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Article

Jurassic benthic foraminiferal diversity, bathymetry and paleoenvironment of the Jaisalmer Basin (Western India)

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With 11 figures

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Abstract: This contribution presents an ammonite age constrained benthic foraminiferal dataset based on a study of 77 samples spanning from Bajocian to Early Tithonian from Jaisalmer (Western India). Species distribution and diversity are documented and changes therein are interpreted in terms of inferred bathymetry, shifts in sea level and paleoenvironment. The similarity and dissimilarity of benthic foraminiferal species from the adjoining Kachchh Basin (Western India) is also discussed. Results indicate that at Jaisalmer, sea level influenced facies deposition and both in turn, in a shallow marginal epicontinental setting, governed the distribution of benthic foraminifera. Further, the observed diversity patterns recognized bed-by-bed are governed by local conditions of the basin but at the stage- and family-levels, are influenced by global eustasy. The strong species dissimilarity observed between adjacent Jaisalmer and Kachchh basins and of increasing similarity at the family-level is most likely a reflection of large-scale changes in global eustasy.

Key words: India, Jurassic, benthic foraminifera, diversity, bathymetry, paleoenvironment.

1. Introduction

Studies on benthic foraminiferal species diversity for the well-exposed sedimentary succession of Jurassic-Cretaceous age at Jaisalmer (Western India; Fig. 1a) are non-existent. Although richly fossiliferous (Garg 1983) foraminiferal studies are largely restricted to (a) a mere documentation of species (Bhatia & Mannikeri 1976; Garg & Singh 1983, 1986; Garg et al. 1998), (b) their distribution from few lithological sections (Subbotina et al. 1960; Kalia & Chowdhury 1983; Garg & Singh 1983) or (c) the usage of impoverished assemblages to create time-diagnostic foraminiferal biozones and range zones that lack well-constrained age-diagnostic ammonite data (Dave & Chaterjee 1996). Hence, the above studies from disparate sections serve only to indicate the presence of benthic foraminifers in these richly fossiliferous Jurassic sediments of the Jaisalmer Basin (Fig. 1a). This contribution attempts to bridge this gap and presents a well-constrained age-limited benthic foraminiferal dataset based on a study of 77 samples spanning Bajocian to Early Tithonian age from the Jaisalmer Basin sediments (Western India). A single sample is collected from each bed and Fig. 2 shows their spatial distribution in and around Jaisalmer. Seventeen benthic foraminiferal assemblages are identified, from bottom to top and the distribution dataset is given as rare (R; beds that have 1-5 specimens), common (C; 6-25) and abundant (A; more than >25 specimens) (Fig. 2). Changes both in species distribution and diversity are interpreted in terms of inferred bathymetry and local and global sea level changes. Paleoecology of the fauna is used to infer the prevailing paleoenvironment. Additionally, foraminiferal faunal similarity/dissimilarity with the adjoining Kachchh Basin is also discussed (Fig. 1b).

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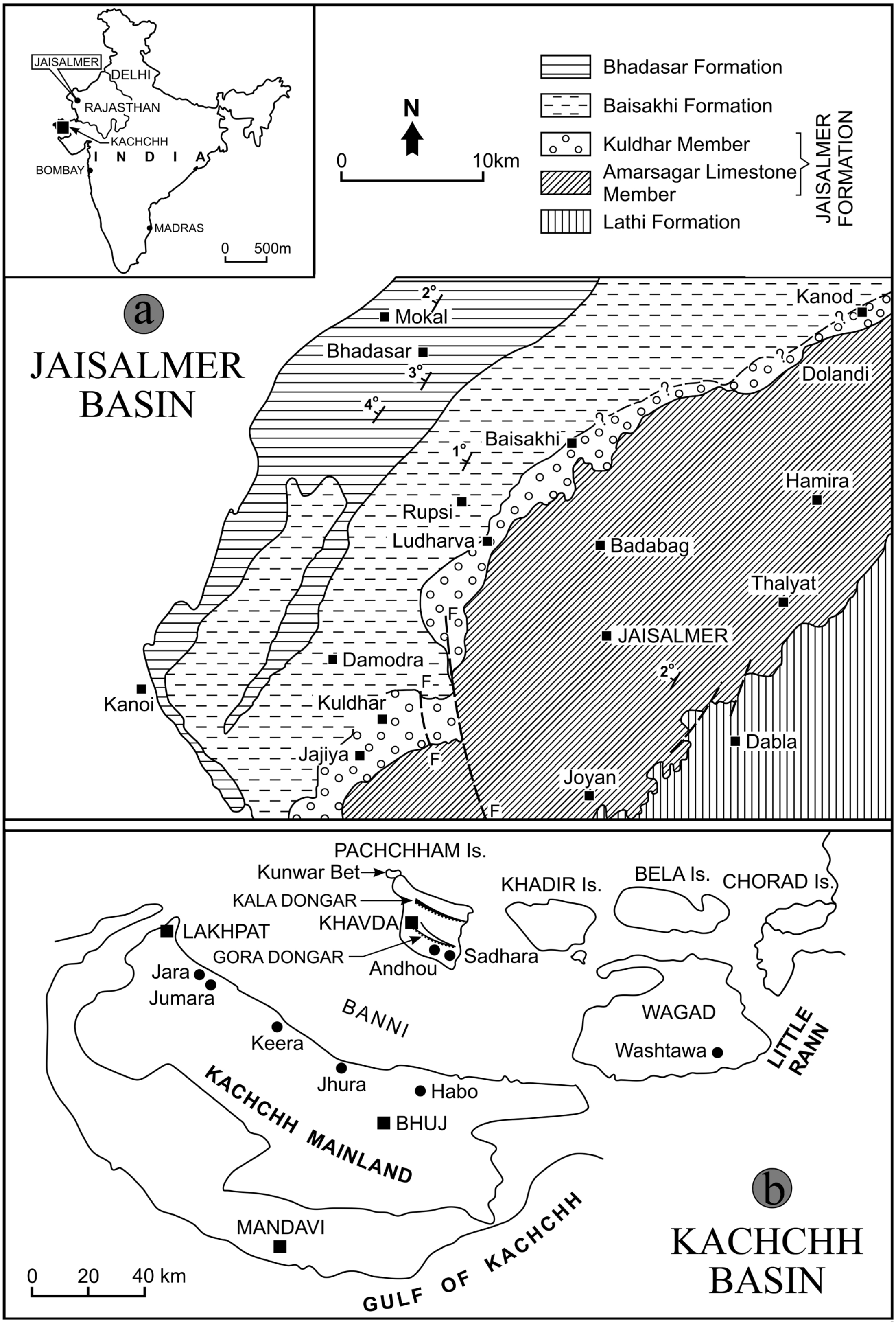


Fig. 1. Map showing Jurassic localities of Western India. **a** – Jaisalmer Basin showing the geographic extent of Formations discussed in text. **b** – Kachchh Jurassic localities. Inset: Map of India and the geographic position of Jaisalmer and Kachchh basins.

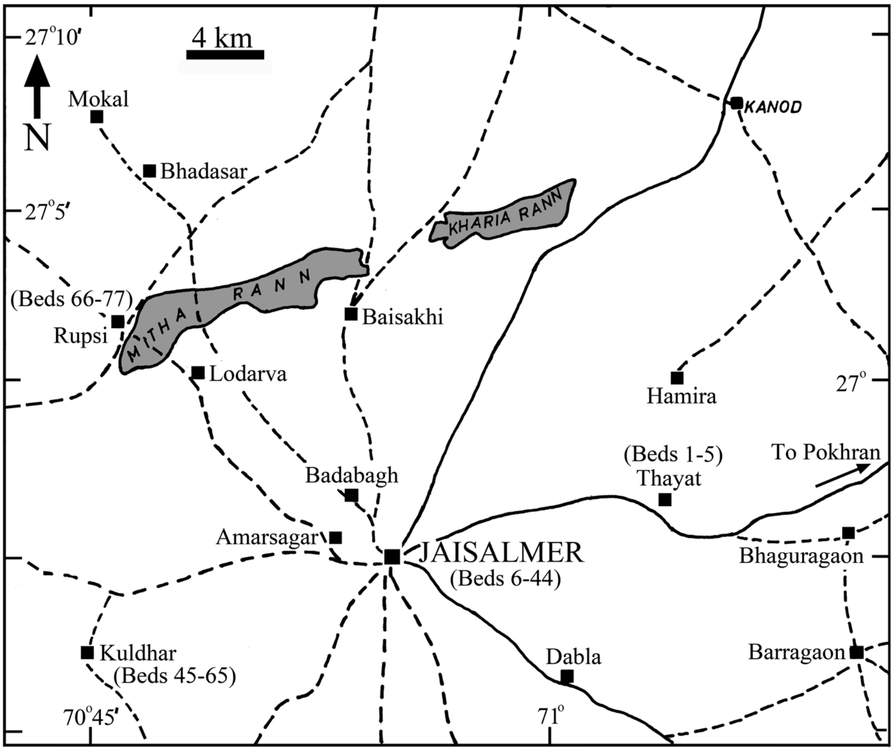


Fig. 2. Jurassic locality map of the Jaisalmer Basin showing the distribution of beds discussed in the text (GARG & SINGH 1983).

2. Stratigraphy

The Jurassic succession in western Rajasthan (Fig. 3) unconformably overlies the Proterozoic Birmania Formation (NARAYANAN 1964) and starts with estuarine to partly marine arenaceous sediments exposed in and around the Jaisalmer city and assigned to the Lathi Formation. These sediments of the Lathi Formation largely consists of medium- to coarse-grained to occasionally gritty, poorly sorted, arkosic, often ferruginous and calcareous sandstones with intercalated bands of sandy shales (beds 1-4; Figs. 2-3). This formation contains plant remains and silicified gymnosperm driftwood. The only evidence of marine influence within this formation is the presence of burrows and other traces of organisms in its uppermost part (bed 4; Figs. 2-3). No megafauna have so far been recorded from this formation.

