CALLOVIAN TO OXFORDIAN BENTHIC FORAMINIFERA FROM LER DOME, KUTCH BASIN (GUJARAT, INDIA): SYSTEMATIC, ECOSTRATIGRAPHY AND PALAEOENVIRONMENTAL RECONSTRUCTION

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Abstract. Analysis of the foraminiferal assemblages of the Chari Formation (Middle-Upper Jurassic transition) exposed at Ler Dome, Kutch Basin (India) allows one to interpret the incidence of different environmental parameters, especially the effect of sea-level changes in this group of microorganisms. The overall deposition of the Chari Formation took place in an open marine environment in the middle to outer shelf, having normal salinity and well-oxygenated bottom waters according to the lithofacies and the composition of the foraminiferal and macroinvertebrate assemblages. Changes in the diversity, abundance of foraminifera, and proportion of specialist forms were associated mainly with the availability of labile organic matter on the sea floor. The changes in trophic resources were associated with fluctuations in the type of sedimentation, which ranges from carbonates to siltstones and sandstones. During the regressive phase, a relatively high input of food resources, probably phytodetritus, was associated with siliciclastic sedimentation and commonly related with increased abundance and diversity of foraminifera, including specialist forms. During the transgressive phase, the influx of food resources from emerged areas and shallow environments decreased; sedimentation was more calcareous, with an accumulation of ammonoid shells that indicates hemipelagic conditions. The decrease in food resources for benthic foraminifera is reflected by a lesser diversity and abundance, and lower proportions of specialist foraminifera.

INTRODUCTION

The analysis of Jurassic benthic foraminiferal assemblages is a useful tool for interpreting the palaeoenvironmental parameters that characterise the sea floor (Bartolini et al. 1992; Nagy 1992; Tyszka 1994; Bouhamdi et al. 2000, 2001; Reolid et al. 2008a, 2012a; 2013; Colpaert et al. 2016; Rita et al. 2016; Talib et al. 2017; among others). Changes in oceanic primary productivity and organic matter input from emerged land may be reflected in the organic matter content and the oxygen availability at the sea floor, exercising a direct influence on the features of the foraminiferal assemblage (e.g., diversity, shell composition, life style and feeding strategies) (Kuhn et al. 1996; Olóriz et al. 2003, 2012; Gebhardt et al. 2004; Reolid et al. 2008a, b, 2013; among others). The depth in the sediment where the foraminifera live is mainly determined by oxygen and nutrient availability (Tyszka 1994; Jorissen et al. 1995; Van der Zwaan et al. 1999; Fontanier et al. 2002; Ernst & Van der Zwaan 2004; Olóriz et al. 2012; Rita et al. 2016). The epifaunal microhabitat is advantageous in environments with nutrient

and/or oxygen limitations, whereas environments with high organic content in the sediment are dominated by infaunal taxa (e.g. Kaminski et al. 1995; Jorissen et al. 1995; Fontanier et al. 2002; Reolid et al. 2008b; Farahani et al. 2018; Hjalmarsdottir et al. 2018). Most of the environmental parameters controlling the abundance, diversity and composition of the foraminiferal fossil assemblages are governed by sea-level fluctuations (sedimentation rate, influx of trophic resources, water energy and oxygenation; e.g. Leckie & Olson 2003; Olóriz et al. 2012; Colpaert et al. 2017). In this sense, Jurassic foraminiferal assemblages can be used to interpret sequence stratigraphy (Cubaynes et al. 1989, 1990; Bonnet et al. 1991, 1992; Rey et al. 1994; Hylton & Hart 2000; Nagy et al. 2001; Olóriz et al. 2003; Reolid & Nagy 2008; Reolid et al. 2010, 2012b; Nikitenko et al. 2013).

