dubium Spath [M]	
Idiocycloceras singulare Spath [M]	*Idiocycloceras singulare* Spath [M]

whorls. In the middle whorls, ribbing is dense and sharp. At this stage, primaries arise rursiradiately from below the rounded umbilical margin and divide at varying flank heights into 2 to rarely 3 sharp, dense and strongly prorsiradiate secondaries with a single intercalatory. Secondaries at the rounded ventrolateral margin show a slight backward bend. Venter is distinctly grooved more so on the earlier whorls. There are 12 to 16 primaries with 30 to 34 secondaries per half whorl. Maximum estimated shell diameter is between 150-160 mm.

Remarks: Ribbing is present in all the specimens. Ribs either bifurcate or rarely trifurcate with a single intercalatory. This character is restricted to the middle whorls; outer whorls display quadrifurcate ribbing (Cariou and Krishna, 1988). Hence, all fragmentary specimens belong to the middle whorl. Another character is the varying heights of ribfurcation, ranging from lower to the outer third of the flank height.

Occurrence and Age: late Early Callovian (beds 7 and 9; Locality II). The species is strictly localised at the top of Early Callovian (Patina subzone, Gracilis Zone; Table 2) in the Submediterranean province (Cariou, 1984). In Kachchh, it spans from the Semilaevis to the Opis Zones of latest early Callovian age. Both at Kuldhar (Jaisalmer) and Jumara (Kachchh), this species disappears before the beginning of the Middle Callovian Anceps Zone (Fig. 5).

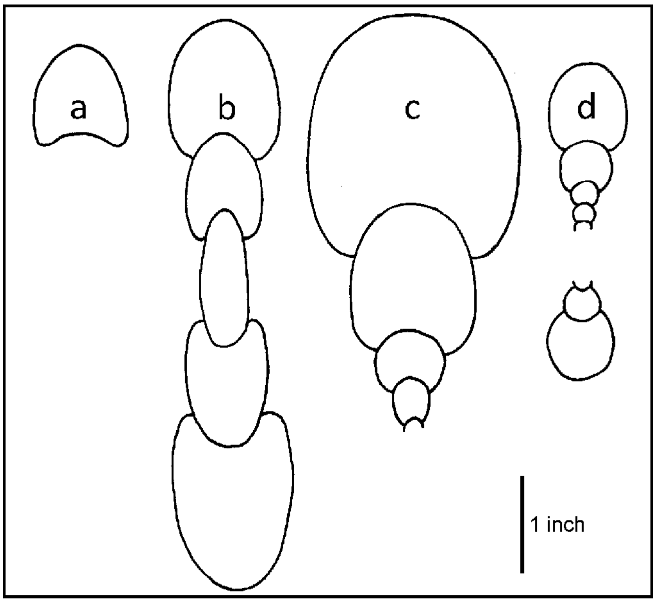


Fig. 6. Whorl sections. (a): *Collotia oxyptycha* (Neumayr) [M]; (b): *Collotia gigantea* Bourquin [M]; (c): *Rehmannia* (*L.*) *balusseaui* Cariou [M]; (d): *Reineckeia*(*R.*)*stuebeli* Steinmann [M].

Collotia gigantea (Bourquin) [M]
(Pl. IV, figs. a-b; Text-fig. 6b)

Collotia gigantea (Bourquin) - Cariou, 1980, p. 550, pl. 49, figs. 1-4; pl. 50, figs 1, 3 and 5; text figs. 170-171, 187-188, 190 and 204. - Cariou and Krishna, 1988, p. 165, pl. 5, figs. 1 a-b, 2 and 3.

Material: 2 specimens (SJK/14/1-2).

Horizon: Bed 14, Gigantea Zone, Locality III (Fig. 2), Kuldhar.

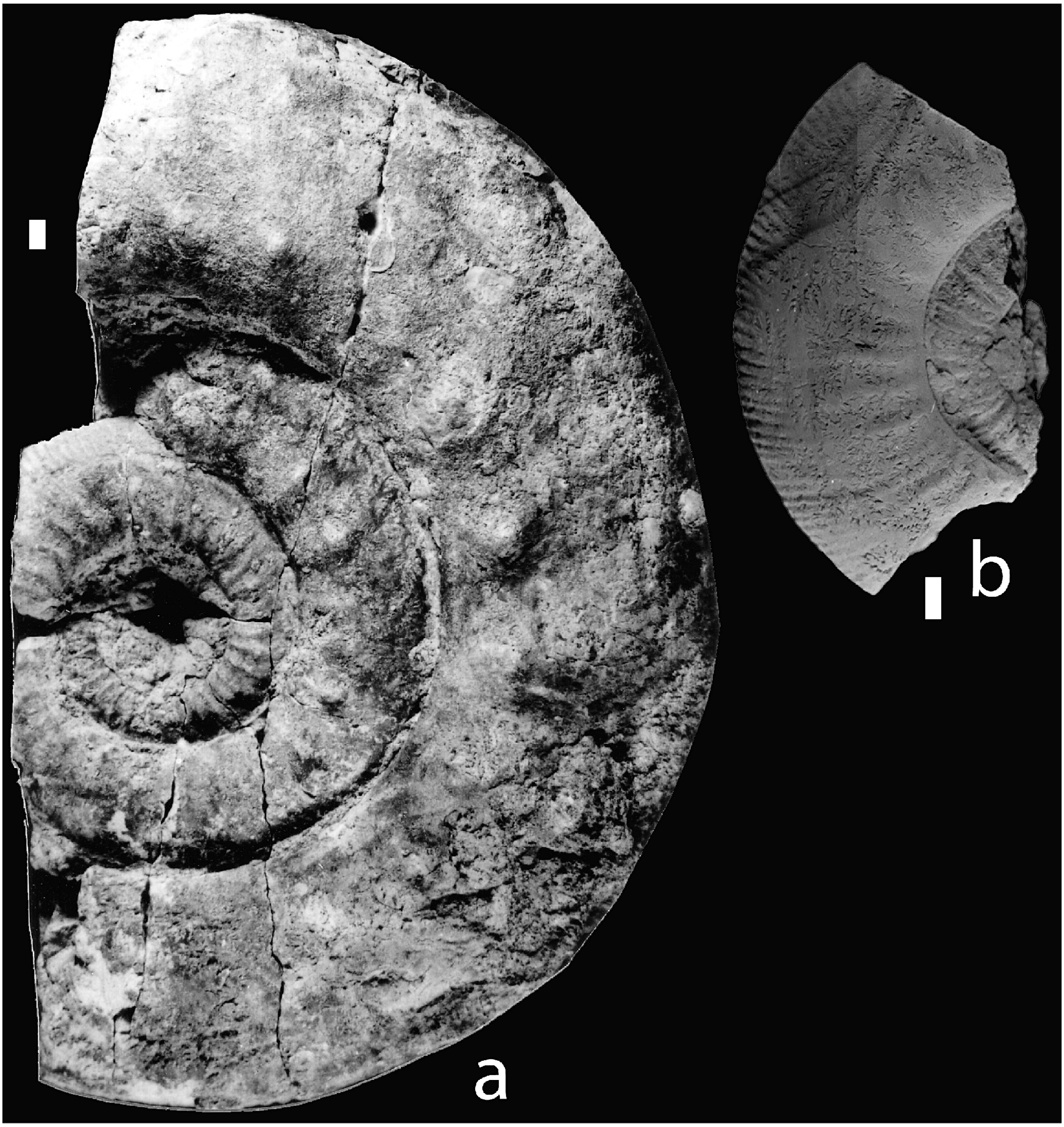
Description: Phragmocone is large (270 mm) with a maximum estimated shell diameter of at least 400 mm. Primaries arise slightly rursiradiately from the broadly rounded umbilical margin and show typical subrectiliniear arrangement until 200 mm; thereafter, they assume a somewhat straighter pattern. Primaries divide at the middle to the lower third of the flank height. Until 120 mm, the primaries divide into 3 prorsiradiate secondaries with a single intercalatory. At around 170-180 mm each primary rib divides into 5-6 prorsiradiate secondaries. Ribbing until 150-170 mm is dense and moderately fine. Thereafter secondaries become somewhat coarse and faint at the body chamber. The secondaries throughout the shell growth remain strongly prorsiradiate. Fine spines are present at the rib furcation points until 50 mm; thereafter they are absent. At around 170-180 mm, faint tubercles appear at the point of branching. Throughout the phragmocone stage the flanks are moderately flat, but near the body chamber become slightly arched. In early whorls venter bears a distinct groove which at the body chamber reduces in prominence. Venter until 200 mm is well rounded but thereafter becomes narrow and somewhat arched.

Remark: It differs from *Collotia oxyptycha* (Neumayr) in its pattern of the branching of ribs and in being considerably larger and slightly more evolute.

Occurrence and Age: late Middle Callovian (bed 14; Locality III). *C. gigantea* (Bourquin), a European species, is restricted to the upper part of the Coronatum Zone (Baylei subzone) of the Submediterranean province (Table 2).

Genus ***Rehmannia*** Schirardin, 1956
Subgenus ***Loczyceras*** Bourquin, 1881
Type species: *Loczyceras sequanicum* (Bourquin)

Plate IV



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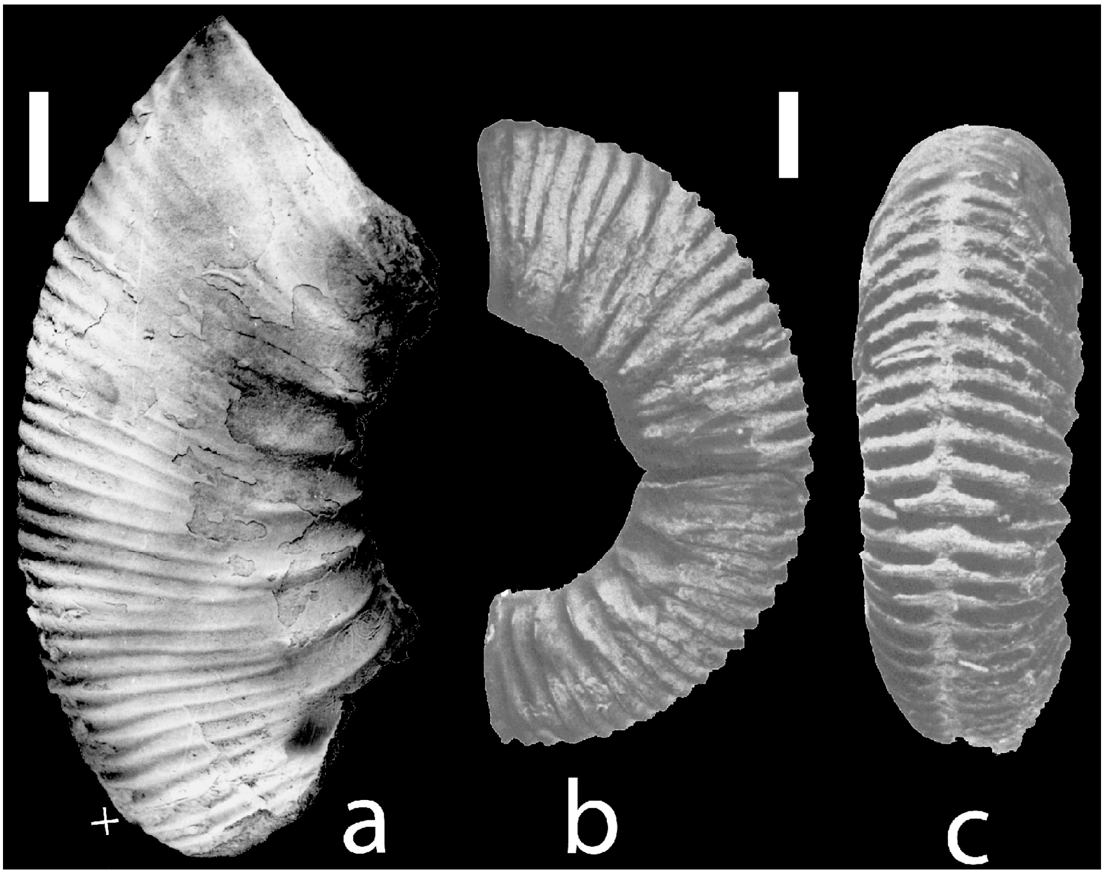
EXPLANATION OF PLATE IV

a-b. ***Collotia gigantea*** (Bourquin) [M], bed 14, Gigantea Zone, sample no. SJK/14/1-2 respectively, septate specimens. Lateral views. Bar represent 1 cm. All specimens unless mentioned belong to the Kuldhar section.

Plate V



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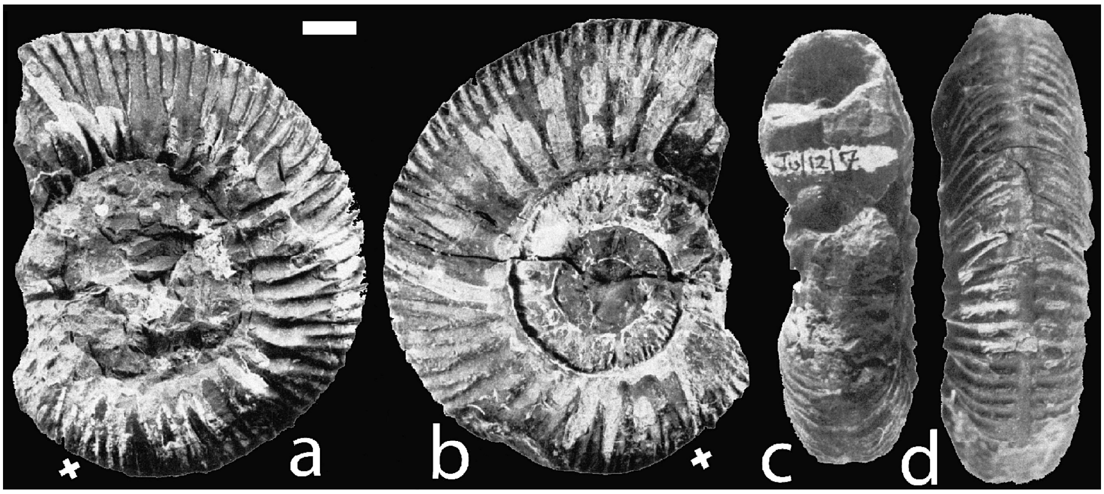
EXPLANATION OF PLATE V

a. ***Rehmannia* (*Loczyceras*) *rudis*** (Bourquin) [M], bed 15, Gigantea Zone, Locality III, Kuldhar section, sample no. SJK/15/4. Lateral view.

b-c. Microconch [m], Bed C13, Jumara (Kachchh) sample no. Ju/C13/12, Obtusicostites Zone, Jumara (Kachchh). Bar represents 1 cm.

Plate VI



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EXPLANATION OF PLATE VI

a-d. ***Rehmannia* (*Loczyceras*) *reissi*** (Steinmann) [m], Bed B35, sample no. Ju/B35/10, Opis Zone, Jumara (Kachchh). a: Lateral view, b: Opposite lateral view, c: Apertural view, d: Ventral view. Bar represents 1 cm.

Rehmannia (*Loczyceras*) *rudis* (Bourquin)
Macroconch [M]
(Pl. V, fig. a)

Rehmannia (*Loczyceras*) *rudis* (Bourquin) - Cariou, 1984, p. 210, pl. 17, figs. 2a-b, 3 and 4 a-b; text-figs. 71-72.

Material: One specimen (SJK/15/4).

Horizon: Bed 15, Locality III, Gigantea Zone (Fig. 2), Kuldhar.

Description: Maximum estimated shell diameter of ~120 mm. In the inner whorls, the primaries are fine, radially arranged with concealed tubercles, due to overlapping by the succeeding whorls. Near the end of the phragmocone, primaries are slightly rursiradiate at the rounded umbilical shoulder and branch into three fine and strongly prorsiradiate secondaries with a single intercalatory. At the point of division, which is at the upper third of the flank height, a tubercle is present. Venter bears a mid-ventral groove. Whorl section subquadratic due to almost flat to slightly converging flanks, being more pronounced at the body chamber, where the venter is narrow but remains rounded. Primaries arise from the umbilical seam rursiradiately. At the end of the phragmocone or at the beginning of the body chamber, ribbing is finer and evenly spaced. The tubercles which are still at the third of the whorl height begin to fade after the end of the phragmocone, being ultimately replaced by a crest. Constrictions are wide, prominent, deeply incised and more forwardly inclined than the ribbing.

Occurrence and Age: late Middle Callovian (bed 15; Locality III).

Microconch [m]
(Pl. V, figs. b-c)

Rehmannia (*Loczyceras*) *rudis* (Borquin) - Cariou, 1980, p. 210, pl. 17, figs. 2a-b, 3 and 4 a-b; text-figs. 71-72.

Material: 2 specimens (Ju/C13/12-13).

Horizon: Bed C13, Obtusicostites Zone (Jain and Pandey, 2000), Jumara, Kachchh (Table 2).

Description: Shell evolute and reaching a T/H ratio of 1. The maximum estimated shell diameter is ~90 mm. The primaries are fine, sharp, evenly spaced and slightly rursiradiate at the umbilical area, becoming more pronounced at the end of the body chamber. Primaries bear a sharp tubercle at the point of branching in the lower third of the flank height, whence they divide into 3 fine sharp and prorsiradiate secondaries, which crosses the narrow but rounded venter with a slight forward sinus. Sometimes one of the secondaries detaches and forms a single intercalatory. Primaries originate rursiradiately from just below the rounded umbilical shoulder. Whorl section is rounded just at the end of the phragmocone but changes to subtrapezoidal at the body chamber. There are 2 constrictions per half whorl, which are distinct, forwardly inclined, deep and well marked.

Remarks: Pattern of ornamentation matches with its Macroconch that are considerably larger in size (for details see Cariou, 1984, p. 210, pl. 17).

Occurrence and Age: late Middle Callovian. This species is restricted to the Obtusicostites Zone at Jumara (Kachchh) (for details see Jain and Pandey, 2000) (Table 2).

Rehmannia (*Loczyceras*) *reissi* (Steinmann) [m]
(Pl. VI, figs. a-d)

Rehmannia (*Loczyceras*) reissi (Steinmann) - Cariou, 1980, p. 480, figs. 2a-b, p. 482, pl. 11, figs. 2 and 5a-b.

Material: One specimen (Ju/B35/10).

Horizon: Bed B35, Opis Zone, Jumara (Kachchh).

Description: Shell is small, evolute and compressed. The cartiform stage persists until 10 mm. Minute tubercles present at the point of branching of the primary ribs. The primaries arise from the umbilical edge, and branch into 3 fine and prorsiradiate secondaries with an occasional single intercalatory until 30 mm. A single intercalatory precedes the constriction also. After the 30 mm stage, and until 50 mm, the primaries branch into 4-5 prorsiradiate secondaries with a single intercalatory. Thus, the Anceps stage persists until 30 mm which is followed by a Reissi stage. Tubercles of the Anceps stage are pyramidal which after 40 mm (Reissi stage) become spinose and die out at 50 mm, replaced by very faint and sharp crests only. This demonstrates degeneration of the tubercles, instead of the normal course of regeneration. Primaries at the body chamber branch into 2 or 3 blunt secondaries with a single intercalatory. Primaries at the body chamber remain crested but the secondaries become somewhat coarse or blunt, being pronouncedly prorsiradiate at the end of the body chamber. 4 forwardly inclined and deep constrictions are present per whorl. Venter bears a strong and distinct mid-ventral groove.

Occurrence and Age: This species has been recorded from the Anceps Zone (Stuebeli Subzone) of the Submediterranean province (Cariou, 1984). In the present record the species has been recorded from the subjacent Semilaevis/Opis Zone from Jumara (Table 2) of latest Early Callovian age. This is the earliest record for this species from Kachchh, western India.

Rehmannia (*Loczyceras*) *balusseaui* Cariou, 1984 [M]
(Pl. VII, figs. a-b, Text-fig. 5c)

Rehmannia (*Loczyceras*) *balusseaui* Cariou, 1984, p. 170, pl. 13, figs. 1a-b, 2 a-b, 3; pl. 14, fig. 1 a-c, text-figs. 39, 42, 62 and 63. - Cariou and Krishna, 1988, p. 157, pl. 11, figs. 3a-b; pl. 2, figs. 1 a-b.

Material: 2 specimens (SJK/13/1 and SJK/13/9).

Horizon: Bed 13, Locality III, Anceps Zone.

Description: Phragmocone is large (still septate at 245 mm; SJK/13/1), evolute and moderately compressed. Primaries arising from the umbilical shoulder are rursiradiate at the umbilical area, and then they become prorsiradiate, branching into 6 prorsiradiate and closely spaced secondaries with one to 2 intercalatories. The ribbing trajectory remains subrectilinear throughout shell growth. Early whorls until 70 mm bear pyramidal tubercles of varying height at the point of branching of the primaries in the upper third to middle of the whorl height. There are 7 primaries with 2-3 prorsiradiate constrictions per half whorl. The tubercles numbering 9 per half whorl are faint and sharp until 30-40 mm, become pyramidal at 70-80 mm and blunt at around 120-130 mm. The tubercles maintain varying heights throughout ontogeny.

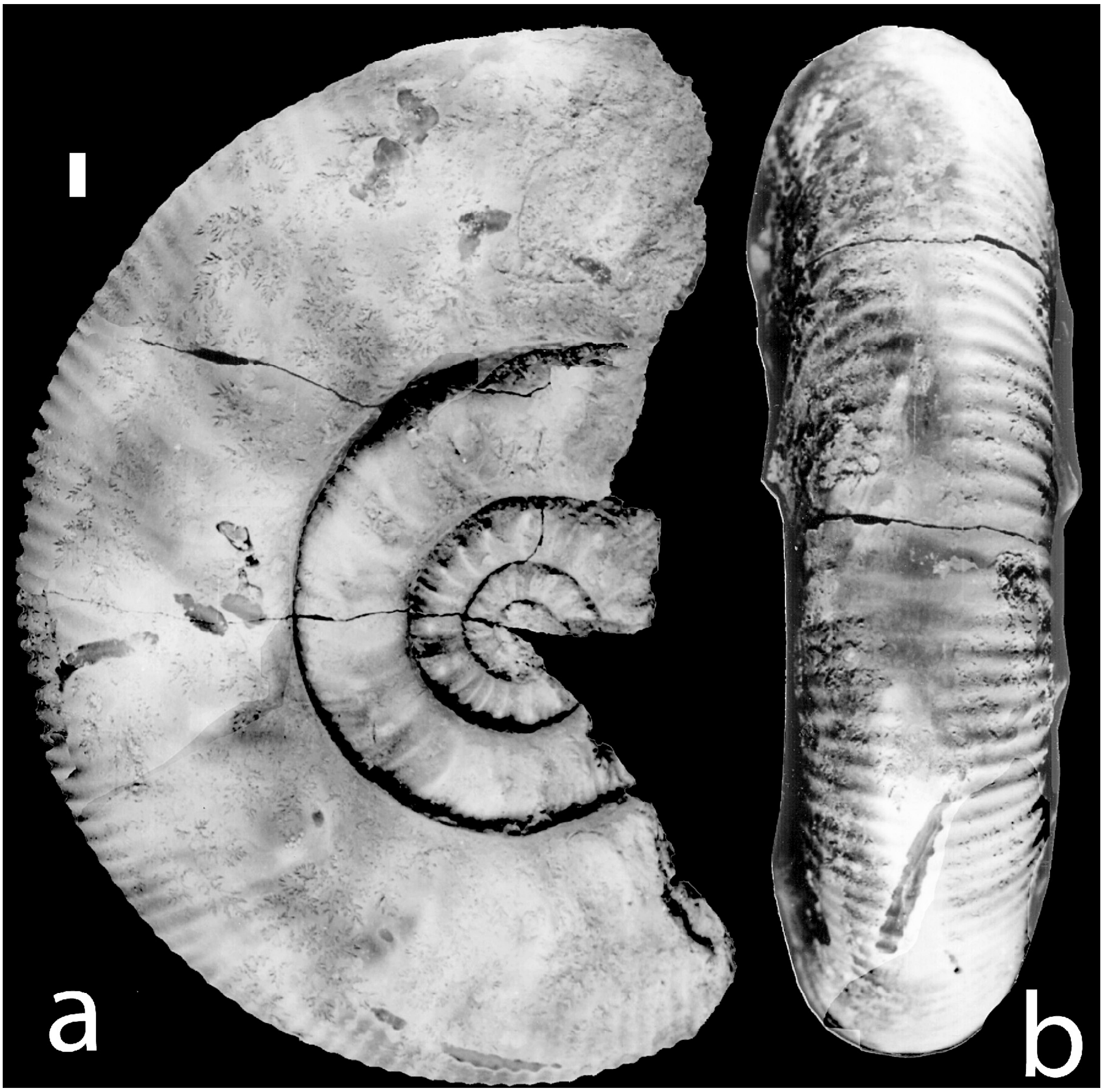
Occurrence and Age: early Middle Callovian (bed 13; Locality III). *R.* (*L.*) *balusseaui* Cariou occurs in the upper part of the Anceps Zone (Tyrraniformis subzone) of the Submediterranean province (Cariou, 1984) (Table 2). Here also at Kuldhar (Jaisalmer), it defines the upper part of the Anceps Zone.

Genus ***Reineckeia*** Bayle, 1878

Type species: *Nautilus anceps* Reinecke, 1818.

Reineckeia (*Reineckeia*) *stuebeli* Steinmann
Macroconch [M]
(Pl. VIII, fig. h)

Reineckeia kiliani Parona and Bonarelli, 1897, p. 162, pl. 6, figs. 3, 3a-b. *Reineckeia* (*R.*) *stuebeli* Steinmann - Cariou, 1980, p. 445, pl. 40, figs. 1-5; pl. 41, figs. 2a-b, 3, 6a-b; Text figs. 131, 147-149, 152,159. - Cariou and Krishna, 1988, p. 159, pl. 3, figs. 2a-b. - Prasad, 2006, p. 40, pl. 10, fig 3.



EXPLANATION OF PLATE VII

a-b. ***Rehmannia (Loczyceras) balusseaui*** Cariou [M], bed 13, Anceps Zone, Locality III, sample no. SJK/13/1, Septate specimen. a: Lateral view, b: Ventral view. Bar represents 1 cm. Specimen belongs to the Kuldhar section.

Material: Two specimens. Kuldhar: SJK/13/9 and Jumara: Ju/C13/3.

Horizon: Bed 13, Anceps Zone, Locality III (Kuldhar) and bed C13, Obstusicostites Zone, Jumara (Kachchh).

Description (*Phragmocone*): Initial cartiform stage exists up to 15 mm. Until this stage, the ribbing in fine, lamellar and forwardly inclined with faint tubercles, at the point of branching of the primaries which bifurcate between the umbilical shoulder and the lower 1/3 of flank height. Umbilical edge remains rounded. It is only after 15 mm shell diameter that the primaries branch in 3 secondaries, and at the body chamber, sometimes into 4 secondaries. At this stage the tubercles are at the lower 1/3 of the flank height. The primaries arise from the umbilical seam and are slightly concave until the tubercle, whence branching into prorsiradiate secondaries which at the ventrolateral margin is slightly concave (retroflexive) and crosses the venter with a distinct groove. The tubercles are placed at the umbilical shoulder until 15 mm; shift higher to the lower third of the whorl height at the phragmocone. The tubercles at 15 - 20 mm are faint and spinose, sharp until 50 mm and then become mammiliform at later stages. Constrictions number 3 per whorl, are well marked and forwardly inclined. Whorl section is subquadratic and compressed with a distinct midventral groove.

Remarks: The present specimen with its compressed and subtrapezoidal whorl section matches with its European counterpart (Cariou, 1984). The present specimens also closely resemble Kachchh *Reineckeia* (*Reineckeia*) *crispus* Spath (1933a, p. 679, pl. 128, figs. 9-12), *R.* (*R.*) *torulosus* Spath (1933 a, p. 679, p.127, figs. 5, 6; pl. 128, fig. 1) and *R.* aff. *torulosus* Spath (1933a, p. 679, pl. 127, figs. 4, 11; pl. 128, fig. 8) in possessing similar ornamentation but differing only in the placement of the position of the tubercles, that are placed slightly away from the umbilical shoulder. Both *R.* (*R.*) *torulosus* Spath and *R.* (*R.*) *crispus* Spath could well be considered subspecies of *R.* (*R.*) *stuebeli* Steinmann which occur in stratigraphically coeval sediments.

Occurrence and Age: early Middle Callovian (Bed 13; Locality III from Kuldhar and Obtusicostites Zone, Jumara, Kachchh).

Microconch [m]

(Pl. VIII, figs. a-g, Text-fig. 6d)

Reineckeia stueblei Steinmann – Enay *et al*., 1984, p. 230, pl. 41, figs. 1a-b, 4a-c and 5. - Enay *et al*., 1994, p. 150, pl. 61, figs. 4a-c and 5.

Material: 3 specimens. Kuldhar: SJK/11/1 and SJK/13/2; Jumara: Ju/C4/5.

Horizon: Kuldhar: Beds 11 and 13, Anceps Zone, Locality III (Fig. 2); Jumara: Bed C4, Anceps Zone, Kleidos subzone.

Description: Phragmocone measures 65 mm with a maximum estimated diameter of 95 mm. Shell compressed and evolute. Cartiform stage is until 15 mm. The European microconch [m] also has a cartiform stage until 12-13 mm. Primaries arise from the umbilical edge and are slightly rursiradiate at the umbilical shoulder, whence become prorsiradiate, strictly bifurcating, at the upper part of the upper third of the whorl height. Sharp and spinose tubercles persist till 30 mm, placed at the point of branching of the primary rib. Rare single intercalatory is also present, which runs through the entire whorl height, always present next to the constriction. Each whorl has 2 prorsiradiate and deeply incised constrictions, which are slightly more prorsiradiate than the ribbing. Primaries at earlier stages (till 35 mm) are sharp, lamellar and subrectilinear, but with increasing shell diameter, become fine and crested. The whorl section changes from being slightly rounded at the end of phragmocone to compressed and subtrapezoidal at the end of the body chamber. Body chamber occupies ¾ of the whorl. Near the end of the body chamber, the costation becomes more prorsiradiate and the secondaries form a slight forward sinus at the grooved venter. This groove is distinct and equal to the rib thickness. At the end of the body chamber a constriction precedes the lappet.

Remarks: The present specimens in their nature of growth, coiling, ornamentation and size are similar to the European lectotype of *Reineckeia* (*R.*) *stuebeli* figured by Enay *et al.* (1994), but differs in possessing sharper ornamentation, being slightly more evolute and moderately compressed. The Jaisalmer specimens are closer to forme *type* (Enay *et al*., 1984, pl. 41, figs. 1a-b) (Fig. 7), than with forme *waageni* (Enay *et al*., 1984, pl. 41, figs. 4a-c and 5) (Fig. 7). The Jumara specimen (Pl. 8, figs. d-f) is much more compressed and less evolute and are more closer to the lectotype (Fig. 7). Collection of more specimens is likely to bridge this dimensional gap.

Occurrence and Age: early Middle Callovian (Beds 11 and 13; Locality III from Kuldhar and Anceps Zone, Kleidos subzone from Jumara, Kachchh). Cariou (in Enay *et al*., 1994) recorded the microconch [m] from the Middle Callovian, Anceps Zone of Europe. He considered this species to be an index of the upper part (Stuebeli subzone) of the Anceps Zone of the Submediterranean province (Table 2). Its occurrence in the adjoining basin (at Jumara, Kachchh; Fig. 1) also comes from a coeval horizon (Anceps Zone, Kleidos subzone).

Reineckeia (*Reineckeia*) *anceps* (Reinecke)

Macroconch [M]

(Pl. IX; figs. a-b)

Reineckeia (*Reineckeia*) *anceps anceps* (Reinecke) - Cariou, 1980, p. 375, pl. 33, figs. 4-5; pl. 34, figs. 1,2 and 5; pl. 35, figs. 1, 4 and 5; Text figs. 123, 126, 137, 155-156. - Cariou and Krishna, 1988, p. 160, pl. 2, fig. 2a-b; pl. 3, fig. 1 a-b. - Prasad, 2006, p. 38, p. 160, pl. 10, fig. 5.

Material: 4 fragmentary specimens (SJK/11/2-5).

Horizon: Bed 11, Anceps Zone, Locality III.

Description: All the specimens are septate and fragmentary but preserved well enough to merit species level identification.

EXPLANATION OF PLATE VIII

a-g. ***Reineckeia* (*Reineckeia*) *stuebeli*** Steinmann [m].

a-c. bed 11, Anceps subzone, Anceps Zone, Locality III, sample no. SJK/ 11/1.

a. Lateral view,

b. Opposite lateral view,

c. Ventral view.

d. sample no. SJK/13/2, bed 13, Anceps subzone, Anceps Zone, Locality III. Lateral view.

e-g. bed C4, Anceps Zone, Kleidos subzone, Jumara (Kachchh), sample no. Ju/C4/5.

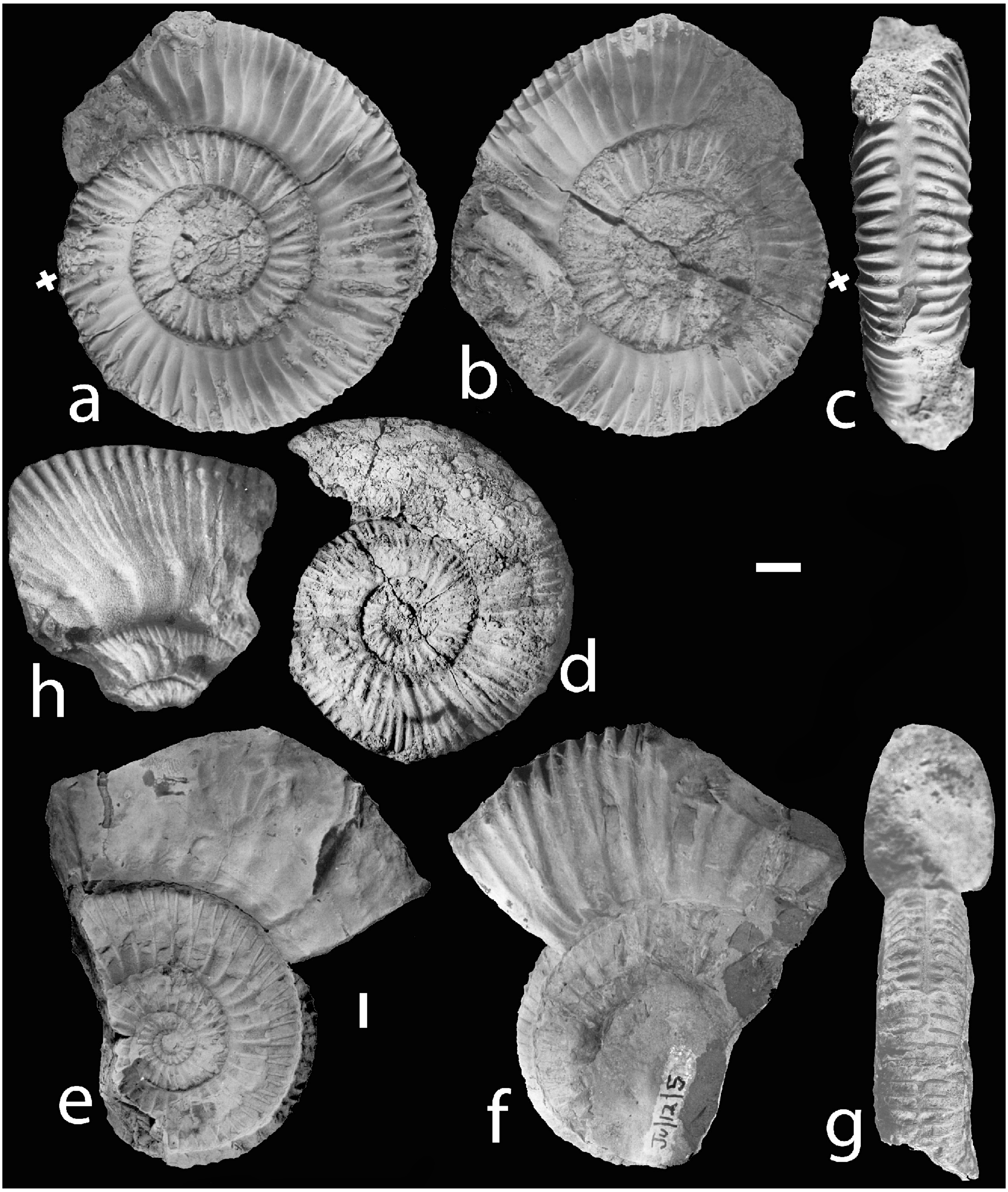
e. Lateral view,

f. Opposite lateral view,

g. Ventral view. h. Macroconch [M], bed 11, Anceps subzone, Anceps Zone, Locality III, sample no. SJK/13/9. Bar represents 1 cm. All specimens unless mentioned belong to the Kuldhar section.

h. *Reineckeia* (*Reineckeia*) stuebdi Steinman [M], bed 13, Aceps Zone, locality III, Sample no. SJK/13/9

Plate VIII



JAIN

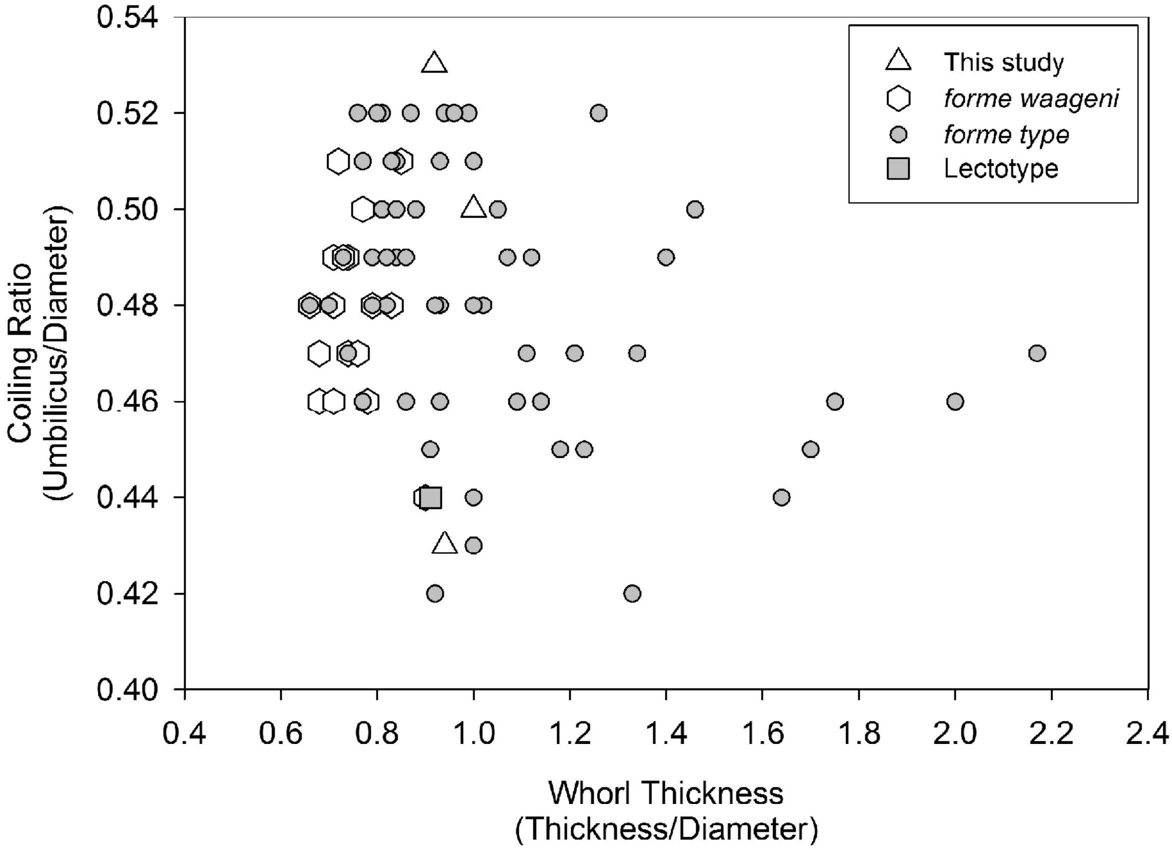


Fig. 7. Comparison of Coiling (U/D) and Whorl thickness (T/H) ratios of the present microconch specimens with European lectotype specimens of *Reineckeia* (*Reineckeia*) *stuebeli* as figured by Enay *et al.* (1994). Note that dimensionally also the Jaisalmer specimens are closer to forme type and the Jumara specimen to the lectotype (see Enay *et al.*, 1984 for details). Collection of more specimens is likely to bridge this dimensional gap.

Simple prorsiradiate primaries are present, numbering 8 per half whorl at 9 mm diameter. At 35 mm, primaries are slightly concave on the rounded umbilical shoulder with a prominent pyramidal tubercle at the upper third of flank height. Each primary branches into 3 prorsiradiate secondaries. Single primaries are also present near the constriction, which number two per half whorl. With increasing shell diameter (50-60 mm), the primaries are pronouncedly prorsiradiate at the broadly rounded umbilical shoulder, with strong, sharp and pyramidal tubercles, numbering 6 per half whorl. Primaries branch into 6 prorsiradiate secondaries with 2 intercalatories in outer whorls. At 35 mm, the whorl section is oval and the venter is broadly rounded. The mid-ventral groove remains distinct and well marked.

Remarks: In Europe, as at Kuldhar, the less evolute forms are more common. Cariou and Krishna (1988) noted that this index species has a large distribution in the Tethys – from France, Spain, Germany, North Africa, to Madagascar and Kachchh. It is considered as an index of the base of Tethyan Middle Callovian (Table 2).

Occurrence and Age: early Middle Callovian (Bed 11; Locality III).

Microconch [m]
(Pl. IX, figs. c-e)

Locality: North East of the village of Jumara in the southern flank of the Dome, Jumara, Kachchh.

Material: One nearly complete specimen (Ju/C2/1).

Horizon: The holotype comes from Bed C2, Ramosa subzone, Anceps Zone.

Diagnosis: Shell small (phragmocone =100 mm) with a maximum estimated diameter of 120-125 mm. Primaries sharp, slightly rursiradiate at the umbilical region, divide at the lower third into 3 prorsiradiate secondaries with a single intercalatory. After 100 mm, there are 4-5 secondaries to a primary with one or 2 intervening intercalatories. At the point of branching, the primaries bear a prominent pyramidal tubercle, which, with increasing diameter becomes blunt and strong. Primaries number 10 at 98 mm and 8 at 110 mm. Constrictions number 2 per half whorl; they are deep, distinct and prorsiradiate. Whorl section is oval.