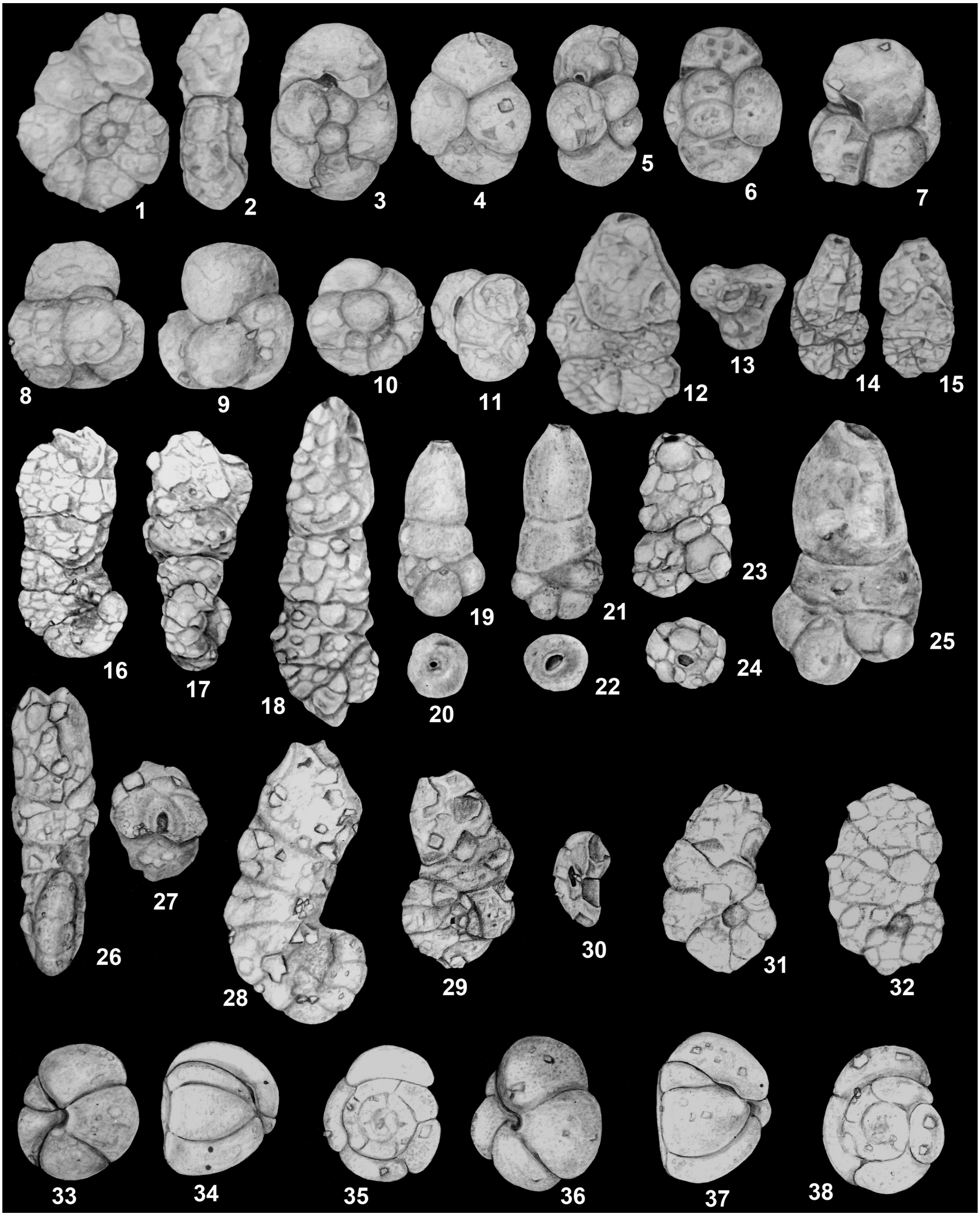
The succeeding Jaisalmer Formation unconformably overlying the Lathi Formation and is dominantly composed of argillaceous sediments with varying calcareous and arenaceous content. The Jaisalmer Formation is here divided into 2 members: the Amarsagar Limestone and the Kuldhar Oolite (Figs. 1-2). The Amarsagar Limestone Member is made up of calcareous to arenaceous limestones with subordinate shales (beds 5-28, Fig. 6). Its basal unit (the Hamira Member of DAS GUPTA, 1975) is exposed at Thaiyat (beds 4-5; Figs. 2-3) and marks the onset of fully marine conditions for the Jaisalmer Basin as indicated by the presence of the Bajocian coral *Isastrea bernardiana* (cf. PANDEY & FÜRSICH 1994). The succeeding upper beds exposed at the Jaisalmer Scarp (beds 6-28; Fig. 2) are highly fossiliferous and made up of argillaceous to marly limestones. The limestones are occasionally oolitic and form alternate hard and soft bands of 0.5 to 1 m thickness. Conspicuous among these are the two hard beds (16-17 and 19-20) that contain abundant regular echinoids (*Hemicidaris*) and several bivalves (including *Corbula lyrata* and *Protocardia grandidieri*). This bivalve association has been dated as Middle Bathonian (ARKELL 1956; GARG 1983). No ammonite fauna has been recorded from these sediments. The succeeding beds are exposed at Amarsagar (5 km W of the Jaisalmer scarp succession; Fig. 2) that comprise of well-bedded fossiliferous argillaceous to arenaceous limestone with minor shaly and sandy intercalations containing bivalves, rhynchonellid brachiopods and

DAS GUPTA, 1975			GARG AND SINGH, 1983			JAIN, 2007	THIS STUDY	
Tithonian	BHADASAR FORMATION	Mokal Mb. Kala Dongar Mb.	BHADASAR FORMATION		Tithonian	Tithonian	Tithonian	BHADASAR FORMATION
Kimmer-idgian	BAISAKHI FORMATION	Rupsi Mb. Ludharwa Mb.	JAISALMER FORMATION	Rupsi Shale Member	Earliest Tithonian-Latest Oxfordian	Earliest Tithonian-Latest Oxfordian	Earliest Tithonian-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

Fig. 3. Biostratigraphy of the Jaisalmer Basin. *Note that the basal unit at Thaiyat (the Hamira Member of Das Gupta 1975) marks the onset of fully marine conditions in the Jaisalmer Basin as indicated by the presence of the Late Bajocian coral *Isastrea bernardiana* (Pandey & Fürsich 1994).

gastropods. Endemic benthic species of *Pseudomarsonella* and *Riyadhella*, also common in the Middle Bathonian of Saudi Arabia, occur in regular abundance in beds 19 to 43, thus indicating a Middle Bathonian age and Arabian affinity for these sediments (Garg et al. 1998). The succeeding beds are exposed at about 1.5 km SW of Badabag (Badabag is 5 km NW of Jaisalmer; Fig. 2). The basal section is made up of fossiliferous limestone, and the upper section constitutes of poorly fossiliferous sandy shales and calcareous sand-

Fig. 4. 1-2 – *Haplophragmoides barrowensis* Tappan. 1: side view, specimen no. LUGMJF 530, magnification: 75x; 2: edge view, specimen no. LUGMJF 530, magnification: 75x; **3-11** – *Recurvoides* spp. 3: spiral view, specimen no. LUGMJF 585, magnification: 100x; 4: umbilical view, specimen no. LUGMJF 585, magnification: 100x; 5: edge view, specimen no. LUGMJF 585, magnification: 100x; 6: spiral view, specimen no. LUGMJF 584, magnification: 100x; 7-9: different side views, specimen no. LUGMJF 598, magnification: 100x; 10: spiral view, specimen no. LUGMJF 586, magnification: 125x; 11: side view, specimen no. LUGMJF 586, magnification: 125x; **12-15**: *Triplasia australiae* Crespin. 12: side view, specimen no. LUGMJF 579, magnification: 50x; 13: top view, specimen no. LUGMJF 580, magnification: 50x; 14-15: spiral view, specimen no. LUGMJF 578, magnification: 50x; **16-25** – *Ammobaculites coprolithiformis* (Schwager). 16: side view, specimen no. LUGMJF 735, magnification: 35x; 17: edge view, specimen no. LUGMJF 735, magnification: 35x; 18: side view, specimen no. LUGMJF 736, magnification: 50x; 19: side view, specimen no. LUGMJF 740, magnification: 125x; 20: top view, specimen no. LUGMJF 740, magnification: 125x; 21: side view, specimen no. LUGMJF 739, magnification: 125x; 22: top view, specimen no. LUGMJF 739, magnification: 125x; 23: side view, specimen no. LUGMJF 737, magnification: 75x; 24: top view, specimen no. LUGMJF 737, magnification: 75x; 25: side view, specimen no. LUGMJF 738, magnification: 75x; **26-32** – *Ammobaculites agglutinans* (d'Orbigny). 26: top view, specimen no. LUGMJF 725, magnification: 65x; 27: edge view, specimen no. LUGMJF 725, magnification: 65x; 28: side view, specimen no. LUGMJF 725, magnification: 65x; 29: opposite side view, specimen no. LUGMJF 727, magnification: 65x; 30: top view, specimen no. LUGMJF 727, magnifica-



tion: 65x; 31: opposite side view, specimen no. LUGMJF 727, magnification: 65x; 32: side view, specimen no. LUGMJF 726, magnification: 100x; **33-39** –*Trochammina quinqueloba* Gerach. 33: Umbilical view, specimen no. LUGMJF 516, magnification: 135x; 34: side view, specimen no. LUGMJF 516, magnification: 135x; 35: spiral view, specimen no. LUGMJF 516, magnification: 135x; 36: umbilical view, specimen no. LUGMJF 517, magnification: 140x; 37: side view, specimen no. LUGMJF 517, magnification: 140x; 38: spiral view, specimen no. LUGMJF 517, magnification: 140x.

stones (bed 45). The calcareous sandstones forms the Badabag Member and are followed by the succeeding Kuldhar Oolite Member (beds 45-65; Figs. 2, 3). From these calcareous sandstones, Prasad (2006) recorded a distinctly latest Bathonian species of *Clydoniceras*, and he correlated these beds with the Late Bathonian Discus Zone of the Submediterranean and Subboreal provinces (for more details see Jain 2007, 2008, 2012).

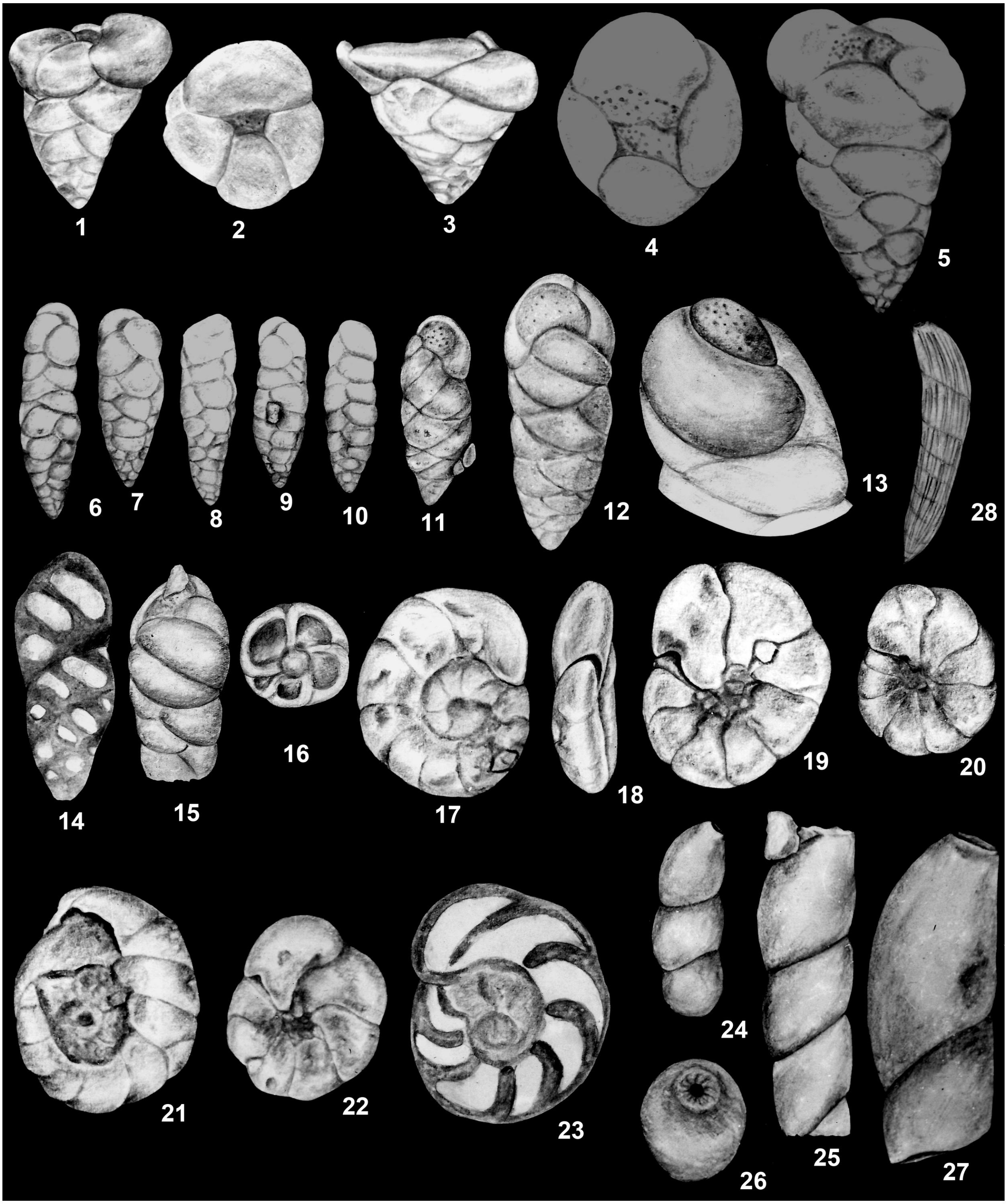
The lower oolitic beds of the Kuldhar Oolite Member (beds 46-65; Figs. 2, 3) have yielded a typical Late Bathonian ammonite association with *Sivajiceras congener* (Waagen) [M] and *Macrocephalites triangularis* Spath [M] (Jain 2007, 2008, 2012), which marks the Bathonian-Callovian boundary in the adjacent Kachchh Basin (Callomon 1993; Jain et al. 1996). Here, this boundary is drawn between beds 46 and 47 (Jain 2007, 2008, 2012; Fig. 2). The succeeding beds from 47 to 50 are assigned to the Early Callovian, based on the presence of *Hecticoceras proximum* Elmi from bed 50, the index of the Patina Subzone of latest Early Callovian age (Jain 2007, 2008, 2012). Beds 51 to 57 yielded a typical Middle Callovian fauna with *Reineckeia* (*R.*) *anceps* (Reinecke) (see Jain 2007, 2008, 2012 for details) and an Early Oxfordian fauna from bed 58 (species of *Mayaites* and *Epimayaites*). The succeeding gypsiferous shales with calcareous sandstone bands (beds 59-65; Figs. 2, 3) are assigned to the Middle Oxfordian. These beds are part of the Baisakhi Member that overlies the Kuldhar Oolite Member, separated by a stratigraphic hiatus (Fig. 3).