The Jurassic rocks of the Kutch area (also spelled Kachchh) in western India are globally known for their rich and varied macroinvertebrate fossils, especially ammonites (Fürsich & Oschmann 1992; Bardhan et al. 1994; Fürsich et al. 1994, 2004; Pandey & Callomon, 1995; Patel et al. 2012; Kanjilal 2014). The fossil macroinvertebrates (ammonites, brachiopods, bivalves and corals) belong to the Ethiopian faunal province (Fürsich et al. 2013). A review of previous research on the Jurassic rocks of Kutch reveals a focus on macrofossils and stratigraphy, with little work on the microfossils, in particular benthic foraminifera. The only significant studies on the Jurassic foraminifera of the Kutch region are by Subbotina et al. (1960), Bhalla & Abbas (1978), Bhalla & Talib (1991), Pandey & Dave (1993), Gaur & Talib (2009), Al-Hussain (2014), Talib et al. (2016, 2017), Bilal et al. (2016) and Jain et al. (2019) —mainly systematic accounts, with little emphasis on the application of microfossils for the interpretation of biostratigraphy, palaeoecology and palaeobiogeography. In view of the above, this work aims to arrive at an environmental interpretation of the Chari Formation based on the analysis of benthic foraminiferal assemblages in the Ler Dome. Ecostratigraphic analysis of the benthic foraminiferal assemblages from the shelf environment of the Kutch Basin allow us to characterise the incidence of control parameters such as sedimentation rate, organic matter input, and redox conditions and their fluctuations related to sea-level changes.

GEOLOGICAL SETTING AND STUDIED SECTION

The Jurassic succession of the Kutch marks the sedimentation of a small rift basin situated at the western palaeomargin of the Indian Plate. The sedimentary rocks, which are well exposed, range in age from Bajocian to Tithonian (Krishna 1984). These marine sediments occupy nearly half of the area in the Kutch region, overlying the Precambrian basement (Bardhan & Data 1987; Biswas 1993), and are deposited in an east-west oriented pericratonic rift basin at the westernmost periphery of the Indian Craton (Biswas 1987). The basin, located in the eastern Tethys, is a fossil rift located at the southern end of the Indus Shelf, bordered to the north by the fossil rifts of the Thar and Southern Indus basins (Zaigham & Mallick 2000). The rifting phase started during the Late Triassic with the development of alluvial fans; it was followed by an Early Jurassic alternation of shallow marine and non-marine deposits. From the Bathonian to the end of the Jurassic, marine sedimentation dominated. During the Bathonian carbonates were widespread, and subsequently siliciclastic sediments dominate the Middle and Upper Jurassic, from silty clays in the low-energy offshore areas to cross-bedded sandstones and oolithic ironstones in high-energy shallow water areas (Fürsich et al. 2013). Jurassic sedimentary rocks from the Kutch region are exposed in three sectors: the so-called Island Belt in the north, the Wagad Uplift, and the Kutch Mainland to the south. Of these, the Kutch Mainland is the most extensive. It consists of a series of domed outcrops covering about 193 km, from Jara Dome in the west to Habo Dome in the east, through Jumara, Nara, Keera and Jhurio domes. These domed outcrops are distributed in three E-W trending, parallel anticlinal ridges. The ones with good exposure are largely found in the middle ridge, including the study area. The Ler Dome is located 12 km southeast of Bhuj, the district headquarter of the Kutch region (Fig. 1).