Description: Phragmocone measures 100 mm with a maximum estimated diameter of 120-125 mm. Shell small, complete, evolute and moderately inflated with a T/H ratio of 1. The primaries, until 60 mm, are sharp, slightly rursiradiate at the umbilical area and divide at the lower third of the whorl height into 3 prorsiradiate secondaries with a single intercalatory. At the point of branching, the primaries bear a prominent pyramidal tubercle, which, with increasing shell diameter becomes blunt and strong. Primaries at 110 mm are prorsiradiate, secondaries more blunt and inclined, crossing the rounded venter with faint but distinct mid-ventral groove. Primaries become distant, 10 at 98 mm to 8 at 110 mm and the tubercles, placed at lower third of the whorl height, become stronger and higher, though retaining their pyramidal nature. Shell at 110 mm is nearly complete, judging by the absence of the umbilical seam of the succeeding whorl. Whorl section is

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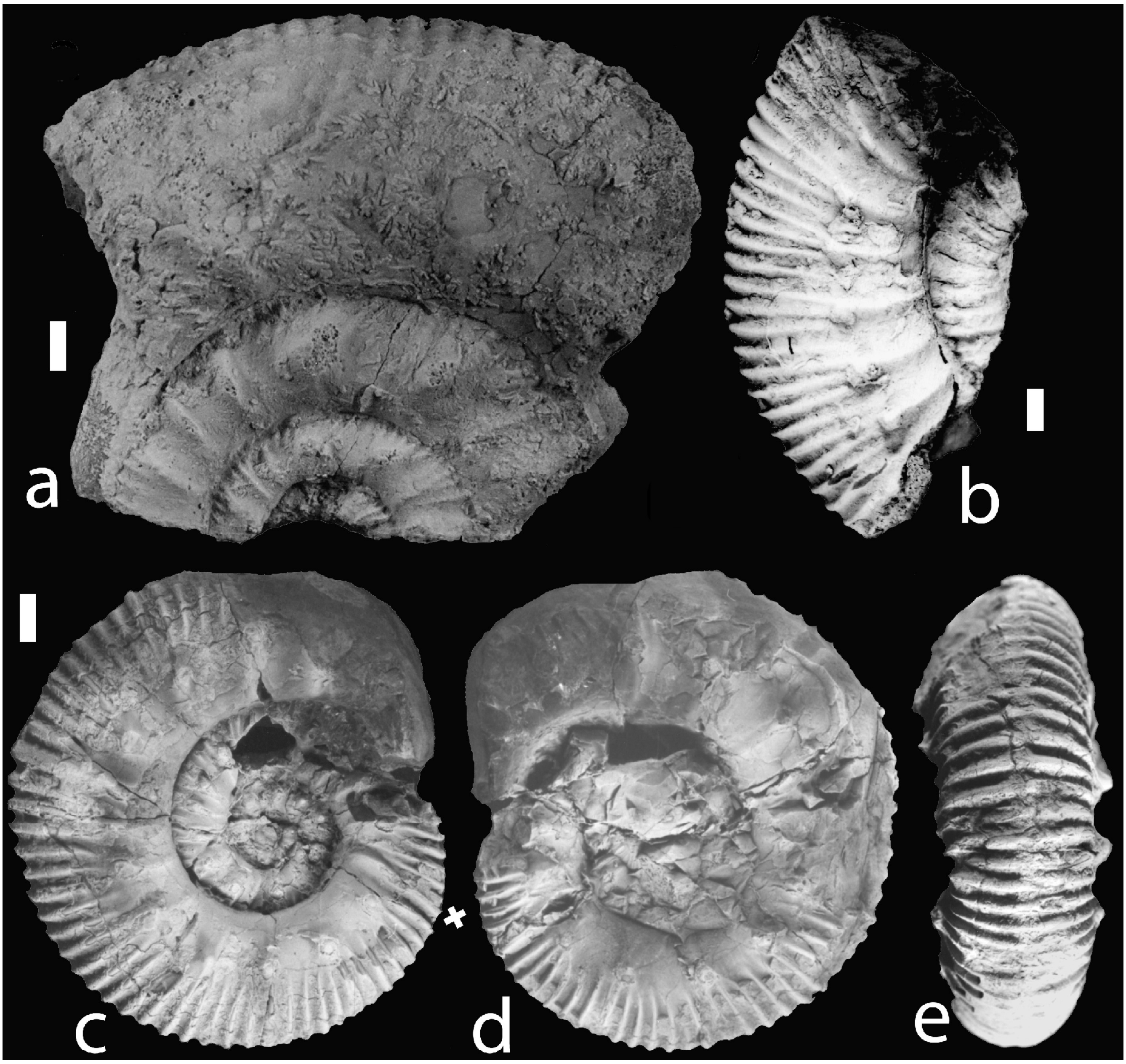
Plate IX



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EXPLANATION OF PLATE IX

a-b. ***Reineckeia* (*Reineckeia*) *anceps*** (Reinecke) [M], Septate specimens, bed 11, Locality II, Anceps subzone, Anceps Zone,

a. sample no. SJK/ 11/4. Lateral view,

b. sample no. SJK/ 11/5. Lateral view.

c-e. Microconch [m], Bed C2, sample no. Ju/C2/1, Ramosa subzone, Anceps Zone, Jumara (Kachchh). Bar represents 1 cm. All specimens unless mentioned belong to the Kuldhar section.

oval. Constrictions are deep, distinct and prorsiradiate, numbering 2 per half whorl. Absence of trace of umbilical seam, sudden prorsiradiate nature of ribbing and the presence of 4 - 5 secondaries to a primary with one or 2 intervening intercalatories, attest to its adult nature. The body chamber occupies ¾ of the outer whorl.

Remarks: Its small size, pattern of ornamentation, dimensional proportions and the absence of umbilical seam indicates its maturity and hence a microconch designation. So far, the description of *Reineckeia* (*R.*) *anceps* (Reinecke) is based solely on Macroconch forms, as done by Cariou (in Enay *et al.*,1994) based on examples of d'Orbigny [(1847, p. 462 (pars), pl. 166, figs. 1-2 (non figs. 3-5), pl. 167, figs. 1-2 (non fig. 3)] and Bayle (1878, pl. 56, fig. 1). The present specimens match closely in terms of both morphological and dimensional proportions with the macroconch specimens of illustrated by d'Orbigny (1847), Bayle (1878), Cariou (1980), Cariou and Krishna (1988) and Cariou (in Enay *et al.*, 1994). However, in the present specimen, the phragmocone only measures 100 mm with a maximum estimated shell diameter of 120-130 mm as opposed to ~300 mm in the macroconchs (Cariou and Krishna, 1988). Hence, based on its small size and maturation of the costations it is considered a microconch.

Occurrence and Age: Both at Jumara (Kachchh) as well as in Kuldhar (Jaisalmer) this species marks the beginning of the Anceps Zone. *R.* (*R.*) *anceps* is an index of the Anceps Zone, the base of Middle Callovian in the Submediterranean province (Cariou, 1984; Cariou and Krishna, 1988).

Subfamily **Eucycloceratinae** Spath, 1928

Remarks: Waagen (1875, p. 107-109) in his Macrocephali considered 2 divisions - the Recticostati and the Curvicostati. In the Recticostati he included *M. semilaevis* and in his Curvicostati both *Subkossmatia opis* and *Eucycloceras eucyclum*. Later Spath (1928) constructed Family Eucycloceratidae and included 4 genera - Genus *Nothocephalites, Eucycloceras, Subkossmatia* and *Idiocycloceras* which included Waagen's Macrocephali division. Spath (1928) was of the view that the "runcinate stage" (tabulate stage) first appeared in the inner whorls of the Macrocephalitids or Eucycloceratids and considered the Eucycloceratids to have evolved from *Dolikephalites subcompressus* (Waagen).

Spath (1928) was also of the view that *Eucycloceras* and *Subkossmatia* are transitional forms between Macrocephalitids and Kosmoceratids. However, Arkell (1956), Arkell *et al.* (1957) and Westermann (1968) placed Eucycloceratids under Macrocephalitidea. Later Westermann and Wang Yi-Gang (1988) included Eucycloceratins under Mayitanae. But Westermann and Callomon (1988) gave the Eucycloceratids a subfamily status. He was of the view that Macrocephalitinae were "replaced by their endemic offshoot Eucycloceratinae" which in turn were the ancestors of Mayitanae. Thierry (1978) considered Eucycloceratids as a subfamily under Macrocephalitidea. But Callomon in Donovan *et al.* (1981) had placed Eucycloceratids as an independent subfamily under Family Sphaeroceratidae. Jana *et al.* (2005) in their analysis from the adjoining Kachchh basin noted that of the 14 species under 4 genera described for subfamily Eucycloceratinae Spath, can be grouped into 2 highly variable monospecific genera of *Eucycloceras* Spath, 1924 and *Idiocycloceras* Spath, 1928. But, morphological changes in the present specimens could not confirm this integration. Hence, the classical version of Spath (1928) and as followed by Callomon in Donovan *et al.* (1981) is used here. However, for sake of comparative morphology, the present species described in this contribution have also been categorized following the classification of Jana *et al.* (2005) and is given in Table 5.

Additionally, Jana *et al.* (2005) divided the microconch [m] of their *Eucycloceras opis* (Sowerby) into 5 variants (infrasubspecies). Their general characters and corresponding species described in the present study are given in Table 6: However, a comparative plotting of all the Jaisalmer (this study) and Kachchh data (Jana *et al.*, 2005) reveals that the Jaisalmer *Subkossmatia*/*Eucycloceras* population, though numerically very low, is significantly different ($p<0.001$) and more evolute (Fig. 8). Thus, pending collection of further specimens, this contribution follows the taxonomic classification of Spath (1924-1928) and Callomon in Donovan *et al.* (1981).

Eucycloceras eucyclum (Waagen) 1875 [M]
(Pl. X, figs. a-c)

Stephanoceras eucyclum Waagen, 1875, p. 142, pl. 35, fig. 1. - Spath, 1924, p. 8 and 12. -Spath, 1928, p. 209, pl. 23, fig. 4; pl. 25, fig. 4; pl. 27, fig. 7. - *Eucycloceras opis* var *opis* (Waagen) - Jana *et al.*, 2006, p. 902. pl. 3, figs. 6-10.- Prasad, 2006, p. 25, pl. 5, fig. 2.- non Prasad, 2006, p. 25, pl. 19, fig. 3. - *Eucycloceras dungrakotti* Prasad, 2006, p. 26, pl. 5, fig. 4.

Material: 4 specimens (SJK/9/5, SJK/11/8, SJK/12/8, SJK/13/4-5).

Horizon: Bed 9, Anceps Zone, Locality II; beds 11-12, Anceps subzone, Anceps Zone, Locality III; bed 13, Eucyclum subzone, Anceps Zone, Locality III.

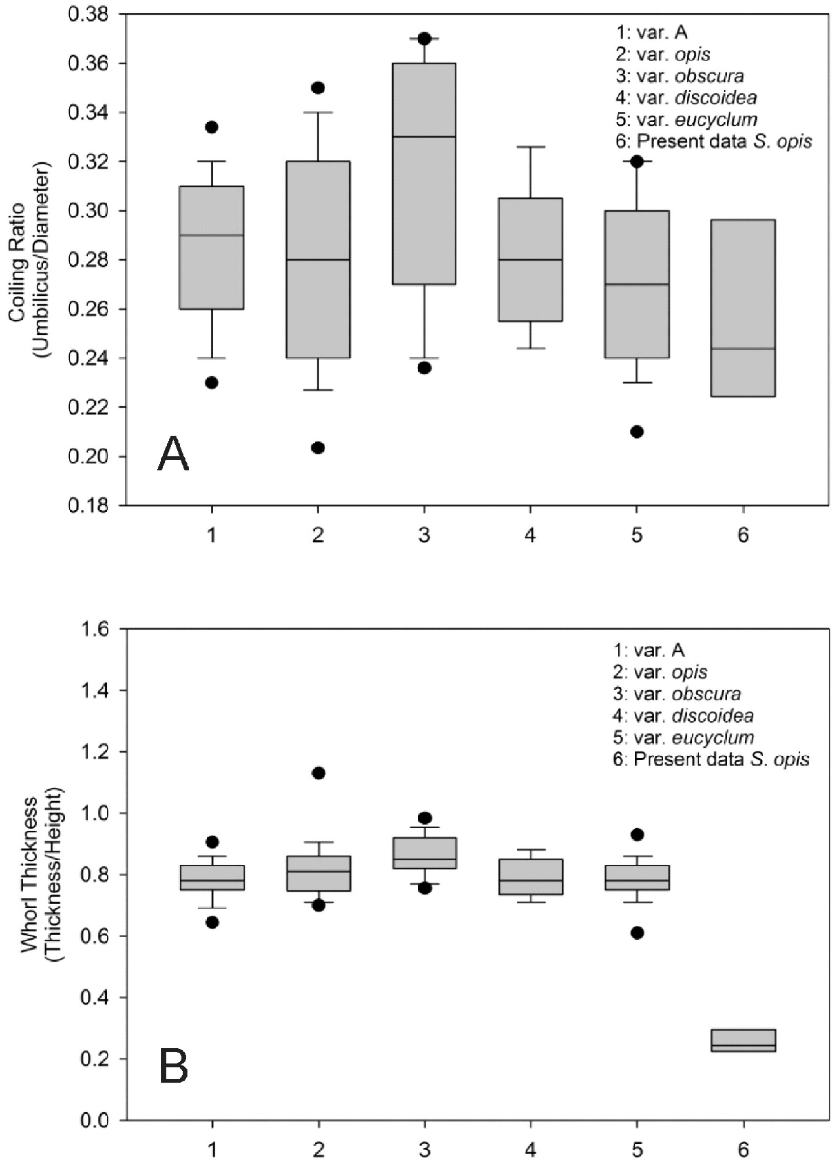
Emended Diagnosis: Shell large, tabulate to discoidal and strongly to moderately compressed. Phragmocone large, compressed initiating very late between 90-130 mm (could be as large as 165 mm). Primaries until 70-80 mm are long, sharp to moderately crested, strongly prorsiradiate and branch into 2 or rarely 3 secondaries with a single intercalatory, arising from just below the rounded umbilical margin. At or near the end of the phragmocone primaries are blunt, coarse and strong, branching into 3-4 secondaries. On the body chamber the primaries become very strong and the secondaries fade leaving the outer laterals and the venter smooth. Umbilical wall vertical, becomes steep to slanting with increasing shell diameter. Umbilical edge always remains distinct and rounded. Laterals tabulate in the initial whorls which change to slightly arched in the middle whorls to moderately convex at the outer whorls. Venter changes from being slightly tabulate (initial whorls) to broadly rounded (middle whorls) to narrowly rounded (outer whorls). Maximum estimated shell diameter 260-270 mm.

Description (*Early stage*): Shell is strongly compressed and discoidal with maximum inflation near the umbilical shoulder. The primaries form a distinct concave sinus near the umbilical area and are then strongly projected forward at the slightly arched to flat laterals. The primaries arise from just below the distinct but rounded umbilical edge. They branch into 2 or rarely 3 secondaries with a single intercalatory. The rib furcation varies from middle to the outer third of flank height. The primaries, at this stage are moderately crested and sharp, becoming slightly thick near the end of the phragmocone. The secondaries are sharp forming a faint sinus at the broadly rounded to slightly tabulate venter. Umbilical wall until 60 mm is vertical and changes to gently slanting at around 70-80 mm. Whorl section is compressed oval.

Table 6: A correlation and listing of general characters of the *Subkossmatia* species presently identified from Kuldhar with the variants (infrasubspecies) recorded by Jana et al. (2005).

Eucycloceras opis [m and M] of Jana et al. (2005)				This study	
				Description	Species
1	MICROCONCH	*E. opis* var. A.	Smallest variant (D=67-83 mm, D at end-phragmocone=45-54 mm); most compressed (T/H = 0.71–0.84); relatively less evolute (U/D=0.30–0.34); very densely, finely ornate until the end (P=21–29, S=46–68); rib-crest sharp, symmetrical in cross-section; ribs always isocostate and show approximation towards adult aperture. Umbilical wall remains more or less steep in adult stage, umbilical margin always prominent and sharp; abundant.	Smallest variant (D=70-110 mm, D at end-phragmocone =~86 mm); most compressed (T/H = 0.70-0.82); relatively less evolute (U/D=0.21–0.24); very densely, finely ornate until the end (P=32-34, S=45-50); costation sharp; ribbing isocostate. Umbilical wall steep throughout, umbilical margin always sharp.	*Subkossmatia opis* (Sowerby) [m]
2		*E. opis* var. *opis*.	Small (D = 88-113 mm, D at end-phragmocone = 63.5-67 mm); moderately compressed (T/H=0.76-0.89); evolute (0.31-0.35); densely, finely ornate (P=21-29, S = 49-66). Ribs isocostate, sharp, symmetrical crest; most abundant		
3		*E. opis* var. *obscura*	Largest variant (D=121-128 mm, D at end-phragmocone=71–82 mm); weakly compressed (T/H=0.80-0.89); most evolute variant (U/D=0.32–0.38); strongly, distantly ornate (P=17–27, S=40-53); ribs isocostate, high-crested, rounded and asymmetrical with gentler slope towards aperture; abundant	D=112-132 mm, D at end-phragmocone=70–90 mm); weakly compressed (T/H=0.70-0.88); evolute (U/D=0.21); strongly, distantly ornate (P=18-21, S=42-47); ribs isocostate, primaries slightly concave at the umbilical region and then moderately prorsiratiate, bifurcating with very rare single intercalatory. Scondaries cross the venter with a sinus. Extraumbilication begins close to the end of the phragmocone stage.	*Subkossmatia obscura* Spath [m]
4		*E. opis* var. *discoidea*	Small (D=77-97 mm, D at end-phragmocone=52-70 mm); moderately compressed (T/H=0.75-0.89); evolute (U/D=0.31-0.35); distantly ornate (P=17-18, S=36-45); ribs isocostate with angular crest; rare	Small (D=77-97 mm, D at end-phragmocone=52-70 mm); moderately compressed (T/H=0.77-0.83); evolute (U/D=0.31-0.35); distantly ornate (P=~21, S=~42); ribs isocostate, Primaries very slightly concave at the umbilical region and then moderately prorsiratiate, bifurcating with very rare single intercalatory. Scondaries cross the venter with a pronounced sinus.	*Subkossmatia discoidea* Spath [m]
5		*E. opis* var. *eucyclum*	Small to medium sized (D=85–115 mm, D at end-phragmocone=73 mm); strongly to moderately compressed (T/H=0.72-0.86); least evolute variant (U/D=0.27-0.33); primaries broad, blunt, concave forward and fewer in number (P=14-20); ribs variocostate, primaries much stronger than secondaries (S=49-54) which become faint to obscure on venter; common	Not recorded in Jaisalmer; present in Jumara	*Eucycloceras pilgrimi* (Waagen) [m]

1	MACROCONCH	*E. opis* [M]	Shell large (200-220mm), relatively to strongly evolute (U/D=0.20-0.42), compressed (T/H=0.67-0.96). Whorl section elliptical to subrounded. D at end-phragmocone =102-135 mm. P=16–21 and S=51–62. Umbilical margin sharp with steep wall. Ribs fine, dense; primaries rise rursiradiately from umbilical shoulder, straight with forward projection and furcate below mid-flank; secondaries have the same forward bend, pass over rounded ventrolateral margin with a further bend and cross venter with prominent forward projection.	Large (D=90-~190 mm, D at end-phragmocone = ~165-~175 mm); strongly to moderately compressed (T/H=0.72-0.86); moderately evolute (U/D=0.18-0.28); primaries broad; rounded at middle whorls and blunt at outer whorls, concave at the umbilical region and then strongly prorsiratiate, number (P=16-20); ribs variocostate, primaries much stronger than secondaries (S=48-56) which become faint to obscure on venter only at the body chamber. Scondaries cross the venter straight. Extraumbilication at the phragmocone stage.	*Eucycloceras eucyclum* (Waagen) [M]



C

ANOVA						
N = 184		Sum of Squares	df	Mean Square	F	Sig.
COILING RATIO	Between Groups	0.008	1	0.008	4.607	**0.003**
	Within Groups	0.32	182	0.002		
	Total	0.329	183			
WHORL THICKNESS	Between Groups	0.013	1	0.013	1.189	**0.277**
	Within Groups	1.982	182	0.011		
	Total	1.995	183			

Fig. 8. A comparative plotting of all Kuldhar (this study) and Kachchh population data (after Jana *et al.*, 2005) of the *Subkossmatia*/*Eucycloceras* group reveals that the Jaisalmer population, though numerically very low, are significantly different ($p<0.001$) (C) in its coiling ratio (B) and is more evolute (A). Although, the whorl thickness (T/H) (B) does seem to indicate a separate population too but statistically, it cannot be separated. Additionally, the coiling ratio also shows more variability as demonstrated by the boxplot diagram (A). Note that the line in each boxes indicates the median value of the dataset for that variety and that the "box" outlines 75% of the data. The "whiskers" show the high and low values and the black dots the outliers.

Middle stage: At this stage, the primaries are long, prorsiradiate, strong, blunt, and divide at the middle of the whorl height into somewhat indistinct 3-4 secondaries with an intervening single intercalatory. The secondaries persist until this stage, crossing the venter with a negligible forward sinus. Maximum inflation remains at the umbilical edge. Umbilical edge continues to be rounded and distinct. Umbilical wall is steep. At the end of the phragmocone uncoiling is noticed. The shell at this diameter is compressed and discoidal with a broadly rounded to slightly flat venter. Whorl section is subelliptical. There are 22 primaries at 95 mm.

Adult stage: Primaries are very strong, prorsiradiate and branching into 3 secondaries with a single intercalatory. Branching is at the middle of the whorl height. The secondaries persist until 170-180 mm and fade after 190-220 mm leaving the outer one third of the lateral and the broadly rounded venter smooth. Maximum estimated diameter is 260-270 mm.

Occurrence and Age: latest Early Callovian to early Middle Callovian (Beds 9-13; Locality II). This species is restricted to the early Middle Callovian sediments in Kachchh and at Kuldhar (Jaisalmer) ranges from latest Early Callovian to early Middle Callovian, being recorded from bed 9 and associated with latest Early Callovian *Collotia oxyptycha* and first *Indosphinctes errans* (Fig. 3).

Genus ***Subkossmatia*** Spath, 1924

Subkossmatia opis (Sowerby) [m]

(Pl. XI, figs. a-d and f-h)

Ammonites opis Sowerby, 1840, pl. 23, fig. 9. *Subkossmatia opis* (Sowerby) - Spath, 1928, p. 210, pl. 36, fig. 2; pl. 39, figs. 2a-b and 7. *S.* cf. *opis* (Sowerby) - non Prasad, 2006, p. 27, pl. 17, fig. 10.

Material: 5 specimens (SJK/9/3-4, SJK/11/5, SJK/12/1, SJK/13/3).

Horizon: Bed 9, Anceps Zone, Locality II; beds 11-12, Anceps subzone, Anceps Zone, Locality III; bed 13, Eucyclum subzone, Anceps Zone, Locality III.

Description (*Early stage until 45 mm*): Primaries are fine, dense and sharp, arising rursiradiately from below the rounded umbilical margin. By 25 mm, the primaries become prorsiradiate, branching occasionally into 2 and rarely into 3 prorsiradiate, equally fine and sharp secondaries that cross the acutely rounded venter straight. By 40 mm, the forward ventral sinus becomes noticeable. Flanks at this stage are tabulate to flat, umbilicus shallow and umbilical wall vertical. At 50 mm there are 60-64 primaries per whorl.

Middle stage (*Phragmocone*): The ribbing is fine and dense but with increasing shell diameter becomes coarse and sparse. Primaries become less prorsiradiate and secondaries cross the somewhat tabulate venter with a more pronounced forward ventral sinus. The phragmocone measures 81 mm with 42 primaries per whorl.

Adult stage (*Body chamber*): Shell tabulate with sparse and coarse ribbing. Primaries at this stage are comparatively straight, prorsiradiate and long, dividing into 2 or rarely 3 secondaries that cross the acutely rounded venter with a pronounced forward sinus and without fading. Maximum estimated shell diameter is between 165-170 mm (Plate 9, figs. a-b). Body chamber occupies nearly a complete whorl.

Remarks: The specimens described here match with the holotype of *Subkossmatia opis* (Sowerby). Interestingly, even with such a small population, *S. opis* displays variability in its ribbing pattern. Table 6 gives a brief comparative description of the various *Subkossmatia* species / morphs recorded in this study (based on the traditional taxonomic approach of Spath, 1927-33) and the one by Jana *et al.* (2005) from a much larger Kachchh population. Where these two populations (Jailsamer and Kachchh) are plotted together on coiling ratio (umbilicus/ diameter) and whorl thickness (thickness/height), the Jaisalmer population is separate with a significantly ($p<0.002$) different coiling ratio (Fig. 8). For the various morphs identified by Jana *et al.* (2005), the coiling ratio (U/D) also shows large variability as opposed to whorl thickness (T/H). More samples from Jaisalmer are needed to confirm the stand-alone nature of the Kuldhar population.

Occurrence and Age: Jaisalmer - Kuldhar - late Early Callovian to early Middle Callovian (Beds 9 and 11-13; Locality II).

Subkossmatia cogni-browni Spath [M]

(Pl. XI, figs. i-j)

Subkossmatia cogni-browni Spath, 1928, p. 212, pl. 31, fig. 6; pl. 35, fig. 7, pl. 38, fig. 2; pl. 41, figs. 4a-c. - Prasad, 2006, p. 28, pl. 3, fig. 2.

Material: One specimen (SJK/12/5).

Horizon: Bed 12, Anceps subzone, Anceps Zone, Locality III.

Description (*Middle Stage Phragmocone*): Phragmocone measures 132 mm. Ornamentation is coarse and sparse. The primaries are long, arising from below the rounded and distinct umbilical shoulder with a forward convexity at the umbilical region. Primaries strictly divide into 2 prorsiradiate secondaries at the outer one third of the whorl height with a rare single intercalatory. Lateral flanks are slightly arched with a narrowly rounded venter that becomes somewhat broad with increasing shell diameter. Umbilical wall is vertical and low. Umbilicus is wide and shallow. Ventral sinus becomes more pronounced with increasing shell diameter.

Remarks: The present specimen apart from its much larger size compares well with the holotype of *Subkossmatia cogni-browni* described by Spath (1928, p. 212, pl. 41, figs. 4a-c; suture line in pl. 31, fig. 6 and paratype in pl. 35, fig. 7 and also the illustration in pl. 38, fig. 2). Present species differs from *S. opis* (Sowerby) in the absence of the characteristic tabulate flanks. Additionally, *S. opis* is less compressed, more densely ribbed; possesses finer ribbing with an acutely rounded venter. *S. discoidea* Spath with which it compares closely is more compressed with sparser ornamentation with a highly tabulate flanks.

Occurrence and Age: early Middle Callovian (Bed 12; Locality II).

Subkossmatia discoidea Spath [M]

(Pl. XI, fig. e)

Subkossmatia discoidea Spath, 1928, p. 213, pl. 40, Figs. 2a-b.

Material: One specimen (SJK/11/6).

Horizon: Bed 11, Anceps subzone, Anceps Zone, Locality III.

Description (*Adult Stage body chamber*): Shell small, compressed, finely ribbed and evolute. Phragmocone measures 60 mm with a maximum estimated shell diameter of 95 mm. Ribbing fine with primaries arising rursiradiately from below the umbilical shoulder. With increasing shell diameter, they become more prorsiradiate and divide into two slightly rursiradiate secondaries. A single intercalatory is also present which in very rare cases also joins as a secondary. Alternate pairing of ribs is noted. The secondaries cross the narrow rounded venter straight. There are 18 primaries and 40 secondaries per half whorl. Laterals are tabulate. Umbilicus is large, shallow with vertical umbilical walls that with increasing shell diameter become somewhat slanting. Whorl section is compressed oval.

Remarks: This species resembles the fine-ribbed forms of *Subkossmatia opis* (see Pl. IX), but differs in possessing strongly tabulate laterals and a compressed whorl section. *S. cogni-browni* has more distant and coarser ornamentation with a more rounded whorl section. Though Spath's example (1928, pl. 35, fig. 7) of *S. cogni-browni* also has a closely comparable compressed whorl section but it has more finer costations. Thus, Spath's example appears to be transitional form between *S. discoidea* and *S. cogni-browni*. The inner whorls of S. *ramosa* are also a close match for *S. discoidea*, but the secondaries in the latter, cross the venter straight as compared to a sinus in the former.

Occurrence and Age: early Middle Callovian (Bed 11; Locality II).

Subkossmatia ramosa Spath
(Pl. XII, figs. f-g)

Subkossmatia ramosa Spath, 1928, p. 214, pl. 39, fig. 1 and pl. 41, figs. 1a-b. - Prasad, 2006, p. 27, pl. 5, figs. 1 and 3a-b.

Material: One specimen (SJK/12/3).

Horizon: Bed 12, Anceps subzone, Anceps Zone, Locality III.

Description (*Adult Stage*): Shell large, compressed and fragmentary. The prorsiradiate primaries are strong, coarse and sparse. There are 14 primaries and 28 secondaries per half whorl at 155 mm. The primaries arise rursiradiately from below the broadly rounded and low umbilical shoulder and thence become strongly prorsiradiate at the arched venter, dividing at the outer third of flank height into 2 prorsiradiate secondaries. These secondaries cross the venter with a pronounced forward sinus that fades with increasing shell diameter. Whorl section is compressed oval.

Remarks: Prasad's *Subkossmatia ramosa* Spath (2006, p. 27, pl. 5, figs. 1 and 3a-b) has a somewhat straighter ribbing across the venter (pl. 5, fig. 3c) as compared to the present specimen.

Occurrence and Age: Early to mid of Middle Callovian (Bed 12; Locality II).

Genus ***Idiocycloceras*** Spath, 1924

Idiocycloceras dubium Spath

Macroconch [M]
(Pl. XII, figs. b-c)

Idiocycloceras perisphinctoides Spath - Jana *et al*., 2005, pl. 5, figs. 5-7; pl. 6-10; text-figs. 13-18. *I.* cf. *dubium* Spath - Prasad, 2006, p. 29, pl. 6, figs. 4a-c.

Material: One specimen (SJK/12/6).

Horizon: Bed 12, Anceps subzone, Anceps Zone, Locality IV.

Description (*Early Stage*): Primaries at the early stage are fine, sharp, distant and radial in arrangement and arise from the sharp umbilical margin with a slight rursiradiate pattern. Umbilical wall is high and vertical. Whorl section rounded, approaching a T/H ratio of 1.

Middle Stage (*Phragmocone*): Phragmocone measures 120 mm. Primaries remain sharp, though somewhat coarser and sparse, arising rursiradiately from below the rounded umbilical margin and strictly bifurcate into strongly prorsiradiate secondaries that form a forward sinus at the broadly rounded venter. There are 20 primaries and 41 secondaries per half whorl.

Adult stage: Primaries coarse, blunt and sparse with 15 primaries per half whorl. Primaries arise rursiradiately from below the rounded umbilical shoulder. Umbilical wall is slanting. Primaries branch into two strongly prorsiradiate secondaries with a rare single intercalatory. Whorl section changes from being rounded to compressed oval, but always approaching a T/H ratio of 1. Venter also changes from being strongly rounded at 113 mm to being acutely rounded at 215 mm. At this stage, the secondaries form a pronounced ventral sinus. Umbilical wall is high and vertical.

Remarks: The present specimen in ornamentation, nature of coiling and whorl section matches with the holotype (Spath, 1928, p. 218, pl. 39, figs. 6a-b). The only difference lies in the bigger phragmocone of the holotype (still septate at 153 mm as compared to 120 mm in the present specimen). The present specimen also closely resembles *Idiocycloceras perisphinctoides* Spath [M] (Spath, 1933, p. 215, pl. 38, figs. 3a-b; holotype), but differs in having more strongly prorsiradiate secondaries and a pronounced ventral sinus at comparable diameters.

Occurrence and Age: middle part of Middle Callovian (Bed 12; Locality IV).

EXPLANATION OF PLATE X

Eucycloceras eucyclum (Waagen) [M].

a-b. bed 13, Locality II, Eucyclum subzone, Anceps Zone.

a. sample no. SJK/13/4, Lateral view.

b. sample no. SJK/13/5, Lateral view. c: sample no. SJK/11/8, bed 11, Locality II, Anceps subzone, Anceps Zone. Lateral view. Bar represents 1 cm. All specimens belong to the Kuldhar section.

EXPLANATION OF PLATE XI

a-d & f-h. ***Subkossmatia opis*** (Sowerby) [m].

a-b. sample no. SJK/13/3, bed no. 13, Locality II, Eucyclum subzone of the Anceps Zone.

a. Lateral view,

b. Apertural view.

c. sample no. SJK/11/6, bed 11, Locality II, Anceps subzone, Anceps Zone. Lateral view.

d. sample no. SJK/12/1, bed 12, Locality II, Anceps subzone, Anceps Zone. Lateral view.

f. sample no. SJK/9/4, bed 9, Locality II, Dimerus-Transitorius-Opis Zone. Lateral view.

g-h. sample no. SJK/9/3, bed 9, Locality II, Dimerus-Transitorius-Opis Zone.

g. Apertural view. h: Lateral view.

e. ***Subkossmatia discoidea*** [M], sample no. SJK/11/7, bed 11, Locality II, Anceps subzone, Anceps Zone. Lateral view.

i-j. ***Subkossmatia cogni-browni*** Spath [M], sample no. SJK/12/5, bed 12, Locality III, Stuebeli subzone, Anceps Zone.

i. Lateral view.

j. Ventral view. Bar represents 1 cm. All specimens belong to the Kuldhar section.

Plate X

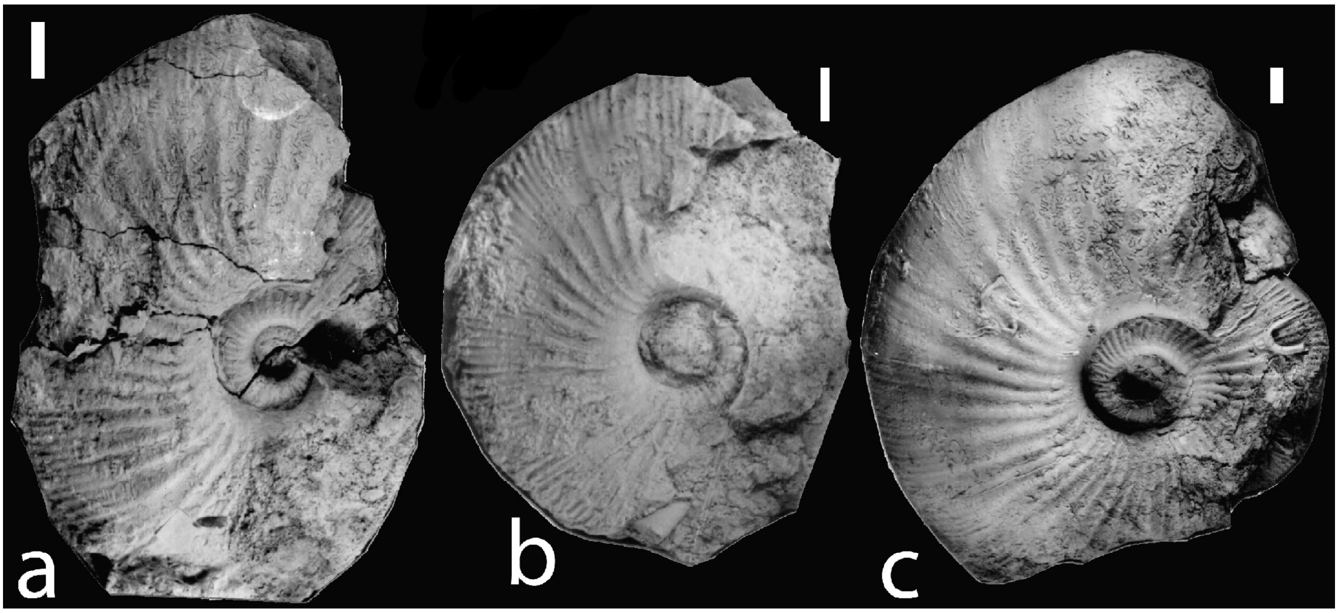
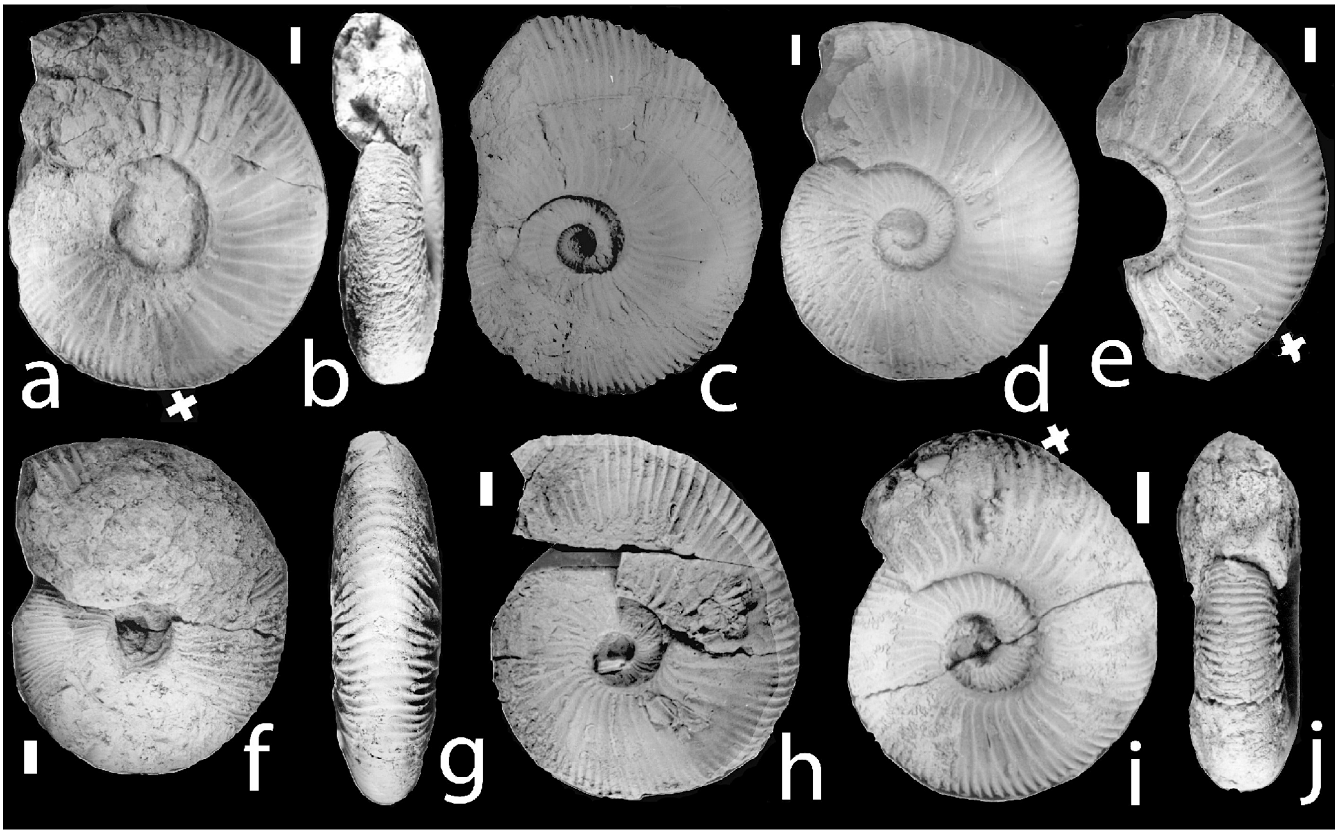


Plate XI



Microconch [m]

(Pl. XII, fig. a)

Idiocycloceras perisphinctoides Spath - Jana *et al*., 2005, pl. 6, figs 1-9.

Material: One specimen (SJK/13/6).

Horizon: Bed 13, Eucyclum subzone, Anceps Zone, Locality III.

Description (*Adult stage*): Shell evolute and nearly complete. Inner whorls are not visible. Phragmocone measures 85 mm with a maximum estimated shell diameter of 130 mm. Ribbing is sharp and distant. Primaries arise from just below the umbilical edge more or less straight and strictly branch into 2 slightly prorsiradiate secondaries with 14 primaries and 28 secondaries per half whorl. Secondaries form a forwardly inclined sinus. Umbilicus is large, open and shallow. Umbilical wall is high and vertical with distinct but rounded umbilical edge. Venter well rounded. Body chamber occupies nearly ¾ of the last whorl.

Occurrence and Age: middle part of Middle Callovian (Bed 13; Locality IV).

Idiocycloceras perisphinctoides Spath [M]

(Pl. XII, figs. d-e)

Idiocycloceras perisphinctoides Spath, 1933, p. 215, pl. 38, figs. 3a-b; pl. 36, fig. 3.

Material: One specimen (SJK/12/4).

Horizon: Bed 12, Anceps subzone, Anceps Zone, Locality IV.

Description (*Middle Stage*): Phragmocone small and evolute measuring 115 mm with a maximum estimates shell diameter of 155 mm. Primaries arise slightly rursiradiately from the rounded umbilical edge and branch into two prorsiradiate secondaries with a rare single intercalatory. Ribbing is sparse and sharp with 38 primaries and 80 secondaries at 115 mm. Lateral flanks are slightly arched at the phragmocone stage and change to slightly flat at the beginning of the body chamber but retaining the well-rounded venter. Primaries cross the venter with a faint forward sinus. Umbilical wall remains high throughout the shell diameter. Whorl section changes from being compressed at 66 mm to well-rounded at 90 mm. Body chamber occupies ¾ of the entire whorl.

Remarks: This species closely resembles *Idiocycloceras dubium* Spath (1928, p. 218, pl. 39, figs. 6a-b), but differs in possessing prorsiradiate secondaries, higher rib density, greater inflation and in being less evolute at comparable diameters. Stratigraphically *I. perisphinctoides* Spath occurs slightly earlier as compared to *I. dubium* Spath.

Occurrence and Age: middle part of Middle Callovian (Bed 12; Locality IV)

Superfamily **Haploceratoidea** (Zittel, 1884)
Family **Oppeliidae** (Bonarelli, 1894)
Subfamily **Hecticoceratinae** (Spath, 1925)
Genus **Hecticoceras** (Bonarelli, 1893)

Type species: *Hecticoceras hecticum* (Reinecke, 1818).

Hecticoceras Bonarelli is the type genus of the subfamily Hecticoceratinae. It is used to demarcate subzones and horizons in the Subtethyan Province of Europe (Cariou 1984). In Kachchh, Hecticoceratinae are represented by eight genera ranging from the Middle Bathonian to Lower Oxfordian and are distributed throughout the Patcham and Chari formations (Spath, 1928; Kanjilal, 1980; Roy and Bardhan, 2007). Genus *Hecticoceras* is represented by two taxa, *H. giganteum* Spath and *H.* aff. *turgidum* Loczy (now synonymised with *H. giganteum*; see Roy and Bardhan, 2007) which ranges from the top of Early to the later part of Middle Callovian (=the upper part of the Coronatum Zone). A more detailed taxonomic study is underway and will be published elsewhere.

Hecticoceras cf. *giganteum* Spath, 1928 [M]

(Pl. XIII, fig. d and Pl. XIV, fig. h)

Harpoceras hecticum (Reinecke), Waagen, pars 1875, p. 61, pl. 12, figs. 3-5; Bonarelli, pars 1893, pp.78, 83; *H. giganteum* Spath, 1928 p. 104, pl. 16, fig. 5; *H.* aff. *turgidum* Loczy, Spath, pars 1928, p. 105, pl. 16, fig. 4; *H. giganteum* Spath, Roy and Bardhan, 2007, figs. 3-5.

Material: Two specimens (SJK/14/5-6).

Horizon: Bed 14, Gigantea Zone, Locality IV.