The overlying thick sequence of areno-argillaceous sediments of the Rupsi Shale Member conformably overlies the Baisakhi Member (Figs. 2, 3). The lower beds of the Rupsi Shale Member are unfossiliferous and consist of sandstones and sandy shales (beds 66-77; Figs. 2, 3). The succeeding sandy marls are highly fossiliferous and contain abundant ammonites (*Dichotomosphinctes*, *Kranaosphinctes*, and small *Perisphinctes*), bivalves, and brachiopods. The ammonites indicate a Late Oxfordian age. The succeeding silty to sandy shales contains plant remains with no body fossils but profuse arenaceous benthic foraminifers. Up section, these shales are gypsiferous (post-depositional) and contain ammonites. These include species of *Pachysphinctes*, *Torquatisphinctes* and *Hildoglochiceras* of Late Kimmeridgian age (Garg et al. 1998). This unit is followed by a thick succession of thinly laminated sandy shales alternating with hard nodular ferruginous sandy bands. This unit yielded a rich (?later part of) Early Tithonian ammonite fauna (species of *Aulacosphinctoides*, *Parapallasiceras*, *Hildoglochiceras*, *Subplanites* and *Pseudinvoluticeras*) (Garg et al. 1998). A detailed taxonomic study of this rich ammonite and benthic foraminiferal fauna is in progress and will be published elsewhere. The most abundant species recorded from these Bajocian-Early Tithonian sections are illustrated in Figs. 4-6.

3. Species distribution and diversity

In the present contribution, based on species abundance, seventeen benthic foraminiferal assemblages are identified. Of the 77 beds spanning from the Bajocian to the Early Tithonian; the basal 14 beds did not yield foraminifers, expect for rare specimens of *Ammobaculites agglutinans* from bed 9 (Figs. 4.26-4.32). Only 58 beds contained foraminifers, yielding 149 species assigned to 58 genera and 21 superfamilies. Of the 33 three families, Vaginulinidae is the most dominant with 25 species (16.9% of the total species), followed by Nodosariidae with 18 species (12.2%), Lituolidae with 13 species (8.8%), Trochamminidae with 10 (6.8%), and Eggerellidae with 10 species making 6.8% of the total dataset. The bed-by-bed distribution reveals that the calcareous foraminifers predominate in the early part of the Middle Bathonian and also between the Late Bathonian and the Middle Callovian.

Fig. 5. 1-3 – *Pseudomarsonella bipartita* Redmond. 1: side view, specimen no. LUGMJF 657, magnification: 135x; 2: top view, specimen no. LUGMJF 657, magnification: 135x; 3: side view, specimen no. LUGMJF 656, magnification: 100x; **4-5** – *Pseudomarsonella primitiva* Redmond. 4: top view, specimen no. LUGMJF 658, magnification: 100x; 5: side view, specimen no. LUGMJF 658, magnification: 100x; **6-10** – *Riyadhella regularis* Redmond. 6: side view, specimen no. LUGMJF 666, magnification: 135x; 7: side view, specimen no. LUGMJF 667, magnification: 135x; 8: side view, specimen no. LUGMJF 668, magnification: 135x; 9-10: different side views, specimen no. LUGMJF 665, magnification: 135x; **11-16** – *Pfenderina inflate* Redmond. 11: side view, specimen no. LUGMJF 682, magnification: 65x; 12: side view, specimen no. LUGMJF 681, magnification: 100x; 13: enlarged side view, specimen no. LUGMJF 681, magnification: 200x; 14: longitudinal section, specimen no. LUGMJF 684, magnification: 100x; 15: side view (broken), specimen no. LUGMJF 683, magnification: 100x; 16: basal view of a broken specimen, specimen no. LUGMJF 683, magnification: 135x; **17-23** – *Singhamina jaisalmeriensis* Garg & Singh. 17: spiral view, specimen no. LUGMJF 692, magnification: 135x; 18: edge view, specimen no. LUGMJF 692,



magnification: 135x; 19: umbilical view, specimen no. LUGMJF 692, magnification: 135x; 20: umbilical view, specimen no. LUGMJF 695, magnification: 135x; 21: umbilical view, specimen no. LUGMJF 694, magnification: 135x; 22: umbilical view, specimen no. LUGMJF 696, magnification: 135x; 23: equatorial section, specimen no. LUGMJF 697, magnification: 135x; **24-27** – *Dentalina guembeli* Schwager. 24: side view, specimen no. LUGMJF 632, magnification: 100x; 25: side view (broken specimen), specimen no. LUGMJF 633, magnification: 100x; 26: top view, specimen no. LUGMJF 634, magnification: 100x; 27: side view (broken specimen), specimen no. LUGMJF 634, magnification: 100x; **28** – *Dentalina* cf. *tenuistriata* Terquem, side view, specimen no. LUGMJF 635, magnification: 135x.