In this work, the lithostratigraphic framework adopted for the Jurassic sedimentary succession of Kutch region is that of Biswas (1980), modified by Fürsich et al. (2001). The Bajocian to Tithonian rocks are divided into five formations: Jhurio, Patcham, Chari, Katrol and Umia (from older to younger order; see Fig. 1). The Jurassic sequence of the Ler Dome includes the Chari and Katrol forma-
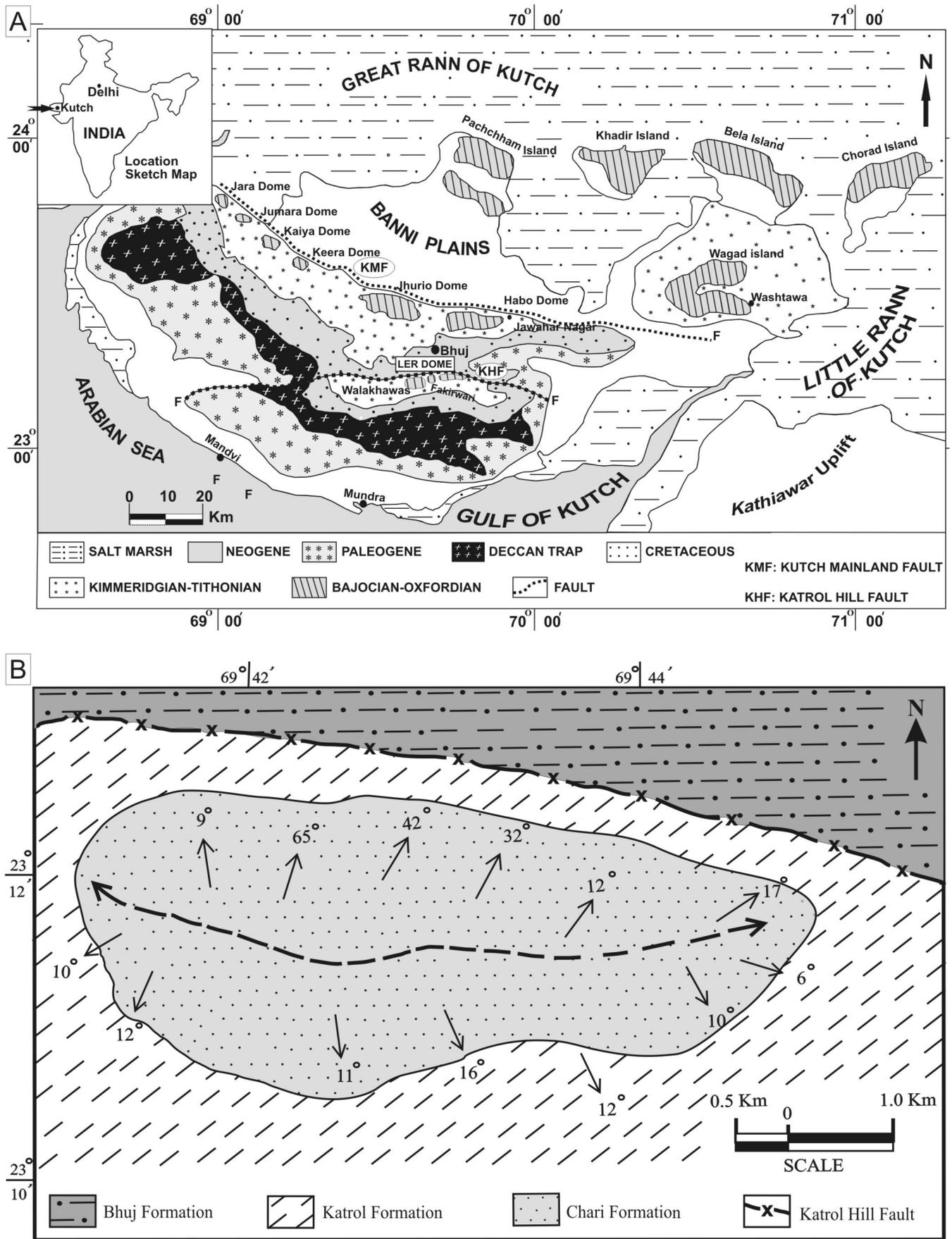
Fig. 1 - Geological setting of the studied area. A) Geological map of Kutch, Gujarat (Western India) showing the most representative Jurassic localities and major geological structures (after Biswas 2002; Pandey et al. 2009), and B) geological map of the Ler Dome (modified after Kanjilal 1978).