Description: Shell discoidal with a subcircular whorl outline. Primaries (as noted in part of early whorls; Pl. XIII, fig. d) appear prosiradiate, arising from the rounded umbilical margin. At the mid-outer whorl, they become strong, forming elongated bullae on the lower flank and then bifurcate. At the outer whorl, the inner flank become somewhat smooth due to the disappearance of primaries from the lower flank. Now the secondaries are flat, distant, wide and rectiradiate. There are ~14 secondaries per half whorl. Other reports have noted 15-26 secondaries per half whorl (Roy and Bardhan, 2007, p. 269). Umbilicus is wide with a rounded margin. Venter is wide, and tricarinate, becoming rounded at the end. The ventrolateral margin is sharp but becomes somewhat rounded at the end of the shell diameter. Suture is complex and highly frilled (Pl. XIII, fig. d; also faintly represented in Pl. XIV, fig. h). The first lateral lobe is indistinctly trifid, broad and the first lateral saddle is narrow and long (Pl. XIII, fig. d). The present suture line (Plate 13, fig. d) matches well with the external suture line of the lectotype (Roy and Bardhan, 2007, fig. 3).

Remarks: *Hecticoceras hecticum* resembles the present species in possessing discoidal shell, similar degree of involution and in having smooth inner flank on the body-chamber (Jeannet, 1951, pl. C, fig. 5; Elmi, 1967, pl. 11, figs. 1-4). *H. giganteum*, however, can be distinguished by its large size, and in having broad and flat crested secondaries. Moreover, secondary ribs are straight and mostly rectiradiate (as in the present specimen, Pl. XIV, fig. h), while they may be concave in the type species (see Elmi, 1967, pl. 4, fig. 2; Roy and Bardhan, 2007, figs. 4-5). The closest comparison of the present specimen

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EXPLANATION OF PLATE XII

a. ***Idiocycloceras dubium*** Spath [m], sample no. SJK/13/6, bed 13, Locality III, Eucyclum subzone of the Anceps Zone. Lateral view;

b-c. ***Idiocycloceras dubium*** Spath [M],

b. Lateral view, sample no. SJK/12/6, bed 12, Locality III, Anceps subzone, Anceps Zone.

c. Same specimen, ventral view;

d-e. ***Idiocycloceras perisphinctoides*** Spath [M],

d. sample no. SJK/12/4, bed 12, Locality IV, Anceps subzone, Anceps Zone. Lateral view;

f-g. Opposite lateral view. f-g: ***Subkossmatia ramosa*** Spath [M], sample no. SJK/12/3, bed 12, Locality II, Anceps subzone, Anceps Zone.

f. Lateral view, g: Ventral view;

h. ***Sivajiceras paramorphum*** Spath [M], sample no. SJK/17d/1, bed 17, Locality IV, Eucyclum subzone of the Anceps Zone, lateral view. Bar represents 1 cm. All specimens belong to the Kuldhar section.

Plate XII

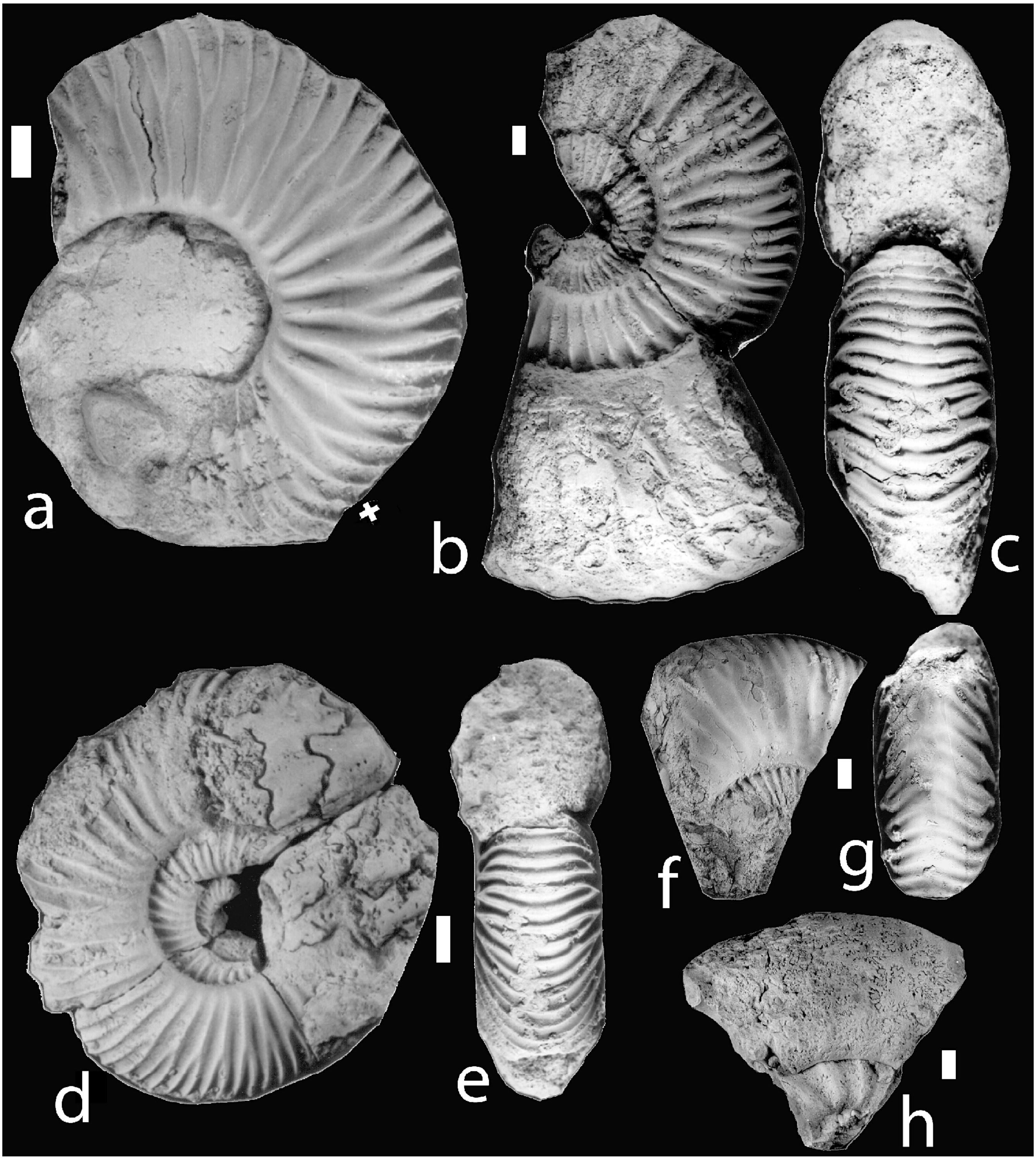

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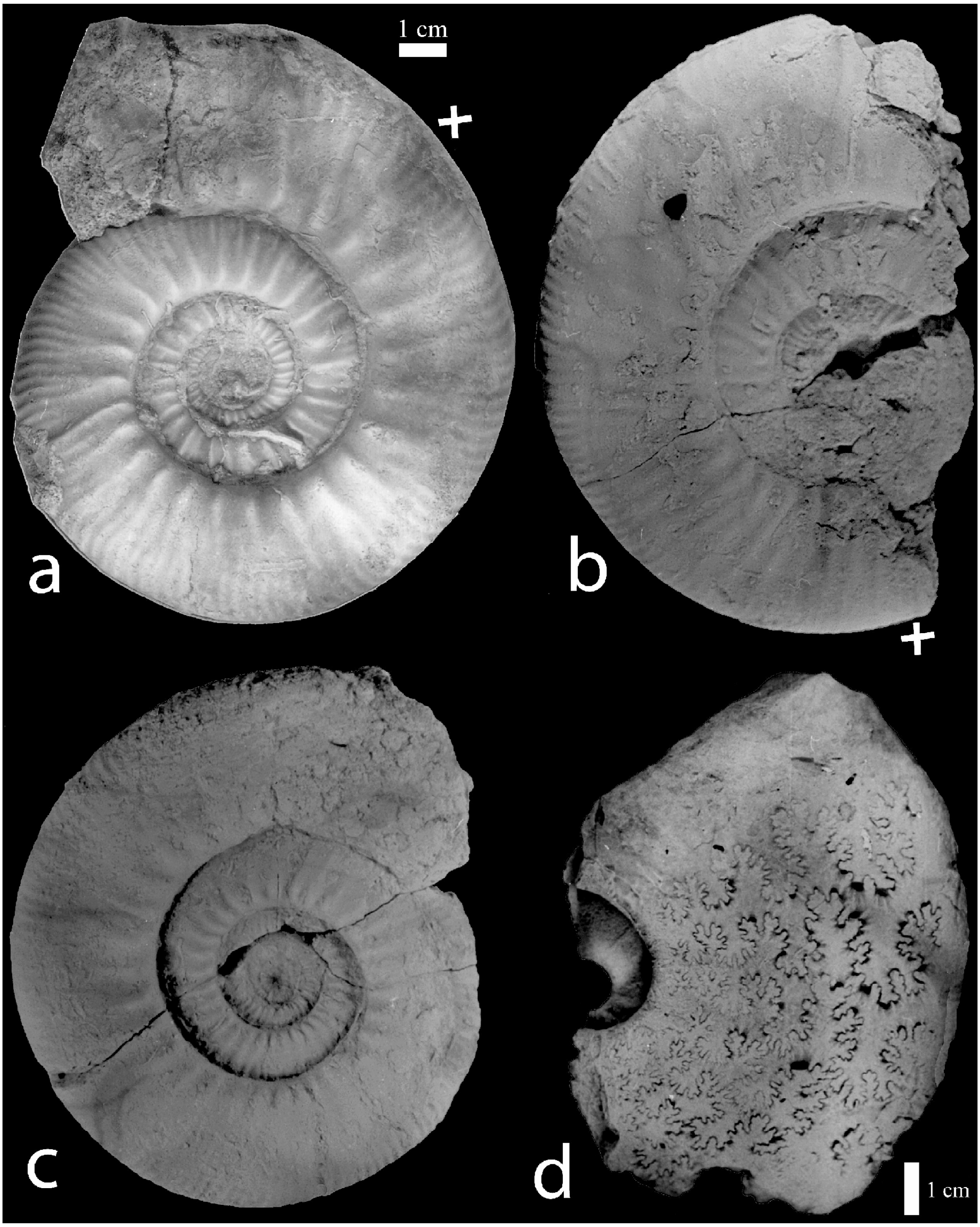
Plate XIII



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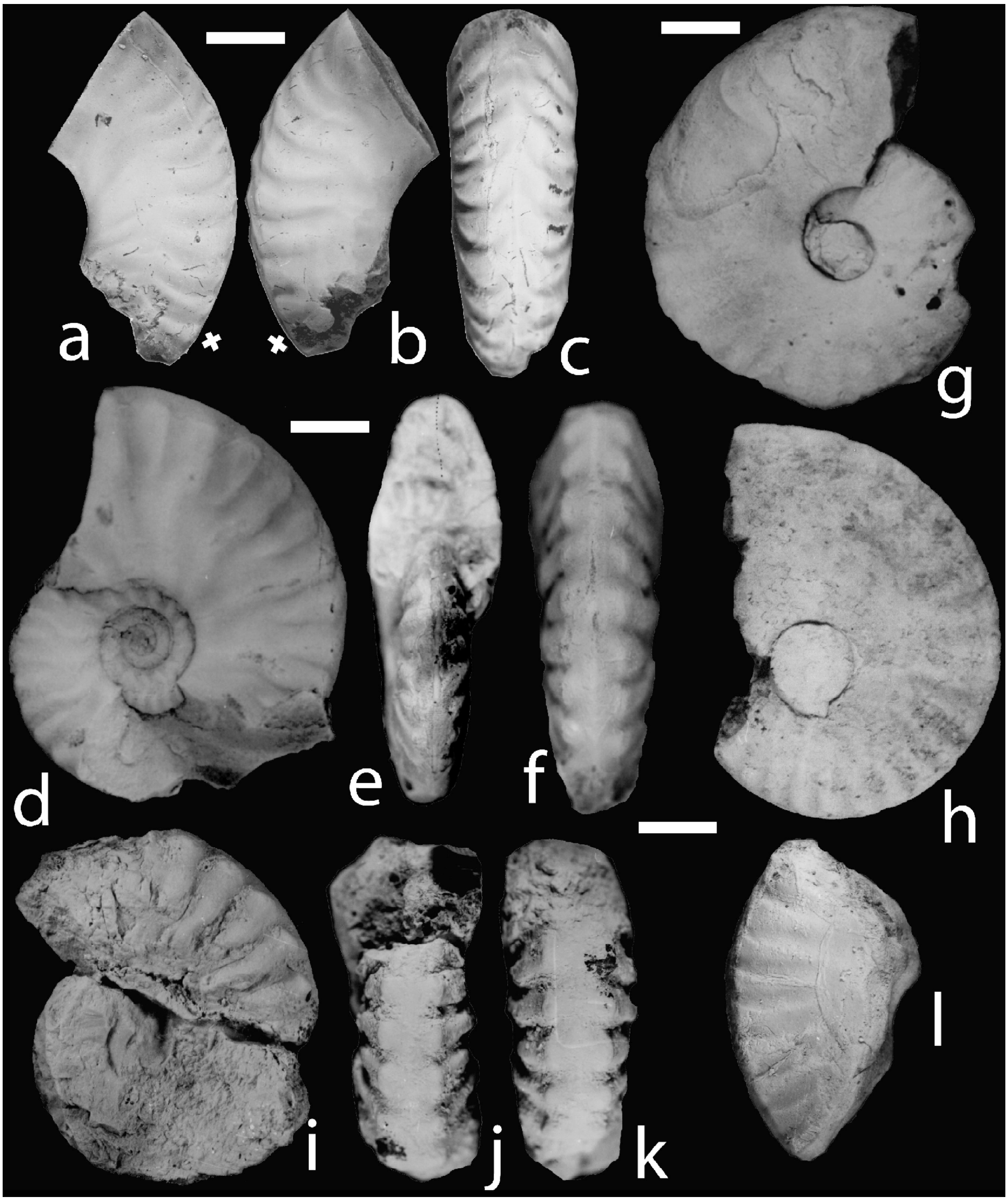
EXPLANATION OF PLATE XIII

a. ***Indosphinctes urbanus*** Spath [M], bed 11, sample no. SJK/11/9, Locality II, Anceps subzone, Anceps Zone, lateral view;

b. ***Choffatia transitoria*** Spath [M], sample no. SJK/9/6, Locality II, Dimerus-Transitorius-Opis Zone, lateral view;

c. ***Indosphinctes peregrinus*** Spath [M], sample no. SJK/9/7, Locality II, Dimerus-Transitorius-Opis Zone, lateral view. d: ***Hecticoceras* cf. *giganteum*** (Spath) [M], sample no. SJK/14/5, Locality IV, Gigantea Zone, Lateral view. Bar represents 1 cm. All specimens belong to the Kuldhar section.



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EXPLANATION OF PLATE XIV

a-c. ***Hecticoceras proximum*** Elmi [M], bed 7, Dimerus-Transitorius-Opis Zone, Locality II, sample no. SJK/7/6;
a. Lateral view,
b. opposite lateral view,
c. Ventral view,
d-f. ***Hecticoceras hecticum*** (Reinecke), sample no. SJK/17c/2, Locality IV, Gigantea Zone.
d. Lateral view,
e. Apertural view,
f. Ventral view;
g. ***Hecticoceras ignobile*** Waagen [M], sample no. SJK/17c/1, Locality IV, Gigantea Zone, lateral view;
h. ***Hecticoceras* cf. *giganteum*** (Spath) [M], sample no. SJK/14/6, Locality IV, Gigantea Zone, Lateral view;
i-k. ***Sindeites madagascariensis*** Spath [M], sample no. SJK/12/7, bed 12, Locality IV, Anceps subzone, Anceps Zone.
i. Lateral view,
j. Apertural view,
k. Ventral view;
l. ***Hecticoceratoides* cf. *suborientalis*** Spath [M], bed 7, Dimerus-Transitorius-Opis Zone, Locality II, sample no. SJK/7/5. Bar represents 1 cm. All specimens belong to the Kuldhar section.

(Pl. 14, fig. h) is with the Macroconch specimen illustrated by Roy and Bardhan (2007, fig. 4N). This specimen has come from their Bed 9 of Jumara, and dated similarly as middle part of Middle Callovian. Being fragmentary in nature, the present specimen is only tentatively assigned to this species.

Occurrence and Age: middle part of Middle Callovian (Locality IV, Gigantea Zone)

Genus *Hecticoceratoides* Spath, 1924

Type species: *Hecticoceratoides suborientalis* Spath, 1924,
Early Callovian, Kachchh.

Hecticoceratoides cf. *suborientalis* Spath, 1924
(Pl. XIV, fig. l)

Hecticoceratoides suborientalis Spath, 1924, p. 106, pl. 13, fig. 11.

Material: One specimen (SJK/7/5).

Horizon: Bed 7, Opis-Dimerus-Transitorius Zone, Locality III.

Description: Shell fragmentary with a maximum estimated diameter of 60 mm. The preserved body chamber shows the characteristic anguliradiate ribs with a spiral groove. Flanks are tabulate and converge towards a narrow but rounded venter. Costation is strong and well-spaced, starting from the spiral groove, placed at the upper third of the flank height. Ribs end as nodes at the ventro-lateral edge. Venter is with no keel.

Remarks: The absence of the keel at the venter and the anguliradiate nature of the costation separate the present form from *Kheraites crassefalcatum* Waagen. The latter form also possesses rursiradiate ribbing. Owning to the fragmentary nature of the present specimen, it is only provisionally assigned to this species.

Occurrence and Age: later part of Early Callovian (bed 7; Locality III).

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All measurements for examples used in this study.

Appendix 1

Species names	Locality	Sp. nos.	Phragmocone / Body chamber	D	H	T	U	T/H	U/D	P/2	S/2	Plates
										P	S	
Macrocephalites triangularis Spath [M]	Jaisalmer	SJK/4/1	at body chamber	88.6	42.4	49.0	11.5	1.16	0.13			Pl. 2, figs. a-c
Macrocephalites dimerus Waagen [m]	Jaisalmer	SJK/7/1	at body chamber	62.09	21.34	24	15.07	1.12	0.24			Pl. 2, fig. g
Macrocephalites formosus (Waagen) [M]	Jaisalmer	SJK/4/3	at body chamber	61.8	32	35.8	9.1	1.12	0.15			Pl. 2, figs. d-f
Sivajiceras congener (Waagen) [M]	Jaisalmer	SJK/4/6	at phragmocone	171.5	42.13	29	89.36	0.69	0.52			Pl. 2, fig. i
Collotia fraasi (Oppel) [M]	Jaisalmer	SJK/18/1	at body chamber		43.0	49.0		1.14				Pl. 1, fig. a
		SJK/18/2		~179.3	49.5	52.0	75.4	1.05	0.42	~10		Pl. 1, fig. b
Collotia oxyptycha (Neumayr)	Jaisalmer	SJK/7/2	at body chamber		28.5	20.4		0.72				Pl. 3, figs. a-c
		SJK/9/1	at phragmocone	102.0	33.3	25.6	44.8	0.77	0.44			Pl. 3, fig. d
		SJK/9/2	at body chamber		30.9	22.0		0.71				Pl. 3, fig. e
		SJK/7/3			33.6	24.5		0.73				Pl. 3, fig. f
		SJK/7/4			41.8	31.2		0.75				Pl. 3, fig. g
Collotia gigantea (Bourquin) [M]	Jaisalmer	SKJ/14/1		210.0	56.0	39.0	98.0	0.70	0.47	12		Pl. 4, fig. a
			at body chamber	360.0	94.0	72.0	164.0	0.77	0.46	10		
Rehmannia (Loczyceras) rudis (Borquin) [M]	Jaisalmer	SJK/15/4		~95	31.3	28	~41	0.89	0.43			Pl. 5, fig. a
Rehmannia (Loczyceras) rudis (Borquin) [m]	Jumara	Ju/C13/12		72.8	24.0	23.0	30.7	0.96	0.42	14	37	Pl. 5, figs. b-c
Rehmannia (Loczyceras) reissi (Steinmann) [m]	Jumara	Ju/12/7		86.4	29.7	28.0	38.7	0.94	0.45	15	36	Pl. 6, figs. a-d
		Ju/C2/2		32.6	11.6	12.8	13.0	1.10	0.40	6	24	
Rehmannia (Loczyceras) balusseaui Cariou [M]	Jaisalmer	SJK/13/1	at phragmocone	122.6	43.5	41.6	53.0	0.96	0.43	8	-	Pl. 7, figs. a-b
				245.0	74.0	69.0	110.0	0.93	0.45	8	53	
Reineckeia (Reineckeia) stuebeli Steinmann [m]	Jaisalmer	SJK/11/1	end of phragmocone	95.0	25.8	23.7	50.0	0.92	0.53	25	43	Pl. 8, figs. a-c
			at phragmocone	65.0	18.3	18.3	32.8	1.00	0.50	19	38	
		SJK/13/2		81.0	23.4	-	34.7		0.43	18	38	Pl. 8, fig. d
	Jumara	Ju/12/5		65.0	24.6	19.0	24.4	0.77	0.38	19	39	Pl. 8, fig. e-g
			at phragmocone	130.0	35.7	27.0	51.0	0.76	0.39	-	-	
Reineckeia (Reineckeia) stuebeli Steinmann [M]	Jumara	Ju/C13/2		120.0	34.0	30.3	43.7	0.89	0.36	12	40	
			at phragmocone	55.7	19.4	21.9	21.8	1.13	0.39	14	54	
	Jaisalmer	SJK/13/9		47.3	16.0	18.0	18.3	1.13	0.39	13	34	Pl. 8, fig. h
Reineckeia (Reineckeia) anceps (Reinecke) [M]	Jaisalmer	SJK/11/4		62.0	17.8	18.5	27.8	1.04	0.45	6	-	Pl. 9, fig. a
Reineckeia (Reineckeia) anceps (Reinecke) [m]	Jumara	Ju/C2/1		110.0	34.9	35.0	46.9	1.00	0.43	8	39	Pl. 9, figs. c-e
			at phragmocone	98.0	34.0	33.7	39.0	0.99	0.40	10	36	
Eucycloceras eucyclum (Waagen) [M]	Jaisalmer	SJK/12/8	at phragmocone	90.0	40.6	34.4	17.0	0.85	0.19	20	56	
		SJK/13/4		165.0	62.9	48.0	32.0	0.76	0.19	16	-	Pl. 8, fig. a
		SJK/13/5		90.0	42.3	-	17.5		0.19	19	-	Pl. 8, fig. b
		SJK/11/8		100.0	49.8	36.2	28.0	0.73	0.28	17	-	Pl. 8, fig. c
Subkossmatia opis (Sowerby) [m]	Jaisalmer	SJK/13/3	at body chamber	111.5	44.7	31.4	32.3	0.70	0.29	40	-	Pl. 11, figs. a-b
			at phragmocone	81.4	35.6	27.2	19.8	0.76	0.24	42	-	
			at body chamber	108.0	42.0	30.0	32.3	0.71	0.30	41	-	Pl. 11, fig. c
		SJK/12/1		120.0	45.0	36.0	36.7	0.80	0.31	36	94	Pl. 11, fig. d
		SJK/9/4		54.0	27.6	19.5	11.4	0.71	0.21	60-64	-	Pl. 11, fig. f
		SJK/9/3		72.0	38.7	29.8	17.6	0.77	0.24	-	-	Pl. 11, figs. g-h
			at phragmocone	86.4	39.0	29.2	19.5	0.75	0.23	-	-	
				109.0	39.6	32.6	24.4	0.82	0.22	-	-	
Subkossmatia cogni-browni Spath	Jaisalmer	SJK/12/5	at body chamber	72.8	32.2	27.5	30.6	0.85	0.42	44	-	Pl. 11, figs. i-j
				132.0	43.7	38.8	39.4	0.89	0.30	40	83	
Subkossmatia discoidea Spath [m]	Jaisalmer	SJK/11/7		75.0	26.0	20.0	16.0	0.77	0.21	-	-	Pl. 11, fig. e
		SJK/12/13		-	30.0	25.0	-	0.83		-	-	
Subkossmatia ramosa Spath [M]	Jaisalmer	SJK/12/3		~155	52.0	41.0	~55	0.79		~28	~56	Pl. 12, figs. f-g
Idiocycloceras dubium Spath [m]	Jaisalmer	SJK/13/6		110.0	39.0	-	41.0		0.37	14	28	Pl. 12, fig. a
Idiocycloceras dubium Spath [M]	Jaisalmer	SJK/12/6		57.0	19.8	20.0	18.8	1.01	0.33	18	-	Pl. 12, figs. b-c
				113.5	41.6	42.8	45.0	1.03	0.40	20	41	
				215.0	64.0	55.0	85.0	0.86	0.40	15	-	
Idiocycloceras perisphinctoides Spath [M]	Jaisalmer	SJK/12/4	end of phragmocone	86.0	33.0	33.8	30.1	1.02	0.35	-	-	Pl. 12, figs. d-e
			body chamber	110.0	41.3	40.3	38.0	0.98	0.35	-	-	
Idiocycloceras singulare Spath [M]	Jaisalmer	SJK/14/3		245.0	112.0	62.0	67.0	0.55	0.27	13	-	
Indosphinctes urbanus Spath [M]	Jaisalmer	SJK/11/9		127.6	35.0	30.0	55.7	0.86	0.44	14	54	Pl. 13, fig. a
Indosphinctes peregrinus Spath [M]	Jaisalmer	SJK/11/8		123.7	36.4	28.5	55.8	0.78	0.45	16	-	Pl. 13, fig. c
Hecticoceras cf. *giganteum* (Spath) [M]	Jaisalmer	SJK/14/5	at phragmocone	128.7	60.2		27.4	-	0.21	-	-	Pl. 13, fig. d
		SJK/14/6	at phragmocone	50.5	25.1		9.9	-	0.20	-	14	Pl. 14, fig. h

PALAEONTOLOGICAL SOCIETY OF INDIA, LUCKNOW

Nominations for the awards for the year 2012

The Palaeontological Society of India invites nominations for the following awards :

1. Prof. S.N. Bhalla Medal for outstanding contributions in Micropalaeontology and allied disciplines for the year 2012.
2. Sharda Chandra Gold Medal for the best original published contribution on Indian material in any field of palaeontology for the year 2012.

Nominations can be made as per the following format.

1. Name of the award
2. Full name, age and address of the nominee
3. Qualifications and positions held by the nominee
4. List of significant publications for the S.N. Bhalla Gold Medal and the name of the publication with full details for the Sharda Chandra Gold Medal
5. Brief statement by the proposer (not more than 250 words) about the scientific achievements/contribution of the nominee for justification of the award

Fellows of the Palaeontological Society of India and Head of the Institutions/Academic Societies can nominate the candidates for the award. The nominations for the Bhalla and Sharda Chandra medals should reach the Secretary on or before 30th May, 2013. Email:mpsinghgeology@gmail.com

ANNOUNCEMENT

The Palaeontological Society of India has instituted from 2010 the Prof. S.K. Singh Memorial Gold Medal for the best paper published in the society's journal. The medal will be awarded every year at the Annual General Body Meeting.

NOTICE

All esteemed fellows are requested to send their e-mail ID for better and faster communication. In future, notices will be sent only by e-mail.

Prof. M.P. Singh
Secretary PSI
(mpsinghgeology@gmail.com)

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FOSSIL FISH FAUNA FROM THE LOWER SIWALIK BEDS OF JAMMU

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ABSTRACT

Prospecting for microvertebrates in the Lower Siwalik Subgroup of the Ramnagar area of Jammu province led to the delineation of three piscean producing sites at Dehari, Nambel and Basi. These sites have yielded several isolated dental remains and pectoral and dorsal spines of fishes represented by Cyprinidae, Siluridae, Claridae, Bagridae and Channidae. Siluridae are being reported for the first time from the Siwalik deposits of the Indian subcontinent, whereas Claridae and Bagridae that were known earlier from Middle Siwalik are being reported for the first time from older rocks, thus extending their stratigraphic distribution to the Lower Siwalik.

Keywords: Lower Siwalik, Fish fauna, isolated dental remains/pectoral spines, Jammu

INTRODUCTION

A complete succession of the Siwalik Group (3146 m) is exposed in the southern limb of Udhampur Syncline, in Kishanpur–Raun–Jinghanu section west of Ramnagar (Fig.1a), district Udhampur, Jammu and Kashmir state (Gupta and Shali, 1989; Gupta, 2000). The area exhibits excellent development of the Mansar Formation of the Lower Siwalik Subgroup. The Mansar Formation comprises two members, the lower Dodenal Member and the upper Ramnagar Member (Gupta, 2000). The Ramnagar Member named after the Ramnagar town that lies 38 km northeast of Jammu, has been equated with the Lower Siwalik Chinji deposits of Pakistan by Gupta and Verma (1988) and Gupta (1997, 2000). Recently, Parmar and Prasad (2006), Parmar (2007), based on rodent biochronology assigned an age of 14–13 Ma for the rocks occurring in the vicinity of Ramnagar. The Ramnagar Member is dominantly argillaceous with brown, orange, red clay; claystone; siltstone; fine to medium-grained, grey, greyish-green, brown, sandstone (Gupta, 2000). Several localities close to Ramnagar were investigated from which three sites namely Dehari, Nambel and Basi (Fig.1b) proved productive in terms of microscopic remains of fossil fishes represented by several isolated dental remains and pectoral and dorsal spines. The fossil locality near Dehari is 0.5 km northeast of the village Dehari and 8 km southwest of Ramnagar. The fossiliferous horizon is gritty, brownish-grey sandstone. The other fossil-yielding locality Basi is 5 km southwest of Ramnagar comprising reddish-brown mudstone. The fossil locality at Nambel is exposed about 2 km southwest of Ramnagar. Here, the fossiliferous bed is brownish-grey sandstone.

The credit for the earliest record of the Siwalik fishes goes to Cantor (1837), who described a skull of a gigantic batrachian. This report was followed by a paper of McClelland (1844), who suggested the affinity of Cantor's specimen to the genus *Pimelodus*, and also mentioned the occurrence of the fossil remains of the family Channidae. Later, Lydekker identified the Cantors's skull as *Bagarius yarrelli* (Lydekker, 1882). Gunther (1881) provisionally referred a fish palate collected by Theobald from the Siwaliks of Punjab to the genus *Arius*. The work on the lower vertebrates is confined mainly to the contributions of Lydekker who described a number of fish remains (Lydekker, 1886). Lydekker's (1886) contribution to the taxonomy and morphology of the Siwalik fishes was based upon the collections made by Theobald, Wynne, Fedden, Colvin, Baker, and Durand as well as on the specimens collected by Cautley and Falconer. Since no record was kept by these early prospectors about the exact horizon or even the locality that yielded fish remains, most of the earlier works as well as Lydekker's paper does not give spatial or temporal details of fossil sites. Since this collection was made over a distance of 500 km (Hora, 1952) extending from Ramnagar near Nainital in the east to Jammu in the west, the data is ambiguous and cannot be used for correlation or palaeoecological analysis. However, Lydekker's (1886) contribution was a comprehensive contribution to our knowledge of Siwalik fishes, after which no systematic work or revision of Siwalik fishes was carried out so extensively. Sahni and Khare (1977) reported a prolific fish fauna from the Middle Siwalik rocks of Ladhyani and Lehri-Sarail near Haritalyangar, Himachal Pradesh, which consisted of isolated skeletal remains. Munthe *et al.* (1983), Conroy *et al.* (1985) listed the presence of fossil fishes from the Siwalik deposits of Nepal that included Channiformes, Cypriniformes and Siluriformes. However, they did not provide any description or illustrations of this material. Roe (1987, 1996) published abstracts on fishes of the Siwalik Group of Northern Pakistan and on the biogeography and geologic importance of Siwalik Chacidae. Gayet (1988) reported a new genus and species of Channiformes, *Parachannichthys ramnagarensis* from the Chinji beds of Ramnagar, Jammu and Kashmir. Mathur and Kotlia (2002) published an abstract on micro remains of fishes comprising of Cyprinidae and Channidae recovered from the Surai Khola Formation of Nepal. The Siwalik piscean fauna is thus represented by four families Channidae, Cyprinidae, Claridae and Bagridae (Lydekker, 1882, 1886; Sahni and Khare, 1977; Gayet, 1988). Most of these reports deal with cranial remains and little information is available on isolated dental remains and/or pectoral or dorsal spines, which is the focus of the present work.

The specimens described in this paper are housed in the Vertebrate Palaeontology Laboratory of the Department of Geology, University of Jammu, Jammu, under the acronym VPL/JU/SFF (Vertebrate Palaeontology Laboratory, Jammu University, Siwalik Fossil Fishes).

SYSTEMATIC PALAEONTOLOGY

Class **Osteichthyes** Huxley, 1880
Subclass **Actinopterygii** Klein, 1885

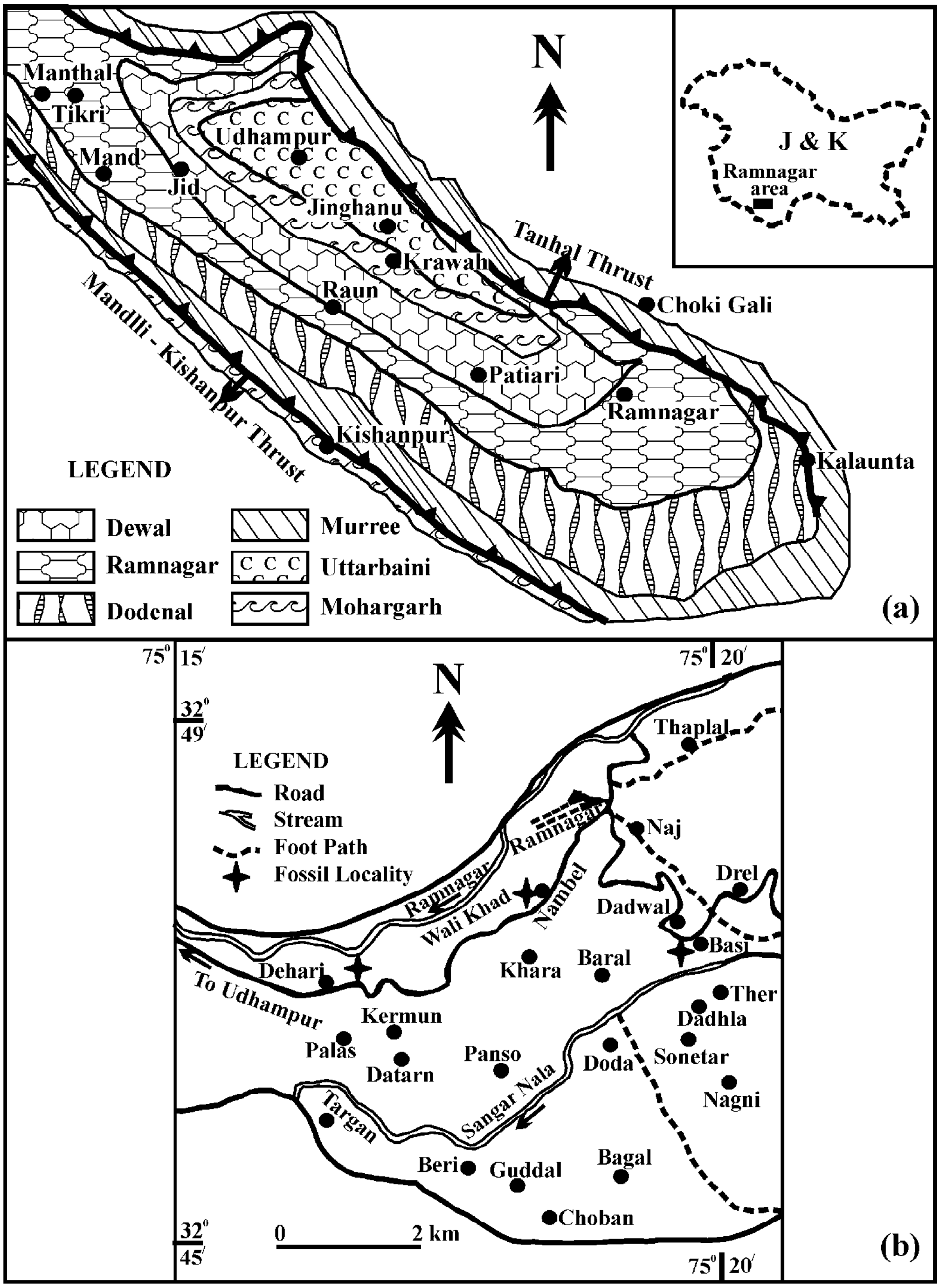

Fig. 1. (a) Geological map of Udhampur Syncline (after Gupta and Shali, 1989; Gupta, 2000), (b) Location map of the fossil-yielding sites

Division **Teleostei** Müller, 1846
Superorder **Ostariophysi** Sagemehl, 1885
Order **Cypriniformes** Bleeker, 1859
Family **Cyprinidae** Cuvier, 1817
Gen. et sp. indet.
(Pl. I, figs.1a-11)

Material: VPL/JU/SFF/1-66, isolated pharyngeal teeth and several uncatalogued specimens.

Horizon and Locality: Ramnagar Member of the Mansar Formation, Lower Siwalik Subgroup exposed near Dehari and Basi villages, district Udhampur, Jammu and Kashmir state, India.

The pharyngeal teeth of cyprinidae recovered from the Lower Siwalik deposits of Dehari and Basi, more than hundred in numbers (VPL/JU/SFF/1-66 and several uncatalouged pharyngeal teeth), are of heterodont type. Based on morphological variation, these teeth are described under seven morphotypes.

Morphotype I: VPL/JU/SFF/1-15, recovered from Dehari site (Pl. I, figs.1a-2).

Description: The teeth are cylindrical in shape, more or less laterally flattened to slightly round in cross section. The height of the crown is one-fifth of the total height of the tooth, which bears a slightly distally bent conical hook that overhangs over an undifferentiated masticatory area. Towards the basal part of the crown is a small masticatory process, well defined in some of the specimens (VPL/JU/SFF/4) to poorly define in others (VPL/JU/SFF/3).

Remarks: The teeth belonging to Morphotype I compare well to the teeth referred by Gayet (1987) to Cyprinidae (Gayet, 1987, fig. 18) and Cyprinodontidae (Gayet, 1987, fig. 19A-C) from the Lower-Middle Eocene Kuldana Formation, Pakistan. Tiwari *et al.* (1991) assigned similar teeth recovered from the Oligocene-Early Miocene Upper Dharmsala Formation, Kangra valley (Tiwari *et al.*, 1991, plate 1, figs. 11, 13) to Cyprinidae (pharyngeal teeth Type C). However, some of the teeth referred to Type C by Tiwari *et al.* (Tiwari *et al.*, 1991, plate 1, figs. 9, 10) resemble the teeth assigned to Morphotype III in this study. The latter referral is based on analogy to recent works (Gaudant, 1994, 1997; Gaudant *et al.,* 2002). Similar type of teeth from the Upper Siwalik deposits of Nepal has been referred to Cyprinidae by Kotlia and Mathur (1997). The similarity in morphology of the teeth recovered from the Lower Siwalik deposits of Dehari to those reported from Pakistan, Dharmsala (India) and Nepal secures their (VPL/JU/SFF/1-15) referral to Cyprinidae. These teeth possibly represent second anterior teeth of the principal series.

Morphotype II: VPL/JU/SFF/16-24, recovered from Dehari site (Pl. I, figs.3a-3c).

Description: The teeth referred to this morphotype are globular in shape with a swollen base and oval cross section. The crown in these teeth terminates distally in a slightly blunt to conical inclined hook. The masticatory area below the terminal hook is moderately developed.

Remarks: Gayet (1987) reported similar type of teeth from the Lower-Middle Eocene Kuldana Formation, Pakistan and referred them to Cyprinidae on account of their globular shape, oval cross section, slightly blunt and bent hook, and narrow and moderately developed grinding surface (Gayet, 1987, fig. 17). The teeth recovered from the Lower Siwalik deposits of Dehari have all these characters and are thus referred to the family Cyprinidae. These teeth possibly belong to outer row of fifth pharyngeal as suggested by Gayet (1987).

*Morphotype III***:** VPL/JU/SFF/25-38, recovered from Dehari and Basi sites (Pl. I, figs.4a-5).

Description: Teeth referred to this morphotype have a broad and anteroposteriorly compressed crown that terminates distally in a blunt but well-marked hook. The masticatory area under the hook is elongated and arcuate in form, bounded on either side by well defined crests. The crests are split in to four coarse, blunt tubercles. The central part of the masticatory area between the crests is ornamented with another row of tubercles, which are as strongly developed as marginal tubercles in some specimens whereas in other specimens, the central tubercles are not strongly developed.

Remarks: The teeth described under this morphotype have been recovered from two Lower Siwalik localities, Dehari (VPL/JU/SFF/25-37) and Basi (VPL/JU/SFF/38), both falling in the Ramnagar area. In bearing coarse tubercles on the margins of the masticatory area, these teeth compare well with those of *Scardinius* and *Palaeoleucisus* described from the Oligocene and Miocene of Austria and France (Gaudant, 1994, 1997; Gaudant *et al.*, 2002, plate 2, figs. 15-17) and possibly represents second anterior tooth of the posterior or principal series. As discussed earlier, the teeth assigned to Morphotype III also resemble the Type C pharyngeal teeth of cyprinids described by Tiwari *et al.* (Tiwari *et al.*, 1991, plate 1, figs. 9, 10) from Dharmsala Formation, H.P.

Morphotype IV: VPL/JU/SFF/39-43, recovered from Dehari and Basi sites (Pl. I, figs.6a-6c).

Description: Teeth of this morphotype are flattened to arched, with an elongated, laterally flattened to arcuate crown. The crown terminates distally in relatively blunt and recurved, short hook. Below this terminal cusp a wide, depressed masticatory area occurs. The masticatory area is bounded on either side by a small inconspicuous worn cusplet.

Remarks: These teeth have been collected from the Lower Siwalik deposits exposed near Dehari (VPL/JU/SFF/39-40) and Basi villages (VPL/JU/SFF/41-43). The teeth show similarities to third anterior teeth of median series of cf. *Tor tor* reported from the Late Neogene-Quaternary Lukundol Formation of Nepal (West *et al.*, 1988, fig. 4C) or to posterior median teeth of *Barbus steinheimensis* reported from the Miocene of Germany (Gaudant, 1989, plate 4, fig. 6) and to *Barbus* sp. reported from the Oligocene-Miocene of Switzerland and France (Gaudant *et al.*, 2002, plate 3, fig. 4). On account of the morphological similarities to the above mentioned taxa, teeth belonging to this morphotype are placed under the family Cyprinidae.

Morphotype V: VPL/JU/SFF/44-48, recovered from Dehari site (Pl. I, figs.7a-7c).

Description: These teeth are cylindroconical in shape with a short globular crown. The crown is conical in outline with a circular to semi-circular base. Distally the crown tapers, ending in a straight pointed apex. The masticatory area is undifferentiated.

Remarks: The teeth described under this morphotype have been recovered from the Lower Siwalik rocks exposed near Dehari. In having a pointed to slightly smooth tip and elliptical to semi-circular outline of the crown, and conical to cylindrical shape of the pharyngeal teeth VPL/JU/SFF/44-48 compare well with the teeth of *Schizothorax esocinus*, a cyprinid reported from Pliocene-Pleistocene Karewa deposits of the Kashmir basin by Kotlia (Kotlia, 1989, plate 3, figs. 8a-b, 10a-b).

Morphotype VI: VPL/JU/SFF/49-57, recovered from Dehari site (Pl. I, figs.8-9).