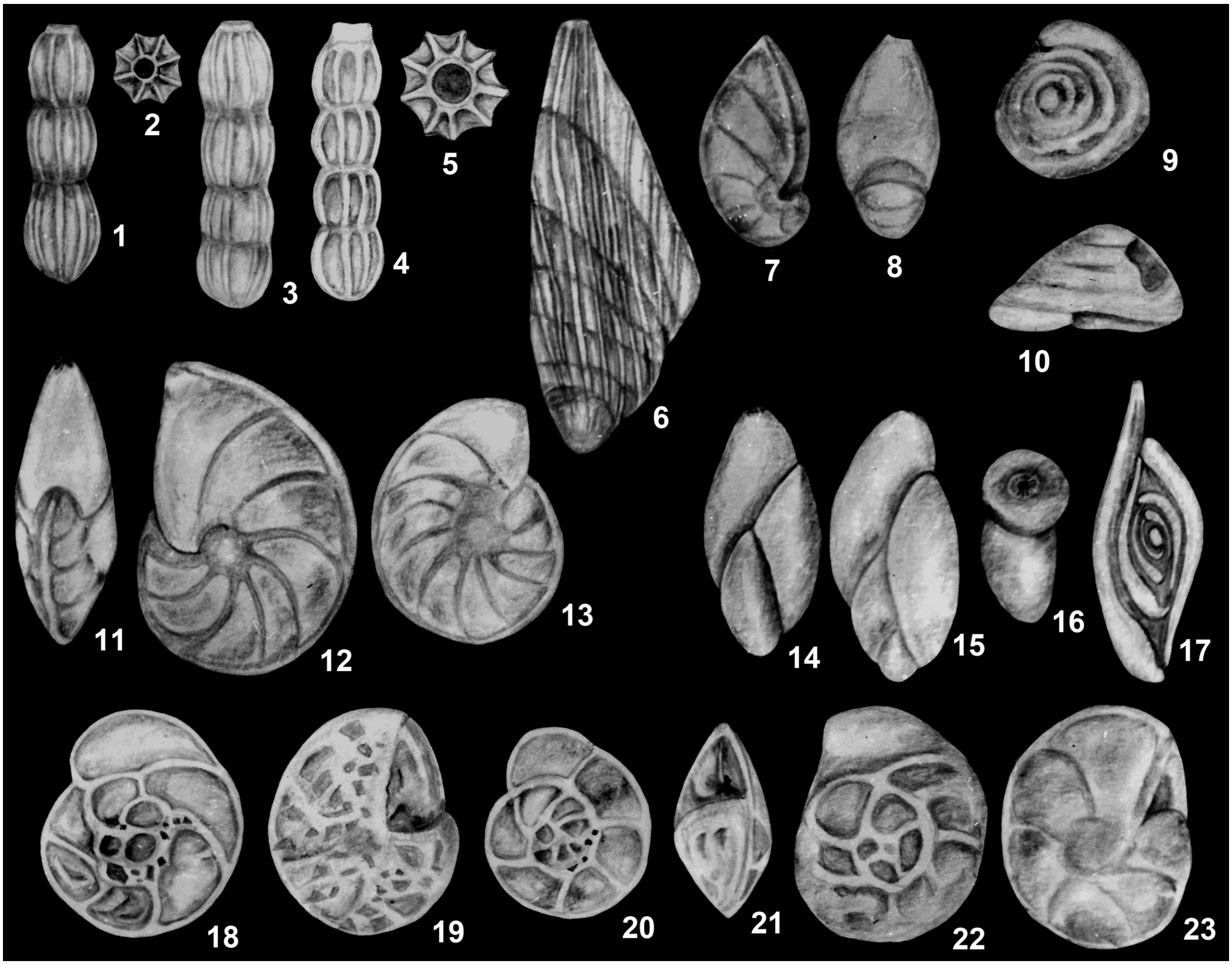


Fig. 6. 1-5 – *Nodosaria hortensis* Terquem. 1: side view, specimen no. LUGMJF 623, magnification: 100x; 2: top view, specimen no. LUGMJF 623, magnification: 100x; 3: side view, specimen no. LUGMJF 624, magnification: 100x; 4: side view, specimen no. LUGMJF 625, magnification: 100x; 5: top view, specimen no. LUGMJF 625, magnification: 160x; **6** – *Citharina flabellata* (Gumbel), side view, specimen no. LUGMJF 644, magnification: 100x; **7-8** – *Saracenaria phaedra* Tappan. 7: side view, specimen no. LUGMJF 615, magnification: 100x; 8: edge view, specimen no. LUGMJF 615, magnification: 100x; **9-10** – *Trocholina conica* (Schlumberger). 9: spiral view, specimen no. LUGMJF 550, magnification: 100x; 10: side view, specimen no. LUGMJF 551, magnification: 100x; **11-13** – *Lenticulina muensteri* (Roemer). 11: edge view, specimen no. LUGMJF 603, magnification: 65x; 12: side view, specimen no. LUGMJF 603, magnification: 65x; 13: side view, specimen no. LUGMJF 602, magnification: 65x; **14-16** – *Eoguttulina liassica* (Strickland). 14: side view, specimen no. LUGMJF 591, magnification: 100x; 15: side view, specimen no. LUGMJF 590, magnification: 100x; 16: top view, specimen no. LUGMJF 590, magnification: 100x; **Fig. 17** – *Opthalmidium* cf. *carinatum* Kübler & Zwingli, side view, specimen no. LUGMJF 594, magnification: 100x; **18-19** – *Epistomina regularis* Terquem. 18: spiral view, specimen no. LUGMJF 562, magnification: 135x; 19: umbilical view, specimen no. LUGMJF 562, magnification: 135x; **20-21** – *Epistomina* cf. *turgidula* Pazdro. 20: spiral view, specimen no. LUGMJF 561, magnification: 135x; 21: edge view, specimen no. LUGMJF 561, magnification: 135x; **22-23** – *Epistomina coronata* Terquem. 22: spiral view, specimen no. LUGMJF 560, magnification: 135x; 23: umbilical view, specimen no. LUGMJF 560, magnification: 135x.

The agglutinated forms dominate in the middle part of the Middle Bathonian and in the Kimmeridgian.

At the substage-level the calcareous foraminifers dominate between the Late Bathonian and the Middle Callovian, and the agglutinated forms in the Kimmeridgian (Fig. 7a). Interestingly, the porcellaneous foraminifers dominate in the Middle Bathonian (Fig. 7). At the stage-level (Fig. 7b) calcareous forms dominate during Bathonian and Callovian times, the agglutinated forms during the Kimmeridgian. However, at the

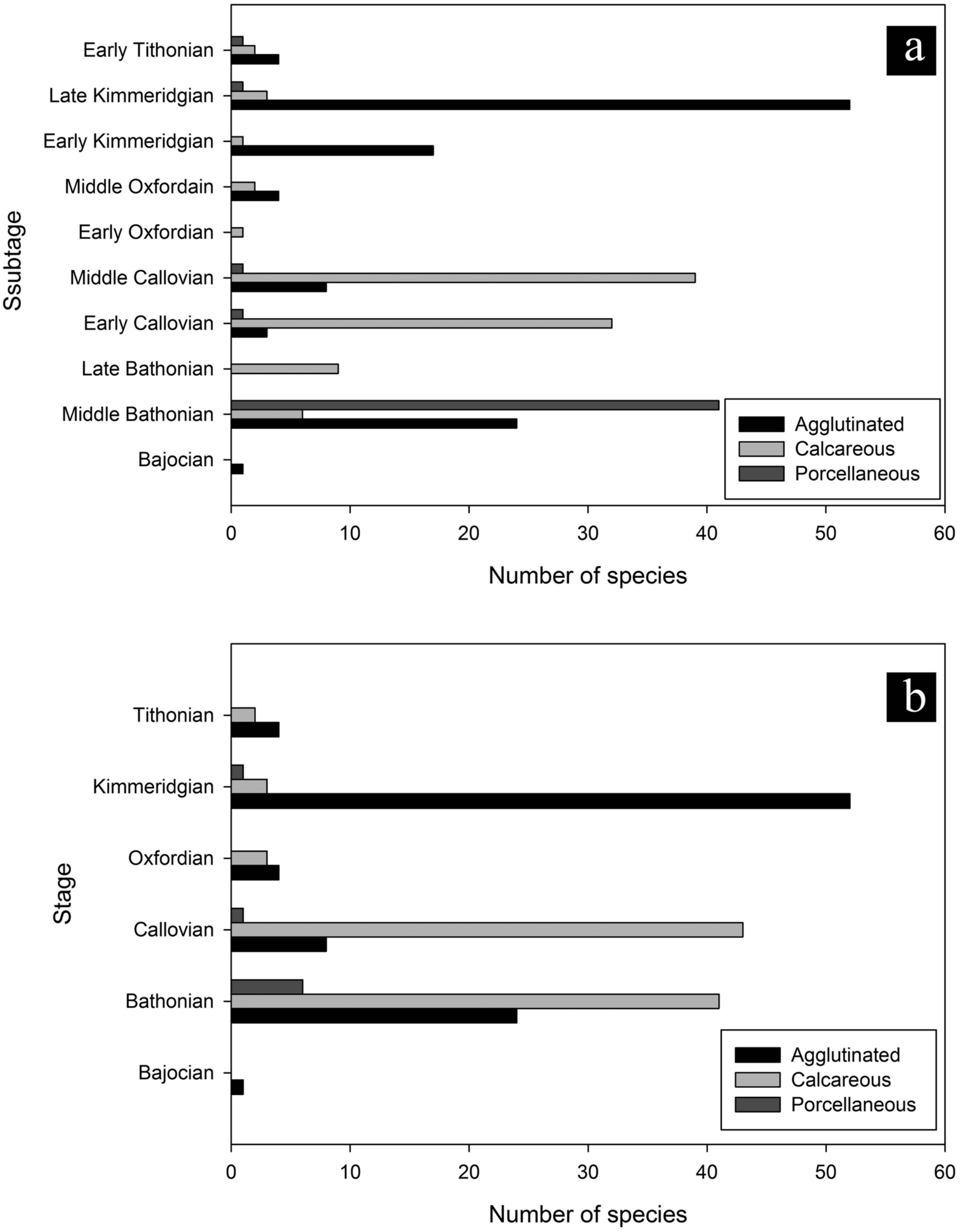


Fig. 7. Substage- and stage-wise distribution of agglutinated, calcareous, and porcellaneous foraminiferal species within the Jaisalmer Basin.

stage-level the porcellaneous forms only form a fraction in the Middle Bathonian.

Stratigraphically, at the genus-level the maximum of first occurrences (FO) is noted in the Bathonian (32 genera) and then in the Kimmeridgian (21), whereas the maximum of last occurrences (LO) lies in the Kimmeridgian (24) and then in the Callovian (11). The maximum number of restricted genera within a stage lies in the Bathonian (16), followed by the Kimmeridgian (7).

At the species-level, the maximum of FO is also noted in the Bathonian (77 species) and then in the Kimmeridgian (44), whereas the maximum of LO is in the Callovian (34) and then in the Kimmeridgian (10). The maximum number of restricted species within a stage is also within the Bathonian (50) followed by the Kimmeridgian (43) and the Callovian (28). Thus, major changes at both at the genus- and species-levels are noted in the Bathonian and Kimmeridgian and, to a lesser amount, in the Callovian.

Putting together all the available dataset, a moderate cyclicity in species diversity with peak values during the Middle Bathonian, Middle Callovian and Late Kimmeridgian and lower values during the Late Bathonian, Oxfordian and Tithonian is observed (Fig. 8).

4. Bathymetry and paleoenvironment

Bathymetry, paleoecology and paleoenvironment are inferred from:
(1) the contained facies (ex. limestones, sandstone, etc.),
(2) sedimentary structures within the identified assemblage (ex. current bedding, etc.) and
(3) the associated occurrences of a) body fossils (ammonites, bivalves, brachiopods, echinoids and belemnites), b) trace fossils, c) pollen, spores and wood, d) charophytes, e) algae (Dasycladaceae), f) serpulids, g) holothurian sclerites, h) crinoids (*Isocrinus*), i) fish remains (otoliths), j) nannofossils and k) foraminifers.

Maximum depth of deposition for all the sections studied does not exceed more than 50 m. These deepest parts also contain ammonite horizons. Bathymetry, paleoecology and paleoenvironment of each assemblage are described below.

Assemblage 0 (Zero; beds 1-14) is unfossiliferous. The lower beds (beds 1-4) belong to the Lathi Formation which is marked by a predominance of medium- to coarse-grained clastic sediments with interspersed pollen, spores and fossil wood. Medium- to coarse-grained clastics indicate high-energy near-shore conditions. Additionally, intermittent exposures of the sea floor and/or well-oxygenated conditions are inferred based on the ferrugineous nature of the sediments. Presence of interspersed pollen and spores and fossil wood indicate shallow estuarine to brackish conditions. The bioturbated upper beds indicate some marine influence at the top. Thus, the sediments of the Lathi Formation (beds 1-4) indicate high-energy estuarine conditions within a hot and dry climate (pollen and spores). Low salinity due to increased freshwater influence might have led to an extremely low diversity of the microfauna and the total absence of any macrofauna. A deposition depth of around 5 m is inferred (Fig. 8). The succeeding beds (beds 5-14) that belong to the lower part of the Jaisalmer Formation (Fig. 2) are also largely unfossiliferous. However, the occurrence of the agglutinated foraminifer *Ammobaculites agglutinans* in bed 9 indicates a marine influence. This is also indicated in bed 5 based on the first occurrence of the coral *Isastrea bernardiana* (cf. Pandey & Fürsich 1994). Overall, the lower part is made up of a thick medium- to coarse-grained sandstone (bed J0) with current bedding indicating shallow high-energy conditions. The continuous presence of charophytes from beds J1 to J9 (beds 7-15) also suggests freshwater influence. However, the presence of Dasycladaceae and the regular echinoid *Hemicidaris* in beds J10-11 (beds 16-17) indicate a warm water low-energy regime. Dasycladaceae generally live in depths less than 5 m (Fig. 8). Further up in the section, the presence of bivalves and gastropods (bed J6; bed 12) in glauconitic shales suggests a deepening of the basin and reducing conditions. Thus, overall, for beds J5-14, based on the occurrence of the abovementioned fauna and flora, the maximum estimated depth is around 10 m (Fig. 8). The presence of *Hemicidaris* suggests clear water and the charophytes indicate freshwater influence.

Assemblage 1 is marked by the dominance of *Lenticulina muensteri*, *Lenticulina subalata*, and species of *Epistomina*. The facies is carbonate with associated marls. The presence of the bivalves *Indocorbula lyrata* (Sowerby) and *Protocardia grandidieri* (Newton) have also been noted in coeval Middle Bathonian sediments of Middle East and East Africa (Arkell 1956; Hallam 1975) and are interpreted to indicate a transgressive shallow-water facies. The presence of thick-walled species of *Lenticulina* and *Epistomina* also suggests deeper conditions, however, comparable presence of bivalves does not indicate depths greater than 15 m (Fig. 8). Additionally, the presence of dwarf specimens of *Quinqueloculina* in this assemblage is quite intriguing and possibly suggests modifications due to an increased brackish influence.