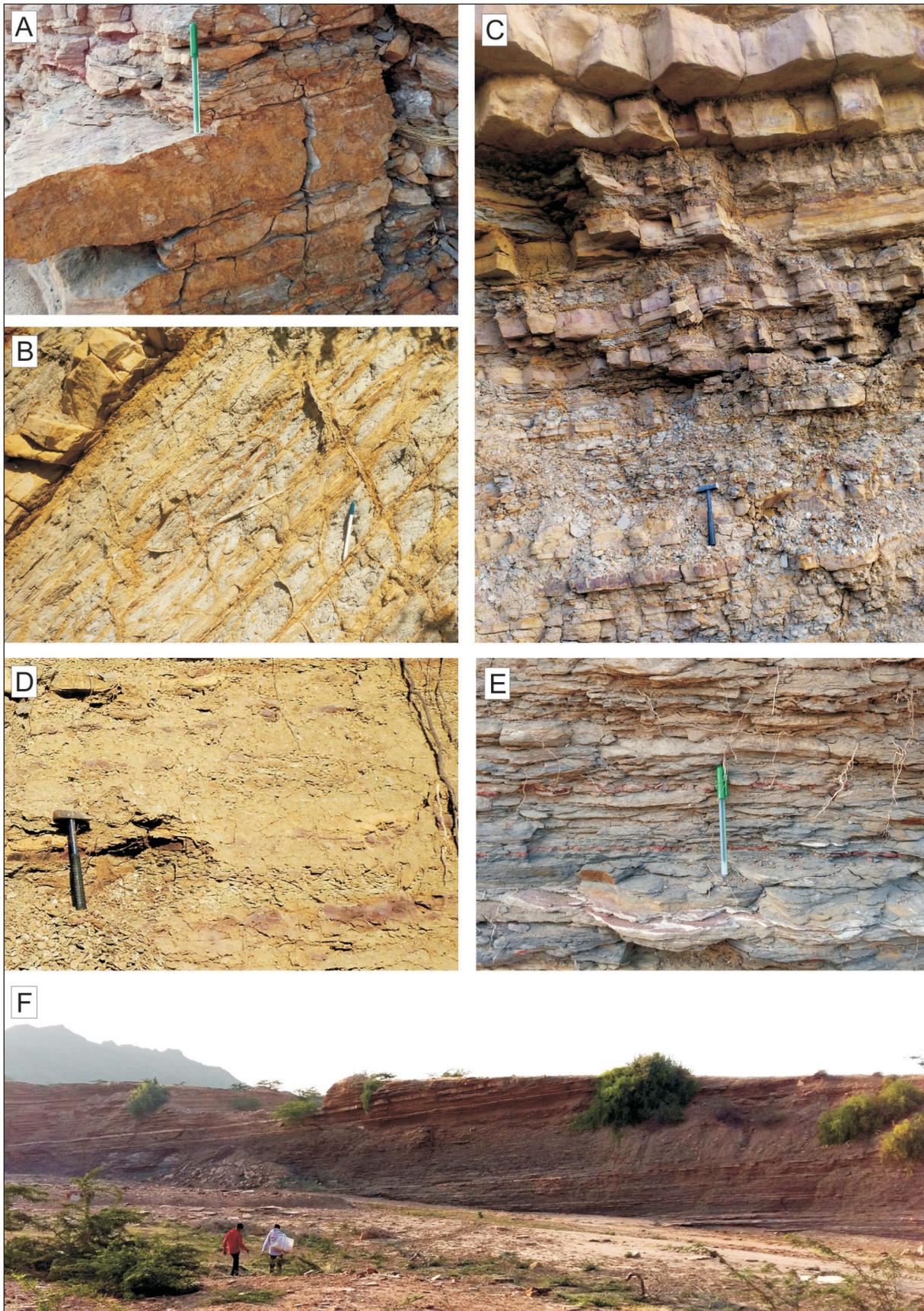
Fig. 2 - Field view of lithological units 1 to 6 of the Chari Formation. A) Reddish limestones of lithological unit 1. B) Thinly laminated shales of lithological unit 2. C) Thickening upward sequences with increasing carbonate content of lithological unit 2. D) Yellowish grey shales (4 m thick) with thin-laminated interbedded of shales and sandstones. E and F) Close view and general view of shales interbedded with thin sandstone layers.
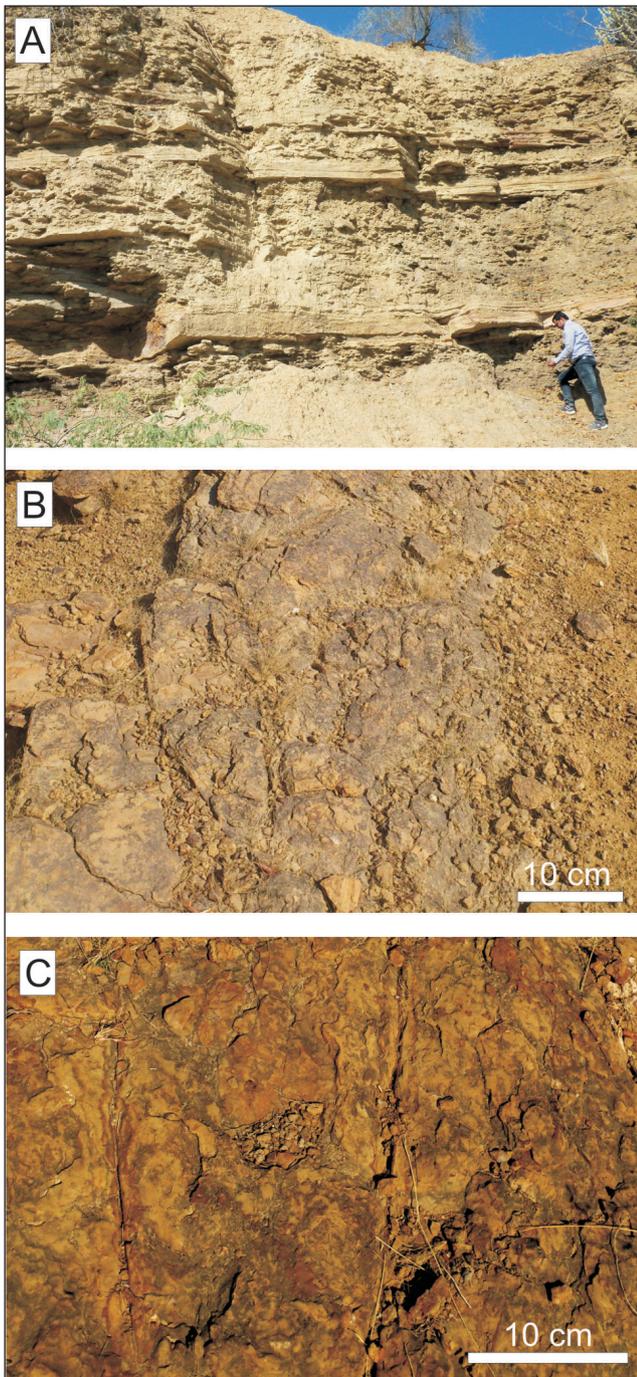
Fig. 3 - Field view of lithological units 7 and 9. A) Limestones and marly limestones of lithological unit 7. B and C) The Dhosa Oolite Member (lithological unit 9) with ferruginous concretions at the top of the Dhosa Conglomerate Bed.