Description: The teeth belonging to this morphotype are cylindrical in shape with the masticatory surface located dorsally. It is flat, circular to oval in outline. Some of the teeth have straight lateral margins whereas others have slight constriction proximally, a little below the middle of the teeth. The periphery of the tooth is smooth.

Remarks: The morphotype VI teeth referred to Cyprinidae indet. have been recovered from the Lower Siwalik deposits of Dehari. These teeth closely resemble the anterior teeth of *Cyprinus carpio communis* reported by Kotlia (1989) from the Pliocene-Pleistocene Karewa deposits of the Kashmir Basin (Kotlia, 1989, plate 1, fig. 5a-b) and the anterior teeth of *Tinca micropygoptera* reported from Miocene of Germany (Gaudant, 1989, fig. 6A).

Morphotype VII: VPL/JU/SFF/58-66, recovered from Dehari site (Pl. I, figs.10a-11).

Description: The teeth are cylindroconical in shape with a blunt, circular to oval apex. The surface of the teeth is smooth and equally developed on all sides making it appear globular.

Remarks: The teeth referred to morphotype VII are morphologically similar to the posterior teeth of *Cyprinus carpio communis* described from the Pliocene-Pleistocene Karewa deposits of the Kashmir Basin (Kotlia, 1989, plate 2, figs. 2a-b, 8a-b).

As the teeth are isolated in nature, additional fossil material is required to secure a generic and/or specific level position for the material. However, as discussed above these teeth can be confidently referred to the family Cyprinidae.

Order **Siluriformes** Cuvier, 1817

Family **Siluridae** Cuvier, 1817

Gen et sp. indet.

(Pl. II, figs.1a-1c)

Material: VPL/JU/SFF/98, a partly preserved pectoral spine.

Horizon and Locality: Ramnagar Member of the Mansar Formation, Lower Siwalik

Subgroup exposed at Nambel village, district Udhampur, Jammu and Kashmir state, India.

Description: The spine is incompletely preserved with most of its proximal end as well as distal end broken. The proximal part of the shaft bears partially preserved head of the spine. The ventral side of the shaft is convex, whereas the dorsal side is flat. Both the ventral and the dorsal surfaces bear numerous tubercles and striations. The tubercles are prominent towards the anterodistal margin of the spine which grades into striations proximally. The posterolateral margins lack tubercles and are dominated by striations and grooves. The striations are parallel and continuous towards the basal part of the spine. The anterior margin is ridged and bears a row of moderately sized, separate, erect rounded retrose dentations. The posterior margin has a posterior groove, which runs all along the length of the shaft and extends up to the distal end of the basal recess. The posterior edge lacks dentations. The basal recess is a deep cavern on the posterior face of the shafts base. Its outer rim is rather indistinct and its distal end not continuous with the posterior groove. The cavity of the basal recess is continuous through a pore with the hollow center of the spine. Almost all the processes are missing except a little part of dorsal process, which is preserved.

Remarks: Pectoral fin of a number of Siluriformes (catfishes) is characterized by the presence of spine. However, some of them lack spine (e.g. aspredinids, astroblepids, and cetopsids) (Arratia, 2004). When present, the pectoral spine is generally long and strongly ossified. The posterior margin of the spine often has a series of strong well developed denticulations (e.g. diplomystids, ictalurids, *Mystus*, *Rita*, *Horabagrus*) (Arratia, 2004) or both anterior and posterior margins may bear denticulations (e.g. *Bunocephalus*, some clarrids) (Arratia, 2004). Other spines may bear odontodes (e.g. loricariids) or present a combination of both, i.e. odontodes as well as denticulations (e.g. *Nematogenys*) (Arratia, 1987, 2004). The spine recovered from Nambel bears both dentations and odontodes. The dentations are confined to the anterior margin and the odontodes to the anterior end of the dorsal and ventral margins, which progressively grade into striations proximally as well as posteriorly. These features of the pectoral spine relate it to *Nematogenys*. However, Nematogenyidae are endemic to South America (Gayet and Meunier, 2004) and as such VPL/JU/SFF/98 cannot be referred to this family. Gaudant (1994) described a pectoral spine of Siluridae that he referred to *Silurus* sp. from the Upper Miocene of the Vienna Basin, Austria. The axial processes of this spine are little developed compared to the dorso-lateral processes, which are distinct. The ornamentation is limited to a row and comprises of small tubercles, which are internal, whereas the external surface is smooth. VPL/JU/SFF/98 compares well with the morphology of the spine described by Gaudant (Gaudant, 1994, plate 2, figs. 6-8). According to Gayet and Meunier (2004), the family Siluridae, though known from Asia, is unrepresented as fossil in India. However, a solitary report of dentary impression and a dorsal spine fragment of Siluridae exists in literature from the Tertiary deposits of Ladakh, India (Sahni *et al.*, 1984). Moreover, the family is well represented today in fresh water bodies of the Indian rivers. Keeping this in mind and the close similarity of VPL/JU/SFF/98 to the pectoral spine of *Silurus* sp. reported by Gaudant (1994) from the Upper Miocene of Austria, the pectoral spine recovered from the Lower Siwalik deposits of Nambel is referred to Siluridae gen. et sp. indet.

Family **Clariidae** Günther, 1864

Gen et sp. indet.

(Pl. II, figs.2a-3)

Material: VPL/JU/SFF/83-97, partly preserved pectoral spines.

Horizon and Locality: Ramnagar Member of the Mansar Formation, Lower Siwalik Subgroup exposed near Dehari and Basi villages, district Udhampur, Jammu and Kashmir state, India.

Description: The pectoral spines recovered from Dehari (VPL/JU/SFF/83-95) and Basi (VPL/JU/SFF/96-97) represent the proximal part with only the spine head preserved partially. The spines have only their dorsoproximal part and the proximal part of the shaft preserved. The shaft is dorsoventrally flattened. The anterior margin of the shaft is not ridged, rather flat. The shaft bears prominent, straight, parallel striations and grooves on the dorsal and ventral surfaces as well as on the anterior and posterior margins which extend up to the head of the spine. No anterior or posterior dentations are evident on the spine shaft. Towards the proximal end of the spine a dorsal process is preserved. The dorsal process is broader than high,

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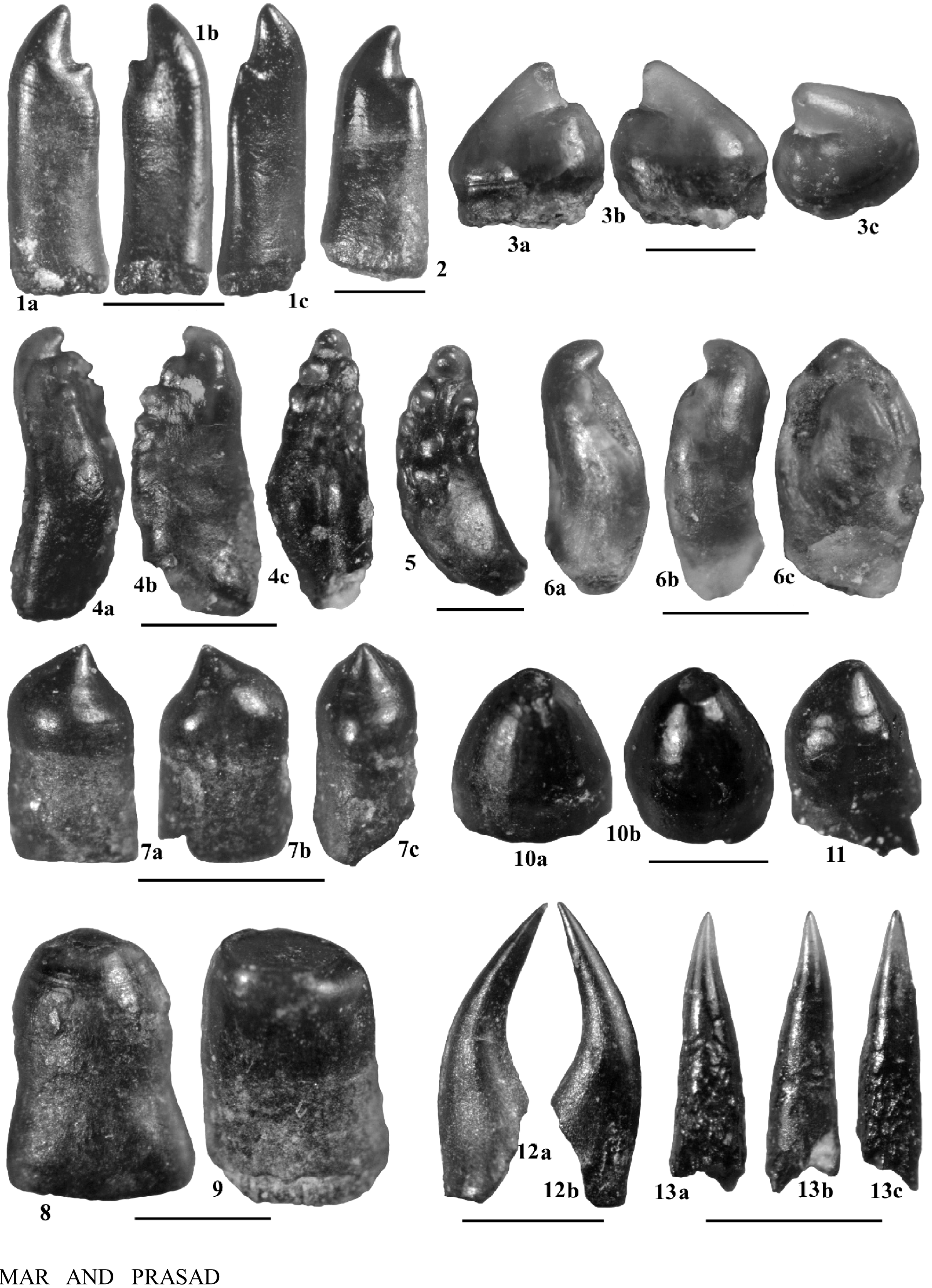
EXPLANATION OF PLATE I

(Scale bar represents 1 mm)

1a-10c.	**Pharyngeal teeth** of **Cyprinidae** indet.
1a-1c.	Morphotype I (VPL/JU/SFF/4), 1a-1b lateral views, 1c occlusal view
2.	Morphotype I (VPL/JU/SFF/3), occlusal view
3a-3c.	Morphotype II (VPL/JU/SFF/17), 3a-3b lateral views, 3c occlusal view
4a-4c.	Morphotype III (VPL/JU/SFF/25), 4a-4b lateral views, 4c occlusal view
5.	Morphotype III (VPL/JU/SFF/26), occlusal view
6a-6c.	Morphotype IV (VPL/JU/SFF/41), 6a-6b lateral views, 6c occlusal view
7a-7c.	Morphotype V (VPL/JU/SFF/44), 7a-7b lateral views, 7c anterior view
8.	Morphotype VI (VPL/JU/SFF/49), lateral view
9.	Morphotype VI (VPL/JU/SFF/50), lateral view
10a-10b.	Morphotype VII (VPL/JU/SFF/58), occlusolateral views
11.	Morphotype VII (VPL/JU/SFF/59), lateral view
12a-13c.	**Premaxillary and prevomerine teeth** of **Channidae** indet.
12a-12b.	Type I (VPL/JU/SFF/67), lateral views
13a-13c.	Type II (VPL/JU/SFF/76), 13a-13b lateral views, 13c anterior view

Plate I



PARMAR AND PRASAD

with a flat proximal face and a gently arched to flat outer edge. The ventral process is missing. The anterior process is little preserved towards its dorsal end and is connected to dorsal process by a narrow strut that forms the proximal crest. The head of the spines has the basal recess preserved, which is moderately large and is continuous with a posterior groove. The posterior groove is devoid of dentations.

Remarks: The only report of pectoral spines from the Siwalik deposits of the Indian subcontinent is from the Middle Siwalik rocks of Ladhyani and Lehri-Sarail near Haritalyangar, Himachal Pradesh (Sahni and Khare, 1977). These workers documented the presence of pectoral spines of Bagridae and Claridae from these localities. The Bagridae spines referred to *Mystus seenghala* (Sahni and Khare, 1977) are slightly convex and dorsoventrally compressed having closely placed fine denticles on the anterior border and hook–shaped sharp spines on the posterior margin. These spines thus differ from the present material which lacks both anterior and posterior dentations. The pectoral spines referred to Clarridae, *Clarias batrachus* and *C. falconeri* by these workers (Sahni and Khare, 1977) too bear anterior dentations but VPL/JU/SFF/83-97 correspond well to Clariidae as the later bears numerous fine ridges and furrows that extend up to the head of the spine. The reports on pectoral spines of fishes from other formations of the Indian subcontinent of more or less similar age that deserve some discussion are by Hora (1939) and Gayet (1987). Hora (1939) described pectoral spine of Ariidae, *Arius* from Miocene Baripada beds, Balasore, Orisa. The spine as well as shaft lacks serrations and thus compares well with VPL/JU/SFF/83-97, but the Baripada spine is devoid of any ornamentation whereas spines referred to VPL/JU/SFF/83-97 all have well developed prominent striations and as such the new spine cannot be referred to Ariidae. Gayet (1987) reported pectoral spines of Bagridae and Clarridae from the Lower-Middle Eocene, Kuldana Formation of Pakistan. The Bagridae spines have a nearly semicircular dorsal process, whereas in Clariidae the dorsal process represents only a quarter of circle and is therefore much reduced than that of Bagridae. The spines recovered from Dehari and Basi sites compare well with the sculptured shaft morphology of Clariidae described by Sahni and Khare (1977) from the Middle Siwalik rocks of Himachal Pradesh and with the spine head morphology of Clarridae described and figured by Gayet (Gayet, 1987, fig. 12) from the Kuldana Formation, Pakistan. Based upon this comparison, the pectoral spines from the Lower Siwalik deposits of Jammu have been referred to Clarridae.

Family **Bagridae** Bleeker, 1858

Gen et sp. indet.
(Pl. II, figs.4a-5b)

Material: VPL/JU/SFF/99-100, two dorsal spines.

Horizon and Locality: Ramnagar Member of the Mansar Formation, Lower Siwalik Subgroup exposed near Dehari village, district Udhampur, Jammu and Kashmir state, India.

Description: The dorsal spine has two well preserved anterior processes. The articular foramen is moderately large. The shaft of the spine as well as its proximal part is smooth, devoid of any striations, tubercles or dentations. The anterior surface is unequal and little raised on one side. Laterally, the dorsal spine is compressed and flattened. Posteriorly, a moderately deep and wide posterior groove is present, which is continuous throughout the length of the spine. The posterior groove lacks dentation. It rather has minute oval to circular pits.

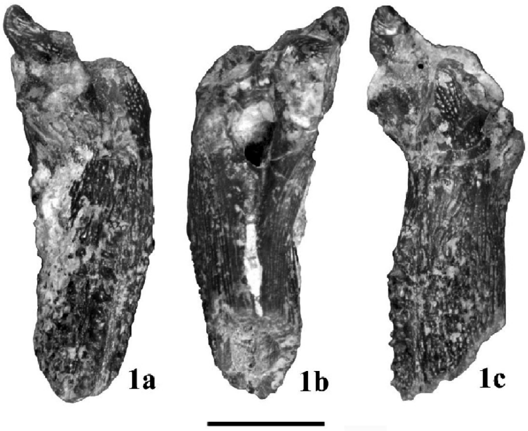
Remarks: Sahni and Khare (1977) described dorsal spines of bagrids (*Mystus seenghala* and *Rita rita*) from the Middle Siwalik rocks of Ladhyani and Lehri-Sarail near Haritalyangar, Himachal Pradesh. The dorsal spine of *Mystus seenghala* is marked laterally by fine striations. The anterior margin of the spine is sharp and devoid of denticles or tubercles, whereas small denticles with sharp apices exist in a narrow groove arising from the proximal end on the posterior margin (Sahni and Khare, 1977). *Rita rita* dorsal spine is laterally compressed. The anterior margin bears few tubercles towards the proximal end as in recent specimen of *R. rita*. On the posterior border a few, sharp, small spines are placed in a groove distally (Sahni and Khare, 1977). VPL/JU/SFF/99-100 differs from these spines on account of lacking both serrations and striations. The other report of spines belonging to Ariidae is that of Hora (1939) from the Miocene, Baripada Beds, Balasore, Orisa, who reported the genus *Arius* from these beds. The dorsal spine is grooved along the posterior border, flattened anteriorly and again grooved at the anterior proximal end. The spine is compressed from side to side and ornamented with faintly marked longitudinal ridges. VPL/JU/SFF/99-100 corresponds well with *Arius* spine in lacking serrations but differs from the latter in the presence of surface striations. Moreover, dorsal spines of Ariidae have special granulous ornamentation (Gayet, 1987), which is missing in VPL/JU/SFF/99-100. Gayet (1987) described Bagridae dorsal spine from the Lower-Middle Eocene Kuldana Formation, Pakistan. The spine bears parallel longitudinal lines on its surface and lacks serrations. The dorsal spines recovered from the Lower Siwalik rocks of Jammu show closer resemblance to this spine (Gayet, 1987, fig. 10) and as such have been referred to the family Bagridae rather than Ariidae, as the latter has a dorsal spine with very special granulous ornamentation (Gayet, 1987). Clariidae is not supposed to possess dorsal spine (Gayet, 1987; Arratia, 2004).

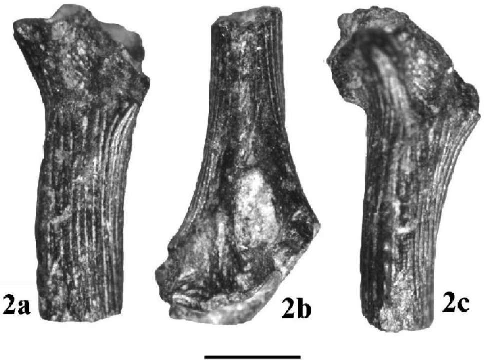
EXPLANATION OF PLATE II

(Scale bar represents 5 mm for 1a-1c; 1mm for 2a-15b)

1a-1c. **Pectoral spine** of **Siluridae** indet. (VPL/JU/SFF/98), 1a anterior view, 1b posterior view, 1c ventral view
2a-2c. **Pectoral spine** of **Clariidae** indet. (VPL/JU/SFF/83), 2a ventral view, 2b posterior view, 2c anterior view
3. **Pectoral spine** of **Clariidae** indet. (VPL/JU/SFF/84), dorsal view
4a-4b. Dorsal spine of **Bagridae** indet. (VPL/JU/SFF/99), 4a anterior view, 4b posterior view
5a-5b. Dorsal spine of **Bagridae** indet. (VPL/JU/SFF/100), 5a anterior view, 5b posterior view
6a-15b. Spine shafts of Siluriformes indet.
6a-6b. Morphotype I (VPL/JU/SFF/101), lateral views
7a-7b. Morphotype II (VPL/JU/SFF/103), lateral views
8a-8b. Morphotype III (VPL/JU/SFF/106), lateral views
9a-9b. Morphotype III (VPL/JU/SFF/104), lateral views
10a-10b. Morphotype IV (VPL/JU/SFF/109), lateral views
11a-11b. Morphotype IV (VPL/JU/SFF/108), lateral views
12a-12b. Morphotype V (VPL/JU/SFF/114), lateral views
13a-13b. Morphotype VI (VPL/JU/SFF/115), 13a posterior view, 13b lateral view
14a-14b. Morphotype VII (VPL/JU/SFF/117), 14a lateral view, 14b posterior view
15a-15b. Morphotype VII (VPL/JU/SFF/118), 15a lateral view, 15b posterior view

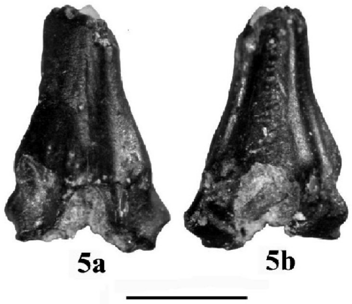
Plate II

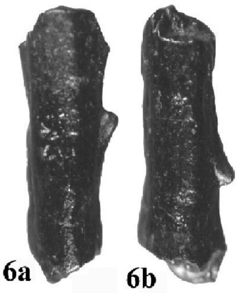

1a 1b 1c

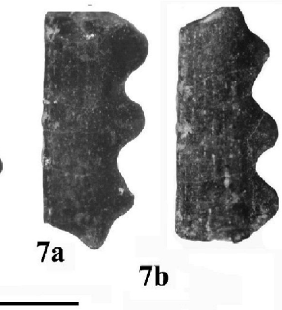

2a 2b 2c


3

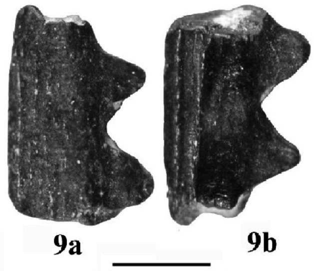

4a 4b

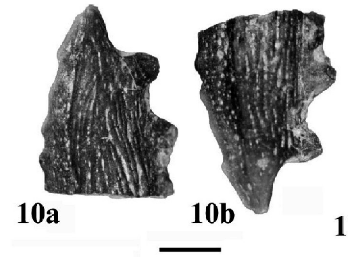

5a 5b

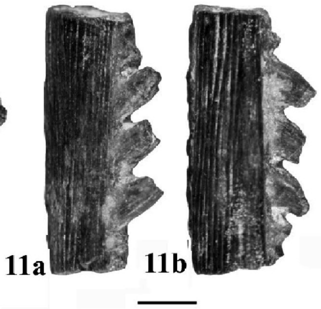

6a 6b

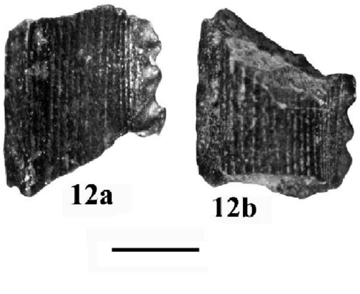

7a 7b


8a 8b


9a 9b

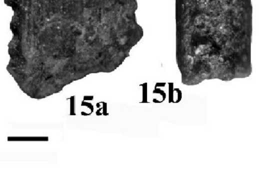

10a 10b


11a 11b


12a 12b


13a 13b


14a 14b


15a 15b

Order **Siluriformes** Cuvier, 1817
Incertae sedis
(Pl. II, figs.6a-15b)

Material: VPL/JU/SFF/101-120, partly preserved spine shafts.

Horizon and Locality: Ramnagar Member of the Mansar Formation, Lower Siwalik Subgroup exposed near Dehari and Basi villages, district Udhampur, Jammu and Kashmir state, India.

Description: Several spine shafts have been recovered from the Lower Siwalik rocks exposed near Dehari and Basi villages in Ramnagar area. Based on the spine shaft morphology especially the type of striations and serrations seven morphotypes has been recognized. Only those spine shafts used for description have been given the number. In the present collection, there are several uncatalouged spines as well.

Morphotype I: VPL/JU/SFF/101-102, from Dehari site (Pl. II, figs.6a-6b). The shaft is somewhat rounded with smooth dorsal and ventral surfaces devoid of ornamentation. The anterior margin of the shaft is straight having a thin narrow ridge devoid of dentations. The posterior margin is serrated by moderately large, proximally directed isolated dentations.

Morphotype II: VPL/JU/SFF/103, from Dehari site (Pl. II, figs.7a-7b). The shaft is dorsoventrally flattened. The dorsal surface bears faint parallel and straight striations whereas the ventral surface is smooth. The anterior edge is flat and lacks serrations. The posterior margin is serrated by erect circular and flat dentations, which are broader at base and narrow towards top.

Morphotype III: VPL/JU/SFF/104-105, from Dehari (Pl. II, figs.9a-9b) and VPL/JU/SFF/ 106-107, from Basi sites (Pl. II, figs.8a-8b). The shaft is dorsoventrally flattened. Laterally both the sides of shaft are striated. One of the sides has prominent, deep, parallel, straight grooves and striations whereas the other side is less grooved and striated. The anterior margin lacks dentations and is ridged whereas the posterior margin is serrated by isolated, inclined, subtriangular dentations.

Morphotype IV: VPL/JU/SFF/108-113, from Dehari site (Pl. II, figs.10a-11b). The shaft is dorsoventrally flattened to slightly convex. Both the lateral sides of the shaft are striated with numerous, dense parallel straight striations that are not as prominent as those present on morphotype III. The anterior margin bears wavy crenulated continuous dentations. The posterior margin has a shallow posterior groove, which bears strong, long and large, inclined, isolated dentations that taper upwards.

Morphotype V: VPL/JU/SFF/114, from Dehari site (Pl. II, figs.12a-12b). One side of the shaft is flattened whereas the other side is strongly convex. Both the dorsoventral sides bear numerous, parallel straight striations and grooves. The anterior margin has a prominent, little elevated, narrow ridge with parallel and straight furrows on its side. The posterior edge is serrated by small, erect, continuous dentations.

Morphotype VI: VPL/JU/SFF/115-116, from Dehari site (Pl. II, figs.13a-13b). The shaft is cylindrical in shape with rounded dorsoventral surfaces. The dorsal and ventral surfaces towards the anterior margin bear continuous longitudinal ridges partly tuberculated at intervals, whereas towards the posterior margin the dorsoventral surfaces bears fine, dense, fainter striations. The anterior and posterior margins are devoid of serrations. The posterior groove is broad and moderately deep.

Morphotype VII: VPL/JU/SFF/117-121 from Basi site (Pl. II, figs.14a-15b). The shaft is dorsoventrally flattened to convex. The dorsoventral surfaces bear prominent, dense, thick, parallel, inclined striations and grooves, which dip posterodistally. The anterior edge bears several minute, isolated, erect, pointed dentations whereas the posterior margin has a shallow, broad posterior groove. Though the dentations are not preserved in the posterior groove, sockets for accommodating them are present. The sockets are fairly large and rounded triangular in shape, which suggest that the spine bore prominent posterior dentations.

Remarks: A number of reports exist in literature dealing with the shaft morphology of Siluriformes spines (Arridae, Bagridae and Clarridae) from the Tertiary deposits of the Indian Subcontinent. Hora (1939) described a spine of Ariidae, *Arius* from the Baripada Beds of Miocene age, Balasore, Orisa. This shaft is greatly compressed and is devoid of any ornamentation and serrations. *Arius sahnii* reported from the Middle Eocene Subathu Formation of Beragua Coal Mine, Jammu and Kashmir (Khare, 1976) has a stout, robust, dorsoventrally compressed spine shaft, ornamented by a series of longitudinal striations. The anterior and posterior margins of the shaft are denticulated. On the anterior border the denticles are long, closely placed, and directed distally, whereas on the posterior margin the dentations are small, closely spaced, directed proximally, and are present in a groove. The spine of *Arius* sp. reported by Mehrotra (1981) from the lower Miocene Baripada Beds, Baripada, Orissa has a robust, sigmoidally curved shaft with its anterior edge bearing backwardly directed serrations and the posterior border has a groove with worn out serrations. The shaft bears faint longitudinal striations on its surface. Though Ariidae is largely a marine family that is distributed worldwide throughout the tropical and subtropical region, fresh water forms too are known (Gayet, 1987). Moreover, the family has also been documented from other freshwater deposits of the world such as Lower-Middle Eocene Kuldana Formation of Pakistan (Gayet, 1987) and various South American localities (Gayet, 1987).

The Bagridae, *Mystus seenghala* spine from the Middle Siwalik rocks of Ladhyani, Himachal Pradesh, is slightly convex and dorsoventrally compressed. Its dorsal and ventral surfaces are marked by fine longitudinal striations. The anterior border has fine, closely placed denticles, whereas the posterior margin bears hook-shaped, sharp serrations (Sahni and Khare, 1977). Gayet (1987) described an unidentified Bagridae spine from the Lower-Middle Eocene Kuldana Formation, Pakistan, which bears sharp tooth–like serrations on the posterior as well as on the anterior margin of the shaft. Similar shafts with prominent anterior and posterior serrations have also been reported from other localities in Asia viz., Miman *et al.* (Miman *et al.*, 1985, figs. 38-39). However, it is not necessary that the bagrids always bear serrations on both the margins. Forey and Young (1999) figured a *Bagrus* recovered from the Upper Miocene Baynunah Formation, Abu Dhabi, United Arab Emirates in which the denticles are restricted to the outer edge of the shaft (Forey and Young, 1999, fig. 12.5).

The spines of Clarridae have been reported from the Middle Siwalik rocks of Ladhyani and Lehri-Sarail, Himachal Pradesh by Sahni and Khare (1977) and have been assigned to *Clarias batrachus* and *C. falconeri*. *C. batrachus* spine is stout, long and convex whose anterior margin possesses a number of small closely packed anteriorly directed denticles. Both the dorsal and ventral surfaces of the shaft are ornamented by fine longitudinal striations. *C. falconeri* spine is same as *C. batrachus* except for its larger size, greater stoutness and robustness (Sahni and Khare, 1977).

Since it is difficult to assign isolated fragmentary spines shafts to a particular family, the morphotypes I-VII have been referred to Siluriformes in general. The pectoral spines of Ariidae, Bagridae and Clariidae display variation in their shaft morphology. Ariidae and Clariidae spines do not have sharp tooth-like serrations on posterior and anterior margin of the spine as in Bagridae (Gayet, 1987). Moreover, the variation in Ariidae in terms of both serrations and striations is much greater. *Arius sahnii* reported from the Middle Eocene Subathu Formation of Jammu and Kashmir has both anterior and posterior margins denticulated (Khare, 1976) as do *A. egertoni* reported from the Middle Eocene of England and Belgium (Woodward, 1901). In *A. kitsoni*, *A. russi*, and *A. hewardbelli*, described from the Eocene of Nigeria (White, 1926) as well as *Arius* sp. reported by Hora (1939) from Balasore, Orissa, the dentations are absent. Moreover, the serrations may only be confined to the terminal part of spines as in living members of *Arius* (Hora, 1939). Even the type of striations varied within different taxa of Ariidae, such as *A. egertoni* and *A. kitsoni* have irregular longitudinal ridges which are partly tuberculated (Woodward, 1901; White, 1926), *A. hewardbelli* has fine and rather irregular longitudinal rugae (White, 1926), *A. russi* has reticulating longitudinal rugae (White, 1926), whereas *Arius* sp. is devoid of ornamentation (Hora, 1939).

The morphotype I resembles spines of Ariidae (Hora, 1939; Khare, 1976) and Bagridae (Forey and Young, 1999); morphotype II resembles spines of Bagridae (Forey and Young, 1999); morphotype III resembles spines of Ariidae (Hora, 1939; Khare, 1976) and Bagridae (Forey and Young, 1999); morphotypes IV and VII compare well with spines of Ariidae (Woodward, 1901; Khare, 1976), Bagridae (Sahni and Khare, 1977; Miman *et al*., 1985; Gayet, 1987) and Clarridae (Gayet, 1987); morphotype V is comparable to the spines of Ariidae (Hora, 1939; Khare, 1976) and Bagridae (Forey and Young 1999); and morphotype VI resembles spines of Ariidae (White, 1926).

Superorder **Acanthopterygii** Gouan, 1770
Order **Perciformes** Bleeker, 1859
Suborder **Ophicephaloidei** Bleeker, 1859
Family **Channidae** Berg, 1940
Gen. et sp. indet.
(Pl. I, figs.12a-13c)

Material: VPL/JU/SFF/67-80, isolated premaxillary and prevomerine teeth and several uncatalogued specimens.

Horizon and Locality: Ramnagar Member of the Mansar Formation, Lower Siwalik Subgroup exposed near Dehari and Basi villages, district Udhampur, Jammu and Kashmir state, India.

Description: The teeth referred to Channidae are cardiform that show great variation in tooth size. Two types of teeth are present in the collection. Type I teeth (VPL/JU/SFF/67-75) (Pl. I, figs.12a-12b) are larger in size, moderately to strongly curved with narrow tapering distal end and a broader laterally compressed base. The crown of the teeth is pointed and is enveloped by a thin layer of enameloid. The surface of Type I teeth is smooth. Type II teeth (VPL/JU/SFF/76-80) (Pl. I, figs.13a-13c) are short, straight, conical in outline, with a pointed apex and a cylindrical base. The crown of these teeth is enveloped by a thin layer of enameloid. The proximal part of these teeth bears faint striations on their surface.

Remarks: The present teeth show close similarity to Type D teeth reported by Kotlia and Mathur (Kotlia and Mathur, 1997, figs. 8-9) from the Upper Siwalik deposits of Surai Khola, Nepal. According to these authors, similar kind of numerous conical teeth of different sizes are present on the premaxilla and prevomer of the recent *Channa* (*Ophiocephalus*), such as *C. stratus* and *C. mullius*. VPL/JU/SFF/67-80 teeth compare well with the teeth of recent *Channa* as well as Type D teeth of Kotlia and Mathur (1997), as all of them possess curved or inclined conical teeth of different sizes with well developed crown covered with thin transparent enameloid layer. However, *C. stratus* and *C. mullius* as well as Type D teeth of Kotlia and Mathur (1997) are narrower anteriorly and broader posteriorly, whereas the teeth recovered from Lower the Siwalik beds of Dehari and Basi have both the anterior and posterior margins of same dimensions. In addition, *C. stratus* and *C. mullius* have tooth bases sculptured with wrinkles and striations. The Type D teeth of Kotlia and Mathur (1997) have blunt crown with striations on the crown as well as at the base, whereas in VPL/JU/SFF/67-80 the striations are confined to only few teeth bases, the other teeth being smooth. From these comparisons, it appears that the Siwalik teeth may represent a new taxon of Channidae, but the absence of complete dentition does not permit designation of a new taxon.

CONCLUSIONS

Application of bulk screen-washing techniques have led to the recovery of five taxa of teleostean fishes from the Ramnagar Member of the Mansar Formation (Chinji equivalents of Pakistan) exposed at Dehari, Nambel and Basi in the vicinity of the Ramnagar area of Udhampur district, Jammu and Kashmir. The fish taxa include five families Cyprinidae, Siluridae, Clariidae, Bagridae and Channidae represented by several isolated teeth and dorsal and pectoral spines. Cyprinidae are represented by pharyngeal teeth of at least seven morphotypes, whereas Channidae are known by premaxillary and prevomerine teeth. Pectoral spines recovered from Nambel have been assigned to Siluridae, whereas those recovered from Dehari and Basi have been assigned to Claridae based on the spine morphology. Two dorsal spines have also been recovered from Dehari and are identified as belonging to Bagridae. Other than these, several spine shafts with varied striations and serrations recovered from Dehari and Basi have been categorized into seven morphotypes. Though generic and species level identification of these specimens is not possible at present, the present finds are significant as no such microvertebrates fossils have earlier been reported from this area. The Siluridae remains are being reported for the first time from the Siwalik deposits of the Indian subcontinent, whereas the Claridae and Bagridae that were known earlier from younger stratigraphic levels are being reported for the first time from the older rocks, thereby extending their stratigraphic distribution to the Lower Siwaliks.

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TRACE FOSSILS FROM THE KALADONGAR FORMATION EXPOSED IN KUAR BET, PATCHAM ISLAND, KACHCHH BASIN, INDIA

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ABSTRACT

The Kachchh palaeorift basin is famous for its Jurassic exposures the world over. The basin, initiated in Early Jurassic, comprises well exposed sediments from Bajocian onwards. The Kuar Bet is a small island on the northern part of Patcham Island, Kachchh, having exposures of the basal part of the Kaladongar Formation. Lithostratigraphically, these are considered to be the oldest exposed beds in the Kachchh palaeorift basin. Eight recurring ichnospecies are reported here. These include *Arenicolites* cf *statheri*; *Cochlichnus* isp; *Diplocraterion parallelum*; *Diplocraterion polyupsilon*; *Ophiomorpha nodosa*; *Paleophycus*; *Rhizocorallium jenense*; *Skolithos linearis*. These ichnotaxa are divided in four Ichnological assemblages (1) *Diplocraterion (2) Ophiomorpha (3) Arenicolites-Skolithos and (4) Rhizocorallium-Paleophycus*. The trace fossil occurrences and their recurrence pattern indicate marginal marine conditions followed by shallow marine conditions for the sediments of Kuar Bet.

Keywords: Trace fossils, Kuar Bet, Patcham Island, Kachchh, India

INTRODUCTION

Ichnology plays an important role in understanding the depositional environment and helping in delineating stratigraphic sequence boundaries. In the Mesozoic sediments of the Kachchh Basin, this has been well exemplified by studies pertaining to omission surfaces (Shringarpure, 1986); depositional environment (Howard and Singh, 1985; Fürsich, 1998). They envisage temporal and geographical variations in palaeoecological parameters (Desai *et al.*, 2008). Previous workers have dealt with more general aspect of ichnology of different parts of the Kachchh Basin (Badve and Ghare, 1978; Ghare and Kulkarni, 1986; Kulkarni and Ghare, 1991; Patel *et al.* 2008). However, there is scarcity of the ichnological studies pertaining to Patcham Island. Previous accounts (Howard and Singh, 1985; Fürsich, 1998) discuss the trace fossil occurrences in Patcham Island but lack any precise stratigraphic details. Specifically, the ichnology of the Dingy Hill Member is still unstudied. The purpose of the present study is to describe trace fossils from the lower part of the Dingy Hill Member, and author follows the stratigraphic classification of Biswas (1977) for the same purpose. The "oldest exposed beds", as commonly understood, stand for those rocks which stratigraphically, form the base of the oldest exposed formation and no rock unit below this is exposed anywhere in the basin.

An attempt is made to describe the trace fossil assemblage from the oldest exposed beds and to interpret the depositional history of the initial part of the Kachchh Basin.

GEOLOGY

The geological sequence exposed on Patcham Island comprises the about 472 m thick, shallow marine Kaladongar Formation overlain by the sub-littoral Goradongar Formation (Biswas, 1977). The Kaladongar Formation is divided into three informal members (1) Dingy Hill member, (also sometimes known as Kuar Bet beds or Kuar Bet Member) (ii) Kaladongar Sandstone Member (iii) Babia cliff sandstone. Stratigraphically, the Dingy Hill Member constitutes the oldest exposed beds of the Kachchh rift basin. The lower part of the member is exposed in Kuar Bet, while the upper part is exposed at Dingy Hill. Biswas (1977, 1993), while discussing the Mesozoic rock stratigraphy, described the Kuar Bet outcrop, and considered it to be equivalent to the Dingy Hill Member on the basis of gross lithology and a coral band. However, he also argued that there is absence of any suitable marker beds. The Kuar Bet island was studied in detail during two field seasons in 2006 and 2007 for their trace fossil occurrences.

The Kuar Bet beds are well exposed in the from of semi-arcuate shaped outcrop, situated 2.5 km NNW of Patcham Island. (Fig.1). This outcrop is surrounded on three sides by Recent Rann sediments, while another bet (Mori Bet) is situated to its west. A bridge named as India Bridge connects the Kuar Bet Island with Patcham Island. The Kuar Bet represents a half-cut dome which is exposed in the form of "C". All the prominent beds are exposed continuously forming C the dipping away from the centre, thus forming a half-cut antiform structure. It can be convincingly said that the other half of the dome/antiform is represented by the Dingy Hill half Dome. The entire sequence is reprensented by alternation of shale/ sandstone, interrupted at few places by calcareous siltstones and intra-formational conglomerates. The detail stratigraphic sequence is given in Fig. 1c. The entire sequence is interrupted by three shell beds (1) *Turritella* shell bed (2) *Rhynchonella* shell bed (3) Bivalve-Coral shell bed. The stratigraphic sequence was mapped following the dip mapping technique combined with strike mapping (band tracing) technique. The stratigraphic divisions are numbered to facilitate easy reference.

Biswas (1977) described the Dingy Hill member and designated bed numbers from 1 to 38 exposed in two sections. of which, bed nos. 1-26 are exposed in Kuar Bet, while bed nos. 22 to 38 are exposed at Dingy Hill. Sedimentologically, the sandstones are calcareous in nature with dominance of fine to medium-grained sand size particles (Fig. 2 a-c). Sedimentary structures comprise various kinds of ripple marks, e.g. lingoidal (Fig. 2b), asymmetrical, etc. along with wavy and flaser beddings the in siltstones in the upper part. Some intraformational conglomerates are also present (Fig. 2 c). The bed no. 22 comprises fine-grained fossiliferous calcareous sandstone containing *Corbulae*, *Astarte, gerviliids* and corals. This band is referred to as Bivalve-Coral shell band (Fig. 2a).

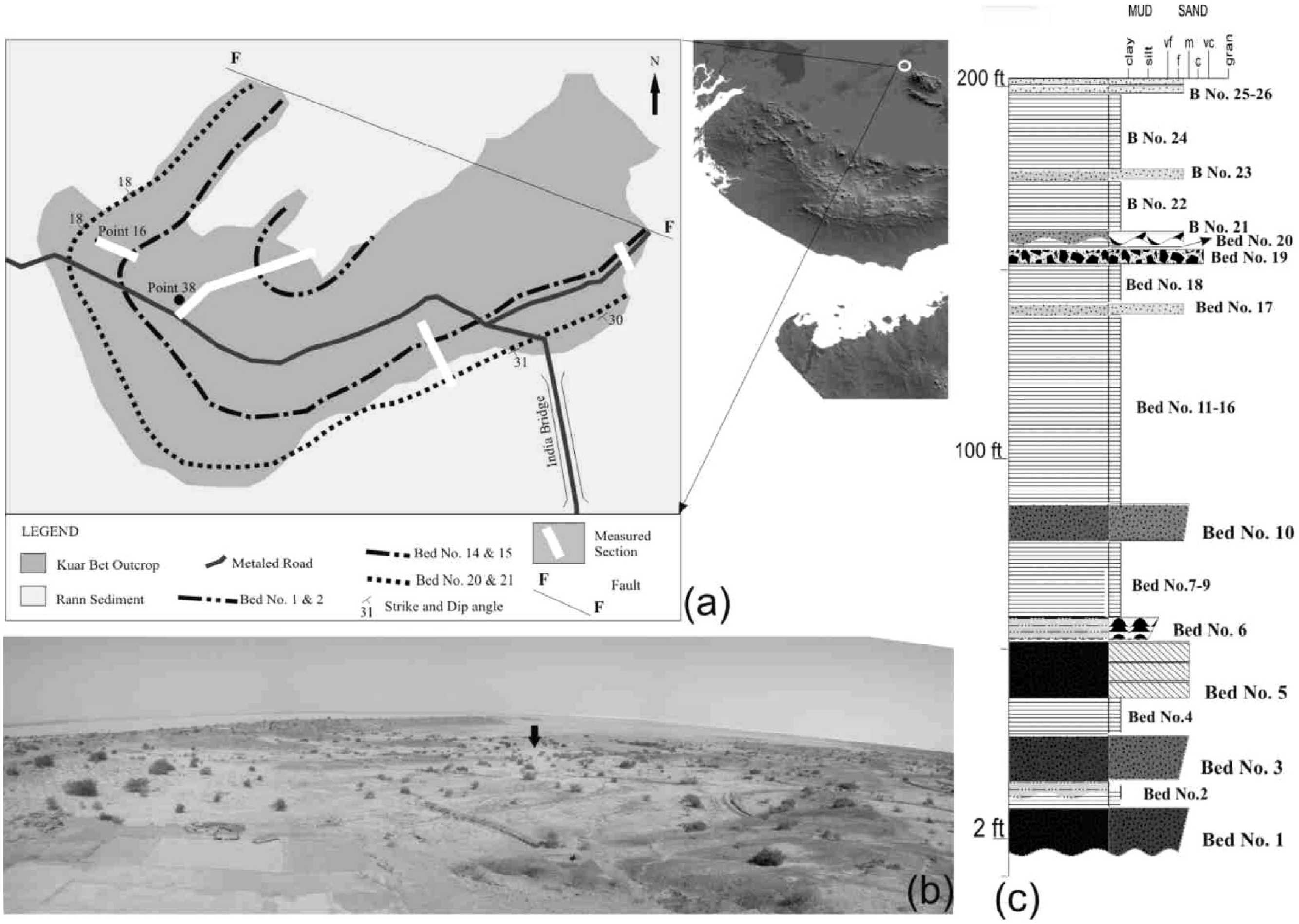


Fig. 1. (a) Generalized map of the Kuar Bet Island, (b) Panaromic view of the Kuar Bet from Point 38, looking towards the East, arrow indicates position of the Bed. No. 1, (c) Measured lithocoloumn of the Kuar Bet section.