Assemblage 2 (beds 19-22) is marked by the dominance of the agglutinated species *Singhamina jaisalmeriensis*, *Riyadhella regularis* and *Trocholina conica*. Beds 19-20 contains the regular echinoid *Hemicidaris*. The assemblage is also dominated by bivalves, nerineid gastropods and rhynchonellid brachiopods (*Cryptorhynchia*, *Globirhynchia*). Nerineid gastropods indicate shallow-marine subtidal conditions, and the presence of echinoids and brachiopods indicate normal salinity with well-oxygenated conditions and clear waters. The brachiopods are represented by monospecific clusters of *Cryptorhynchia* and *Globirhynchia* that indicate calm open-marine conditions and a shallow subtidal environment. In Recent times, brachiopods live in shallower waters of the continental shelf (below the low-tide) and are marginally intertidal (Rudwick in Moore 1965). Echinoids, as characteristic grazers, point to shallow depths within the photic zone. The dominance of agglutinated species of *Singhamina*, *Riyadhella* and *Trocholina* within this assemblage also suggests a shallow subtidal environment. Thus, over all for Assemblage 2, the inferred depth is less and around 10 m with shallow subtidal marine conditions (Fig. 8). The presence of dwarfish specimens of *Quinqueloculina* and *Spiroloculina* indicate a somewhat near-shore brackish influence.

Assemblage 3 (beds 23-28) is dominated by *Lenticulina muensteri*, *Pseudomarsonella media* and *Trocholina conica*. The associated facies is dominantly made up of carbonates with intermittent bands of fossil concentrations, suggesting flooding events. A somewhat deeper depth of 20 m (Fig. 8) is inferred based on the facies and the fossil clusters.

Assemblage 4 (beds 29-32) is marked by the dominance of *Triplasia australias*, *Pseudomarsonella bipartita* and *Pseudomarsonella primitiva*. This assemblage is also marked by the abundance of the brachiopod *Globirhynchia*. The predominant lithology is marl suggesting somewhat deeper and calmer conditions. Maximum inferred depth is 20 m (Fig. 8), similar to Assemblage 3.

Assemblage 5 (beds 33-38) shows abundance of *Singhamina rajasthanensis*, *Trocholina conica* and *Triplasia australias*. The assemblage also contains abundant bivalves and nerineid gastropods indicating very shallow-marine subtidal conditions with depths not exceeding 20 m (Fig. 8).

Assemblage 6 (beds 39-44) is dominated by *Pfenderina inflate*, *Nodosaria mecista* and *Trocholina conica*. The lithology is a sandy limestone. *Pfenderina* is a complex agglutinated foraminifer and is know to occur in limestones deposited in clean clear water at somewhat deeper depths (Smout & Sudgen 1961). Thus, based on the lithology and the associated fauna, a somewhat greater depth of 35 m is inferred (Fig. 8).

In summary, the Amarsagar Limestone Member (beds 5-44) represents near-shore shallow marine environment with varying ecological conditions. The lower part of the member is deposited under fluctuating shallow marginal brackish-marine conditions near the littoral-sublittoral zone within a depth around 5-10 m (Fig. 8). The upper part of the member was deposited in a relatively stable shallow open.-marine environment of the inner sublittoral shelf. The sea was warm, generally well lit and well-oxygenated and of a normal marine salinity with brief intervals of brackish influence. Slightly deeper conditions around 20-35 m are noted for the upper part of the member. The occurrence of charophytes, low diversity of mega- and microfauna, rarity of calcareous foraminifers and the gradual disappearance of echinoids and brachiopods towards the top indicates the presence of some ecological constraint, most likely increased freshwater influence, and turbidity. The total absence of ammonites in the Amarsagar Limestone Member is quite intriguing and might result from some physical barriers restricting these nektobenthic organisms moving into the Jaisalmer Basin.

Assemblage 7 (beds 45-46) forms the Kuldhar Oolite Member and has the abundance of *Citharina flabellata, Dentalina guembeli* and *Nodosaria hortensis*. This assemblage marks the first appearance of ammonites (*Clydoniceras* sp., *Sivajiceras congener*) indicating fully marine conditions. The micro- and macrofauna is profusely rich (ammonites, belemnites, brachiopods, bivalves and rare gastropods) within the interbedded oolitic limestones, marls and shales, associated with the presence of phytoplankton, holothurian sclerites, crinoids (*Isocrinus*) and fish remains. The echinoids are totally lacking, but crinoids and their disarticulated stems are profuse. Bed 46 is a hardground (Fürsich et al. 1991; Jain 2007, 2008, 2012) indicating the presence of a maximum flooding surface with a hiatus or negligible rates of sedimentation. It contains serpulids and small oysters encrusting the ammonites on both sides suggesting their attachment when the ammonites were still alive. However, in some cases, the serpulids, which are sessile epifaunal filterers, are only attached on one side of the ammonite. This points to a post-mortem attachment that occurred while the ammonites lay on the sea bottom and remained uncovered due to a slow sedimentation rate. Throughout the sequence, the ‘golden oolites’ are never as dominant as found in other typical oolitic shoals. The dominance of stenohaline nektonic organisms and of calcareous benthic foraminifera indicates an open-marine, inner to middle neritic environment. The presence of oolites, however, indicates relatively shallow depths and moderately agitated bottom conditions in a high-energy environment but with some substrate stability to allow

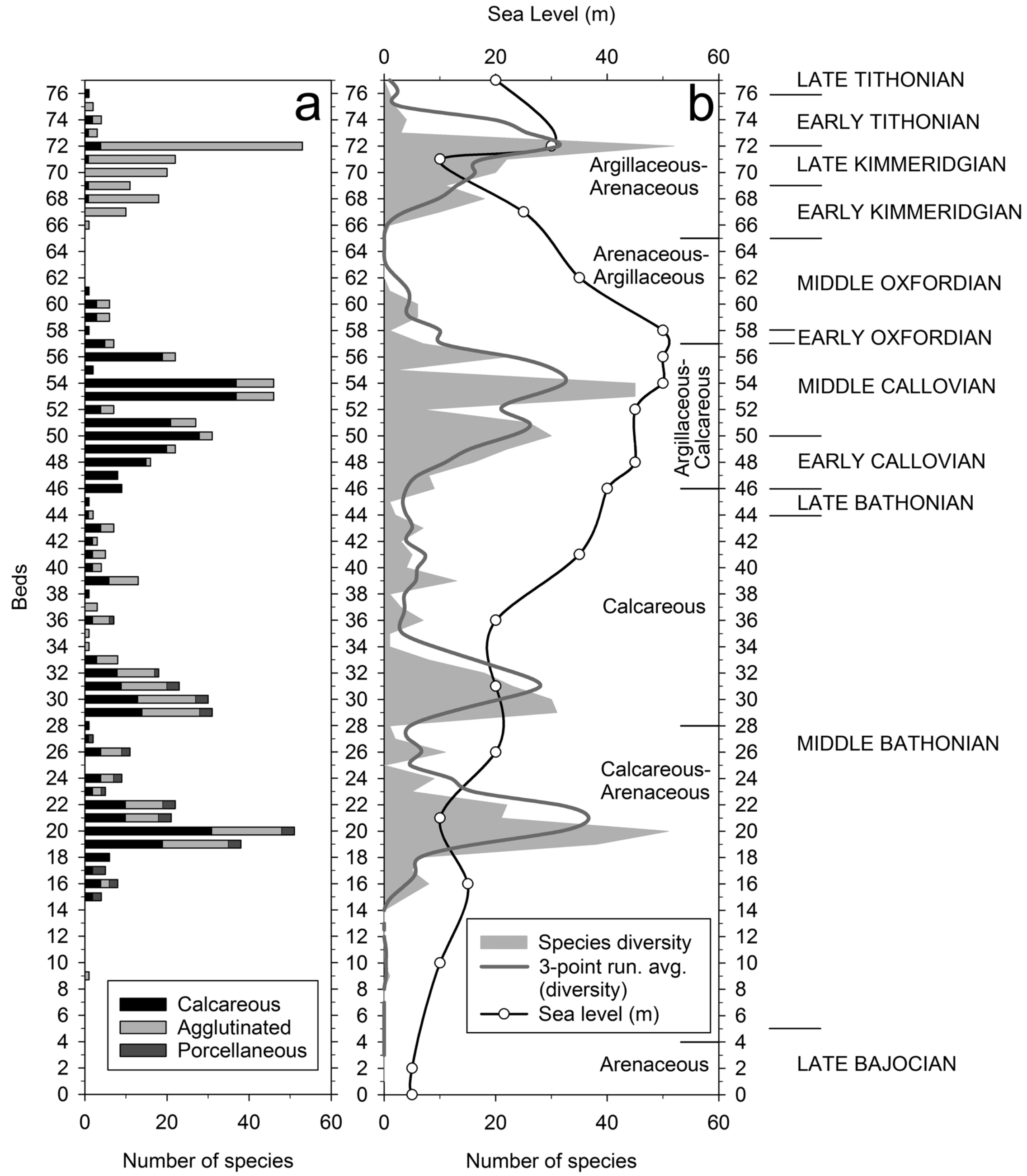


Fig. 8. Species distribution, diversity and inferred sea level of the Jaisalmer Basin. **a** – Bed-wise distribution of calcareous, agglutinated, and porcellaneous foraminiferal species within in the Jaisalmer Basin. **b** – Bed-wise species diversity, 3-point running average of species diversity and inferred sea level within in the Jaisalmer Basin.

the benthic organisms to flourish. The brachiopods represented both by rhynchonellids and terebratulids are known to live in shallow and relatively clear waters. Nevertheless, the rarity of surface dwelling deposit feeders like gastropods and the total absence of echinoids indicate some unspecified environmental constraint for theses organisms. Profuse abundance of ammonites and calcareous forms indicate depths close to 40 m (Fig. 8).

Assemblage 8 (beds 47-50) is dominated by *Citharina flabellata*, *Dentalina guembeli* and *Lenticulina muensteri*. The facies is made up of thin bands of oolitic limestones and marls. Here the nodosariids are large and bearing robust tests. The associated agglutinated foraminifera, polymorphinids and the miliolids are rare and poorly preserved. Ammonites are abundant. The presence of both thick-walled and strongly ornamented foraminifera together with abundant ammonites suggest deeper conditions, but the presence of oolitic bands also indicate intermittent shallowing and high energy conditions. Hence, a somewhat less stable but slightly deeper depositional condition (~45 m; Fig. 8) than the preceding Assemblage 7 is inferred.

Assemblage 9 (beds 51-52) is marked by the presence of the same benthic foraminiferal assemblage as Assemblage 8 with *Dentalina guembeli*, *Lenticulina muensteri* and *Citharina flabellate*, but the species dominance has changed. The ammonites and benthic calcareous foraminifers continue their abundance. Cosmopolitan and index ammonites like *Reineckeia* (*Reineckeia*) *anceps* (Reinecke) [M] dominate. The inferred depth remains unchanged at around 45 m (Fig. 8).

Assemblage 10 (beds 53-55) is dominated by *Lenticulina muensteri*, *Citharina flabellate* and *Falsopalmulina deslongchampsi*. As compared to Assemblage 9, the calcareous forms (especially nodosariids) continue to dominate over the agglutinated foraminifers. The lithology is dominated by glauconitic shales and phosphatic nodules with minor constituent of sandy limestones, marls and coarse sandy to gritty shales higher up in the section. Coccoliths are common in these sediments, together with frequent fish remains (otoliths) and crinoids, the latter represented by *Isocrinus* ossicles and plates. Holothurian sclerites are rare. The phosphatic nodules are rich in organic matter. Based on the fauna and lithology, the inferred depth remains largely unchanged from Assemblage 9, but is slightly deeper at around 50 m (Fig. 8).

Assemblage 11 (beds 56-57) is marked by the dominance of *Conicospirillina trochoides*, *Lenticulina muensteri* and *Lenticulina quenstedti*. The ammonites continue to dominate as in the previous assemblages 7-10. The lithology is essentially made up of marls and suggests deeper and calmer depositional conditions at a depth of around 50 m.

Assemblage 12 (bed 58) is marked by the dominance of *Lenticulina muensteri* and associated with rare ammonites in a highly ferrugineous oolitic sandy limestone. However, the presence of the pelagic phylloceratid ammonoid *Holcophylloceras* sp. suggests deeper conditions. The almost exclusive dominance of *Lenticulina muensteri* also suggests somewhat deeper conditions. This is also favoured by the morphology of ammonite shells (depressed whorl sections) and their coarse ornamentation (*Mayaites* spp.). The estimated depth is still around 50 m (Fig. 8).

Assemblage 13 (beds 59-65) belongs to the Baisakhi Member and marks the first assemblage that is dominated by agglutinated foraminifera, which otherwise were dominated by calcareous forms. The dominant species include *Lenticulina muensteri*, *Haplophragmoides barrowensis* and *Ammobaculites agglutinans*. This assemblage appears somewhat impoverished. The associated lithology is made up of sandy to carbonaceous shales with two hard ferruginous oolitic sandy limestone bands containing brachiopods (terebratulid *Kutchithyris* and the large, globose rhynchonellid *Somalirhynchia*). The upper part of the section is made up of current-bedded sandstones (beds 61, 63) that are bioturbated and contain plant remains. Only the basal part of this assemblage (oolitic sandy limestone bands) contains inflated, coarse-ribbed ammonites (*Mayaites*, *Epimayaites*) along with phylloceratids and belemnites. Shallow depths (~40 m), perhaps approaching the upper part of the inner shelf, with fairly stable substrate conditions and normal marine and well-oxygenated waters are suggested by the overwhelming dominance of brachiopods. However, the dominance and low diversity of the epifaunal suspension feeding benthos along with the rarity of other benthic organisms (ammonites, bivalves, etc. and microfauna) indicates the presence of some ecological constraints. The general impoverishment of the fauna together with the disappearance of calcareous foraminifera up section in the gray (gypsiferous, post-depositional) shales suggests unfavourable environmental conditions, most likely due to the interplay of increased shallowing, reduced oxygen content and lowered salinity. Sedimentologically, for assemblage 13, two similar shallowing trends (coarsening upward sequences; parasequence) are noted. These deposits grade from fine shale (bed SC1) to sandy shale (beds SC2 and SC4) to medium- to coarse-grained sandstones (beds SC3 and SC5) are capped by gray carbonaceous shales (beds SC6-7). This represents a regressive sequence deposited under shallow water conditions with intermittent periods of lower salinity due to the influx of freshwater from estuarine channels as suggested by the occurrence of plant remains. The presence of a sandy sequence showing current bedding and bioturbation indicates rapid deposition under high-energy shallow conditions. Based on the benthic fauna and the associated lithology, a somewhat shallower depth between 30-35 m is estimated for this assemblage (Fig. 8).

Assemblage 14 (beds 66-69), another impoverished assemblage, is dominated by agglutinated forms of *Reophax deckeri*, *Trochammina quinqueloba* and *Lagenammina difflugiformis* with rare small ammonites (*Torquatisphinctes*) and belemnites. The facies consists of sandstones to sandy shales indicating a shallowing of the basin. The maximum inferred depth is around 25 m (Fig. 8).

Assemblage 15 (beds 70-71) is dominated by simple tubular agglutinated species of *Bathysiphon*, *Rhabdammina* and *Rhizammina* that are large, robust, coarsely agglutinated and often with poorly cemented tests. The dominance of simple tubular agglutinated species indicates a deposition under near-shore marshy conditions. Additionally, the foraminifer tests are also frequently distorted, crushed or broken, hence, only determined at the genus-level. The lithology is a gray carbonaceous shale that is occasionally micaceous and contains plant remains. The absence of other benthic marine fauna might be related to a lower salinity. The occurrence of fossil wood attests to the near-shore conditions and the influx of organic matter with land runoff into the basin through estuarine channels (gray carbonaceous shales). Thus, based on the fauna and the lithology, the estimated depth inferred is around 10 m (Fig. 8).

Assemblage 16 (bed 72) is dominated by agglutinated species of *Trochammina bartensteini*, *Reophax agglutinans* and *Ammobaculites gordoni* in a gray to green sandy shale with ferruginous ocherous nodules that contain ammonites. The calcareous forams are rare. The simple tubular agglutinated forms are often large and robust suggesting deposition under stable brackish-marine shallow conditions. Based on the lithology and the contained fauna (essentially ammonites), slightly deeper conditions than for Assemblage 15 at around 30 m are inferred (Fig. 8).

Assemblage 17 (beds 72-77) is also dominated by agglutinated species of *Ammodiscus asper*, *Eoguttulina liassica* and *Reophax agglutinans*. Unidentified and rare internal moulds of calcareous foraminifera are also noted. The presence of coarser terrigenous clastics suggests a shallowing and a gradation towards a near-shore high-energy environment of the inner shelf. The occurrence of moulds of polymorphinids and lenticulinid foraminifers indicates a decalcified shallow shelf assemblage. The reduction in foraminiferal diversity also suggests gradual shallowing, greater influx of coarser sediments, and lack of nutrients and presumably a lowered salinity. The total lack of other benthic fauna also suggests unfavorable conditions. However, the presence of ammonites and belemnites together with the brackish-marine, predominantly agglutinated foraminiferal assemblage suggests that these sediments maintained marine connections, possibly due to stronger currents that transported the nektonic forms into the marginal-brackish regime. Estimated depth is around 20 m (Fig. 8).

Thus, the maximum depth of deposition for the entire section studied here does not exceed more than 50 m; the deepest parts also contain ammonite horizons.

5. Environmental significance of agglutinated assemblages

Assemblages 13 to 17 (beds 59-77; Middle Oxfordian to Early Tithonian) from the Baisakhi and Rupsi Members of the Jaisalmer Formation are dominated by agglutinated foraminifers. Similar benthic foraminiferal assemblages composed dominantly or exclusively of agglutinated forms have been well-documented both in the fossil record and in the Recent (Garg 1983; Tibert et al. 2003b; Tibert & Leckie 2004; Gebhardt 2006; Reolid et al. 2008). Agglutinated assemblages are known to inhabit diverse environmental conditions ranging from lagoons, bays, estuaries or brackish water or hypersaline marshes on the one hand to bathyal and abyssal depths on the other hand (Murray 2001). Studies have noted that agglutinated forms with simple interiors (*Ammobaculites*, *Haplophragmoides*, *Trochomina*, etc.) are predominant in near shore brackish-waters while forms with complex interiors (*Cyclammina*, etc.) are characteristic of the deep waters. Additionally, in general, bathymetrically the thicker and coarsely agglutinated forms dominate in near-shore environment and the thinner, more siliceous tests in deeper and low-energy marine conditions. However, coarse-grained, robust tests are also known to inhabit deep waters. Assemblages composed of calcareous and agglutinated forms (*Bathysiphon*, *Dentalina*, *Lenticulina* and *Nodosaria*) suggest fully marine conditions whereas those dominated by agglutinated forms (*Textularia*, *Ammobaculites*, *Haplophragmoides* and *Trochammina*) indicate marginal (marsh, estuary, and lagoon) marine to brackish conditions (Culver et al. 1996). Modern foraminiferal faunas composed entirely of non-calcareous agglutinated taxa are known only from high intertidal marshes and below the calcite compensation depth in the ocean. The faunas from modern estuarine and epicontinental seas include a mixture of calcareous and non-calcareous taxa, with the non-calcareous agglutinated forms dominating

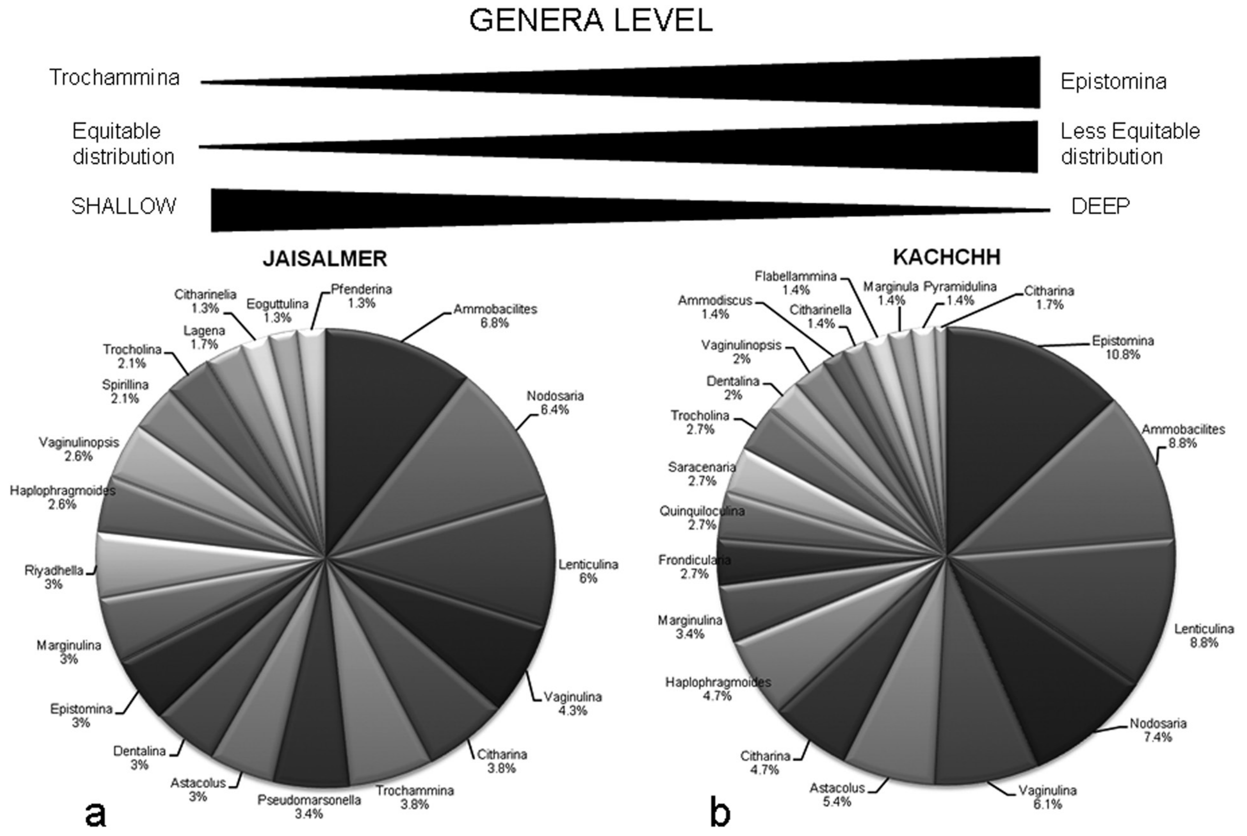


Fig. 9. Comparative genera-wise percentage distribution between the Jaisalmer and Kachchh basins.

in low salinity environments (Murray 1991; Alve & Murray 1994). The predominance of agglutinated foraminiferal species and rarity of calcareous forms in an assemblage has also been noted in other marsh and/or near-shore environments that are subjected to varied ecological conditions due to fluctuations in salinity, pH, substrate, etc. that enable simple agglutinated foraminifers to thrive; these conditions are unfavorable for calcareous forms (Reolid et al. 2008). The total absence of calcareous forms is also attributed variously to the lack of calcium carbonate content in the seawater (Walton 1964) or to low temperature or low pH, or a combination of the two factors (Bolin 1956; Phleger 1960). Another important factor hampering the formation and fossilization of calcareous tests is oxygen depletion and higher carbon dioxide content in bottom waters, which many agglutinated foraminifers with organic-type cement are able to tolerate (Gradstein & Berggren 1981). Thus, generally, the agglutinated foraminifers dominate in areas of low availability of calcium carbonate, characterized by low salinity and/or low temperature, lack of oxygen and fluctuations in pH recorded in most marginal marine brackish waters (Murray 2001). However, dissolution is also likely to result in the predominance of agglutinated assemblages.