The stratigraphic units of Kuar bet are devoid of any ammonites and this absence led earlier worker to suggest Bathonian/ Bajocian age for the Kuar bet sediments (e.g. Wynne, 1872; Nath, 1932; Biswas, 1977; Jaitley and Singh, 1983; Fürsich *et al*., 2001; Jana and Hilton, 2007). The sediments are devoid of any characteristic age-diagnostic fossils. However, recent studies have agreed on Aalenian-Early Bajocian age for the sediments (Pandey and Dave, 1993; Satyanarayana *et al*., 1999).

ICHNOLOGY

The sediments are represented by seven recurring trace fossils; these are described alphabetically along with a short description of their morphology and remarks; for ethological description both Seilacher (1964) and Martinsson (1970) are used. The dimensions, represents ranges of trace fossil morphology as measured in the field and on Laboratory specimens; they may or may not be reflected in the representative photograph.

Arenicolites cf *statheri* Bather 1925

(Pl. I, figs. d-e)

Description: Full relief, endichnial structure comprising simple, vertical U tube without spreite, the tubes are oriented perpendicular to the bedding plane and are parallel to each other; when observed from top of bedding surface, the species appears as paired openings on a bedding plane. Tube diameter ranges from 0.6 to 2 mm, and the distance between two arms varies from 0.3 to 0.8 mm.

Remarks: *A*. cf. *statheri* occurs only at few places only in Kuar Bet, especially in bed no. 3 and 5, but usually in low numbers. It has been identified as A. cf. *statheri*, despite the fact that the tube diameter is very small and the interarm distance is also very little. However, both the tubes are parallel to each other and individual burrows are distinctly lined with walls standing out due to erosion. Since the general morphology is less than the ranges of S.S. *Arenicolites statheri,* an open nomenclature is suggested. In the Mesozoic sediments of Kachchh, *Arenicolites* commonly occurs in the Callovian to Kimmerdgian sediments of Habo, Jhura and Jara Dome (Patel *et al*., 2008; Desai *et al*., 2008). It is also reported from Recent intertidal zone of the Mandvi area (Patel and Desai, 2009), where the burrow was constructed and maintained by suspension-feeding polychaete.

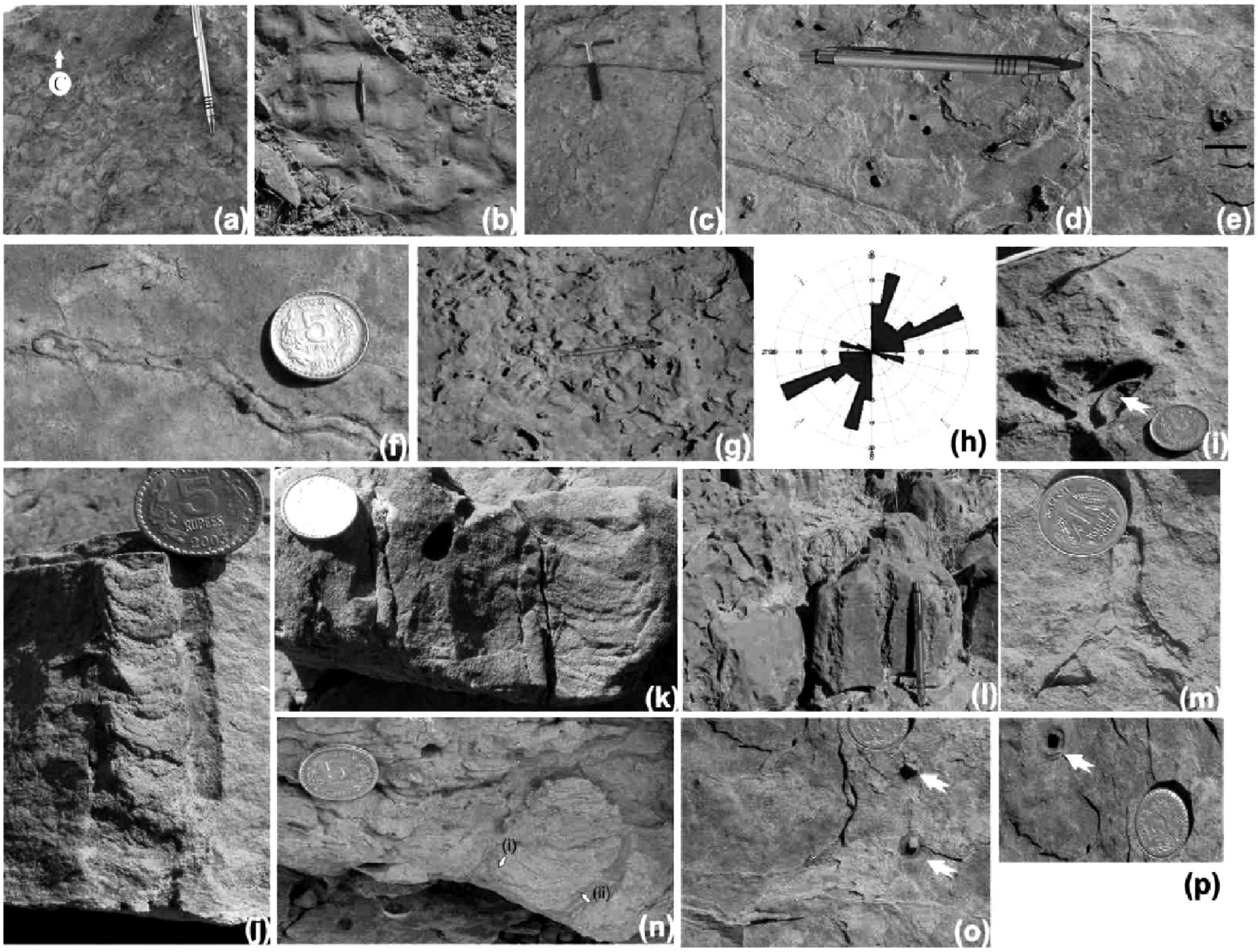
Cochlichnus isp

(Pl. I, fig. f)

Description: The specimen shows endichnial semi relief. Smooth, cylindrical, non-branching, thick meandering burrow; burrow diameter varies from 3-8 mm, the bends are smooth and regular with two sets of wavelength varying from 10 mm to 35 mm. Burrow thinly lined with dark-coloured sediment; burrow fill same as that of the host sediment.

Remarks: It occurs in bed no. 14 to 16. It is included in the ichnogenus *Cochlichnus* on the basis of the regular curves,

Plate I



DESAI

EXPLANATION OF PLATE I

(diameter of the coin 2.2 cm; length of the Pen 12 cm)

(a) Bivalve-Coral Shell bed (Bed. No. 22) containing various fragments of *Corbulae*, *Astarte*, *gerviliids* and corals, arrow indicates Coral fragment, Loc. Near Point 16.

(b) Surface exposure of the beds showing lingoidal ripple marks, Loc Near Point 16.

(c) Nature of intraformational conglomerate (bed. No. 19), Loc. Southe periphery, near India Bridge.

(d) Bedding plane view showing paired burrows of ***Arenicolites***, notes the absence of the spreite between the burrows limbs.

(e) Close up of a paired burrows of ***Arenicolites*** surrounded by dark halo.

(f) Meandering ***Cochlichus*** burrow, note the thin, dark coloured burrow lining.

(g) Bedding plan view with surfacial expression of dumble shaped ***Diplocraterion*** dominated the Bed (Bed. No. 1).

(h) Rose diagram of Orientation of the ***Diplocraterion***, showing bidirectional nature of the trace fossil (n=52).

(i) Bedding plane view and cross section of ***D. polyupsilon*** showing curved and arcuate nature of the burrow.

(j) Vertical cross section of ***D. parallelum*** showing burrow tube and nature of spreite.

(k) Cross section of ***D. polyupsilon*** thin and wide arrangement of spreite

(l) ***Ophiomorpha nodosa***-rich fine grained sandstone.

(m) Branched ***Paleophycus*** isp. tube in siltstone.

(n) ***Rhizocorallium jenense*** in medium grained, shell fragment rich, calcareous sandstone, (i) distinct spreiten structure; (ii) distinct tube structures, indicating protrusive nature.

(o&p) Bedding plan view of sparsely distributed ***Skolithos linearis***, note the varying thickness of the burrow wall.

although the regularity is observed in two individual sets. It occurs in the Callovian sediments of Habo dome (Fürsich, 1998).

Diplocraterion parallelum Torell, 1870

(Pl. I, figs. g-h, j)

Description: Full relief, endichnial structure mainly comprising vertical U-shaped spreiten burrow with parallel tubes. Tubes are cylindrical, circular in cross-section, oriented straight and more or less parallel to each other. The width of the U varies from 20-28 mm; diameter of the arm is 6.5 mm, maximum observed depths of about 90 mm; the tubes are thickly lined. The spreite is always present and well developed with continuous, protrusive nature. The individual spreites are of about 5 mm thick. Some burrows are also preserved as erosive structures, with their cross-sections showing straight and dumb-bell shaped nature of the burrow, and preference for orientation in one direction.

Remarks: *D. parallelum* occurs only at a few places in Kuar Bet, especially in bed no. 1 to 3 but usually in dense population. Based on the general morphology, parallel nature of the burrow arms with inters-burrow distance, it can be placed under *D. parallelum*. The absence of funnel shape indicates that the burrow has undergone considerable erosion. The ichnospecies is earlier reported from the Bathonian of Sadhra dome and the Callovian of Habo dome (Fürsich, 1998). It is interpreted to be made by a suspension feeder in high-energy conditions (Fürsich, 1974 a,b and 1975).

Diplocraterion polyupsilon (Smith, 1893)

(Pl. I, figs. i-k)

Description: Full relief, endichnial structure mainly comprising vertical to near vertical, U-shaped burrow. Tubes are cylindrical, circular in cross-section, oriented straight and more or less parallel to each other. The width of the U is wide and differs from earlier described species; it varies from 45 to 65 mm. The burrow diameter varies from about 4-6 mm. The spreites are partly bidirectional and discontinuous with individual spreite being thinner (between 1-2 mm) than in the earlier described species. The burrows are not dumb-bell shaped throughout their morphology, but are arcuate in nature with spreites forming major portion of arc. On bedding plane, their cross-section often shows curved and arcuate nature of the burrow.

Remarks: *D. polyupsilon* is characterized by bidirectional growth (i.e. vertical and horizontal) and the change of the position of the U tube also (Fürsich, 1974 a,b). This characteristic seems to show arcuate nature of the burrow cross section; the tubes are not parallel to each other. One of the principal differences between the present species and the earlier is the width of the U and nature and thickness of the spreite. The width of the Kachchh form matches with the specimens described by Masson and Christie (1986). This species occurs in low density and till date is not reported from the younger Mesozoic strata.

Ophiomorpha nodosa Lundgren, 1891

(Pl. I, fig. l)

Description: Full relief, endichnia structure vertical, sub-vertical, branched or unbranched, three dimensional burrow system of vertical shafts and horizontal to inclined tunnels. Burrow diameter varying from 30-40 mm, length of burrows varies in different burrow populations. Burrows filled with sediments similar to the surrounding substrate, although unfilled tube segments are also very common; outer surface distinctly pelletted. Sometimes, due to differential erosion only outer pellet nature of the wall is preserved, rest of the burrow wall is eroded away. Wall thickness varies form 3-5 mm.

Remarks: *O. nodosa* shafts are well preserved and occur in Bed no. 6-9 with dense population in Bed no 6 and 7. They indicate dwelling/feeding activity of crustaceans. In the Mesozoic-Cenozoic sediments, *Ophiomorpha* is produced mainly by shrimps comparable to recent callianassids (Weimar and Hoyt, 1964; Frey *et al*., 1978). *O. nodosa* is common in the Mesozoic sediments of Kachchh and is present throughout the stratigraphic column and is indicative of high-energy conditions (Desai *et al*., 2008; Patel and Desai, 2001, 2009).

Paleophycus isp

(Pl. I, fig. m)

Description: Full relief, endichnia horizontal, cylindrical to subcylindrical burrow with diameter ranging from 10 -14 mm. Burrow segments, straight to slightly curved and branched, branching angle large, up to 75 degrees. Burrow lining thin.

Remarks: The present specimens have thin burrow lining and may be assigned to *P. sulcatus,* but since the wall does not show any convincing anastomosing striae, it is kept in open nomenclature. It occurs in bed no. 14-16 and is associated with *Rhizocorallium* in these beds.

Rhizocorallium jenense Zenker, 1836

(Pl. , fig. n)

Description: Full relief, endichnia more or less straight, short U shaped, spreiten burrow which are oblique to the bedding plane. Both retrusive and protrusive forms are common. The width of the U varies from 40-60 mm, with tube diameter varying from 6-8 mm.

Remarks: *R. jenense* is common in the shale-siltstone altenations of bed no. 15-22; they occur in abundance and dense population in bed no 21 and differ from other ichnospecies in being oblique to the bedding plane. This ichnospecies is common in Patcham Island (Fürsich, 1998). *R. jenense* has been reported from a variety of depositional environments; it is related to unstable sedimentary environments, i.e. shoreface to foreshore (Fürsich, 1975; Worsley and Mørk, 2001; Rodriguez-Tovar and Perez-Valera, 2007) and is also known from deep water (Uchmann, 1992) and freshwater environments (Fürsich and Mayr, 1981). They are also associated with storm events (Basan and Scott, 1979). The ichnospecies is interpreted to indicate firmground; however, the present specimen does not reveal any such possibility as the burrows of suspension feeding organisms occurring along with coarse sediments and shell accumulation indicates high-energy condition (possibly a storm event during the deposition of bed no. 21-22). The trace fossil might represent a post-depositional activity (post-storm activity possibly during low-energy conditions).

Skolithos linearis Hall, 1840

(Pl. I, figs. o-p)

Description: Full relief, endichnial structure simple, vertical, cylindrical, unbranched, lined burrow. The diameter of the burrow varies from 8-12 mm, with lining thickness varying from 1-2 mm.

Remarks: *S. linearis* closely co-occurs with *Arenicolites* in bed no. 4-5, and are moderately populated. It is distinguished from other species on account of distinct burrow wall. It is commonly distributed in the Mesozoic sediments of Kachchh (Fürsich, 1998; Patel *et al*., 2008; Desai *et al*., 2008). They are interpreted to be made by suspension feeding polychaete habituating high-energy intertidal zone (Patel and Desai, 2009).

ICHNOLOGICAL ASSEMBLAGES

An ichnological assemblage relates to "all of the trace fossils in a bed that cannot be subdivided into component ichnocoenosis or suites" (refer to McIlroy, 2008). Four Ichnological assemblages are identified and delineated; these are (1) *Diplocraterion* (2) *Ophiomorpha* (3) *Arenicolites-Skolithos and* (4) *Rhizocorallium-Paleophycus*.

Diplocraterion Ichnological assemblage: This Ichnological assemblage comprises low-diversity ichnospecies of *Diplocraterion parallelum* and *D. polyupsilon*. This association is restricted to bed no. 1-3 only with high density and close association of the ichnospecies. On the bedding plane, the *Diplocraterion* shows bidirectional preferred orientation (Fig. 2d-e). Majority of the specimens show protrusive nature of the spreite, reflecting downward migration of the organism in reaction to erosional activities. No funnel-shaped openings were noticed, indicating that erosion/ scouring of the sand might have occurred (Fürsich, 1974 a,b; Goldring, 1964). The purpose of the U-shaped dwelling tube is interpreted to provide protection in a turbulent environment (Cornish, 1986); protection from exposure stress in intertidal environment (Rhoads, 1967) and protection in unstable substrate. The occurrence of the *Diplocraterion*-dominated association is interpreted as dwelling burrows for suspension feeding animals (Fürsich, 1974 a, b). Oloriz and Rodrigues-Tovar (2000) used the occurrence of *Diplocraterion parallelum* in a mid-outer shelf setting to indicate Type-II sequence boundaries and their correlative conformities. The occurrence of *Diplocraterion* is interpreted to indicate fully high-energy, marine intertidal zone (Fürsich, 1974 a,b; 1975; Cornish, 1986 and references, therein). However, whereever they occur, they occur in high to moderate ichnospecies diversity.

Several authors have summarized diagnostic attributes of trace fossils for delineating marginal marine settings (Pemberton *et al*., 1982; Hubbard *et al*., 2004). In Kuar Bet (Bed no. 1-3), the presence of *Diplocraterion* ichnological assemblage is characterized by (1) low species diversity (2) dominance of single ichnogenus (3) high density of individuals, (4) dominance of simple vertical structures and hence indicates marginal marine environment. Although no diminutive trend of the trace fossils was observed, this might be possible as bed exposures were limited to a small area only and rest are covered with Recent Rann sediments. It might be concluded that these beds indicate marginal marine environment. This view is also supported by absence of any ammonites from this horizon.

Arenicolites-Skolithos Ichnological assemblage: This ichnological assemblage overlies the *Diplocraterion* ichnological assemblage and is characterized by low-diversity trace fossils including *Arenicolites* cf *statheri* and thick lined *Skolithos linearis*. At a few places in bed no. 3, the *Arenicolites* occurs with *Diplocraterion,* while in bed no. 4-5 only vertical, non-spreiten traces dominates *Arenicolites* does not show any preference to the orientation; important character of this association is thick lining, indicating protection from unstable substrate and high-energy conditions.

Ophiomorpha Ichnological assemblage: Ichnological assemblage occurring in bed no. 6-9 are dominated by monospecific *Ophiomorpha nodosa* and the sediments are medium grained. Important character of this association is the dominance of vertical shafts of the traces. Such monospecific, low diversity, high density assemblage is indicative of marine subtidal bar conditions (Patel and Desai, 2001, 2009; Pemberton *et al.*, 1982; Hubbard *et al.*, 2004).

Rhizocorallium-Paleophycus Ichnological assemblage: This Ichnological assemblage is common in bed no. 10-22; the sediments are medium to fine grained, and at places show wavy beddings along with lungoidal ripples. The Ichnological assemblage is dominated by *Rhizocorallium jenense; Paleophycus* isp; *Cochlichnus* isp and minor *Skolithos linearis*. The association is dominated by shallow burrowing deposit feeder, with minor dwelling structures like *Skolithos*. Moreover, these beds also contain at a few horizons abundant bivalve shell beds. The Ichnological assemblage indicates that diversity hais increased comparatively from low-diversity assemblage dominated by single ichnogenus to moderately diverse association dominated by deposit feeding activity. The occurrence of *Rhizocorallium jenense* is indicative of low- energy conditions (Fürsich, 1975). At some places, the *Rhizocorallium* is also associated with shell beds (Bed no. 21), which possibly indicate a storm event and the *Rhizocorallium* activity represents post-storm activity.

DISCUSSION AND CONCLUSIONS

1. The trace fossils indicate an archetypal *Skolithos* Ichnofacies for the entire studied lower part of the Dingy Hill member, exposed in the Kuar Bet area.
2. The sequence starts with low-diversity, dwelling, high density *Diplocraterion* Ichnological assemblage, overlain by *Arenicolites-Skolithos*. Overall, there is dominance of low-diversity, high-density trace fossils created by suspension feeding organisms. Such suspension feeding organisms of low diversity indicate marginal marine conditions for beds 1-5. Fluctuating salinity levels in marginal marine depositional system are the main factor for low ichnofossil diversity and burrow diminution (Hubbard *et al*., 2004). The low-diversity ichnoassemblage and suspension-feeding traces thus point to a marginal marine depositional environment.
3. *Ophiomorpha* Ichnological assemblage of Bed no. 6-9 is well known as opportunistic trace fossils indicative of high energy sedimentation probably indicating sub-tidal bar deposit.
4. The depositional environment changes from bed no. 10 and indicates influence of full marine conditions and ichnological assemblage dominated by deposit feeding traces like *Rhizocorallium jenense*, *Paleophycus* isp, *Cochlichnus* isp.
5. Thus, the Kuar Bet sediments represent a minor transgressive event at bed no. 10 characterized by marginal marine conditions overlain by two shallow marine, shell beds which are the result of storm event.

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TRACE FOSSILS FROM THE JURASSIC ROCKS OF GANGTA BET, EASTERN KACHCHH, WESTERN INDIA

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ABSTRACT

The Jurassic rocks are well exposed in Gangta Bet of the Wagad region, Eastern Kachchh. The succession consists of thick arenaceous unit overlain by the calcareous sandstone-siltstone-shales and capped by the algal limestone. The Lower sandstone units are highly ferruginized, fractured, weathered and exposed in core of the Gangta Dome. The calcareous sandstone-siltstone units are marked by well-preserved trace fossils. Total 27 ichnospecies of 19 ichnogenera falling in five ethological categories are identified from the Gangta Bet. The recurrent pattern of the trace fossil assemblages exhibit bathymetric controls and display development of *Cruziana*-like ichnofacies characterizing subtidal conditions of depositional environment. The algal limestone band over the trace fossil horizon is interrupted by the ripple calcareous sandstone and characterized by *Maya* and *Helenae* Assemblage Zones of Early- Middle Oxfordian age.

Keywords: Trace fossils, Ichnoassemblage, Jurassic, Gangta Bet, Eastern Kachchh, India

INTRODUCTION

The Jurassic rocks of Kachchh are world famous for their rich megafaunal remains; however, it also shows preservation of rich and diversified trace fossils in both the clastic and nonclastic rocks (Shringarpure 1986; Kulkarni and Ghare 1989; Kulkarni and Borkar, 2000; Fürsich 1998; Patel *et al.*, 2008, 2009, 2010). The study area, Gangta Bet (N 23°46' and N 23°43' lat, E 70°30' and 70°33' long.), is a highly denuded domal structure of about 5 km in diameter, situated in the northwestern part of the Wagad Highland (Fig.1).

The rocks of Gangta bet is equivalent to the Bambhanka Member of the Khadir Formation and named as the Gangta member by Biswas (1977). The lower part of the Bambhanka member comprises sandstone similar to its underlying Gadhada sandstone member, which is differentiated on the basis of the important fossiliferous bands of the former member also well exposed in Gangta Bet.

The eastern parts of the Kachchh, particularly the Khadir Bela islands and Wagad Highland, have been studied for sedimentological (Mishra and Biswas, 2009), palaeontological (Moser *et al.*, 2006; Krishna *et al.*, 2009), stratigraphic (Biswas, 1977) and ichnological aspects (Shringarpure, 1986; Kulkarni and Ghare, 1989). However, the detailed sedimentological and ichnological analysis of the Gangta Bet succession has not yet been carried out. The main focus of the present study is to describe the taxonomy, ethology, and palaeoecological parameters of trace fossils along with the sedimentological aspects in order to infer the probable depositional environment of the Jurassic rocks of Gangta Bet.

METHODS AND MATERIALS

From the core of the Gangta dome, two different traverses were taken in the east and west directions. The rock types, type of contacts, lateral and vertical continuity and facies variations were studied in each bed and a generalized litholog was prepared (Fig.2). Moreover, the systematic sampling from the gently dipping younger strata of the Middle Jurassic succession, covering most of the Gangta Bet area was also carried out. The trace fossils were observed, photographed and recorded on the litho-sections. They were further studied for ichnoassemblage and ichnofacies analysis.

STRATIGRAPHY AND AGE

The Khadir Formation is subdivided into five members, viz., the Cheriya Bet Conglomerate Member, the Hadibhadang Shale Member, the Hadibhadang Sandstone Member, the Gadhada Sandstone Member and the Bambhanka/Gangta Member, in ascending order (Biswas 1977).

The Gangta Member comprises ~103 m thick sequence of fining upward ferruginous sandstone–shale intercalations overlain by calcareous sandstone-siltstone-shale intercalations and capped by the fossiliferous, ammonite rich limestone and shale sequence. Intraformational conglomerates containing elongated pebbles of mudstone and sandstones often occur with the sandstone units. The units representing the *Athleta* Assemblage zone (Late Callovian) and *Maya-Helenae* Assemblage Zones (Lower-Middle Oxfordian) are important marker horizons in Gangta Bet, which are comparable to various parts of the Mainland Kachchh (Prasad, 1998). A few beds of the Gangta Member are bioturbated and highly fossiliferous which are rich in body fossils (rhynchonellids, terebratulids, ammonites, bivalves, gastropods, belemnites, etc.).

FACIES ASSOCIATION

The term "facies" is used both in a descriptive and an interpretive sense in which the descriptive facies include certain observable attributes of the sedimentary rock bodies that can be interpreted in terms of depositional processes (Miall 1984). Based on the field observations and petrographic studies, eight facies associations, viz., ferruginous sandstone facies, shale facies, cross-bedded sandstone facies, sandy shale facies, conglomerate facies, intercalated calcareous sandstone-siltstone-shale facies, rippled mark sandstone facies, and limestone-shale facies, have been identified. A brief description of these facies is as follows:

Ferruginous Sandstone Lithofacies

This facies is about 2m thick succession exposed at core

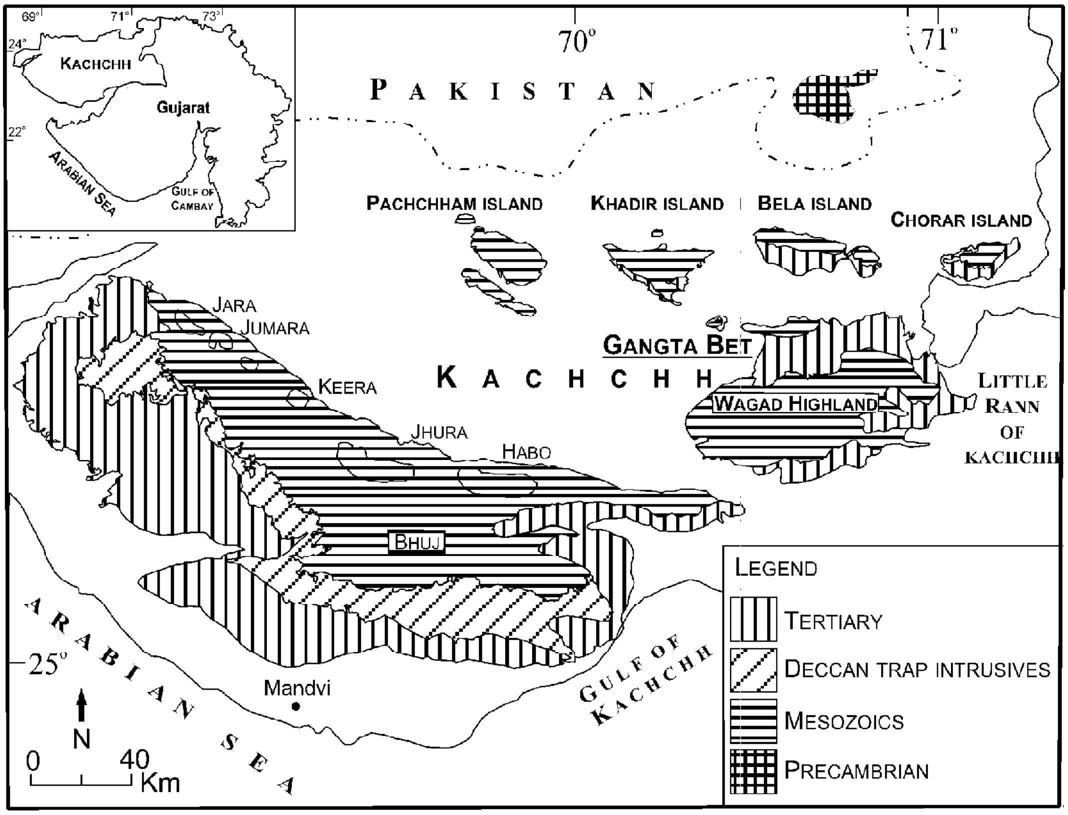

Fig. 1. Location map of the Gangta Bet area.

of the Gangta dome and comprises soft purple colored ferruginous sandstone with hard deep reddish brown ferruginous bands. These rocks contain moderately sorted, subangular to subrounded, medium to fine grains of quartz, microcline feldspar and a few grains of plagioclase, muscovite and rhomb-shaped dolomite, cemented in ferruginous matrix. Highly ferruginous nature and baking effects observed in this facies suggests a post-depositional hydrothermal activity in the sediments. Based on the framework grains, sorting, size, nature of contact and presence of abundant grains of feldspar which are otherwise highly susceptible to chemical weathering indicate a short travel distance and a rapid mode of deposition in a high-energy shallow marine environment.

Shale Lithofacies

This facies is characterized by green to grey coloured, non-bioturbated shale sequence occurring at two different stratigraphic levels, i.e. above the ferruginous sandstone facies and topmost part of the sequence which is gypseous in nature. The gypseous shale unit is green, grey and yellow in colour consisting of abundant flat, fibrous and long gypsum crystals along with evaporate vein deposits. The shale often contains silt-sized quartz grains, argillite and fragments of algae. The grey-green gypseous shale is generally considered to be deposited during the regressive phase in a sedimentary basin The fine grained nature of the facies and the gypsum content suggest that the sediments were deposited in quiet water or low wave and current energy in protected environment, e.g. lagoon. The predominant argillites with ferruginous layers, indicate that the deposition has taken place in shallow marine environment in reducing conditions. The well-developed gypsum crystals indicate detachment from the main sea and predominant evaporation (Hardie and Eugster, 1971).

Cross-Bedded Sandstone Lithofacies

This facies is characterized by ~5 meter thick light yellow coloured cross-stratified sandstone unit. Thin section studies show the rock fabric as that of typical calcareous sandstone; It consists of angular to subangular, moderately to well-sorted grains of quartz and microcline feldspar cemented in calcareous matrix; with calcite, dolomite, and ferruginous materials observed here and there. The cross-stratified nature of the facies indicates deposition of the sediments in high energy subtidal environment.

Sandy Shale Lithofacies

This facies is defined on the basis of predominance of arenaceous material over the argillaceous component in upper part of the succession. This facies is about 30 m thick and comprises intercalated, 1-2 m thick, buff coloured sandstone and shale beds. The thickness of the sandstone bed increases towards the upper part of the succession. The rocks of this facies comprises very fine to fine sand sized detrital quartz

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EXPLANATION OF PLATE I

1. ***Arenicolites*, *carbonarius*.** Endichnial paired burrow on bedding slab. Coin diameter = 2.6.
2. ***Chondrites targionii*** (Scale bar in cm)

3&4. ***Chondrits stellaris***. Coin diameter = 2.6 cms.
5. ***Cochlichnus anguineus***. Coin diameter = 2.6 cms.
6&7. ***Didymaulichnus lylelli***. Coin diameter = 2.6 cms.


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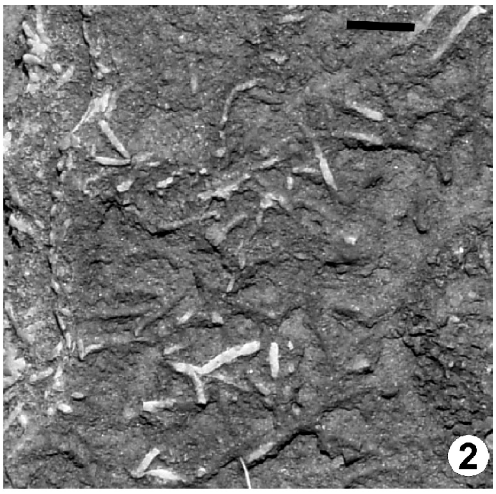
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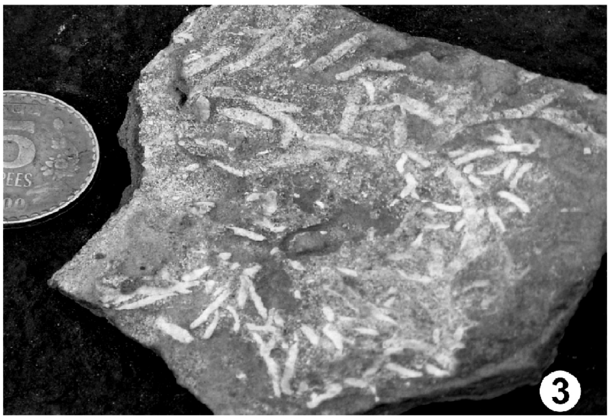
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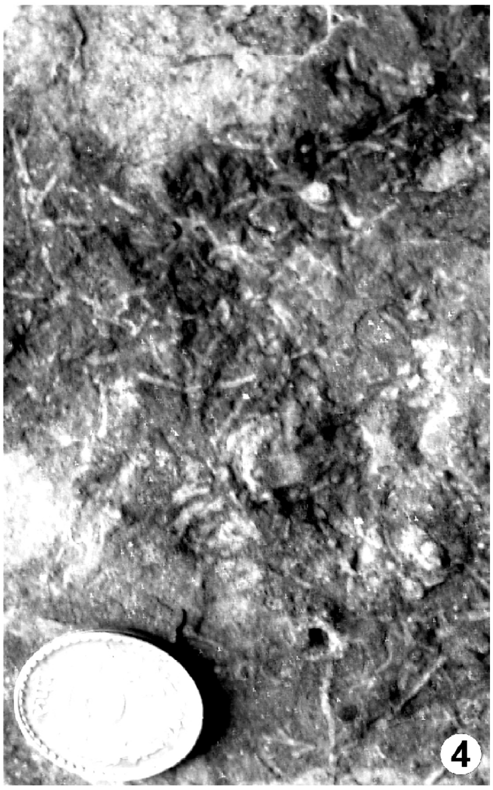
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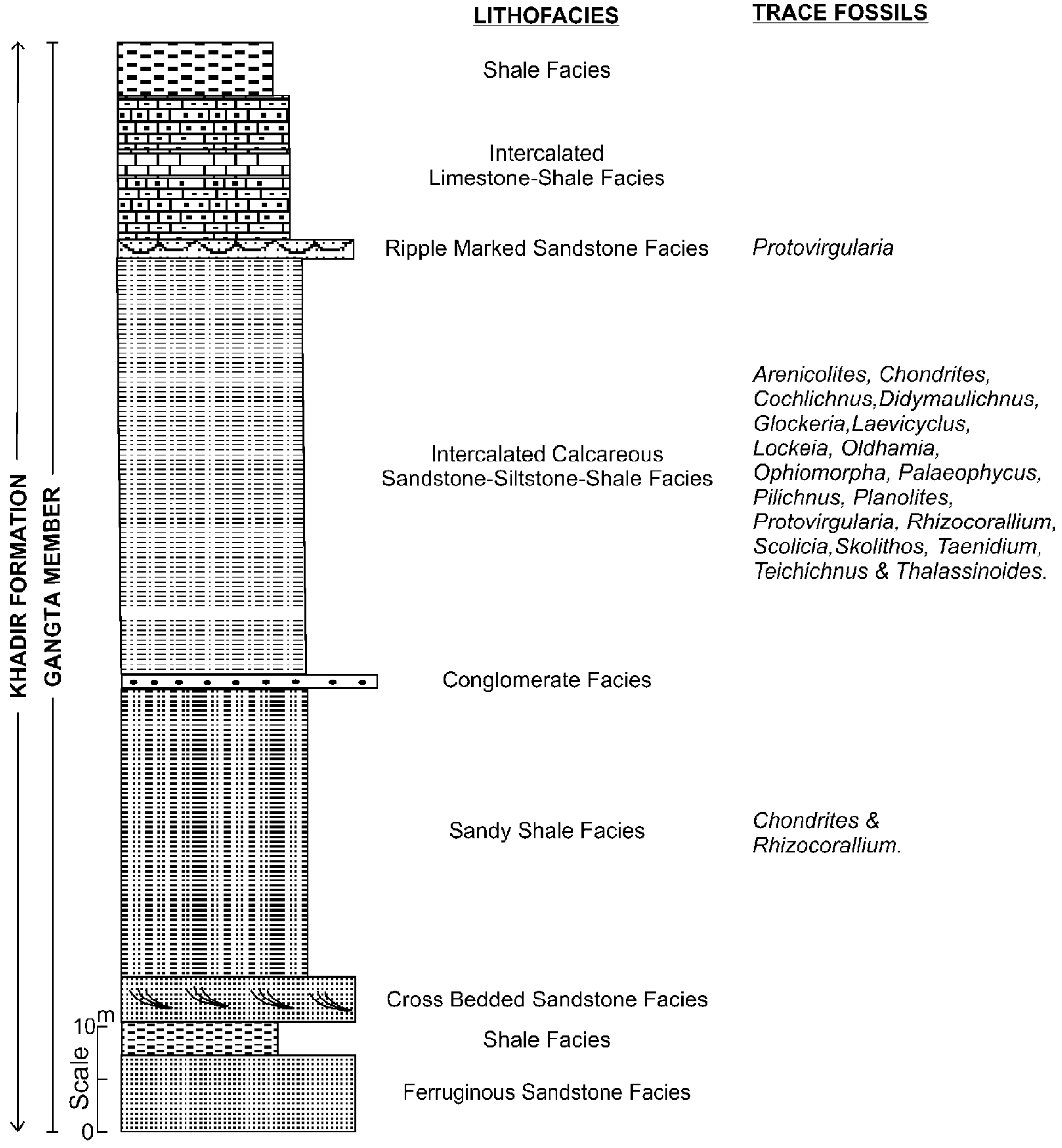

Fig. 2. Generalised litho-section of the Middle Jurassic rocks of the Gangta Bet.

grains with minor amount of feldspar and mica flakes embedded in clayey matrix. Primary sedimentary structures are scarce but a few trace fossils are found which includes *Chondrites, Rhizocorallium*, etc.

The sandy shale facies is capped by the bioturbation zones which indicate a period of quiescence when the organisms burrowed the surface. When compared with the observation of Selley (1970) and Miller and Knox (1985), the laminated shale-siltstone indicates deposition under low-energy conditions. The overall finer material of the facies indicates very slow settling of suspended material in a low energy regime (McCarthy, 1979).

Conglomerate Lithofacies

This facies is approximately one meter in thickness and consists of varying size (up to 3 cm.) of rock fragments, mud drapes, broken burrow tubes and scattered flat pieces of ferruginous materials. The clastic material of the intraformational conglomerate is matrix rich and compositionally and texturally very immature. It consists of different grades of sands, gravels and mud pebbles of either

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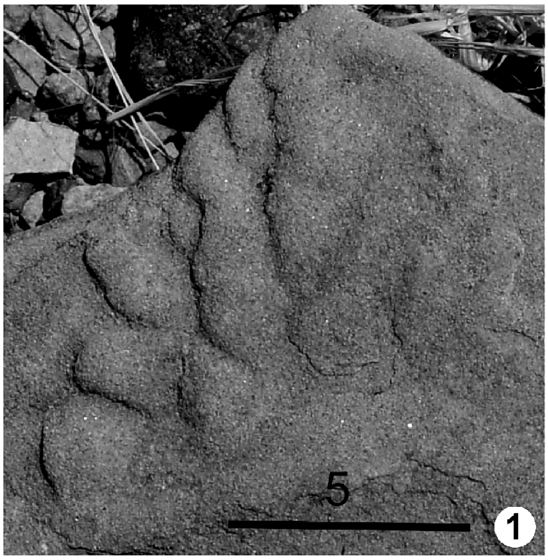
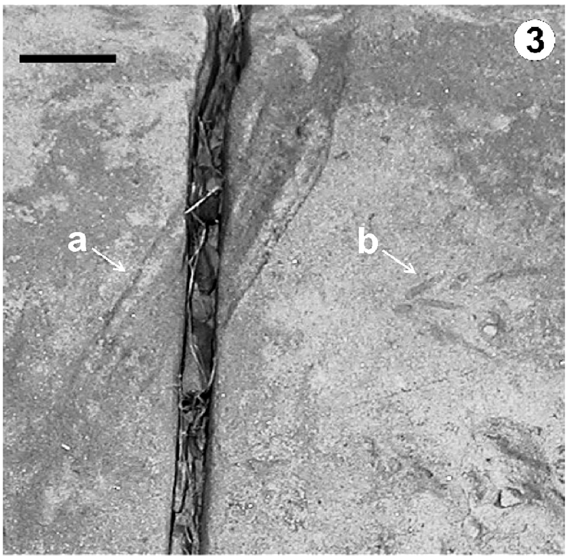
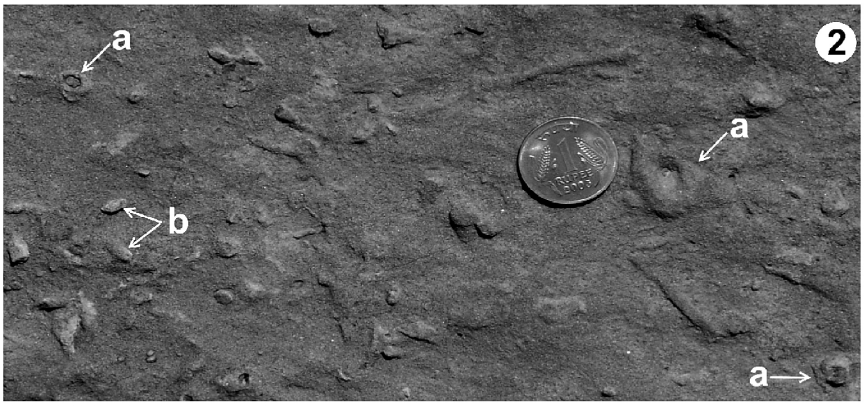
EXPLANATION OF PLATE II

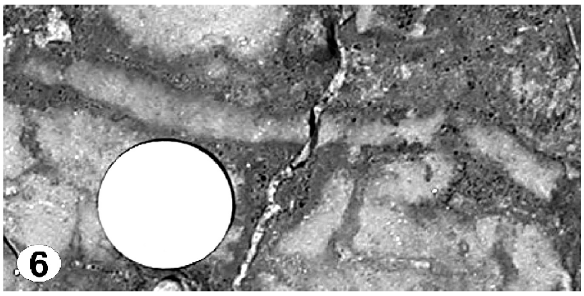
1. ***Glockeria*** isp. (Scale bar in cm)
2 (a). ***Laevicyclus mongraensis*** and (b) ***Lockeia amygdaloides.*** Coin diameter = 2.6 cms.
3 (a). ***Oldhamia*** isp. and (b). ***Chondrites*** isp. (Scale bar in cm)
4. ***Ophiomorpha irregular.*** (Scale bar in cm)
5. ***Palaeophycos tubularis.*** Coin diameter = 2.6 cms.
6. ***Palaephycus heberti.*** Coin diameter = 2.6 cms.
7. ***Pilichnus dichotoma.*** Coin diameter = 2.6 cms.

Plate II









older sediments or pencontemporaneous sediments of the deeper part of the basin which indicates erosion and redeposition of sediments during local storm conditions.