A predominant *Ammobaculites*-*Trochammina* assemblage is characteristic of low-salinity, brackish water, near-shore environments whereas thick-walled coarse, agglutinated foraminifers characterize paralic environments. Low diversity of agglutinated foraminifers with simple species (*Trochammina*, *Jadammina*, *Haplophragmoides* and *Ammobaculites*) proliferate in marsh environments (Murray 2001) while common occurrences of *Saccammina*, *Cribrostomoides*, *Reophax*, *Eggerella* and *Textularia* represent decalcified shelf assemblages. *Saccammina*, *Reophax*, *Eggerella* and *Textularia* are rare in Assemblage 14, common in Assemblage 15 and abundant to common in Assemblage 16. Thus, the role played by dissolution cannot be

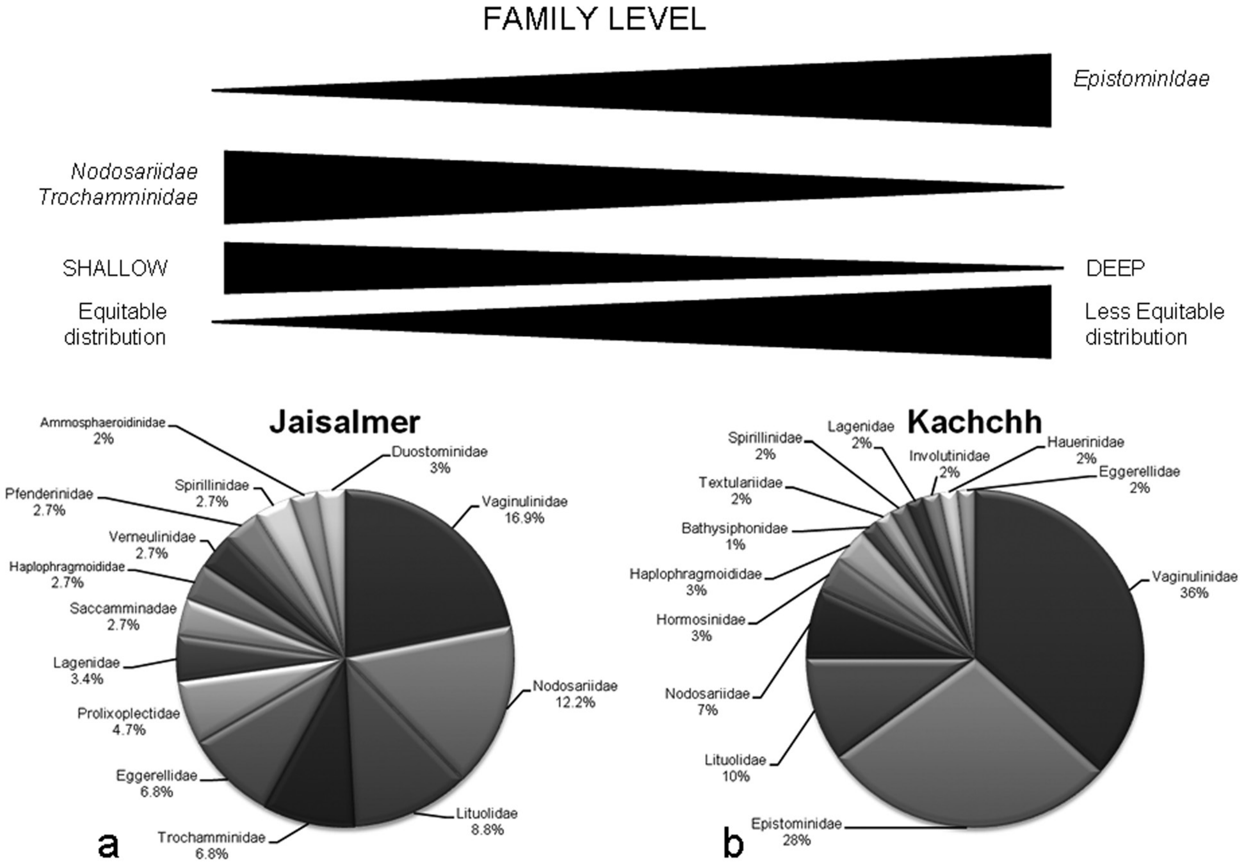


Fig. 10. Comparative family-wise percentage distribution between the Jaisalmer and Kachchh basins.

completely ruled out for these assemblages. However, based on the presence of rare calcareous foraminifers and the absence of overgrowths and etching on them, the foraminiferal trend is considered largely primary.

Thus, for assemblages 13 to 17 (beds 59-77), a low-salinity, brackish-water, near-shore environment is envisaged that is subjected to varied ecological conditions primarily due to fluctuations in salinity and pH, and to a lesser extent by the availability of nutrients. Dissolution, although largely negligible increases from Assemblage 13 to 17.

6. Comparison with previous studies from Jaisalmer and Kachchh

A simple species comparison with previous works from the Jaisalmer Basin (234 species; pooled dataset) reveals striking results with few common species (at most 12). The most likely reasons for this dissimilarity could be due to

a) lack of taxonomic standardization,
b) differences in sampling resolution and
c) that the Jaisalmer benthic foraminiferal fauna is exceedingly diverse.

Interestingly, in the adjacent Kachchh Basin, in spite of higher sampling resolution (279 samples instead of 135), the pooled dataset (Bhalla & Abbas 1978; Pandey & Dave 1993; Talib & Gaur 2008; Gaur & Talib 2008) yielded only 148 species and 44 genera and both basins are dominated by the same families of Vaginulinidae (33.1%), Nodosariidae (12.2%), Lituolidae (10.8%), Epistominidae (10.8%) and Lagenidae (0.7%). The only difference is the higher percentage of Epistominidae, which is expected because the Kachchh area belongs to a deeper depositional regime (Fürsich et al. 1991, 1992).

However, in contrast to this strong similarity on family-level, only 11 species are common even when such a large dataset of the entire Kachchh Basin (Bajocian-Late Tithonian) is compared (Bhalla & Abbas

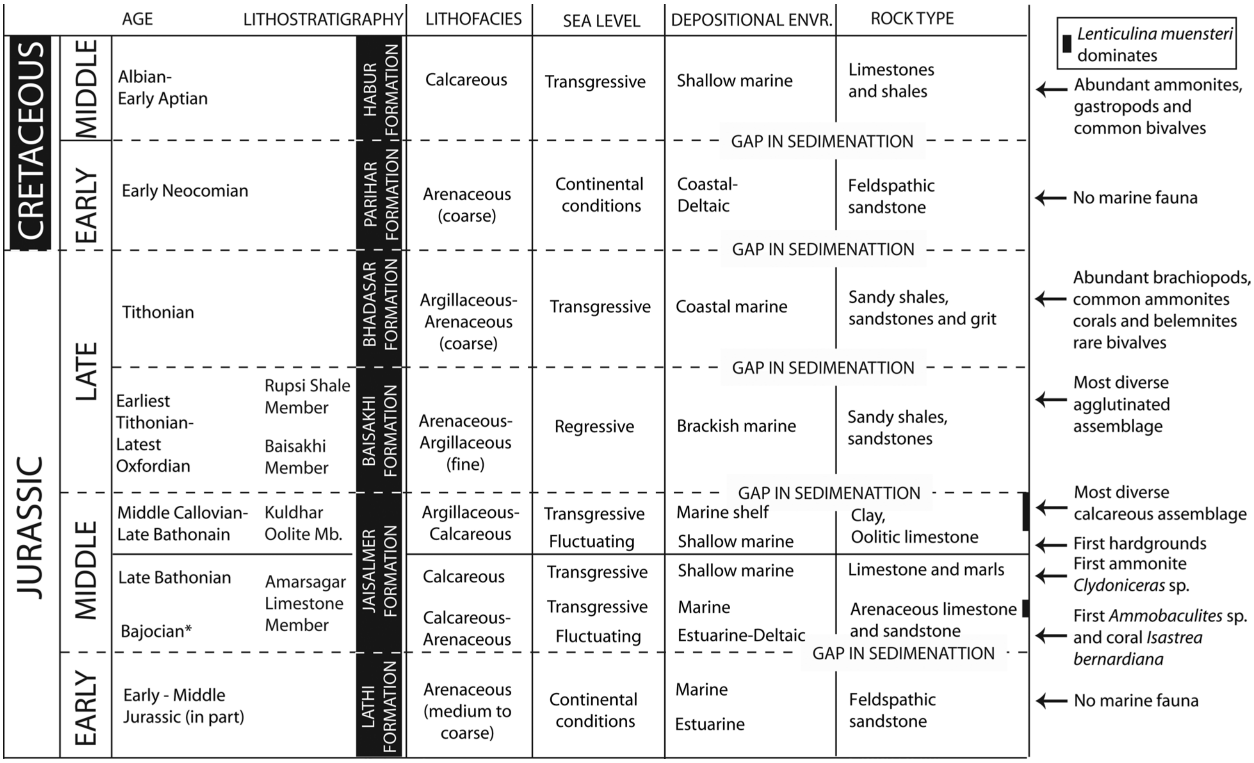


Fig. 11. Lithostratigraphy, sea level changes, depositional environment, rock types and faunal changes within the Jaisalmer Basin

1978; Pandey & Dave 1993; Talib & Gaur 2008; Gaur & Talib 2008).

Genera-wise, for both basins (Jaisalmer and Kachchh) the distribution is equitable with none of the genera exclusively dominating the assemblages (Fig. 9), thus indicating more or less similar bottom conditions, with differences largely due to depth; the deep-dwelling *Epistomina* being distinctly more common in the Kachchh Basin (Figs. 9-10). Contrary to this similarity at family- and genus-level, the specific distribution is strikingly different (as indicated by the presence of very few common species). This difference may well be a reflection of the marginal setting, a greater brackish-water influence, and shallower depths encountered for the Jaisalmer Basin (~50 m) as compared to the Kachchh Basin (~200 m; Fürsich et al. 1991, 1992).

7. Species diversity and sea level changes

The inferred local sea level suggests continued to increase since the Bajocian with a maximum transgression in the Early Oxfordian, followed by a steep regression until the Early Kimmeridgian, then by a sudden transgression in the latest Kimmeridgian and a regressive phase in the Tithonian (Fig. 8). Interestingly, in the adjacent Kachchh Basin, a maximum flooding is also noted during the Oxfordian (Fürsich et al. 2005) and the subsequent deposition of sandy sediments for the post-Oxfordian (until Albian) interval. A similar trend is even noted at the global level (Haq et al. 1987; Hallam 1988, 1990; Sandoval et al. 2001).