Intercalated Calcareous Sandstone-siltstone-Shale Lithofacies

This facies consists of hard, compact and yellowish to reddish coloured, highly bioturbated calcareous sandstone-siltstone layers intercalated with calcareous shale. Texturally, calcareous sandstone/siltstone appears to be moderately sorted, coarse grained to gritty sand/silt size quartz supported by micritic matrix. At places, quartz grains are coated by ferruginous or micritic materials. *Perisphinctes* ammonites are also observed. The facies is highly bioturbated and consists of a variety of trace fossils including *Arenicolites carbonarius, Chondrites stellaris, Chondrites targionii Cochlichnus anguineus, Didymaulichnus lyelli, Glockeria* isp., *Oldhamia* isp, *Palaeophycus heberti, Palaeophycus tubularis, Lockeia amygdaloides, Pilichnus dichotomous, Planolites montanus, Planolites beverleyensis, Protovirgularia dichotoma, Rhizocorallium jenense, Rhizocorallium irregulare,, Scolicia prisca, Skolithos verticalis, Taenidium, Teichichnus* and *Thalassinoides.*

Extensive burrowing indicates that the sandstones were deposited in normal marine salinity well below the fair weather wave base in shallow marine environment.

Ripple Marked Sandstone Lithofacies

This facies is represented by sandstone beds characterized by the wave symmetrical ripples on the top of the surface. These sandstone beds vary in thickness and show maximum thickness of 2.5 m. Trace fossils, e.g. *Protovirgularia dichotoma* are commonly observed with some indistinct crawling trails. Texturally, rocks of this facies consist of fine-grained, moderately to well sorted, subrounded detrital quartz grains, floating in a micritic matrix with subordinate amounts of glauconite and calcareous algae. The wave-rippled sandstone is probably deposited in near shore terrigenous settings.

Limestone-Shale Lithofacies

This facies is ~12 m thick and consists of intercalations of limestone and shale. The limestone units are dirty yellowish to light brown in colours and consist mainly of micritic material with abundant calcareous algae, fossil fragments, ooids and a few subangular to subrounded quartz grains. This facies is highly fossiliferous, consisting of abundant species of ammonites along with belemnites, bivalves (*Trigonia*), gastropods and brachiopods. The intercalated limestone-shale unit suggests low terrigenous sediment supply and low-energy regime. The presence of marine algae and body fossils (ammonites, belemnites and brachiopods) indicates well-lighted subtidal conditions.

DESCRIPTION OF TRACE FOSSILS

Total 27 ichnospecies of 19 ichnogenera are identified and are classified into five ethological groups as proposed by Seilacher (1953) viz., i).Cubichnia- *Lockeia amygdaloides;* ii). Repichnia- *Didymaulichnus lyelli, Scolicia prisca, Protovirgularia dichotoma, Protovirgularia* isp.; iii).Pascichnia- *Pilichnus dichotoma, Oldhamia* isp., *Cochlichnus anguineus, Glockeria* isp.; iv).Fodinichnia- *Rhizocorallium jenense, R. irregulare, Chondrites targionii C. stellaris, Chondrites* isp, *Planolites montanus, P. beverleyensis, Taenidium* isp. *Teichichnus rectus, Thalassinoides horizontalis, Thalassinoides suevicus, Thalassinoides* isp; and v). Domichnia- *Arenicolites carbonarius, Laevicyclus mongraensis, Skolithos verticalis, Ophiomorpha irregularie, Paleophycus heberti,* and *P. tubularis*. The details about the same are as follows:

Ichnogenus ***Arenicolites*** Salter, 1857

Ichnospecies: *Arenicolites sparsus* Salter, 1856

(Pl. I, fig.1)

Description: Simple, vertically oriented, U-shaped, endichnial, paired burrows; visible as paired circular openings on the bedding surface. Collapse structures are very common but at places burrow fill material is identical to the host sediments. Burrow diameter is about 0.2-0.4 cm and burrow arms are about 0.3 cm apart.

Remarks: The specimen is differentiated from the rest of the ichnospecies of the *Arenicolites* by the characteristic simple, regular U-shaped burrow having vertical limbs and lacking a thick lining (Salter, 1856; Rindsberg and Kopaska-merkel, 2005). In the study area, *Arenicolites sparsus* occurs with *Skolithos verticalis* in intercalated calcareous sandstone-shale facies. *Arenicolites* is interpreted as a dwelling burrow of suspension feeding polychaetes (Fillion and Pickerill, 1990) or small crustaceans (Pemberton *et al.*, 2001) in marine environments.

Ichnogenus ***Chondrites*** von Stornberg, 1833

Regularly branching tunnel systems consisting of a small number of mastershafts open to the surface, which ramify at depths to form a dendritic network (after Osgood, 1970; Fursich, 1974)

Remarks: *Chondrites* is a well-established genus and is generally easily recognized and understood but it contains so many species that it is difficult to determine its synonyms. More than 170 species of *Chondrites* have been named (Chamberlain, 1977). Fu (1991) has revised the ichnogenus *Chondrites* and distinguished four ichnospecies viz., *C. targionii, C. intricatus, C. patulus* and *C.recurvus. Chondrites* are thought to be produced by a variety of organisms such as siphunculids (Simpson, 1957), polychaetes (Schäfer, 1972), anthoptiloid, sea pens and arthropods (Pickerill *et al.*, 1984). On the basis of branching patterns two ichnospecies have been identified.

Ichnospecies: *Chondrites targionii* Brongniart, 1828

(Pl. I, fig.2)

Description: Endichnial, full relief, slightly winding, branched burrow. Specimens are characterized by primary successive branching, branches are slightly curved and mostly parallel to bedding planes. The angle of branching is about 45^0 which are usually sharp and dominated by second-order branches. The diameter of the tunnels is almost constant and

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EXPLANATION OF PLATE III

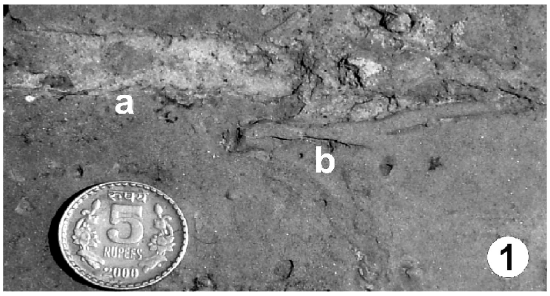
1. (a) ***Palaeophycus tubularis*** and (b) ***Planolites beverleyensis*** Coin diameter = 2.6 cms.
2. ***Planolites beverleyensis***. Coin diameter = 2.6 cms.
3. ***Planolites. montanus***, Coin diameter = 2.6 cms.
4. ***Protovirgularia dichotoma***. (Scale bar in cm)

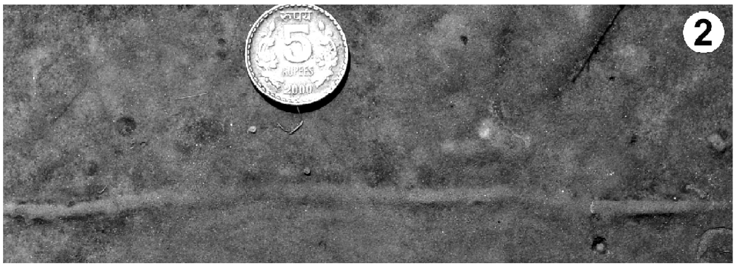
5-6. ***Protovirgularia*** isp. (Scale bar in cm)

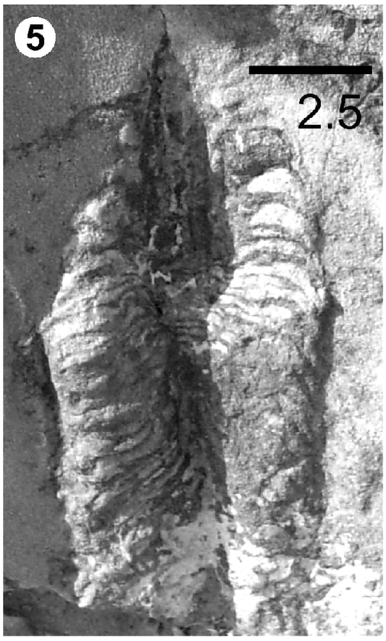
7-8. ***Rhizocorallium jenense***. Coin diameter = 2.6 cms.

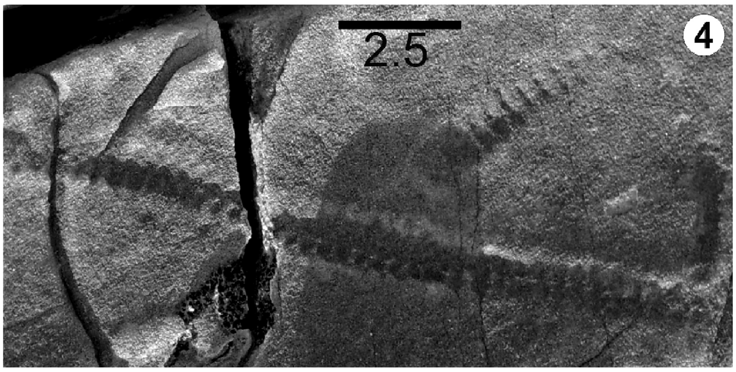
9. ***Rhizocorallium irregulare***. Coin diameter = 2.6 cms.

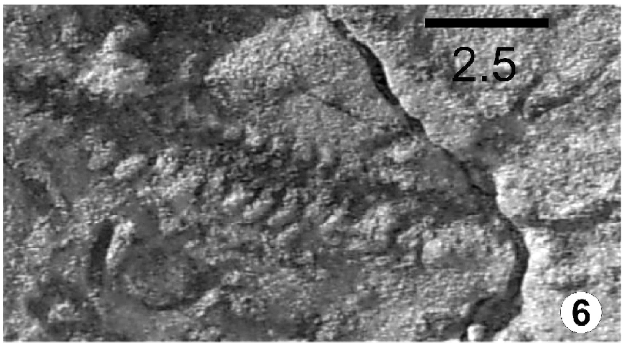
Plate III











ranges between 0.3 and 0.5 cm. Burrow fill is lighter in colour than the host sediments.

Remarks: *C. targionii* specimen differs from the other described ichnospecies of *Chondrites* in the stout nature of tunnels. According to Seilacher (1990) and Fu (1991), the trace maker of *Chondrites* may be able to live at the aerobic/anaerobic interface as an chemo-symbiotic organism. It is associated with *Planolites* and *Palaeophycus* and occurs in the intercalated calcareous sandstone-shale facies.

Ichnospecies: *Chondrites stellaris* Uchman, 1999
(Pl. I, figs. 3-4)

Description: Endichnial, short, straight, dichotomously branched tunnels which are tapering distally. The tunnels are 0.1 to 0.3 cm wide and up to 2 cm long. The whole trace fossil is up to 30 mm across. Angle of branching is acute, less than 45°. Burrows are filled with dark argillaceous material, different from the host sediments and display only second-order branches which occur in intercalated calcareous sandstone - shale facies.

Remarks: The size of the tunnel and overall burrow dimension is lesser than the other *Chondrites* ichnospecies described by Fu (1991). The producer of the burrow may be unsegmented worm-like siphunculids (Simpson, 1957) or polychaete (Schäfer, 1972).

Ichnospecies: *Chondrites* isp.
(Pl. II, fig. 3b)

Description: Endichinal, full relief, tree-like branching tunnels, downward penetrating, and tapering distally. Length of the tunnel varies from 2 to 3 cm and is about 0.1-0.2 cm wide. Angle of branching is less than 45^0. The burrow fill material is darker than the host sediment and associated with *Oldhamia,* it occurs in thin calcareous sandstone bands of the intercalated calcareous sandstone-shale facies.

Remarks: *Chondrites* isp. is characterized by fine, tapering, acute angle of branching tunnels. Fu (1991) mentioned a variety of organisms as possible producer of *Chondrites*: siphunculids, polychaetes, arthropods, bivalves, or nautilaceans and considered worms to be the most likely producers.

Ichnogenus ***Cochlichnus*** Hitchcock, 1958
Ichnospecies: *Cochlichnus anguineus* Hitchcock, 1958
(Pl. I, fig. 5)

Description: Sinuous trails, preserved in convex hyporelief, sediment fill identical to host rock. Maximum length is about 9.6 cm; diameter is constant throughout being 0.2 cm. amplitude of the sine curve is 0.35 cm to 0.4 cm; wavelength of 3.6 cm to 4.0 cm. Single specimen was collected from the intercalated calcareous sandstone - shale facies which is associated with *Chondrites* and *Scolicia*.

Remarks: There are three recognized ichnospecies of *Cochlichnus* namely, *C. anguineus* Hitchcock, *C. kochi* Ludwig and *C. serpens*. The definition and differentiation in the literature by Webby (1970) is confusing and can best be regarded as conspecific. The Kachchh specimen probably represents the mould of a burrow which is identical to the one described as *C. anguineus* burrows by Webby (1970). According to Eager *et al.* (1985), *Cochlichnus* is a crawling trace and probably feeding structures of small worms or worm like animals. *Cochlichnus* has been also reported in the sediments of supposedly low salinity paleoenvironment (Hakes 1976).

Ichnogenus ***Didymaulichnus*** Young, 1972
Ichnospecies: *Didymaulichnus lyelli* Young, 1972
(Pl. I, figs. 6-7)

Description: Long, straight, epichnial gently curved trail consisting of two distinct lobes separated centrally by very narrow median furrow. Surfaces of lobes are smooth to slightly undulatory and parallel to bedding plane. The trace is 0.4 cm wide and 0.4 cm deep and extends for over 30.0 cm, in some specimens traces commonly crossing and occurring in profusion on bedding planes.

Remarks: *Didymaulichnus* is generally regarded as surface trails probably of molluscs (Hakes, 1976) and are also regarded as of shallow water origin. It is usually found with *Planolites* in intercalated calcareous sandstone-shale facies.

Ichnogenus ***Glockeria*** Ksiazkiewicz, 1968
Ichnospecies: *Glockeria* isp.
(Pl.II, fig. 1)

Description: Horizontal, convex, epichnial structure, spread out in circular fashion with numerous long, straight to slightly sinuous radiating tunnel from the central area. Maximum observed length of rays is 6 cm and width is of 0.2-0.3 cm. Burrow fill is similar to host sediments and found in the thin medium-grained sandstone layer of the intercalated calcareous sandstone-shale facies.

Remarks: *Glockeria* is post depositional feeding burrows of polychaete that worked along the sediment-sediment interface, excavating horizontally by extensible proboscis and subsequently filling them by "waste stowing" (Schafer,1972).

Ichnogenus ***Laevicyclus*** Quenstedt, 1879
Ichnospecies: *Laevicyclus mongraensis* Chiplonkar and Badve, 1970
(Pl.II, fig. 2a)

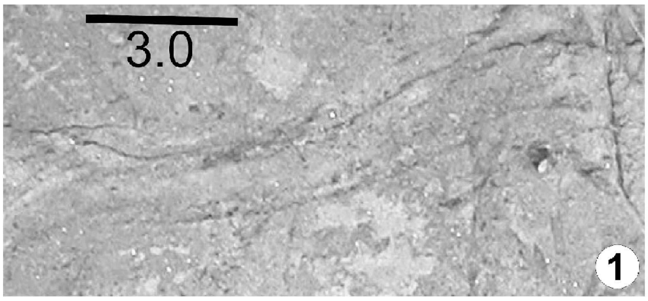
Description: Endichinal, full relief; vertical, cylindrical burrow standing right to bedding plane. It appears as circular bodies with central shaft and surrounded by concentric rings; maximum outer diameter is about 0.7 cm; shaft diameter is of 0.4 cm; visible on bedding plane as regular 1-2 concentric rings.

Remarks: *L. mongraensis* is reported from the Cretaceous of the Bagh beds (Chiplonkar and Badve, 1970) and the Jurassic rocks of the Habo dome (Patel *et al*., 2008). However, *L. mongraensis* is also reported from the deep water flysch deposits, and is considered to be the circular trace of suspension feeding animals (Uchman, 1995).

Ichnogenus ***Lockeia*** James, 1879
Ichnospecies: *Lockeia amygdaloides* Seilacher, 1953
(Pl.II, fig. 2b)

EXPLANATION OF PLATE IV

1. ***Scolicia prisca*** (Scale bar in cm)
2. ***Skolithos verticalis*** Endichnial, appeared as circular opening or as raised cylindrical tube. Coin diameter = 2.6 cms.
3. ***Skolithos. verticalis*** stepply inclined burrows in sandstone Coin diameter = 2.6 cms.
4. ***Taenidium*** isp. (Scale bar in cm)
5. ***Teichichnus*** Coin diameter = 2.6 cms.
6. ***Thalassinoides horizontalis*** (Scale bar in cm)
7. ***Thalassinoides suvevicus*** Coin diameter = 2.6 cms.
8. a. ***Thalassinoides*** isp. and b. collapsed burrow of *Thalassinoides*. isp. (Coin diameter = 2.6 cms.)



1

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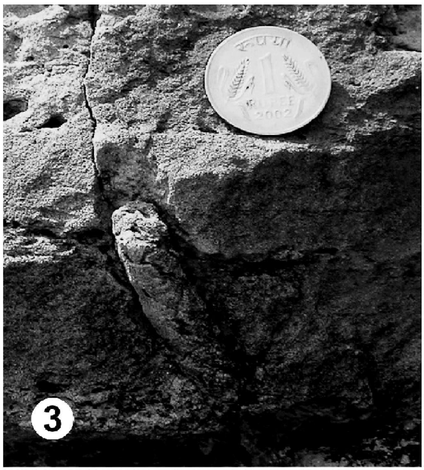

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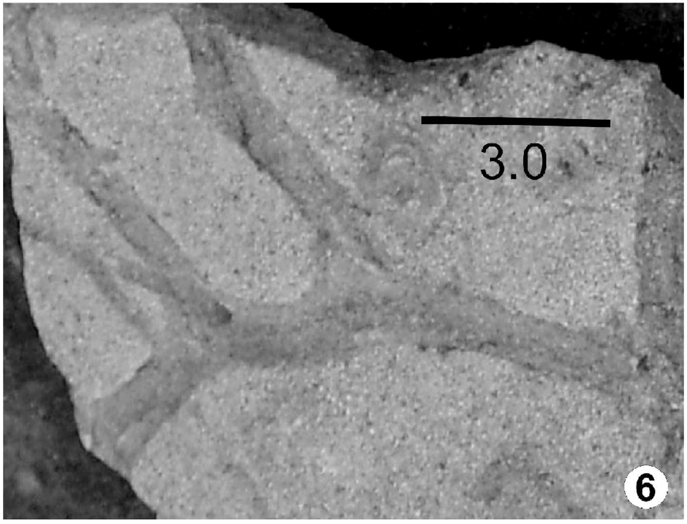

6

7

8

Description: Small, almond-shaped or oblong protuberances on bedding planes; tapering to sharp and obtuse points at both ends; surface commonly smooth; maximum observed length is 2.5cm and width varies from 0.3-0.5 cm, maximum being around the centre. Burrow fill is identical to host sediment and preserved as positive hyporelief in the intercalated calcareous sandstone-shale facies.

Remarks: *Lockeia amygdaloided* is distinguishes from *L. sillquaria* by having stout, almond-shape features (Seilacher, 1953). The trace fossil is interpreted as the resting trail of small burrowing bivalve or semi-sessile forms (Seilacher, 1953; Bromley, 1996).

Ichnogenus ***Oldhamia*** Forbes, 1849

Ichnospecies: *Oldhamia* isp.

(Pl.II, fig. 3a)

Description: The Kachchh specimen of *Oldhamia* contains radiating bunch of fine rills or fine, elongated linear grooves, normally 6.5 cm in length. Laterally, terminal rills are producing acute angles. Rills are attached to the straight or curved sympodial axis, only 1.0 to 6.0 cm in length, commonly made up of a single rill (linear depressions), but sometimes partially showing 2-3 rills. Bunch of rills may be found attached to only one end. Burrow fills occur as positive epirelief and associated with *Scolicia* and *Chondrites* of the intercalated calcareous sandstone-siltstone-shale facies.

Remarks: *Oldhamia* is interpreted as radiating feeding trails supposedly made by worms (Ruedemann, 1942) which typically occur in the turbidite sequence but is also reported from the shallow water (Zamarreńo *et al*., 1975).

Ichnogenus ***Ophiomorpha*** Lundgren, 1891

Ichnospecies: *Ophiomorpha irregulare* Frey, Howard and Pryor, 1978

(Pl.II, fig. 4)

Description: The burrow is straight, horizontal and oval in cross-section, wall consists predominantly of sparse, irregularly distributed, ovoid to mastoid pellets; 22.6 cm in length and 2.3 to 2.8 cm in diameter. Outer wall is covered with irregular wall lining with drawn-out flame structures, evidently reflecting soft-sediment deformation of the muddy wall lining.

Remarks: *O. irregulare* is considered to be a dwelling structure of the suspension feeding crustaceans and ranges from Permian to Recent (Frey *et al*., 1978). It shows much irregular wall structures as compared to *O. nodosa* and *O. borneensis* (Frey *et al*., 1978). *Ophiomorpha* occurs predominately in shallow-water near-shore deposits (Weimer and Hoyt, 1964; Frey *et al*., 1978; Patel and Desai, 2001, 2009).

Ichnogenus ***Palaeophycus*** Hall, 1847

Ichnospecies: *Palaeophycus tubularis* Hall 1847

(Pl.II, fig. 5; Pl. III, fig. 1a)

Description: Cylindrical to slightly flattened, straight to slightly curved, more or less smooth-walled burrow, parallel or slightly oblique to the stratifications. Branching is rare, burrow walls are irregular and the burrow fill is structureless and identical to host rock. Burrow collapse structures are also very common, representing incomplete filling of sediments. Width and length of the burrow tubes are variable in different burrow populations. The burrow shows about 13.2 cm length and diameter of 1.25 cm. Burrow preserved as endichnial and hypichnial at various levels in the intercalated calcareous sandstone-shale facies.

Remarks: *P. tubularis* is distinguished from *P. heberti* by the consistently thicker wall lining of the latter and from other species by the absence of persistent well-developed striae (Pemberton and Frey 1982).

Ichnospecies: *Palaeophycus heberti* Saporta 1872

(Pl.II, fig. 6)

Description: Straight, unornamented, slightly curved unbranched, smooth-walled, lined cylindrical burrows. Diameter of the burrow varies in the given specimens and it is in the range of 0.83 to 1.1 cm and length of the burrow is 12 cm, collapsed burrows are also common. Burrow wall linings typically consist of agglutinated sediment, coarser and better seated than that of adjacent host rock. Burrow fill is structureless and preserved as endichnia and hypichnia.

Remarks: Original specimens of *Palaeophycus heberti* were assigned initially to the ichnogenus *Siphonites* (Saporta 1872), although their affinity with *Palaeophycus* was noted subsequently (Saporta and Marion, 1883). Pemberton and Frey (1982) confirm *Siphonites* as a junior synonym of *Palaeophycus*. It is associated with *Rhizocorallium, Skolithos,* and *Planolites* and occurs in the intercalated calcareous sandstone-shale facies.

Ichnogenus ***Pilichnus*** Uchman, 1999

Ichnospecies: *Pilichnus dichotoma* Uchman, 1999

(Pl.II, fig. 7)

Description: Small, horizontal branch system, straight or curved to irregularly winding, unlined branched strings, preserved as epichnial or endichnial, semi or full-relief on parting surfaces of calcareous sandstone. The length of branched strings is variable, diameter of strings varies from 0.2-0.63 cm. Dichotomous Y-shaped branches are most common and very characteristic. T-shaped branches also occur. When crowded, trace fossil may also occur in regular nets. Burrow fill with argillaceous material and occurs with *Planolites* and *Palaeophycus* in the intercalated calcareous sandstone-shale facies.

Remarks: This form is very thin and differs from a similar type of ichnogenus *Trichichnus,* in the horizontal orientation of burrows. When crowded, it appears as irregular nets (Uchman, 1999).

Ichnogenus ***Planolites*** Nicholson, 1873

Ichnospecies: *Planolites beverleyensis* Billing 1862

(Pl.III, fig. 1b-2)

Description: Irregular, cylindrical, sinuous or undulose small horizontal burrows preserved as endichnial or hypichnial ridges. Burrow length and diameter more or less constant but in some cases it slightly shows small-scale variation. True-branching is relatively rare; horizontal erosional truncation of vertically or obliquely oriented segments gives appearance of knobby bedding surface. Burrow fill consists of cleaner, better sorted sediments compare to the host sediments. Dimension varies from different burrow populations. Length of burrow varies from 6.8 to 18 cm and diameter of 0.3 to 0.4 cm.

Remarks: *Planolites beverleyensis* is exceptionally long and usually lacks burrow lining. It is generally regarded as the pascichnia, product of vermiform deposit feeders actively back-filling its burrow (Uchman, 1995). It is found in the intercalated calcareous sandstone-siltstone-shale facies.

Ichnospecies: *Planolites montanus* Richter, 1927

(Pl.III, fig. 3)

Description: Predominantly cylindrical, smooth-walled, straight to gently curved or undulate, unbranched burrow, typically oriented more or less parallel to bedding plane. Burrows occur as single isolated specimens to crowded masses in which crossovers interpenetrations and reburrowed segments are common. Length of burrow is 5.0 cm and diameter range of 0.5 cm to .0.75 cm. It is preserved as endichnial, hypichnial ridges and epichnial grooves in the intercalated calcareous sandstone-siltstone-shale facies and is commonly associated with *Skolithos* and *Chondrites.*

Remarks: *P. montanus* is consistently smaller in size and more tortuous in appearance which distinguishes it from *P. beverleyensis* (Pemberton and Frey, 1982).

Ichnogenus ***Protovirgularia*** M'Coy, 1850

Ichnospecies: *Protovirgularia dichotoma,* M'Coy, 1850

(Pl.III, fig. 4)

Description: Horizontal to subhorizontal, straight to slightly curved, bilobed trace withing median groove from where paired, lateral, wedge-shaped appendages originate. The diameter of the burrow is variable in single specimen and trapezoid to heart-shaped in cross section. The length of burrow is of 15.4 cm and width varies from 0.8 to 1cm, lateral appendages are almost normal to the median ridge or furrow. It is preserved as positive epirelief in the ripple marked sandstone facies.

Remarks: The wedge-shaped appendages on either side of the median groove distinguish this genus from *Gyrochorte.* The trace is generally made by annelids (Schlirf, 2000).

Ichnospecies: *Protovirgularia* isp.

(Pl.III, figs. 5-6)

Description: Horizontal to subhorizontal, straight to slightly curved, bilobed trace with a median furrow from where paired, lateral, obliquely aligned pads of sediment are arranged. The width of the burrow is usually constant and being of about 1 to 3 cm and length varies from 13 to 20 cm and trapezoid to heart-shaped in cross section. It is preserved as negative epirelief on the ripple marked sandstone facies.

Remarks: *Protovirgularia* isp. is characterized by paired, lateral oblique pads of sediments and is distinguished from *P. dichotoma,* which is usually characterized by the wedge-shaped appendages on either side of the median groove.

Ichnogenus ***Rhizocorallium*** Zenker, 1836

Ichnospecies: *Rhizocorallium jenense* Zenker 1836

(Pl.III, fig. 7-8)

Description: Long, straight to sinuous, horizontal to sub-horizontal, unbranched U-shaped spreiten burrows with tube clearly distinct from spreite section. The tubes are filled with fine to medium-grained sediments. Usually each arm of the tubes is up to 2 to 5 cm apart and 19 cm in length. The diameter of the tube is about 0.8 cm; spreiten commonly are 0.25 cm thick. The isolated occurrence of the burrows is common but crowded form appears to be overlapping and showing cross-cutting relationships. It is preserved as full relief and filled materials are identical to the host rock.

Remarks: The Kachchh specimen *R. jenense* is a long and straight to somewhat sinuous form generally interpreted as deposit-feeders burrows. Similar forms were interpreted by Fürsich (1974) as the burrow of deposit feeding animals mining nutrient-rich sediment on the rippled top. Faint scratch marks on the burrows of the Kachchh specimen indicate that the animal may have been a deposit feeding crustacean. Such an observation is also made by Seilacher (1967a) and Crimes (1975). It is associated with *Palaeophycus, Planolites, Ophiomorpha, Arenicolites, Skolithos,* and *Lockeia* found in the intercalated calcareous sandstone-siltstone-shale facies.

Ichnospecies: *Rhizocorallium irregulare,* Mayer, 1954

(Pl.III, fig.9)

Description: Epichnial, semi-relief, long, horizontal, more or less sinuous to curved, bifurcating U-shaped spreiten burrows. The burrow is branched at 90^0 and the structure consists of partial preservation of two parallel marginal tubes. The tubes are parallel, except the point at bifurcation. Tubes are circular to oval in cross sections with maximum diameter of 1.0 cm. The distance between the two arms varies from 4.5 to 6.0 cm maximum, observed length is 30.0 cm. The spreiten and burrow tubes fills are identical to the host rock and found in the intercalated calcareous sandstone-siltstone-shale lithofacies.

Remarks: *R. irregulare* differs from *R. jenense* in having very long, branched and curved tubes. The tubes are parallel with interven asymmetrical protrusive spreiten. The burrow is interpreted as infaunal deposit-feeding crustaceans by Fürsich (1974), while Seilacher (1967a) suggests that the animal used the spreiten technique for efficient exploration of sediment in search for food.

Ichnogenus ***Scolicia*** De Quartrefages, 1849

Ichnospecies: *Scolicia prisca,* De Quartrefages

(Pl.IV, fig.1)

Description: Epirelief traces are represented by highly variable exogenic trails, usually highly flattened, ribbon-like, trilobate trail. The trail is about 15 cm in length and consists of broad ribbon-like lobe at centre (1 cm wide) and two marginal parallel lobes (0.5 cm wide) separated by a furrow.

Remarks: *Scolicia* has been attributed to the creeping or feeding activities of gastropods (Ksiazkiewicz, 1977) or burrowing echinoids (Smith and Crimes 1983). *Scolicia* is a eurybathic trace fossil and has been reported in the strata of Early Cambrian (Crimes and Anderson 1985) to Holocene (Kitchell and Clark 1979) age. It is associated with *Oldhamia* isp., *Chondrites stellaris* and found in the intercalated calcareous sandstone-siltstone-shale lithofacies.

Ichnogenus ***Skolithos*** Haldeman, 1840

Ichnospecies: *Skolithos verticalis* Haldeman 1840

(Pl. IV, figs. 2-3)

Description: Cylindrical to sub-cylindrical, vertical to steeply inclined unbranched burrows having distinctly or indistinctly annulated walls. The depth of the burrows varies from 3 to 7 cm with the diameter of about 0.9 to 1.1 cm. Burrow occur as crowded or widely spaced circular rim structures the on bedding plane. Endichnial burrow preserved as full relief in the intercalated calcareous sandstone-siltstone-shale lithofacies.

Remarks: *S. verticalis* has rough, annulated burrow walls. It is widely recognized in the shallow water, intertidal deposits (Seilacher, 1967b) and in various shallow marine environments (Fillion and Pickerill, 1990; Alpert, 1974) and is probably thought to be produced by annelids or phoronids (Alpert, 1974).

Ichnogenus ***Taenidium*** Heer 1877

Ichnospecies: *Taenidium* isp.

(Pl. IV, fig.4)

Description: Preserved as endichnial, horizontal, unbranched, straight to gently curved, cylindrical tubes fill with lighter material as compared to host sediment. It consists of symmetrically arranged distinct transverse annulations. Burrow is 11.0 cm in length, diameter vary from 1.3 to 2.3 cm and consists of 0.5 cm wide transverse annulations. Burrow also shows dark and light coloured pelleted fill material arranged in meniscate forms.

Remarks: Taenidium has been reported from the Mesozoic and Cenozoic flysch of Europe by Heer, 1877 and from the Ouachita Mountain (Ordovician) by Chamberlain (1971). The cylindrical burrow exhibits typical active fill of fine grained faecal material lighter in colour than the surrounding, which passed through the gut (Fürsich, 1974). These burrows are associated with *Planolites* and occur in the fine grained sandstone band of the intercalated calcareous sandstone-siltstone-shale facies.

Ichnogenus ***Teichichnus*** Seilacher, 1955

Ichnospecies: *Teichichnus rectus* Seilacher, 1955

(Pl. IV, fig.5)

Description: Horizontal to slighty inclined burrows, slightly sinuous in plan view, distinctly lined, consisting of thick spreiten. Burrow consists of thick, gutter-shaped laminae that form wall structures. Laminae predominantly retrusively arranged; terminals of burrow tubes rarely preserved. Total burrow height is of 6 cm, burrow width 4 cm and length of the burrow is 17 cm. Endichnial burrow preserved as full relief and fill is identical to the host sediments.

Remarks: The burrow has slightly sinuous course in plan view and consists of thick gutter-shaped biogenic laminae which shift upward and terminate distally forming blunt end. It is interpreted as the burrow of a deposit feeding animal (Seilacher, 1955).

Ichnogenus ***Thalassinoides,*** Ehrenberg, 1944

Ichnospecies: *Thalassinoides horizontalis* Myrow, 1995

(Pl.IV, fig. 6)

Description: Endichnial burrow preserved as full relief, predominately horizontal, smooth walled, cylindrical and more or less regularly branched (Y/T shaped), with bedding parallel oriented network, absence of vertical oriented offshoots from polygon framework and nearly constant diameter. Tunnels are straight to curved and 0.6-1.0 cm in diameter. Burrows chiefly consist of horizontal tunnels that bifurcate at an angle of 95^0-125^0.

Remarks: *T. horizontalis* differs from other ichnospecies in lacking the vertical component (Myrow, 1995) and occurring underneath the bedding plane. The presence of scratch marks on the burrow surface indicates that the decapod some crustaceanj is producer of the burrow.

Ichnospecies: *Thalassinoides suevicus* Reith, 1932

(Pl. IV, fig.7)

Description: Endichnial, full relief, horizontal to slightly oblique, three-dimensional regularly branched burrow system, length varies from 9 to 12 cm and diameter from 1.5 to 2 cm. Dichotomous bifurcations are more common than T-shaped branches (Howard and Frey. 1984). The burrow fill (colour and texture) is different than the surrounding sediment.

Remarks: *Thalassinoides* is a facies-crossing form, most typical of shallow marine environment, and is produced mainly by crustaceans (Frey *et al*., 1984). *T. suevicus* differs from the *T. horizontalis* in the sence that the former consists of subhorizontal burrow tubes.

Ichnospecies: *Thalassinoides* isp.

(Pl. IV, fig. 8a-b)

Description: Endichnial irregular branched burrow, with collapsed branches very commonly spread on the bedding plane. The arms are slightly curved to sinuous. Bifurcation occurs at short distances and burrows show swelling/ enlargement at the points of bifurcation. Burrow diameter ranges from 0.4 to 0.7 cm and more than 1.3 cm at the point of bifurcation. Burrow preserved as hypichnial ridges and fill is identical to host sediments.

Remarks: This ichnospecies differs from the other described ichnospecies of *Thalassinoides* in general morphology, i.e. sinuous nature, variable diameter, and thinning of the burrow towards the distal end.

TRACE FOSSIL ASSEMBLAGES

The intercalated calcareous sandstone-siltstone-shale facies and ripple marked sandstone facies of the Gangta Member consist of number of highly bioturbated sandstone-siltstone layers. These layers show single ecologically related group of trace fossils which demonstrates six trace fossil assemblages *Chondrites* assemblage, *Rhizocorallium* assemblage, *Planolites* assemblage, *Palaeophycus* assemblage, *Protovirgularia* assemblage and *Skolithos* assemblage. Each assemblage is named after its most dominat trace fossil and is described as below.

Chondrites **Assemblage**

This assemblage is characterized by *Chondrites* associated commonly with *Planolites* and occasionally with *Oldhamia* found in the argillaceous and ferruginous sandstone bands of the Intercalated Calcareous Sandstone-Siltstone-Shale Facies. *Chondrites* represents a regularly branched burrow system constructed by endobenthic deposit feeding organisms of unknown taxonomic affinity, where the burrows are emplaced well below the water-sediment interface. The nature of burrow structures indicates that the burrow was kept open by its inhabitant and has later filled passively with sediment from above. The *Chondrites* is indicative of very low oxygen levels in the interstitial waters within the sediment at the site of burrow emplacement (Bromley and Ekdale, 1984). Thus, poor oxygen conditions influence the distribution of *Chondrites* making organisms much more distinct.

Rhizocorallium **Assemblage**

This association consists of *Rhizocorallium jenense* and *R. irregulare* associated with *Planolites, Palaeophycus* and *Thalassinoides.* The trace makers of this association are shallow, burrowing deposit feeders found in fine to medium-grained calcareous sandstone. Development of *Rhizocorallium* ichnoassemblage is thought to be low energy in subtidal conditions well below the fair weather wave base and above the storm level. *Rhizocorallium jenense* indicates high energy conditions (Fürsich, 1975) and a high concentration of nutrients that is probably related to storms (Rodriguez-tovar and Pérez-valera, 2008), while *R. irregularre* indicates low-energy conditions and a comparatively organic-poor sediments (Rodriguez-tovar and Pérez-valera, 2008). *Rhizocorallium* assemblage of the Gangta Bet indicates that animal has also possible been a sediment feeding mode of life in the well lighted, oxygenated conditions in the subtidal zone.

Planolites **Assemblage**

This assemblage is mainly dominated by sediment-feeding traces of *Planolites* with occasional occurrence of indistinct crawling traces. The dimension (length 3-23 and diameter 0.8 to 1.3 cm) of *Planolites* varies in different burrow populations.. As postulated by Frey and Pemberton (1985), the *Planolites* traces appears to have been produced by the burrowing activities of large and small organisms over a broader range of depth in the substrates. *Planolites* assemblage characterizes low-energy conditions, colonized by deposits feeders like polychaete (Rodriguez-tovar *et al*., 2011) and also by mobile carnivores, omnivores and suspension feeders (Pemberton et al, 1992).

Palaeophycus Assemblage

This assemblage mainly consists of *Palaeophycus, Planolites, Rhizocorallium, Taenidium, Thalassinoides* and *Cochlichnus* but it also occurs as monodominant in some calcareous sandstone layers. This assemblage indicates subtidal conditions normally below daily wave base but not below the storm wave base. Predominance of feeding and grazing traces suggests low energy condition, less abrupt shifting sediments and normal salinity; their higher diversity is also indicative of extremely quiet water conditions or lowest energy levels (Fursich and Heinberg, 1983). Bromley (1990) considered *Palaeophycus* as semi-vagile, vagile, middle level deposit feeder structures of intermediate to equilibrium or climax trace fossils in oxygenated conditions, which can also be attributed to the Gangta Bet assemblage.

Protovirgularia Assemblage

This assemblage is characterized by dominance of *Protovirgularia* which occurs in the ripple-marked sandstone facies. The *Protovirgularia* represents the crawling activity of annelids (Schlirf, 2000). The crawling trails preserved on ripple sandstone suggest moderate wave and current energy conditions in the subtidal region above the fair-weather wave base. From a taphonomic point of view, fortuitous preservation of *Protovirgularia* on sandy substrate indicates sudden drop of energy conditions which has halted the erosion of the sediment.

Skolithos assemblage

This assemblage is developed in calcareous sandstone layers of the intercalated calcareous sandstone-siltstone-shale facies and consists of *Skolithos verticalis, Arenicolites carbonarius* and *Ophiomorpha irregulare*. *S. verticalis* and *A. carbonarius* occur as vertical burrows, while the *O. irregulare* occurs as a horizontal form preserved in full relief, indicating that the burrows are produced by the suspension feeding animals at sediment-water interface. These structures are the member of the *Skolithos* ichnofacies (Pemberton *et al*., 2001) which indicates sudden change in environmental conditions. Furthermore, calcareous sandstone band consists of fine to medium-sized quartz grains indicating intermittently intermediate energy levels and often exhibiting signs of winnowing, but the absence of physical sedimentary structures rule out the large-scale transport of sediments. The presence of vertical burrows and sediment indicates that the relatively moderate to high-energy conditions and shifting substrate have been exploited by the opportunistic animals in the intertidal-subtidal environments (Mangano and Buatois, 2004).

ICHNOFACIES

The intercalated calcareous sandstone-siltstone-shale facies of the Gangta Member consists of abundant and diverse groups of trace fossils as compared to sandy shale and ripple marked sandstone facies, while the topmost unit, limestone-shale facies, is rich in ammonite. In intercalated calcareous sandstone-siltstone-shale facies the density of trace fossils differ at different levels and represents *Chondrites* assemblage, *Rhizocorallium* assemblage, *Planolites* assemblage, *Palaeophycus* assemblage, and *Skolithos* assemblage. The sandy shale and ripple marked sandstone facies consists of relatively less diverse trace fossils and comprises *Chondrites* and *Rhizocorallium* assemblages and *Protovirgularia* assemblage respectively. Trace fossils intimately related to these assemblages are characteristic of *Cruziana*-like ichnofacies except the *Skolithos* assemblage.

This ichnofacies consisting of mainly horizontal traces mobile carnivores and scavengers (Pemberton *et al*., 2001) indicates that the deposition of the sediments took place in low to moderate energy conditions and an unconsolidated soft sediments substrate. Progressively in upward direction, the population of horizontal burrows increases, indicating further changes in environmental conditions and abundance of food availability in the subtidal environment. Traces show chiefly dwelling and feeding activity of worms and crustaceans. Fine to medium-grained nature of the sediments and bedding styles of the intercalated calcareous sandstone-siltstone-shale facies exhibit considerable diversity including thinly bedded, well-sorted silts and sands, discrete shale layers, physical sedimentary structures such as small scale cross-bedding and ripple marks. The intense bioturbation indicates that deposition of the sediments have taken place in moderate energy condition in shallow waters below the fair weather wave base and above storm wave base. The presence of *Chondrites* and *Rhizocorallium* assemblages in sandy shale also indicate similar environmental conditions but the former assemblage indicates that animal has exploited some anaerobic substrates. The preservation of *Protovirgularia* as positive epirelief on oscillatory ripples indicates trace of infaunal (Schlirf, 2003) probably in near shore terrigenous settings.

Frey and Pemberton (1984) postulated that the *Cruziana* ichnofacies exhibit considerable diversity and occurs in low to moderate energy conditions; characterized by poorly sorted unconsolidated sediments; and also indicate less fluctuations of temperature and salinity (Pemberton et al., 2001) in shallow marine environments. Overall, the Gangta member shows development of *Cruziana* ichnofacies type condition; however, appearance of vertical burrows like *Arenicolites, Laevicyclus* and *Skolithos* indicate intermittent change in energy conditions in the subtidal environments.

CONCLUSIONS

The Gangta Member is exposed in the Gangta Bet area and comprises 103 m thick fining-upward clastic succession capped by limestone-shale sequence. The limestone bands are highly fossiliferous and consist of abundant ammonites - *Maya* and *Helenae* Assemblage Zones which mark the Lower-Middle Oxfordian age. However, the age of the upper part of the intercalated calcareous sandstone-siltstone-shale facies is considered as the Late Callovian (*Athleta* Assemblage zone). Some importent conclusions that emerge out of the present work are:

1. The trace fossils are found in the intercalated calcareous sandstone-siltstone-shale facies, sandy shale facies and ripple-marked sandstone facies.
2. It is represented by 27 ichnospecies beloging 19 ichnogenera further grouped into six ichnoassemblages.
3. Trace fossils exhibit the recurrent patterns of associations which show bathymetric control and display *Cruziana*-like ichnofacies.

   Based on the sedimentological and ichnological data, it can be inferred that the Mesozoic rocks of the Gangta Bet area were deposited in low to moderate wave and current energy conditions in the subtidal environments.

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THREE SPECIES OF *PERIPLOMA* (BIVALVIA: PERIPLOMATIDAE) FROM THE BHUBAN FORMATION (LOWER MIOCENE) OF KOLASIB, MIZORAM, INDIA

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ABSTRACT

Three species of the genus *Periploma* (*Aelga*), namely *Periploma* (*Aelga*) sp. 1, *P.* (*A.*) sp. 2, and *P.* (*A.*) sp. 3, are being described from the grey sandstone and calcareous sandstone beds of the Bhuban Formation, Surma Group (Lower to Middle Miocene), Mizoram, India. This is the first record of this bivalve genus from South Asia including the Indian Subcontinent.

Keywords: Bivalves, Periplomatidae, Systematics, Bhuban Formation, Surma Group, Kolasib, Mizoram.

INTRODUCTION

Miocene sediments of the Indian Subcontinent, including adjoining Myanmar have been extensively studied for their fossil bivalves by several workers (Bhalla and Dev, 1988; Cotter, 1923; Cox, 1936 and 1956; Davies, 1923; Dey, 1962; Eames, 1950; La Touche, 1891; Lyngdoh *et al*., 1999; Mazumder and Tiwari, 2009, 2012; Mathur, 1988; Mukerjee, 1939; Noetling 1895 and 1901; Pascoe, 1973; Sale, 1932; Sale and Evans, 1940; Sengupta, 1964; Spengler, 1923; Tiwari, 1992, 2001, 2006 and Tiwari and Kachhara, 2000, 2003). However, there is no earlier record of the genus *Periploma* Schumacher, 1817 from the Miocene sediments of these areas. We describe, in the present paper, three species of this genus, namely *Periploma* (*Aelga*) sp. 1, *P.* (*A.*) sp. 2, and *P.* (*A.*) sp. 3 from the grey sandstone and the calcareous sandstone beds of the Bhuban Formation (Lower Miocene) of the Surma Group from the Kolasib area of Mizoram, India (Fig. 1). This forms the first record of the genus from the Miocene of South Asia including the Indian Subcontinent. The specimens are the casts of both valves and their internal characters are unobservable. Consequently, the species described here are based entirely upon measurements and morphological attributes of the valves as observed from the exterior.

Periploma Schumacher, 1817 is infaunal, siphonate and actively mobile bivalve. This genus has a narrow bathymetric range in the modern Northeastern Pacific, i.e. 20 m-90 m (Keen and Coan, 1974). It belongs to the bathyneritic to bathyal fauna (Noda, *et. al*., 1994).

The species under study are not assigned the specific names for want of better preserved specimens.

FOSSIL LOCALITIES

The material described here includes eight nearly complete bivalved specimens and an incomplete one. These specimens have been collected from three localities (K5, K9 and K17) near Kolasib Town of Mizoram State (Figure-1). They have been recovered from two lithologies, namely, grey sandstone and calcareous sandstone.

Locality K5 is at Quarry Veng. It is a big stone quarry situated near the 2 km stone on the Kolasib - Silchar road and lies to the left side of the road section. The thickness of grey sandstone bed at this locality is 14.6 m. Locality K9 is a small stone quarry located about 1.5 km from Kolasib on the Kolasib - Silchar road. The exposed thickness of calcareous sandstone bed at this locality is 1.6 m. Locality K17 is another small stone quarry about 1.7 km on the Kolasib - Silchar road. It lies on the left side of the road cutting. The thickness of the grey sandstone bed at this locality is 8.4 m.

SYSTEMATIC PALEONTOLOGY

Phylum **Mollusca** Linnaeus, 1758
Class **Bivalvia** Linnaeus, 1758
Subclass **Anomalodesmata** Dall, 1889
Order **Pholadomyoida** Newell, 1965
Superfamily **Pandoracea** Rafinesque, 1815
Family **Periplomatidae** Dall, 1895
Genus ***Periploma*** Schumacher, 1817

Type species: *Periploma inaequivalvis* =*Corbula margaritacea* Lamarck, 1801; M. Upper Cretaceous-Recent; Cosmop.

Subgenus ***Aelga*** Slodkevich, 1935

Type species: *Tellina bessioensis* Yokoyama, 1924; OD. Oligocene-Miocene; NE Asia.

Periploma (*Aelga*) sp. 1

(Pl. I, figs. 1a,b,c; Pl. II, fig. 3; Pl. III, figs.1,4)

Material: Three specimens (No. K17/B/62, K17/B/73 and K17/B/74) are examined.

Diagnosis: Shell medium sized, elongate-ovate with low inflation; anterodorsal, anterior, posterior and ventral margins form a continuous curve; flanks depressed and with subdued folds and flexures; surface sculpture of undulating concentrics.

Description: Shell medium sized, inequilateral, and elongate-ovate in outline with low inflation, left valve more convex than the right one.

Dimensions:

Sp. no.	length, l	height, h	thickness, t	h/l%	t/l%	valve
K17/B/62 Holotype	54.00	37.40	13.00	69.26	24.07	both valve
K17/B/73 Paratype	52.40	40.00	11.80	76.34	22.52	both valve
K17/B/74 Paratype	50.20	37.00	13.00	73.71	25.90	both valve

Umbo prominent, beak opisthogyrous, placed at posterior-third of length, and carries a slit. Lunule indistinct, escutcheon long and lanceolate. Dorsal margin of the shell slightly arched,

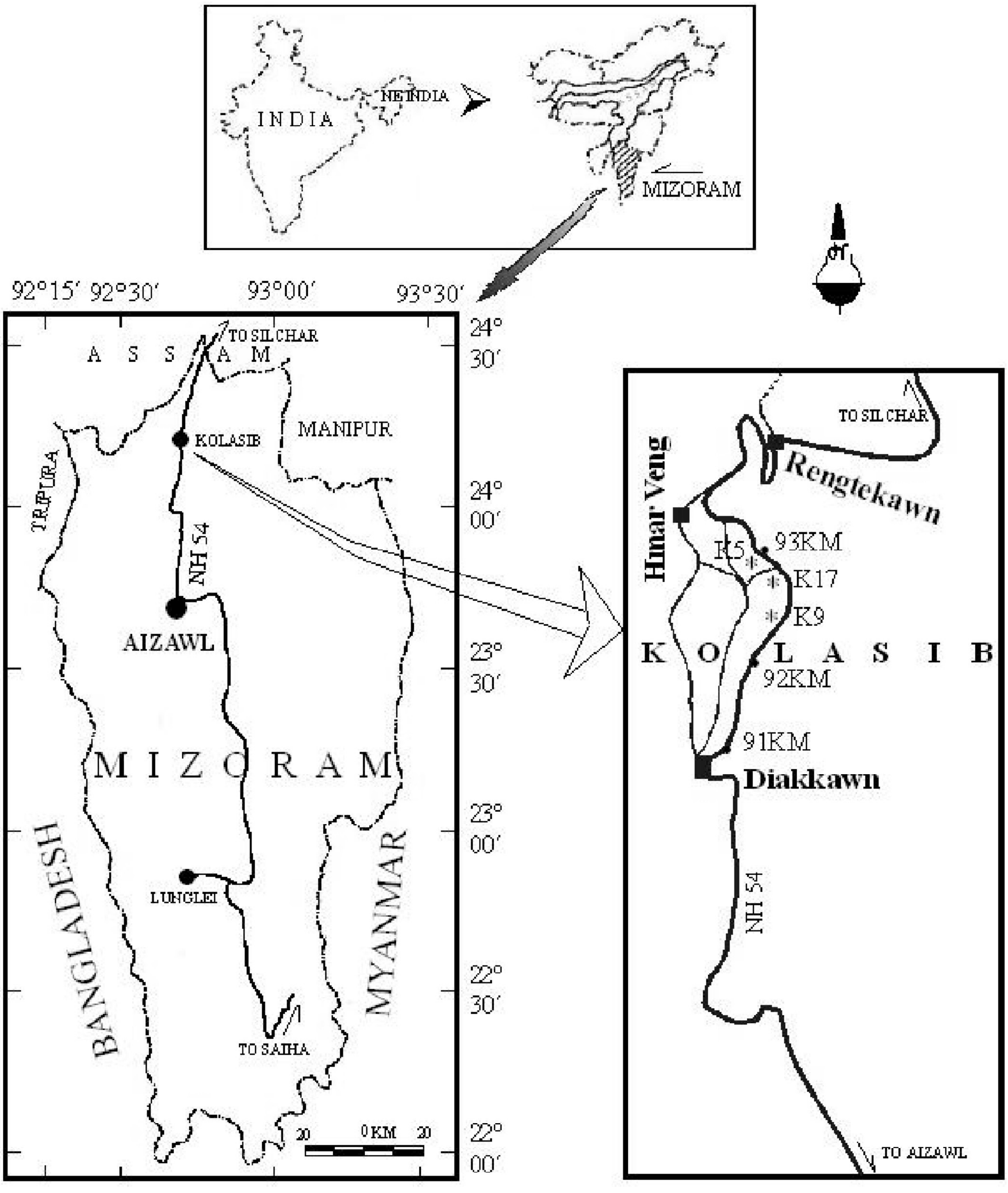


Fig. 1. Location Map.

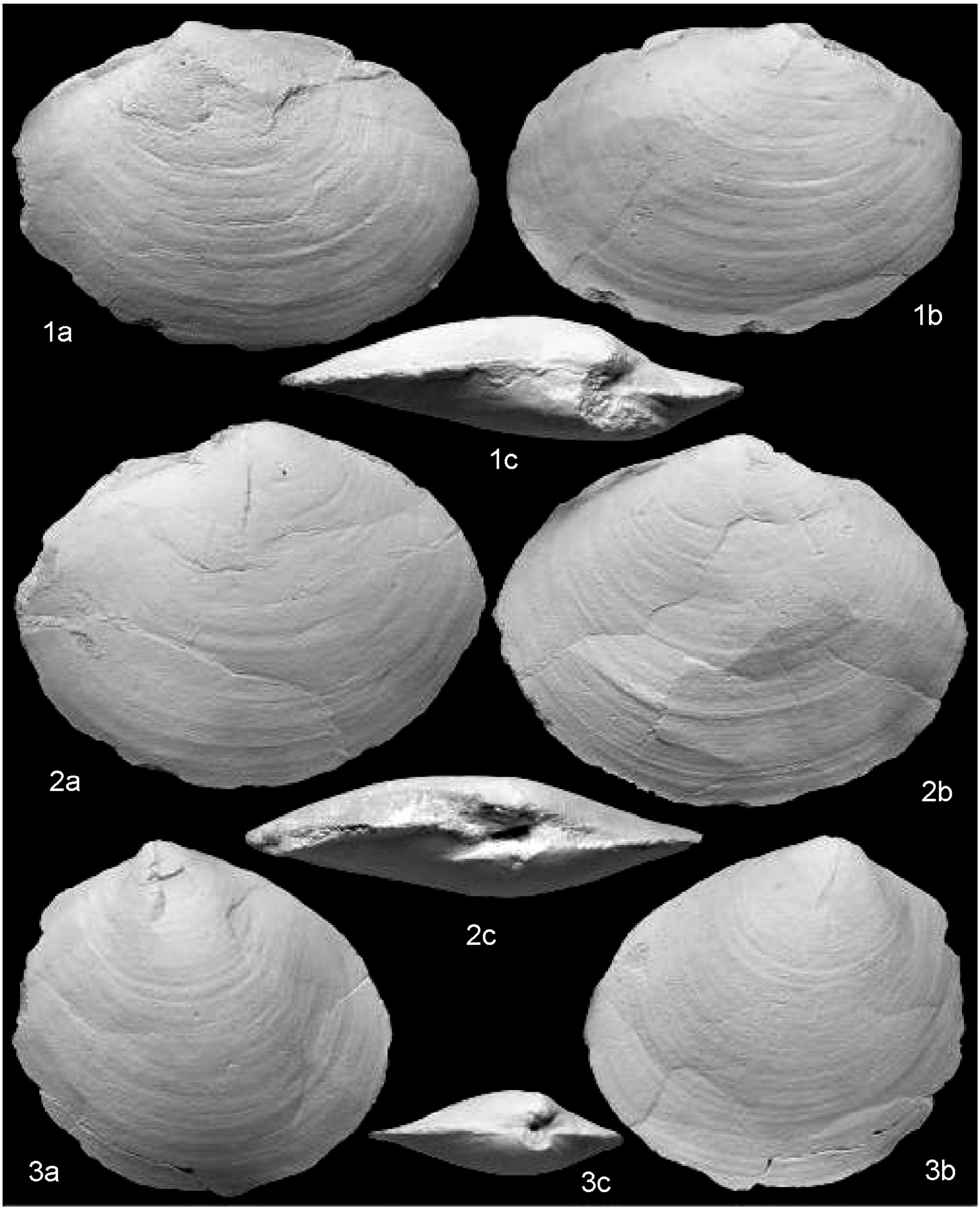
antero-dorsal convex, postero-dorsal almost straight, anterior and posterior margins well rounded, ventral margin broadly arched; antero-dorsal, anterior, posterior and ventral margins form a continuous curve. Ventral side of the shell with a sinuate ventral margin. Both anterior and posterior areas depressed and marked off from the rest of the shell by folds and flexures; posterior area of the right valve bearing two flexures, with a corresponding fold on the left valve; anterior area of right valve bearing a fold, with a corresponding flexure in the left valve. Surface covered with sub-equally spaced, finely striated growth wrinkles. Internal characters are inaccessible.

Remarks: *Periploma* (*Aelga*) sp. 1 shows some resemblance to *Periploma* (*Aelga*) sp. 2. The comparison between the two is attempted in the remarks of *Periploma* (*Aelga*) sp. 2. We have not noticed any other closely allied form for comparison.

EXPLANATION OF PLATE I

1. a) ***Periploma* (*Aelga*)** sp. 1, sp. no. K17/B/62, exterior of right valve, ×1.5
   b) ***Periploma* (*Aelga*)** sp. 1, same specimen, exterior of left valve, ×1.5
   c) ***Periploma* (*Aelga*)** sp. 1, same specimen, dorsal view, ×1.5.
2. a) ***Periploma* (*Aelga*)** sp. 2, sp. no. K17/B/61, exterior of right valve, ×1.5
   b) ***Periploma* (*Aelga*)** sp. 2, same specimen, exterior of left valve, ×1.5
   c) ***Periploma* (*Aelga*)** sp. 2, same specimen, dorsal view, ×1.5.
3. a) ***Periploma* (*Aelga*)** sp. 3, sp. no. K9/B/106, exterior of right valve, ×1.5
   b) ***Periploma* (*Aelga*)** sp. 3, same specimen, exterior of left valve, ×1.5
   c) ***Periploma* (*Aelga*)** sp. 3, same specimen, dorsal view, ×1.

Plate I



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Stratigraphic horizon: The specimens of *Periploma* (*Aelga*) sp. 1 come from the grey sandstone bed of Upper Bhuban Unit, Bhuban Formation of the Surma Group. Fossiliferous bed is exposed in the Kolasib area of Mizoram, India at locality K17 (Fig.1).

Periploma (*Aelga*) sp. 2

(Pl. I, figs. 2a,b,c; Pl, III, figs. 2, 5a,b)

Material: Two specimens (Nos. K17/B/61, K17/B/70) and a broken specimen bearing no. K5/B/43.

Diagnosis: Elliptical shell with low inflation, slightly protruding to the anterior; flanks depressed, separated by subdued folds and flexures; beaks opisthogyrous, slightly higher, with a slit; surface sculpture of undulating concentrics.

Description: Shell medium sized, inequilateral, elliptical in outline; low inflation, the inflation of the right valve slightly more than that of the left one.

Dimensions:

Sp. no.	length, l	height, h	thickness, t	h/l%	t/l%	valve
K17/B/61 Holotype	53.50	43.20	14.20	80.75	26.54	both valve
K17/B/70 Paratype	39.80	34.90	11.30	87.69	28.39	both valve
K5/B/43 Paratype	-	38.20	11.0	-	-	both valve

Umbo prominent, beak opisthogyrous, placed slightly posterior to the midline, and with a slit. Lunule small, depressed and escutcheon long and lanceolate. Dorsal margin of the shell slightly arched, antero-dorsal margin arched, postero-dorsal almost straight, anterior and posterior margins well rounded, ventral margin convex; antero-dorsal, anterior, posterior and ventral margins form a continuous curve; ventral view of the shell with a sinuate ventral margin. Both anterior and posterior areas depressed and marked off from the rest of the shell surface by folds and flexures; anterior area of left valve with a fold, and a corresponding flexure present in the right valve; posterior area of right valve with a fold, and a corresponding flexure present in the left valve. Surface covered with sub-equally spaced, finely striated growth wrinkles. Internal characters are unobservable.

Remarks: *Periploma* (*Aelga*) sp. 2 differs from *Periploma* (*Aelga*) sp. 1 in having more rounded outline, relatively tall form, beak only slightly posterior to the midline, and shell a little protruding to the posterior.

Stratigraphic horizon: The specimens assigned to this new species come from the grey sandstone bed of the Upper Bhuban Unit, Bhuban Formation of the Surma Group. The bed is exposed in the Kolasib area of Mizoram, India at the localities K5 and K17 (Fig. 1).

Periploma (*Aelga*) sp. 3

(Pl. I, figs. 3a,b,c; Pl. II, figs. 1a,b & 2a,b)

Material: Three complete specimens are studied.

Diagnosis: Shell medium to large sized, trigonally-ovate and moderately inflated. Though anterodorsal, anterior, posterior and ventral margins forming a continuous curve, the shell as a whole protruding towards anterior. Surface sculpture made up of fine concentric growth lines.

Description: Shell medium to large, inequilateral, trigonally-ovate, moderately inflated, and right valves are slightly more inflated than the left ones.

Dimensions:

Sp. no.	length, l	height, h	thickness, t	h/l%	t/l%	valve
K9/B/104 Holotype	60.50	52.00	20.00	85.95	33.06	both valve
K9/B/105 Paratype	62.50	50.00	24.00	80.00	38.40	both valve
K9/B/106 Paratype	44.20	40.10	15.00	90.72	33.94	both valve

Umbo prominent, beak opisthogyrous, placed at posterior two-fifths of length, and carries a slit. Lunule indistinct, escutcheon long and lanceolate. Dorsal margin of the shell slightly arched, posterodorsal almost straight, anterodorsal arched, anterior and posterior margins well-rounded and ventral margin convex but sinuate at the flanks. Though, anterodorsal, anterior, posterior and ventral margins form a continuous curve, the shell as a whole is protruding towards anterior. Both anterior and posterior areas are depressed and marked off from the remainder of the shell surface by folds and flexures; however, these are indistinct in the anterior flank. Surface covered with numerous fine concentric growth lines. Internal characters unobservable.

Remarks: The larger shells of *Periploma* (*Aelga*) sp. 3 may be confused with *Periploma* (*Aelga*) *besshoense* (Yokoyama), the sub-genotype species from the Miocene of Japan (Keen, 1969; p. N849, figures F26.7a, 7b). However, figure of the latter reveals that it is slightly bigger, umbo in it is submedian and height to length ratio is more. No other closely comparable form has been encountered during the study.

Stratigraphic horizon: The specimens of this new species are collected from the calcareous sandstone bed of the the Upper Bhuban Unit, Bhuban Formation of the Surma Group. The fossiliferous bed is exposed in the Kolasib area of Mizoram, India at locality K9 (Fig. 1).

REPOSITORY

The illustrated specimens are housed in the Geology Department of Karimganj College, Karimganj - 788710, Assam, India.

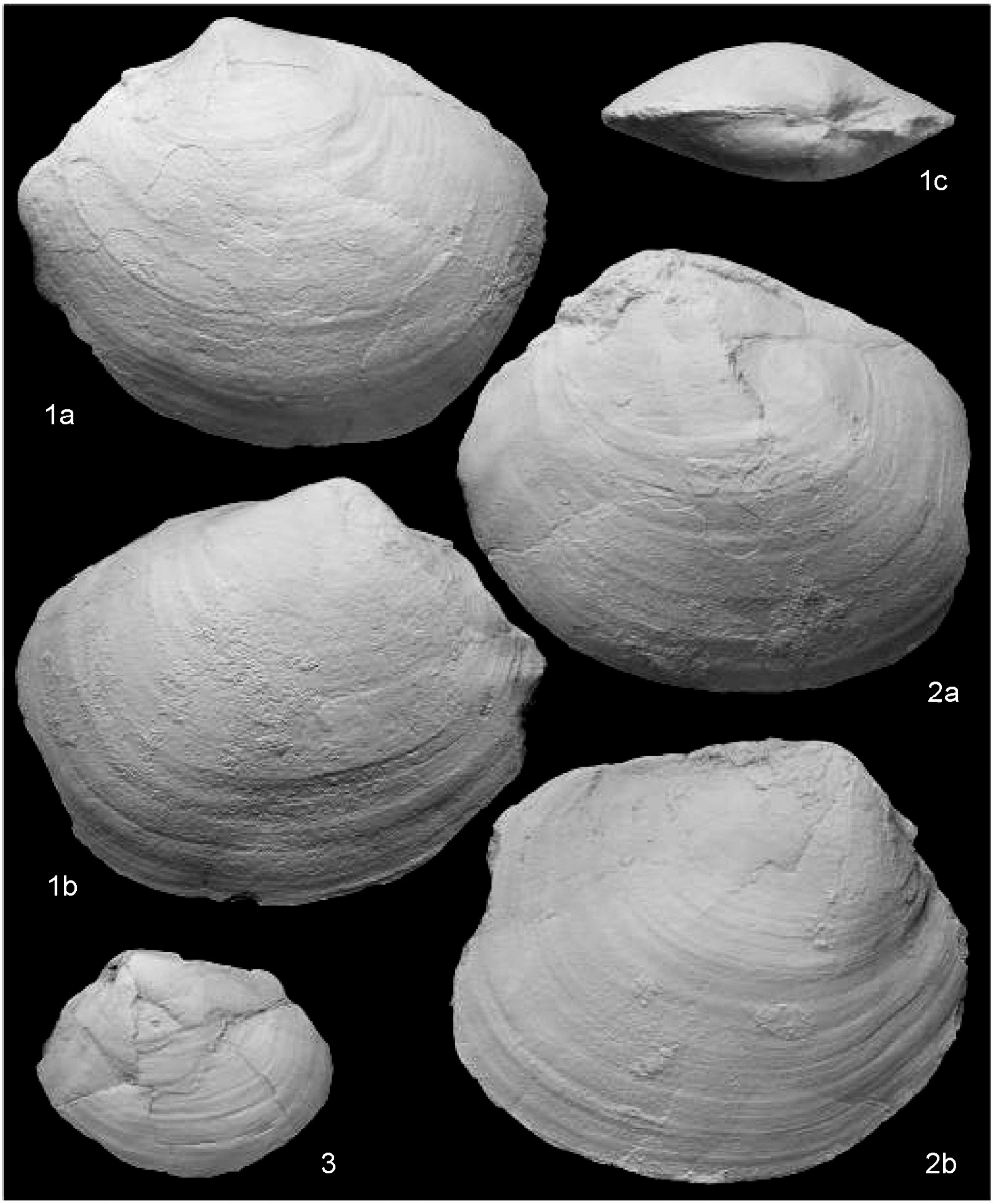
ACKNOWLEDGEMENTS

The authors thank the reviewer (Dr. K. Ogasawara, the University of Tsukuba, Japan) for his fruitful comments. Financial support from UGC-NER, Guwahati (grant no. F.5-68/

EXPLANATION OF PLATE II

1. a) ***Periploma* (*Aelga*)** sp. 3, sp. no. K9/B/105, exterior of right valve, ×1.5
   b) ***Periploma* (*Aelga*)** sp. 3, same specimen, exterior of left valve, ×1.5
   c) ***Periploma* (*Aelga*)** sp. 3, same specimen, dorsal view, ×1.
2. a) ***Periploma* (*Aelga*)** sp. 3, sp. no. K9/B/104, exterior of right valve, ×1.5
   b) ***Periploma* (*Aelga*)** sp. 3, same specimen, exterior of left valve, ×1.5.
3. ***Periploma* (*Aelga*)** sp. 1, sp. no. K17/B/74, exterior of right valve, ×1.

Plate II



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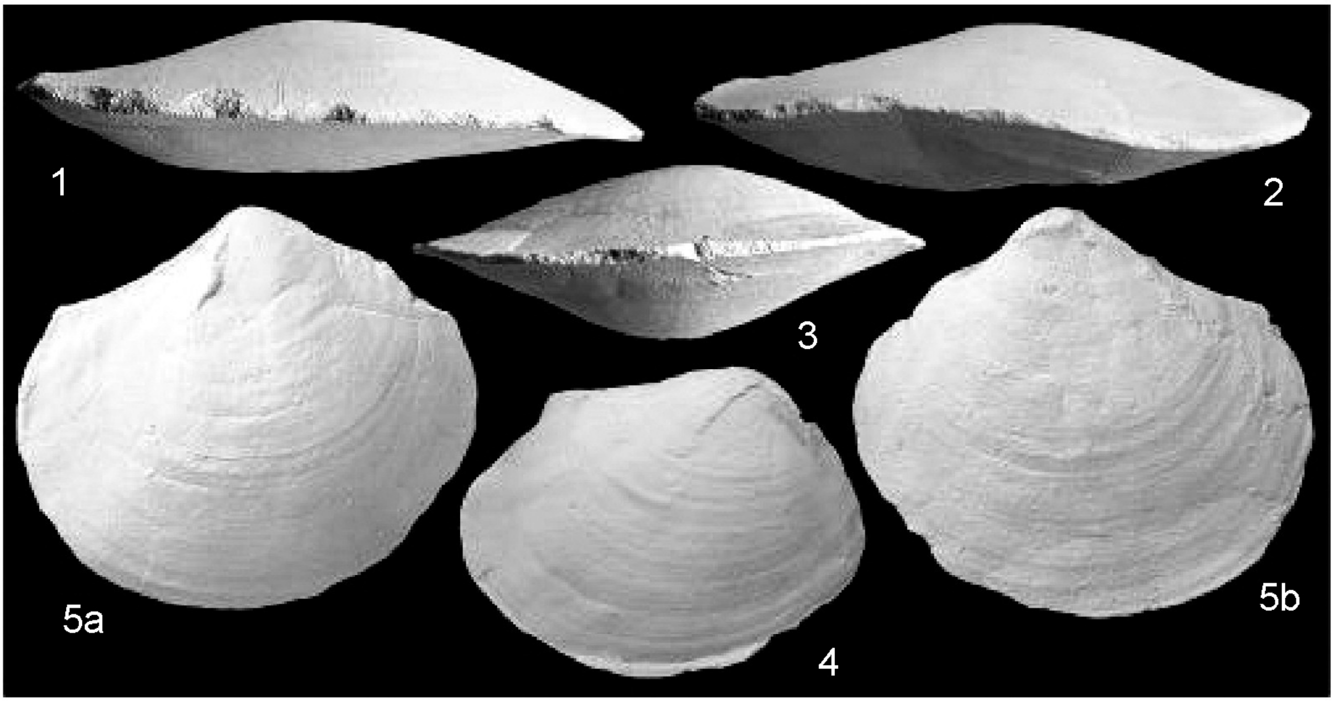
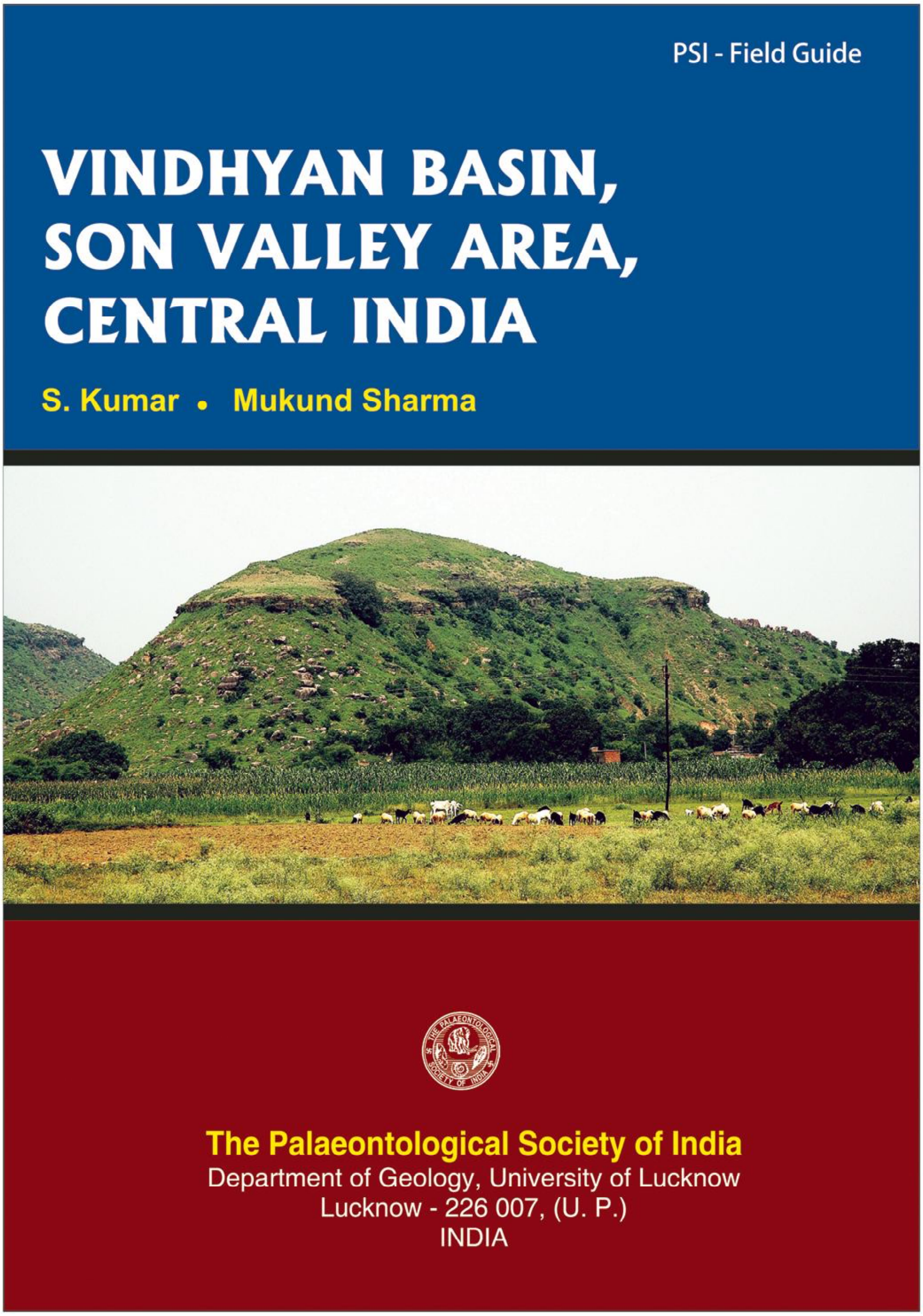


MAZUMDER AND TIWARI

EXPLANATION OF PLATE III

1. ***Periploma* (*Aelga*)** sp. 1, sp. no. K17/B/62, ventral view, ×1.5.
2. ***Periploma* (*Aelga*)** sp. 2, sp. no. K17/B/61, ventral view, ×1.5.
3. ***Periploma* (*Aelga*)** sp. 3, sp. no. K9/B/106, ventral view, ×1.5.
4. ***Periploma* (*Aelga*)** sp. 1, sp. no. K17/B/74, exterior of left valve, ×1.
5. a) ***Periploma* (*Aelga*)** sp. 2, sp. no. K17/B/70, exterior of right valve, ×1.5
   b) ***Periploma* (*Aelga*)** sp. 2, same specimen, exterior of left valve, ×1.5.



PSI - Field Guide

VINDHYAN BASIN, SON VALLEY AREA, CENTRAL INDIA

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A NEW ARECOID FOSSIL PALM WOOD FROM THE DECCAN INTERTRAPPEAN SEDIMENTS OF DHABA, MAHARASHTRA, INDIA

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ABSTRACT

A new fossil palm wood *Palmoxylon dhabaensis* n. sp. is described from the Deccan Intertrappean sediments exposed at Dhaba, Nagpur District, Maharashtra, India. The wood is fairly well preserved and reveals all the important anatomical features for its identification. It shows dermal, subdermal and central zones. The wood is characterized by the frequent presence of fibrous as well as leaf-trace bundles. The fused satellite bundles and divided phloem in the fibrovascular bundles are the features of importance in the stem.

Keywords: New fossil palm wood, Deccan Intertrappean, Dhaba, Maharashtra, India

INTRODUCTION

The Deccan Intertrappean flora of India is represented by a variety of well-preserved wood, leaves, fruits, flowers belonging to all major groups of plant kingdom (Prakash, 1960; Chitaley, 1962, 1990; Bande *et al*., 1988; Bande and Chandra, 1990). The present study represents a fossil palm wood collected by one of the authors (DKK) in 2009 from Dhaba. The intertrappean beds are well exposed here at the foot of a hillock. The fossiliferous cherts associated with the fragmentary wood are spread over 1 km^2 area.

Apart from this, a large number of the fossil palm woods have been described from the different localities of central India. The Indian *Palmoxyla* pieces are known to represent *Palmoxylon hislopi* (Rode, 1934), *P. dakshnense P. chhindwarenses* (Prakash, 1960), *P. eocenum* (Prakash, 1962), *P. deccanense, P. wadiai, P. jammuense, P. indicum, P. rewahense, P.compactum, P. geometricum, P.pondicherriense, P. pyriforme,P. prismaticum, P. intertrappeum, P.khalsa, P.mathuri, P. caudatum* (Sahni, 1931, 1964); *P. parthasarathyi* (Rao and Menon, 1964); *P. kamalam* (Rode, 1934; Shukla, 1939, Sahni, 1964; Mahabale and Kulkarni, 1973), *P. blanfordi* (Schenk, 1882; Sahni, 1931; 1964), *P. keriense* and *P. superbum* (Trivedi and Verma, 1971a,b), *P. paraponiensis* (Lakhanpal *et al*., 1979), *P. livistonoides* (Prakash and Ambwani, 1980); *P. shahpuraensis* (Ambwani, 1983); *P. dilacunosum* (Ambwani, 1984), *P. hyphaeneoide* (Rao and Shete, 1989), *P. taroides* (Ambwani and Mehrotra, 1989), *P. binoriensis*, *P. vaginatum* and *P. lunarianum* (Guleria and Mehrotra, 1999).

A number of fossil palm woods are also known from different strata of the world. The important species include *Palmoxylon aschersoni, P. libycum, P. stromeri, P. zitteli, P. lacunosum* (Kräusel and Stromer, 1924). *P. simperi* and *P. pristine* (Tidwell *et al*., 1970) from the Cretaceous of Utah, (Wagieh *et al*., 2004) from the Tertiary of Egypt and *P. enochii* (Estrada and Cevallos, 2009) from the Upper Cretaceous of Mexico.

The present fossil palm specimen was recovered from Dhaba, a new locality of the Deccan Intertrappean beds, in Nagpur District, Maharashtra, India. It is well preserved and reveals all the anatomical details for its identification. Efforts are also made to discuss affinities with modern taxa.

GEOLOGICAL SET-UP

Dhaba locality lies (lat. 21°10'10"N and long 79° 2'00"E.) about 6 km from the Hazari Pahad, Nagpur-Katol road, Nagpur District, Maharashtra. The exposures represent the Deccan Intertrappean sediments in the area and these sedimentary beds are 0.25m in thickness, sandwiched between the gray to dark gray trap rocks. The upper trap rock measures about 2 m in thickness where the base of this section is not fully exposed. Here, the Intertrappean sediments constitute mostly siliceous matter intermixed with gray to brown coloured cherts. The fossil palm wood pieces are scattered in these sediments. However, the frequency of these silicified woods is very low, while the preservation of these wood specimens is fairly good to reveal all the internal structures (Fig.1).

MATERIAL AND METHODS

For detailed anatomical characterization, the specimen was cut into thin sections referable to transverse and longitudinal planes (TS & LS). These sections were ground and polished using carborundum powder of different grades. All the slides and residues are kept in the repository section of the Birbal Sahni Institute of Palaeobotany, Lucknow .

SYSTEMATIC DESCRIPTION

Family **Arecaceae**
Genus ***Palmoxylon*** Schenk, 1882
Palmoxylon dhabaensis n. sp.

Description: Fossil palm stem measures about 15 cm in length and 8cm in width, comprising dermal, subdermal and central zones. There is no clear distinction between the above zones; however, based on the orientation of the fibrovascular bundles and other features, these zones can be visualized (Pl. I, fig.1).

Dermal zone: Fibrovascular bundles in this zone are almost uniformly placed and the xylem points towards the centre of stem (Pl. I, figs. 2 &3). They are small, generally oval in shape, measuring about 400-700 µm in size, the smaller fibrovascular bundles are generally located near the peripheral part of the stem; the frequency of the bundles in this zone ranges from 90 -100 per cm^2. The fibrovascular bundles have a prominent

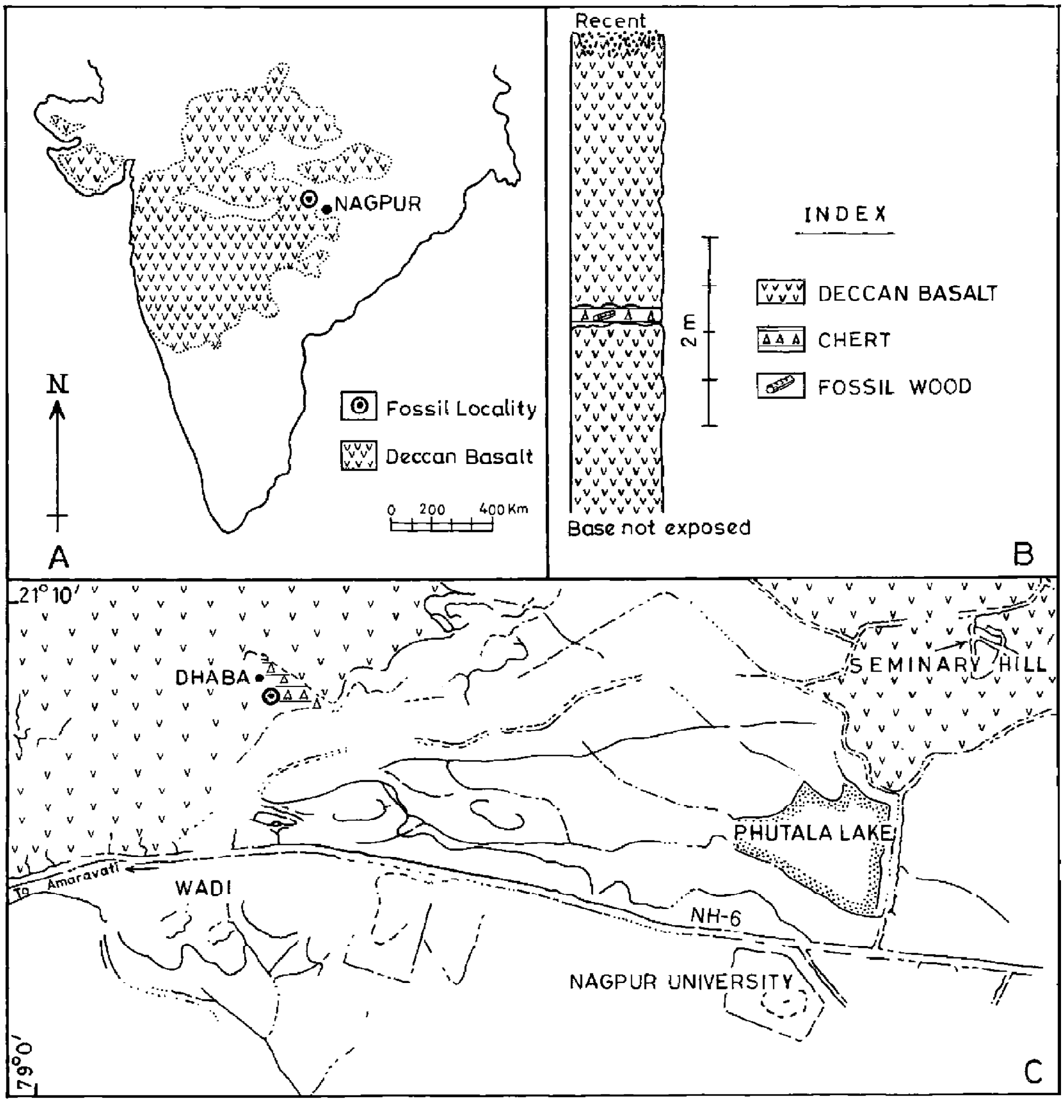

Fig. 1 A. Map showing the Deccan Intertrappean area, B. Lithological succession exposed along Dhaba from where samples were collected, C. Geological map of the area showing the fossil locality.

sclerenchymatous sheath and the cells are thick walled. The dorsal sclerenchymatous sheath is generally reniform sometimes lunate type; the fibrovascular ratio (f/v) varies from 1/2 - 1/3; however, it may vary up to 1/4.The auricular lobes are generally rounded, sometimes they may be slightly pointed. The auricular sinus is prominent; tabular parenchyma can be

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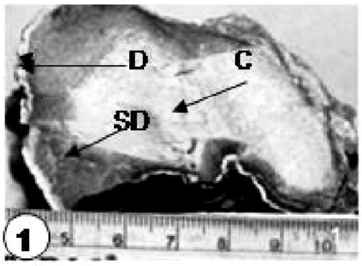
EXPLANATION OF PLATE I

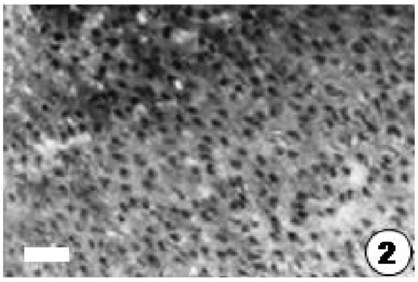
(Scale Bar equals for 2 - 6, 10, 11 = 1 µm; for 7, 13 = 300 µm; for 8, = 600 µm; for 9, 12 = 200 µm; for 14 = 50 µm; for 15 =10 µm)

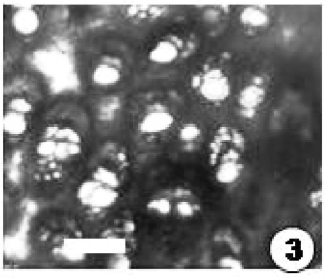
1-9, 14. ***Palmoxylon dhabaensis*** n. sp.