Of the three highest benthic foraminiferal diversities noted for the Jaisalmer Basin, the one with an upward-trend starting from the Late Bathonian to the Early Oxfordian parallels sea level increase and is also marked by the dominance of calcareous forms indicating deeper conditions (Fig. 8). The other two diversity maxima are located in the Middle Bathonian and in the Kimmeridgian. These are essentially regressive phases in a shallow setting with increasing freshwater influence (Middle Bathonian) and brackish-marine conditions (Kimmeridgian), but marked by the dominance of calcareous and agglutinated species, respectively. This suggests that probably in shallow brackish or freshwater-dominated settings, the dominance of calcareous forms may not be a good indicator of deeper bathymetry (Fig. 8). A more detailed analysis from the adjacent Kachchh Basin may yield some clues to this anomaly.

8. Conclusion

Based on the data presented here, it appears that at Jaisalmer, sea level-influenced facies deposition and both in turn in a shallow marginal epicontinental setting governed the distribution of species. Further, the benthic foraminiferal diversities observed here by sampling bed-by-bed are largely governed by local basinal conditions but at the stage- (i.e. Bathonian, Callovian, etc.) and family-level by global eustasy. This might also explain the strong species differentiation between the Jaisalmer and Kachchh basins. But the increasing similarity at the family- and genus-levels (that are long-ranging and transgress several stages) is likely a reflection of large-scale changes in global eustasy. A brief oberview on the depositional and faunistic events within the Jaisalmer Basin is presented in Fig. 11.

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References

Alve, E. & Murray, J.W. (1994): Ecology and taphonomy of benthic foraminifera in a temperate mesotidal inlet. – Journal of Foraminifera Research, **24**: 18-27.

Arkell, W.J. (1956): Jurassic Geology of the World. – 1-806 pp.; London (Oliver & Boyd).

Bhalla, S.N. & Abbas, S.M. (1978): Jurassic foraminifera from Kutch, India. – Micropaleontology, **24**: 160-209.

Bhatia, S.B. & Mannikeri, M.S. (1977): On the occurrence of the foraminifera Sporobulimina in the Callovian (Middle Jurassic) of Jaisalmer, Rajasthan. Abstracts 7th Indian Colloquium on Micropalaeontology and Stratigraphy, Varanasi, p. 6-10.

Bolin, E.J. (1956): Upper Cretaceous Foraminifera, Ostracoda, and Radiolaria from Minnesota. – Journal of Paleontology, **30**: 278-298.

Callomon, J.H. (1993): On *Perisphinctes congener* Waagen, 1875, and the age of the Patcham Limestone in the Middle Jurassic of Jumara, Kutch, India. – Geologische Blätter für NO-Bayern, **43**: 227-246.

Culver, S.J., Woo, H.J., Oertel, G.F. & Buzas, M.A. (1996): Foraminifera of coastal depositional environments, Virginia, USA: distribution and taphonomy. – Palaios, **11**: 459-486.

Dave, A. & Chatterjee, T.K. (1996): Biostratigraphy of Jurassic sediments. – Journal of Geological Society of India, **47**: 477-490.

Das Gupta, S.K. (1975): A revision of the Mesozoic-Tertiary stratigraphy of the Jaisalmer Basin, Rajasthan. – Indian Journal of Earth Sciences, **2**: 77-94.

Fürsich, F.T., Oschmann, W., Jaitly, A.K. & Singh, I.B. (1991): Faunal response to transgressive-regressive cycles: example from the Jurassic of western India. – Palaeogeography, Palaeoclimatology, Palaeoecology, **85**: 149-159.

Fürsich, F.T., Singh, I.B., Joachimski, M., Krumm, S., Schlirf, M. & Schlirf, S. (2005): Palaeoclimate reconstructions of the Middle Jurassic of Kachchh (western India): an integrated approach based on palaeoecological, oxygen isotopic, and clay mineralogical data. – Palaeogeography, Palaeoclimatology, Palaeoecology, **217**: 289-309.

Fürsich, F.T., Pandey, D.K., Callomon, J.H., Jaitly, A.K., & Singh, I.B. (2001): Marker beds in the Jurassic of the Kachchh Basin, Western India: their depositional environment and sequence stratigraphic significance. – Journal of the Palaeontological Society of India, **46**: 173-198.

Garg, R. & Singh, S.K. (1983): Distinctive Bathonian agglutinated forminiferids from Jaisalmer, western India. – Journal of the Palaeontological Society of India, **28**: 118-133.

Garg, R. & Singh, S.K. (1986): *Singhamina* and *Tandonina*, new foraminiferal genera – evidence of discorbid lineage from the Middle Jurassic of Jaisalmer, Western Rajasthan, India. – Journal of the Palaeontological Society of India, **31**: 50-62.

Garg, R. Singh, S.K. & Mandwal, N. (1998): A new species of marker crysalidinid foraminifera *Riyadhella* from the Upper Jurassic of Jaisalmer, western India. – Journal of the Palaeontological Society of India, **43**: 101-106.

Garg, R. (1983): Stratigraphy and micropalaeontology of the Mesozoic rocks exposed around Jaisalmer, Rajasthan. – Unpublished Thesis, Lucknow University. – 489 pp.; Lucknow.

Gaur, K.N. & Talib, A. (2008): Middle-Upper Jurassic Foraminifera from Jumara Hills, Kutch, India. – Revue de Micropaléontologie, **52**: 227-248.

Gebhardt, H. (2006): Resolving the calibration problem in Cretaceous benthic foraminifera paleoecological interpretation: Cenomanian to Coniacian assemblages from the Benue Trough analysed by conventional methods and correspondence analysis. – Micropaleontology, **52**: 151-176.

Gradstein, F.M. & Berggren, W.A. (1981): Flysch-type agglutinated foraminifera stratigraphy and the Maastrichtian to Paleogene history of the Labrador and North seas. – Marine Micropaleontology, **6**: 211-268.

Hallam, A. (1975): Evolutionary size increase and longevity in Jurassic bivalves and ammonites. – Nature, **258**: 493-496.

Hallam, A. (1988): A re-evaluation of Jurassic eustasy in the light of new data and the revised Exxon curve. – In: Wilgus, C.K. et al. (Eds.): Sea-level Changes: An integrated approach. – SEPM, Special Publications, **42**: 261-273.

Hallam, A. (1990): Biotic and Abiotic Factors in the Evolutions of Early Mesozoic Marine Mollusks. – In: Ross, R.M. & Allmon, W.D. (Eds.): Cause of Evolution. A Paleontological Perspective, 249-260; Chicago (University Chicago Press).

Haq, B.U., Hardenbol, J. & Vail, P.R. (1987): Chronology of fluctuating sea levels since the Triassic. – Science, **235**: 1156-1167.

Jain, S. (2007): The Bathonian-Callovian Boundary in the Middle Jurassic Sediments of Jaisalmer Basin, Western Rajasthan (India). – Journal of Geological Society of India, **69**: 79-89.

Jain, S. (2008): Integrated Jurassic biostratigraphy: a closer look at nannofossil and ammonite evidences from the Indian subcontinent. – Current Science, **95**: 326-331.

Jain, S. (2012, in press): Biostratigraphy and Paleoenvironment of the Middle Jurassic Sediments at Kuldhar (Jaisalmer), Western India. – Journal of the Paleontological Society of India.

Jain, S., Callomon, J.H. & Pandey, D.K. (1996): On the earliest known occurrence of the Middle Jurassic ammonite genus *Reineckeia* in the Upper Bathonian of Jumara, Kachchh, Western India. – Paläontologische Zeitschrift, **70**: 129-143.

Kalia, P. & Chowdhury, S. (l983): Foraminiferal biostratigraphy, biogeography and environment of the Callovian sequence, Rajasthan, northwestern India. – Micropalaeontology, **29**: 223-254.

Moore, R.C. (1965): Treatise on Invertebrate Paleontology. Part H. Brachiopoda 1 and 2. – Geological Society of America and University of Kansas Press, 927 pp.

Murray, J.W. (2001): The niche of benthic foraminifera, critical thresholds and proxies. – Marine Micropaleontology, **41**: 1-7.

Murray, J.W. (1991): Ecology and palaeoecology of benthic foraminifera, 316-322; Harlow (Longman).

Narayanan, K. (1964): Stratigraphy of the Rajasthan Shelf. – Proceedings of the Symposium on Problems of the Indian Arid Zone, Jodhpur, 92-100.

Pandey, D.K. & Fürsich, F.T. (1994): Bajocian (Mid Jurassic) Age of the Early Jaisalmer Formation of Rajasthan, western India. – Newsletters on Stratigraphy, **30**: 75-81.

Pandey, J. & Dave, A. (1993): Studies in Mesozoic foraminifera and chronostratigraphy of western Kutch, Gujarat. Palaeontographica Indica, **1**: 1-221.

Phleger, F.L. (1960): Ecology and distribution of recent Foraminifera. – 297 pp.; Baltimore (John Hopkins Press).

Prasad, S. (2006): Ammonite biostratigraphy of Middle to Late Jurassic rocks of Jaisalmer Basin, Rajasthan, India. – Paleontologica Indica, **52**: 146 pp.

Reolid, M., Rodríguez-Tovar, F.J., Nagy, J. & Olóriz, F. (2008): Benthic foraminiferal morphogroups of mid to outer shelf environments of the Late Jurassic (Prebetic Zone, southern Spain): characterization of biofacies and environmental significance. – Palaeogeography, Palaeoecology, Palaeoclimatology, **261**: 280-299.

Sandoval, J., O'dogherty, L. & Guex, G. (2001): Evolutionary rates of Jurassic ammonites in relation to sea-level fluctuations. – Palaios, **16**: 311-335.

Smout, A.H. & Sugden, W. (1961): New information on the foraminiferal genus Pfenderina. –Paleontology, **4**: 581-591.

Subbotina, N.N., Dutta, A.K. & Srivastava, B.N. (1960): Foraminifera from the Upper Jurassic deposits of Rajasthan (Jaisalmer) and Kutch. – Indian Bulletin of Geological, Mining and Metallurgical Society of India, **23**: 1-48.

Talib, A. & Gaur, K.N. (2008): Foraminiferal composition and age of the Chari Formation, Jumara Dome, Kutch, – Current Science, **95**: 367-373.

Tibert, N.E. & Leckie, R.M. (2004): High-resolution estuarine sea level cycles from the Late Cretaceous: Amplitude constraints using agglutinated foraminifera. – Journal of Foraminiferal Research, **34**: 130-143.

Tibert, N.E., Leckie, R.M., Eaton, J.G., Kirkland, J.I., Colin, J.P., Leithold, E.L. & McCormic, M. (2003b): Recognition of relative sea level change in Upper Cretaceous coal-bearing strata: A paleoecological approach using agglutinated foraminifera and ostracodes to detect key stratigraphic surfaces. – In: Olson, H. & Leckie, R.M. (Eds.): Microfossils as proxies for sea-level change and stratigraphic discontinuities. – SEPM, Special Publications, **75**: 263-299.

Walton, W.R. (1964): Recent foraminiferal ecology and paleoecology. – In: Imbrie, J. & Newel, N.D. (Eds.): Approaches to Paleoecology, 151-237; New York (Wiley).

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