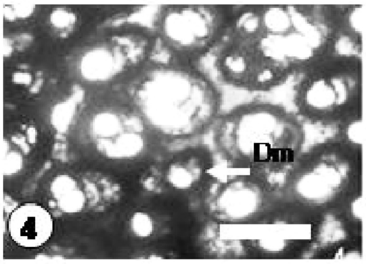
1. Fossil specimen in surface view (D - dermal, SD- subdermal , C- Central zones).
2. Showing the general distribution of fibrovascular bundles in the stem.
3. Part of the dermal zone enlarged showing presence of fibrovascular bundles usually with one small vessel and leaf traces.
4. Part of the subdermal zone enlarged showing fibrovascular bundles with one to two metaxylem vessels and compact ground tissue. (Dm = Diminutive bundles)
5. Part of the subdermal zone enlarged to show compact ground tissue and presence of irregular distribution of fibrovascular bundles.
6. Part of the central zone enlarged to show FVB, leaf - traces and fusion bundles. (Lt- Leaf – trace bundles).
7. Single FVB showing two xylem vessels and divided phloem with number of small protoxylem vessels.
8. Showing fused fibrovascular bundles and compact ground parenchyma.
9. Part of the dermal zone in fossil showing fibrovascular bundles with two xylem vessel and divided phloem. (tb- tabular parenchyma)
10. Cross-section of ***Calamus linndnii*** showing distribution of FVB with one xylem vessels and two patches of divided phloem, fibrovascular bundles with reniform to lunate dorsal sclerenchymatous sheath and ground tissue showing isodiametric compact parenchyma cells.
11. Cross section of ***Chamaerops humilis*** showing distribution of FVB with two xylem vessels and phloem tending to divide into two parts, ground tissue impregnated with tannin.
12. A single FVB of ***Livistona mauritiana*** showing almost divided phloem and two or more metaxylem vessels whereas the ground parenchyma cells slightly elongated in between two adjacent FVBs.
13. Single vascular bundle of ***Livistona mauritiana*** enlarged to show lunate dorsal sheath and divided phloem with one circular metaxylem vessel.
14. L.S. of fossil showing annular type of sculpture in the vessels and presence of stegmata.
15. L.S. of ***Calamus linndnii*** showing annular type of sculpture in the vessels.

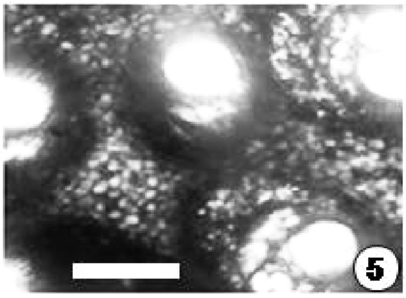
Plate I

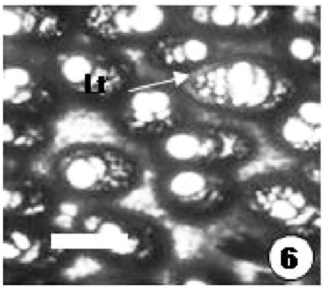


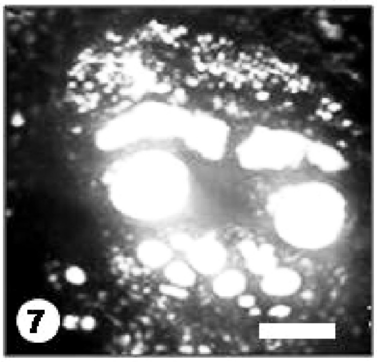


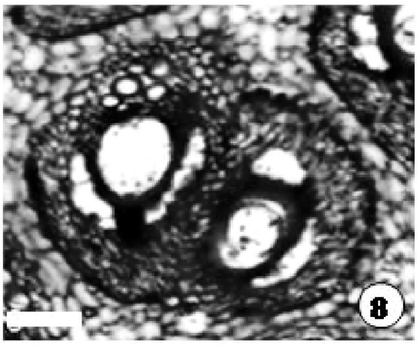


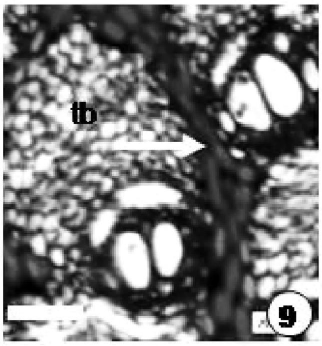


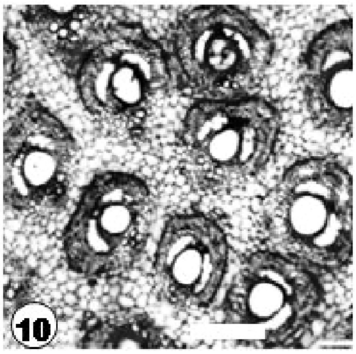


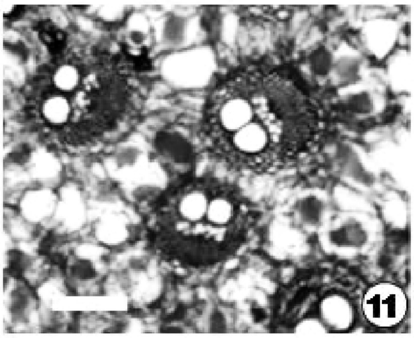


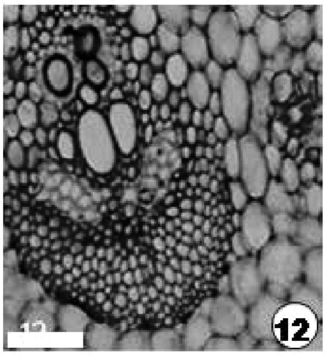


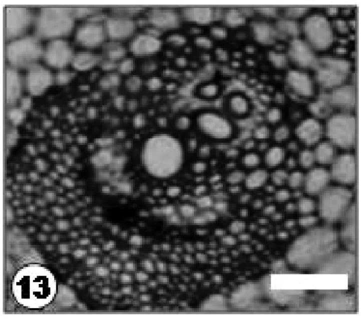


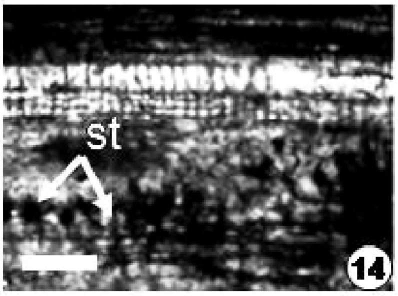


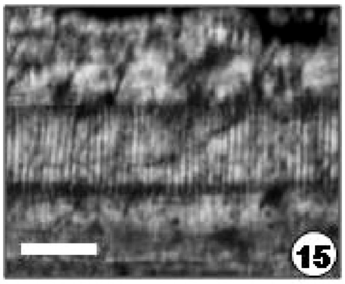












seen around the fibrous part of the bundles (Pl.I fig. 9). One to two excluded metaxylem vessels can be seen in the bundles; sometimes 3-4 vessels are also present; stegmata of druse type is also present. The ground tissue in this zone is compact, composed of small isodiametric cells; phloem, though poorly preserved, can be seen divided into two parts (Pl. I, fig.7).

Sub-dermal zone: The fibrovascular bundles in this zone are sparsely placed and regularly oriented; sometimes a few bundles show irregular orientation; the bundles in this zone are slightly bigger in size ranging from 500 -800 µm, their frequency varies from 70 -75 per cm^2.The f/v ratio ranges from 2/1 – 3/1. The dorsal sclerenchymatous sheath is mostly reniform in shape and the cells of this sheath are thick walled (similar to sclerieds) having small lumen. The auricular lobes are generally round, while the auricular sinus is not very distinct and the medium sinus is slightly concave. Generally, two metaxylem vessels are seen in each fibrovascular bundle. Stegmata can be observed in the fibrous part of the bundles. Phloem is mostly represented by a cavity; however, two patches can be observed. Sometimes fibrous bundles are seen and they vary from 200 -300 µm in size and comprise of 20-30 fibrous cells (Pl. I, figs, 4 -5).

Central zone: The fibrovascular bundles are regularly oriented and sparsely placed in the ground matrix; they are generally oval in shape. The size of these bundles is up to 800 x 1000 µm, whereas the f/v ratio ranges from 2/1-1/1. The dorsal sclerenchymatous sheath is prominently reniform in shape and the cells have larger lumen at the peripheral part of the sheath. Two to three metaxylem vessels are present in each fibrovascular bundle. Tabular parenchyma is present enclosing stegmata (Pl. I, fig. 9). Phloem generally represented by a lacuna, one to two patches in a bundle; presence of diminutive bundles is recorded, whereas leaf–trace, satellite bundles are commonly seen in this zone. The ground tissue is compact composed mostly of isodimetric parenchyma cells.

Diminutive Fibrovascular Bundles: The diminutive fibrovascular bundles are generally observed in all the three zones, however, their frequency in each zone varies. They measure up to 380 – 400 µm in size enclosing one metaxylem bundle. These bundles exhibit similar structure to that of normal fibrovascular bundles (Pl. I, fig. 4).

Leaf-Trace Bundles: Leaf-trace bundles are frequently present throughout the stem distinguished with their protruded tongue-like vascular part with multiple xylem vessels ranging from 4 to 20 in number (Pl. I, fig.6).

Satellite Bundles: The satellite bundles are frequently seen in central zone. These bundles generally shoot out from the leaf bases. (Pl. I, fig.6). They measure 500-1000 µm in size. These bundles in the vascular supply have distinct topographical relationship with the leaf-trace bundles. They also serve as a part of vascular supply to the vegetative branches as propounded by Zimmermann and Tomlinson (1972).

Fusion Bundles: These bundles are frequently present in the central zone. Generally, two to three bundles fuse in their fibrous sheath keeping the xylem part free. The size of these bundles is much larger than the normal bundles and they measure up to 1200 µm (Pl. I, fig. 8).

Phloem: It is divided into two patches. Due to imperfect preservation of the phloem in the bundles, cellular details could not be observed (Pl. I, figs. 7-9).

Ground Tissue: Ground tissue in this stem is compact throughout, and the parenchyma cells are closely placed and measure 10-20 µm in size; these cells in the sub-dermal and central zones become slightly bigger in size and range up to 40 µm. These cells are generally isodiametric in shape and may be slightly elongated around the peripheral part of the fibrovascular bundles (Pl. I, figs.8-9)

COMPARISON WITH LIVING TAXA

The present fossil palm wood shows affinities with the modern counterparts (e.g. *Calamus linndnii, Chamaerops humilis* and *Livistona mauritiana*) belonging to the arecoid and sabaloid groups. Both *Calamus linndnii* and *Chamaerops humilis* show bundles with reniform type of sclerenchyma, presence of stegmata and less frequent fibrous bundles; the f/v is much smaller than the present fossil, whereas the number of vascular bundles are much lower in the above living species. The ground tissue is compact both in *Calamus linndnii* and *Chamaerops humilis* but presence of tannin is noted in *Chamaerops* and the cells in *Livistona* are generally elongated in shape. The phloem, as compared to the present species, is divided into two distinct parts in *Calamus,* whereas in *Chamaerops* and *Livistona* it tends to divide into two patches (Pl. I., figs. 10 -13). The general sculpture of vessels in all the three taxa shows annular type of thickenings. The characters of the fossil species are more closely comparable to *Calamus* (Table 2). It seems that during the Intertrappean time the *Calamus*-type plants must have been growing in the ecosystem of the Dhaba area.

DISCUSSION AND CONCLUSIONS

The earliest known Indian fossil palm stems from the Deccan Intertrappean beds were reported by (Hislop and Hunter, 1855); subsequently, a large number of petrified palm stems from these beds were recorded from central India (Madhya Pradesh and Maharashtra state). The localities are mainly referable to Mohgaonkalan, Keria in Chhindwara District. The Shahpura and Ghugua are located in Dindori District, whereas Binori belongs to Seoni District. The localities Mahurzari, Takli, Sitabaldi are located in Nagpur District, Maharashtra state. The fossil palm stems reported from the Deccan Intertrappean beds are *Palmoxylon blanfordii* (Schenk, 1882; Sahni, 1931, 1964), *Palmoxylon hislopi* (Rode, 1933), *P. dakshinense* and *P. chhindwarense* (Prakash, 1960), *P. eocenum* (Prakash, 1962), *P. wadiai* and *P. jammuense* (Sahni, 1931, 1964), *P. kamalam* (Rode,1933; Shukla, 1939; Sahni, 1964; Mahabale and Kulkarni, 1973), *P. parthasarathyi* (Rao and Menon, 1964), *P. feistmanteli* (Rao and Achutan, 1969), *P. keriense* and *P. superbum* (Trivedi and Verma, 1971 a,b), *P. parapaniensis* (Lakhanpal *et al.*, 1979) and *P. livistonoides* (Prakash and Ambwani, 1980), *P. shahpuraensis* (Ambwani, 1983), *P. dilacunosum* (Ambwani, 1984), *P. hyphaeneoides* (Rao and Shete, 1989), *P. taroides* (Ambwani and Mehrotra, 1989), *P. binoriensis*, *P. vaginatum* and *P. lunarianum* (Guleria and Mehrotra, 1999).

The present fossil species was compared with the earlier known fossil species, e.g. *Palmoxylon intertrappeum, P. livistonoides, P. shahpuraensis, P. taroides, P. binoriensis* and *P. siltherensis* in having reniform dorsal fibrous sheath of the the fibrovascular bundles. The fibrous bundles are generally absent and stegmata present in *P. shahpuraensis* and *P. siltherensis*, whereas the fibrous bundles are present and stegmata are absent in *P. livistonoides* and *P. binoriensis*. The

Table 1: Showing comparision with various fossil species of *Palmoxylon*.

Fossil Species	**Stenzel's Classification (1904)**	**Fibrous Bundles; Stegmata**	**F/V Ratio**	**Distribution of fibrovas cular bundles /cm^2**	**Ground tissue**	**Any special character**	**Locality**
P. prismaticum (Sahni,1964)	Cordata	Both present	D.5 - 6/1;SD- C.4.5 -5/1	D.71-85 SD.37 -41 C.30 -34	Compact in dermal, lacunar in SD & central zones	Palisade cells & roots present	Unknown
P. intertrappeum (Sahni, 1964)	Cordata	Present, stegmata absent	D.32/1 SD.-NA C.-NA	D.140 SD-NA C-NA	Compact in dermal, lacunar in SD & central zones	Palisade cells present	Chhindwara District, M.P.
P. livistonoides (Prakash & Ambwani,1980)	Reniformia	Fibrous bundles present; stegmata absent	D.1/1 -6/1 SD.3/1-7/1 C. NA	D.240-800 SD.400-800 C.NA	D.Compact SD.Slightly lacunar C-NA	Roots present in bark region	Nawargaon, Wardha District.
P. shahpuraensis (Ambwani,1983)	Cordata to reniformia	Fibrous bundles absent; stegmata present	D.4/1 -6/1 SD.2/1-4/1 C.1/1-2/1	D.140-150 SD.65 -70 C.40-45	D.Compact SD.cells with small air spaces C.cells with bigger intercellular spaces.	----NA------	Ghughua, Dindori District.
P. dilacunosum (Ambwani,1984)	Reniformia to cordata	Fibrous bundles present; stegmata absent	D.4/1 -6/1 SD.2/3-3/1 C.1/1-2/1	D.160-170 SD.120 -130 C.65-70	D.Compact & scanty;SD. slightly lacunar; C. Highly lacunar	Extra large air spaces in central zone	Shahpura, Dindori District, M.P.
P. taroides (Ambwani & Mehrotra, 1989)	Reniformia	Both present	O .1.5-2/1 SD. 1/1 – 5/1	O. 256 -360 SD. 170 -248	Compact	Leaf scars on outer surface.	Ghughua, Dindori District
P. siltherensis (Ambwani, 1984)	Reniformia	Fibrous bundles absent; stegmata present	D. 18/1 – 23/1 SD . 24/1 – 30/1 C . 30/1	D.130 -140 SD.100 -110 C. 80 - 85	Compact to slightly spongy in central zone	Presence of different types of parenchyma cells varying from isodiametric to rectangular	Silther, Dindori District
P. binoriensis (Guleria & Mehrotra, 1999)	Reniformia	Fibrous bundles present; stegmata absent	SD. 12/1 - 16/1	SD . 50 -56	Spongy to lacunar	Absence of tabular parenchyma	Binori, Seoni District.
P. vaginatum (Guleria & Mehrotra, 1999)	Vaginata	Fibrous bundles absent; stegmata present	SD. 8 -30/1	SD. 150 - 275	Compact	Vaginate dorsal sclerenchymatus sheath present	Binori, Seoni District.
P. lunarianum (Guleria & Mehrotra, 1999)	Lunaria	Fibrous bundles present; stegmata absent	SD. 4.5 – 14/1	SD. 200 - 220	Compact	------NA-----	Binori, Seoni District
P. bhisiensis (Dutta *et al*, 2007)	Reniform	Both present	O.5/1 -6/1 I. 5/1	O. 40 -60 I. 30 -35	O. Cells with small air spaces I. Cells with lacunar condition air spaces.	Outer and inner zones present	Bhisi, Nagpur District
P. lametaei (Dutta *et al*, 2007)	Reniform to Lunaria	Both present	D. ½ 1/3 SD. 2/3 C.3/4	D. 20 – 25 SD.15 -20 C.15	Small compact dermal, lacunar in subdermal central zones	Radiating parenchyma inbetween the fibrovascular bundles	Bhisi, Nagpur District
P. enochii (Estrada & Cevallos, 2009)	Reniform	---NA----	----NA---	D.17 -34	Lacunar cells with small air spaces	Aerenchyma of different shapes	Mexico
P. dhabaensis sp. nov.	Reniformia to lunata	Fibrous bundles absent; stegmata present	D . 1/2 -1/3 SD. 2/1 – 3/1 C. 2/1 -1/1	D. 90 -100 SD. 70 -75 C. 60 -65	Compact	Satellite bundles and fusion bundles prominent	Dhaba, Nagpur District

Abbreviations: D= Dermal zone; SD= Subdermal zone; C= Central zone; O=Outer zone, I= Inner zone; NA= Not available.

f/v ratio in *P. livistonoides, P. shahpuraensis* and *P. taroides* is almost comparable. However, this ratio is much higher in *P. siltherensis* and *P. binoriensis*. The frequency of fibrovascular bundles is similar in *P. siltherensis,* while it is much higher in *P. livistonoides* and *P. shahpuraensis*. The ground tissue is compact in *P. shahpuraensis, P. siltherensis P. taroides* but in *P. livistonoides*, it is slightly lacunar in subdermal and central zones. The present species, with compact ground tissue having fibrovascular bundles with divided phloem, shows presence of fusion and satellite bundles which differ from the above-

Table 2: Anotomical characters of modern taxa.

Living species	Classification	Fibrous bundles; stegmata	F/V	Distribution of Fibrovascular bundle/cm^2	Ground tissue	Any special characters
Calamus linndnii (BSIP,No-2545)	Reniformia to Lunaria	Fibrous bundles rare; stegmata present	1/1 - 1/3	30 - 35	Compact,parenchyma cells isodiametric with very small intercellular spaces.	Phloem divided into two patches; bundles with one broad metaxylem vessel.
Chamaerops humilis (BSIP,No-1285)	Reniformia to Lunaria	Fibrous bundles rare; stegmata present	1/1 – 1/2	20 - 25	Cells of variable shape, sometimes loosely arranged & impregnated with tannin.	Phloem tending to divide into two parts.
Livistona mauritiana (BSIP,No-1555)	Lunaria	Fibrous bundles & stegmata present	1/1	20 - 25	Compact, cells round to slightly elongated	Phloem divided into two patches. Bundles with one small metaxylem vessel.

mentioned species. As the present fossil form is distinct from the other known species, it is described as a new species, *P. dhabaensis n.* sp.

Fossil palm woods known from the different parts of the world are also taken into account; these are *Palmoxylon lacunosum* Unger and *P. vasculosum* (Schenk) Stenzel (1904). These possess lacunar ground tissue and higher number of fibrovascular bundles which are different from the present species. As regards *P. simperi* and *P. pristine* (Tidwell *et al.*, 1970), the f/v ratio differs to a great extent and the ground tissue is spongy in nature. *P. enochii* (Estrada-Ruitz *et al.*, 2009) has less number of fibrovascular bundles per cm^2 and higher f/v ratio as well as absence of diminutive and satellite bundles. According to Wagieh *et al.* (2004), all the species described by the authors have been assigned to those already recorded by Sahni (1964) (Table 1).

The recovery of *Palmoxylon dhabaensis* n. sp. shows close affinity with the extant genus *Calamus,* a lepidocaryoid palm, indicating tropical to subtropical vegetation. Palms are usually found along the sea coast, chinks of boulders, dry beds of rivers, rivural edges, plains, strand forests and also along temporary streams. The growth of Arecaceae is dependent on water available in abundance and atmospheric humidity. Structurally and physiologically, palms are also well adapted for growth in arid, sandy to marine habitats and hence occur in the most extreme environments (Croat, 1990). Presence of divided phloem in the fibrovascular bundles in the fossils constitutes a unique feature of plant which is shown by lepidocaryoid climber palms where some species can reach to 10,000 ft height. The taxa *Chamaerops humilis* and *Livistona mauritiana*, apart from growing in the plains, also show a great ecological range (Blatter, 1926; Hutchinson, 1959;Tomlinson, 1961, 1990; Corner, 1966; Mahabale, 1982).

Majority of the reported Indian fossil palms are known from the Deccan Intertrappean sediments that belong to the Upper Cretaceous (Maastrichtian) age. The age of these beds has long been debated, although the geologists have considered the Deccan volcanism as an Upper Cretaceous activity. The Intertrappean fossils were believed by Sahni (1937) as Tertiary in age. However, the recent discoveries of dinosaurian fossil remains from Nagpur and Asifabad (Sahni *et al.*, 1984) indicate that, at least in central India, the Intertrappean beds are of Maastrichtian age. Moreover, Wensik *et al.* (1979), based on recent radiometric dates and correlations with the marine palaeomagnetic time scale, concluded that volcanic activity in the Deccan area ended at about 65 MY BP. (Nambudiri and Tidwell, 1998).

SPECIFIC DIAGNOSIS

Monocotyledons

Genus ***Palmoxylon*** Schenk,1882

Palmoxylon dhabaensis n. sp.

(Pl. I, figs, 1-9; 14)

Holotype: BSIP Museum Slide no. 39827 (A,B) ; (Pl. 1, figs, 1-9; 14 & 15).

Horizon: Deccan Intertrappean.

Derivation of name: The specific epithet is based on the locality Dhaba.

Material: The species is based on a small piece of petrified palm wood measuring about 15 cm in length and 8 cm in width. The specimen seems to be a part of a broken palm stem having fairly good preservation.

Specific Diagnosis: Palm stem showing dermal, subdermal and central zones. Fibrovascular bundles densely arranged in dermal and gradually becoming sparse towards central zone; size 400 x 700 to 800 x 1000 μm. The dorsal sclerenchymatous sheath reniform, sometimes lunate, f/v ratio ranging from 1/2 - 1/1. Leaf–traces diminutive, fusion and satellite bundles as well as stegmata present. Ground tissue compact in nature, generally composed of compact parenchyma cells.

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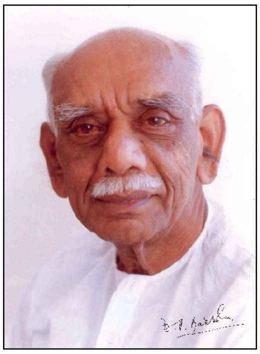
OBITUARY

B. P. RADHAKRISHNA



B. P. RADHAKRISHNA
(April 30, 1918 – January 26, 2012)

Padma Shri Dr. B.P. Radhakrishna was born in Bangalore on 30 April 1918. BPR, as he was popularly known, had his early schooling at Fort High School during which he had developed deep love for Kannada language and literature. As he grew up, he started thinking on the use of scientific knowledge and development for the poor and the downtrodden of our society- something he inherited from the ideals of his father, Shri B. Puttaiah, who was an eminent social figure of the erstwhile State of Mysore.

Dr. Radhakrishna passed his B.Sc. (Hons) degree in 1937 with a first division and a Gold Medal. He then joined the Mysore Geological Department. With a humble beginning as a Field Assistant, he rose to the position of its Director and then retired in 1974. During the service career, he carried out intensive and extensive studies related to geological mapping and mineral investigations of the Mysore state. He had an inquisitive mind with inborn craving for knowledge and an aptitude for research. All these qualities coupled with his great interest on the Closepet Granite earned him the Ph.D. degree of Mysore University in 1954.

It is perhaps his retirement after which he entered into a saga during which he could show the real spectrum of his caliber and could prove him a worthy son of soil. His love for the varied aspects of geology, especially the Precambrian geology of Southern India, geomorphology, groundwater resources and evolution of landscape and crustal evolution advanced the literature with jewels. He also brought into light, and gave a scientific/geological base to, several little-known scientific facts of ancient India along with the relevant Sanskrit renderings. His keen interest in the mineral investigations of Karnataka gave a big boost to the mineral industry of the state. A new mineral- a lead tellurium chloride-collected from the Kolar Gold Fields was named by the Russian scientists as *Radhakrishnaite* after BPR in 1985.

A rare quality that BPR possessed is his love for the Kannada literature. He wrote the biography of his father entitled *Nanna Thande* (My Father) and a book on groundwater entitled *Antarjala*. He wrote in Kannada the biographies of *Darwin*, *Madame Curie* and *Einstein* mainly with the motive to bring before the society the great ideas that moved the world. His acumen to Kannada literature brought him laurels and two of his books (*Darwin* and *Madame Curie*) earned him Sahitya Academy Awards.

One of his best contributions came through his association with the Geological Society of India which got a new life from him. To many, the mane of this Society is synonymous to BPR. His untiring efforts and unending dedication brought the Journal of the Geological Society of India to national and international fame. His editorials contained the inner voice of the geological community as transmitted to the government, administrators, industrialists, educationists and even to the commoner. He brought out a number edited books on behalf of the Society and all these are treasures to Indian geology. His book on the "Geology of Karnataka" (co-authored with R. Viadyanadhan) stands as a baseline. Awards and honours continued to galore one after another, some important ones include: Fellow of the Indian Academy of Sciences, Bangalore, (1956); National Mineral Award (1971); Fellow of the Indian National Science Academy (1971); "Rajyothsava Award" of Karnataka (1974); Honorary Fellow of the Geological Society of London (1986); Honorary Fellow of the Geological Society of America (1990); Padma Shri Award of the Government of India (1991); Millennium Award of the Geochemical Society of India (2000); National Mineral Award for Excellence (2000); Jawaharlal Nehru Centenary Award at the 94th Session of the Indian Science Congress (2007).

BPR's death created a big chasm in Indian geology that is difficult to be bridged. With the finest qualities of head and heart he was a messiah of geologists and a great humanist by nature. Dr. Radhakrishna himself was an institution and can aptly be described as a doyen of Indian geology.

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ANNUAL REPORT FOR THE YEAR 2011-2012

I have great pleasure in presenting the Annual Report of the Palaeontological Society of India for the year 2011-12.

Annual General Meeting

The 55th Annual General Meeting of the Palaeontological Society of India was held on 1st March 2011 at 3:15 P.M. at the Department of Geology, University of Lucknow. It was presided over by Prof. Ashok Sahni. Forty four Fellows attended the meeting. The Annual Report of the Society was presented by the Secretary and the audited statement of accounts by the Treasurer, which were approved.

Council Meetings

The council of the Palaeontological Society met seven times during 2011-12 for transacting the routine business of the Society. In addition, the council also decided the names of the speakers for Profs. S.N. Singh and M.R. Sahni Memorial Lectures. National Field Workshop on Lignite Mines, Surat Gujarat was also planned and discussed.

Lectures

1. **29th M.R. Sahni Memorial Lecture** was delivered on 1st March 2011 by Dr. D.M. Mohabey, Director, Palaeontological Division, G.S.I. Nagpur on "History of Dinosaur Finds in India, Late Cretaceous Evidences".
2. **13th S.N. Singh Memorial Lecture** was delivered on 27th Sept. 2011 by Prof. A.K. Jain, F.N.A., Senior INSA Scientist, Wadia Institute of Himalayan Geology, Dehradun on, "Geology and Tectonics of the Trans-Himalayan and Karakoram Mountains".

Awards :

1. **M.R. Sahni Memorial Gold Medal** : Instituted by the Society, it will be awarded at the forthcoming convocation to Ms. Mridul Gupta for securing highest marks in Palaeontology at 3rd & 4th semester examinations of 2011 of University of Lucknow.
2. **Sharda Chandra Memorial Gold Medal** : It was awarded to Dr. Saswati Bandhyopadhyay of Indian Statistical Institute, Kolkata for her paper entitled, : Osteology of *Barapasaurus tagori* – Dinosauria : Sauropoda from early Jurassic of India" published in "Palaeontology" for the year 2010.
3. **Mani Shanker Shukla Memorial Gold Medal** : (for persons below 40 years) which was instiuted last year (2010) by Mr. Sudhir Shukla, Dy. General Manager (Geology), O.N.G.C., Dehradun, will be awarded in September 2012 to Dr. Rajiv Saraswat, Scientist C, N.I.O., Goa for his outstanding contributions in the field of micropalaeontology for the year 2011.
4. **S.K. Singh Memorial Gold Medal** : Instituted by the Palaeontological Society of India for the best paper published in the Journal of the Palaeontological Society of India in the year 2010, was awarded to Prof. D.K. Pandey of Geology Department, University of Rajasthan, Jaipur for his paper, entitled, "Early Pliocene–Holocene *Favia* from the northern and northwestern coastal areas of Saurashtra Peninsula, western India," published in the journal (vol. 55, no. 2, 2010).

A special honour was conferred on Mr. Pankaj Srivastava, IFS by presenting the citation for his painstaking efforts for preserving the fossil sites in Madhya Pradesh.

Field Workshop on Vastan Lignite Mines, Surat Gujarat :

The Society organized a Field Workshop on Vastan Lignite Mines, Surat, Gujarat from 16th Jan. to 19th Jan. 2012, which was cosponsored by the Geology Department, University of Lucknow. In total, 29 delegates from the universities of Lucknow, B.H.U., H.N.B. Garhwal, Kumaun, and I.I.T. Mumbai, B.S.I.P. Lucknow, W.I.H.G. Dehradun and O.N.G.C. Dehradun participated. There were 9 delegates from the U.S.A., Germany and Belgium. The three-day workshop was a grand success. After the field work during daytime, the delegates interacted with other delegates and presented their views on diverse biotic remains in the evening.

Current Membership

Life Member	267
Ordinary Member	21
Honorary Member	1
Institutional Member	1
Total	**290**

Publication

Publication of the Journal continues to be the major activity of the society. Besides publishing the original research work in palaeontology, the journal also serves to cater to the needs of the allied branches such as biostratigraphy, palaeobotany, sedimentology, hydrocarbon exploration and coal geology by maintaining regularity and high-quality printing. The journal has been accepted for *Science Citation Index – Expanded* (SCIE) from 2011 .

Library

The Society maintains its library by addition of the journals and research publications received in exchange from the sister organizations from abroad.

Finances

The Society is trying hard to procure finances to meet out the steadily growing expenditure on publications and in organizing other activities. Department of Science and Technology Govt. of India has sanctioned Rs.75,000/= to meet out expenses on publication. The MOES, Govt. of India has given a grant of Rs.Three lacs for the Field Workshop on Vastan Lignite Mines. Rs.25,000/= has been sanctioned by the Wadia Institute of Himalayan Geology, Dehradun for the Field Workshop.

Obituary

The Society records with deep regret the sad passing away of Dr. B.P. Radhakrishna, a father figure of Indian geological fraternity. The society regrets the sad demise of Sri S.M. Mathur, Honorary Fellow and a well-wisher of the society.

Acknowledgements

The Society expresses its deep sense of gratitude to the Ministry of Earth Sciences Govt. of India for granting Rs.3 lacs for organizing a Field Workshop on Vastan Lignite Mines, Surat, Gujarat. The sanction of Rs.75,000/= by the Department of Science and Technology, Govt. of India for publication of the Journal, is gratefully acknowledged. The society is deeply obliged to the Directorate General of Hydrocarbons, Noida for becoming an Institutional Member of the Society. The society is also grateful to Wadia Institute of Himalayan Geology, Dehradun for extending financial assistance of Rs.25,000/= towards the Field Workshop on Vastan Lignite Mines.

We are obliged to the Head, Department of Geology, University of Lucknow for extending all possible help and support in all activities of the society. A large number of referees are assisting the editors in evaluating scientific contributions received for publication. The society acknowledges with thanks their kind help. Special thanks are due to Prof. A.K. Jauhri and Prof. S. Kumar, the Editors for maintaining the high quality, regularity and punctuality of the publication of the Journal.

I am personally obliged to all the members of the Executive Council of the Society and fellows for their unreserved support, guidance and assistance in the smooth functioning of the Society.

M.P. Singh
Secretary,
Palaeontological Society of India

Prof. M.K. Mishra, Vice-Chancellor, University of Lucknow presenting on 3rd March 2012 the citation on behalf of the Palaeontological Society of India to Mr. Pankaj Srivastava, IFS for his outstanding contributions in preserving the fossil sites of Madhya Pradesh

Prof. M.K. Mishra, Vice-Chancellor, University of Lucknow presenting the first Prof. S.K. Singh Memorial Gold Medal to Prof. D.K. Pandey of Rajasthan University, Jaipur for the best paper published in the journal of the society in 2010

PALAEONTOLOGICAL SOCIETY OF INDIA, LUCKNOW

STATEMENT OF RECEIPT AND PAYMENTS

(From 1st April 2010 to 31st March 2011)

RECEIPTS	AMOUNT	PAYMENTS	AMOUNT	AMOUNT
Opening Balances :				
F.D.R.	477763.00			
UCO Bank (A/C No. 16644)	2342.34	Remuneration to Part-Time Worker		25200.00
IOB (1867)	16602.88	Auditors Fees		6067.00
Cash in hand	10718.73	Printing & Stationery Expenses		6762.00
Sub-total	**507426.95**	Postage & Telegram Expenses		25442.00
		Telephone Expenses		4377.00
Admission & Subs. Fee	15000.00	Journal Expenses		159465.00
Sale of journal	166845.00	Miscellaneous Expenses		5293.00
Intrest on S/B A/C	11757.00	M.R. Sahni Memorial Lecture Expenses		9049.00
Intrest on FDR	115621.00	Conveyance Charges		1280.00
		TDS 2010-2011		12000.00
		S.N. Singh Mem. Lecture Expenses		6274.75
Receipt from Advertisement	100000.00	Membership Subscription Expenses (IPA)		799.00
Receipt from Sudhir Shukla	51000.00	Brain Storming Session expenses		339620.60
(For Award of Gold medal)		International Field Workshop Expenses		397363.00
Receipt from Power Grid Corp. of India	500000.00			
(For Brain Storming Session)		**Closing Balances:**		
International Field Workshop Income	400000.00	Cash in hand	9863.38	
		UCO Bank (16644)	2440.34	
		IOB (1867)	433132.88	
		F.D.R.	638343.00	1083779.60
Total Rs.	2082771.95			2082771.95

AUDITOR'S REPORT:

We have checked the above statement of receipt & Payment of Palaeontological Societyof India, Lucknow for the period from 1st April 2010 to 31st March 2011 and found correct as per the records produced before us and information & explanation given to us.

For Amit Agarwal & Co.
Chartered Accountants

(Prof. S.Kumar)
Treasurer

(A.K. Agarwal)
Partner
Place : Lucknow
Date : 28.06.2011

(Prof. M.P Singh)
Secretary

PALAEONTOLOGICAL SOCIETY OF INDIA PUBLICATIONS (PSIP)

Monographs of the Palaeontological Society of India

No.1 Supplement to a Monograph of the Terebratulidae of British Chalk
by M. R. Sahni, 1958
Price: Rs. 75.00 (Inland)
U.S. $ 10.00 (Foreign)
No. 2 On *Indobrachyops panchetensis* Gen. Et Sp. Nov. from the Upper Panchets (Lower Trias) of the Raniganj Coalfied
by Baron Friedrich von Huene and M. R. Sahni, 1958
Price: Rs. 100 (Inland)
U.S. $ 10.00 (Foreign)
No.3 Lower Tertiary Vertebrates from western India
by Ashok Sahni and Vijay Prakash Mishra, 1975
Price: Rs. 100.00 (Inland)
U.S. $ 10.00 (Foreign)

Special Publication of the Palaeontological Society of India
No.1 Cenozoic Stratigraphy and Palynology in India
Edited by S. K. Singh, 1982
Price: Rs. 350.00 (Inland)
U.S. $ 45.00 (Foreign)

No. 2 Lameta and Bagh Beds, Central India
Field Guide
by S. Kumar, M. P. Singh and D. M. Mohabey, 1999
Price: Rs. 150.00 (Inland)
U.S. $ 15.00 (Foreign)

No.3 Himalayan Orogen-Foreland Interaction
Edited by A. R. Bhattacharya and K. K. Agarwal, 2005
Price: Rs. 750.00 (Inland)
U.S. $ 25.00 (Foreign)

No.4 Atlas of the Middle Jurassic Ostracods from western India
by S.C. Khosla, S.R. Jakhar and Manisha Kumari, 2009
Price: Rs. 5000.00 (Inland)
U.S. $ 100.00 (Foreign)
No.5 Vindhyan Basin, Son Valley area, Central India : PSI (Field-guide)
by S. Kumar and Mukund Sharma, 2012
Price: Rs. 300.00 (Inland)
U.S. $ 25.00 (Foreign)

20% discount only for members of the Palaeontological Society of India

Order information

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Lucknow - 226 007, India
Ph. No. 0522- 2740015
E-mail: mpsinghgeology@gmail.com

INSTRUCTIONS TO AUTHORS

The Journal is devoted to the publication of original papers and review articles dealing with all aspects of Palaeontology, Palaeobotany, Stratigraphy, Geochronology and Pre-history.

Authors interested in submitting articles to the Journal of the Palaeontological Society of India should send their manuscripts, in duplicate, to the Editor. Format of the previously published papers of recent issues should be followed:

1. **Manuscripts:** Manuscripts should be concise and neatly typed in English, on one side of the A4 paper, with double spacing between the lines and sufficient margin on the left hand, top and bottom sides of the paper. *The authors are requested to send their revised manuscripts on* C.D., *together with a hard copy.*
2. **Title:** It should be informative, brief and typed in bold, upper case letters throughout, centred, with only the names of genera and species underlined or italicised.
3. **Author's Name:** Should be in bold, upper case letters and followed by author's full address in upper case letters.
4. **Abstract:** An abstract of not more than 250 words should be given at the beginning of the paper. Five or six suitable keywords should be added.
5. **Text:** The text should be concise, subdivided by suitable headings which should be in bold and upper case letters and on the extreme left margin (not underlined); 2nd order headings should be in bold but lower case letters and 3rd order headings in lower case letters and italics followed by text on the same line.
6. **Acknowledgements:** Acknowledgements should be given at the end of the main text.
7. The names of the genera and species should be underlined or italicised everywhere in the text and in the legend to the figure. For taxonomic papers, the following format should be adopted:

SYSTEMATIC PALAEONTOLOGY

Subclass **Ostracoda** Latreille, 1806
Order **Podocopida** Müller, 1894
Suborder **Podocopina** Sars, 1866
Superfamily **Cypridacea** Baird 1845
Family **Cyprididae** Baird, 1845
Subfamily **Cypridinae** Baird, 1845
Genus ***Sclerocypris*** Sars, 1924
Sclerocypris dharwadensis n. sp.
(PI. I, figs. 2a-e; PI. III, figs. 4a-b,5)
or
Paijenborchella (*Eopaijenborchella*) *angulosa* Siddiqui, 2006

(PI. I, figs. 7-8)

Synonymies - **to be presented in the following abbreviated order:** *Globulina gibba* d' Orbigny, 1846, p. 227, pl. 13, figs. 13-14. - Bhatia and Mohan, 1959, p. 635, text-fig. 3, fig. 10. - Mohan and Bhatt, 1968, p. 171, pl. 13, fig. 36.

Where necessary, the following subheadings should be used in this order: *Material, Derivation of name, Holotype, Diagnosis, Description, Dimensions, Remarks, Type Locality, Type Horizon.* In the case of known species, the following subheadings would suffice: *Remarks, Dimensions, Locality* and *Horizon.*

8. **References:** Reference to literature in the text should be indicated by the author's name followed by the year of publication, e.g., Wadia (1940) or (Wadia, 1940). This should be done every time the particular reference is repeated. The words *op. cit.* should not be used. In the case of joint authorship of more than two authors, the name of the first author should be mentioned, followed by the words *et al.* and year of publication (e.g. Srivastava *et al.,* 1951).

A complete list of the references mentioned in the text should be given at the end of paper under the heading References. The words *Idem* and *Ibid* should not be used. Full names for all journals should be cited. Authors will be responsible for the accuracy of their references.

Examples:

Wadia D. N. and Swinton, W. E. 1928. *Actinodon risinensis* n. sp. in the Lower Gondwana of Vihi District, Kashmir. *Records of the Geological Survey of India,* **59**(1) : 142-145.

Wadia, D. N. 1971. *Geology of India.* Macmilan & Co., London.

Moore, R. C. (Ed.). 1961. *Treatise on Invertebrate Paleontology.* Pt. Q, Arthorpoda., 3 xxiii, 442 p., 334 figs. Geological Society of America and University of Kansas Press.

Cox, L. R. 1969. Family Terquemidae Cox, 1964, p. N 380-N 382. In : *Treatise on Invertebrate Paleontology* (Eds. Moore, R.C. *et al.),* Pt. N, 1 (of 3), Mollusca 6, Bivalvia, Geological Society of America and University of Kansas Press.

Sanfillippo, A., Westberg, M. J. and Riedel, W. R. 1986. Cenozoic Radiolaria, p. 631-713. In : *Plankton Stratigraphy* (Eds. Bolli, H.M., Saunders, J.B. and Perch-Nielson, K.), Cambridge University Press, Cambridge.

Riedel, W. R. and Sanfillippo, A. 1971. Cenozoic Radiolaria from the western tropical Pacific, Leg 7, p. 1529-1672. In : *Intlial Report of Deep Sea Development Program* 7. U.S. Government Printing Office, Washington.

Nanda, A. C. 1973. Contributions to the Stratigraphy and Palaeontology of the Upper Siwaliks of a part of Naraingarh Tehsil, Ambala (India). *Unpublished Ph.D Thesis, Panjab University, Chandigarh.*

9. **Illustrations:** The maximum area of the plate to be reproduced the same size is 18 x 23 cm. While preparing plates, authors should make use of the maximum space of this size. The desired reduction should be clearly stated and the magnifications mentioned in the legend must conform to this reduction. *Figures larger than for one-half or one-third reduction will not be accepted.* Photographs and line drawings should be separately mounted. *All photographs must be of very good quality, otherwise they will be rejected.* Photographs cut as rectangles should be glued on *white board,* or individual specimens cut round should be mounted on glossy *black background.* All the photographs should be numbered by the author using *arabic numerals. Five plates per article are acceptable for publication. If this number exceeds, the authors will have to bear the cost of publication of extra plates.* The colour plates and figures are printed in the journal, *but their cost will have to be borne by the authors.*

10. The explanation of the plates and figures in the text should be typed and appended to the manuscript and not attached to individual plates. Figures should be numbered 1, 2, etc. without the prefix Fig. Figure magnification should be either indicated in this manner: x 450 at the end of the explanation of each figure or given on the photographs with appropriate scale bar.

11. **Tables, Charts and Graphs:** *Unwieldy tables, charts and graphs cannot be composed within single page. Fold-outs are not accepted.* Tables must be neatly typed in double spacing throughout. Charts and figures must be drawn on white paper in black ink. *Ferro-prints will not be accepted.* Figures drawn in *coral draw* programme will be preferred.

12. **Reprints:** Authors should indicate the number of reprints they wish to have on payment in response to the letter of acceptance of the paper. **Fifteen reprints** will be given free.