tions (Fig. 1). The Chari Formation is the best developed, with a total thickness of about 50 m. The stratigraphic sequence corresponds to the Dhosa Sandstone Member and the Dhosa Oolite Member. We distinguish nine lithological units, from L-1 to L-9, consisting of shales and limestones of different colours and lithological characters (Fig. 2–4):

- L-1 is constituted by 10 m of brown to reddish limestones (Fig. 2A) with very fine grain and usually mudstone texture. Fossil macroinvertebrates are very common (ammonites, belemnites, bivalves and brachiopods).

- L-2 is composed by thinly laminated shales 5 m thick of variable colour (light to dark grey and reddish brown), locally showing thickening upward sequences (Fig. 2B-C).

- L-3 corresponds to 13 m of yellow shales, locally thin-laminated layers, highly fossiliferous, with common fragments of bivalve shells (*Nicaniella*, *Praesaccella* and *Bositra*).

- L-4 is predominantly composed by yellowish grey shales (4 m thick) with thin-laminated interbedded shales and sandstones (Fig. 2D). This stratigraphic interval is very fossiliferous, having abundant benthic macroinvertebrates (mainly bivalves *Bositra* and *Nicaniella*).

- L-5 is constituted by 2 m of fine-grained limestones with abundant brachiopods (mainly *Kutchithyris*), bivalves (particularly common *Actinostreum*, *Nanogyra* and Nuculoida) and ammonites.

- L-6 is represented by 7.6 m of grey to yellowish shales interbedded with thin sandstone layers (Fig. 2E-F). The shales are fossil-rich, with abundant bivalve broken shells (*Bositra*, *Nicaniella* and *Praesaccella*). The shales show thin-laminated fabric.

- L-7 is constituted by fossiliferous limestones and marly limestones (3 m thick), yellow to green in colour (Fig. 3A), rich in cephalopods (ammonites and belemnites) and benthic macroinvertebrates (bivalves and brachiopods including *Kutchithyris*).

- L-8 corresponds to 2.5 m of silty claystone, yellowish grey in colour.

- L-9 are oolithic limestones (6.6 m thick) of the Dhosa Oolite Member (Fig. 3B-C). This stratigraphic interval is rich in ferruginous ooids and fossil macroinvertebrates, mainly cephalopods. The upper part, corresponding to the Dhosa Conglomerate Bed, contains limestone rich in ferruginous concretions (Fig. 3C), coarse skeletal debris and ammonite moulds. This unit can be traced across the Kutch Mainland for more than 100 km, and it dates back to the early Oxfordian (Ramkumar et al. 2013).

A detailed study of benthic macroinvertebrates focused on the faunal response to transgressive-regressive cycles in the Chari Formation from Ler was presented in Fürsich et al. (1991, 2013).
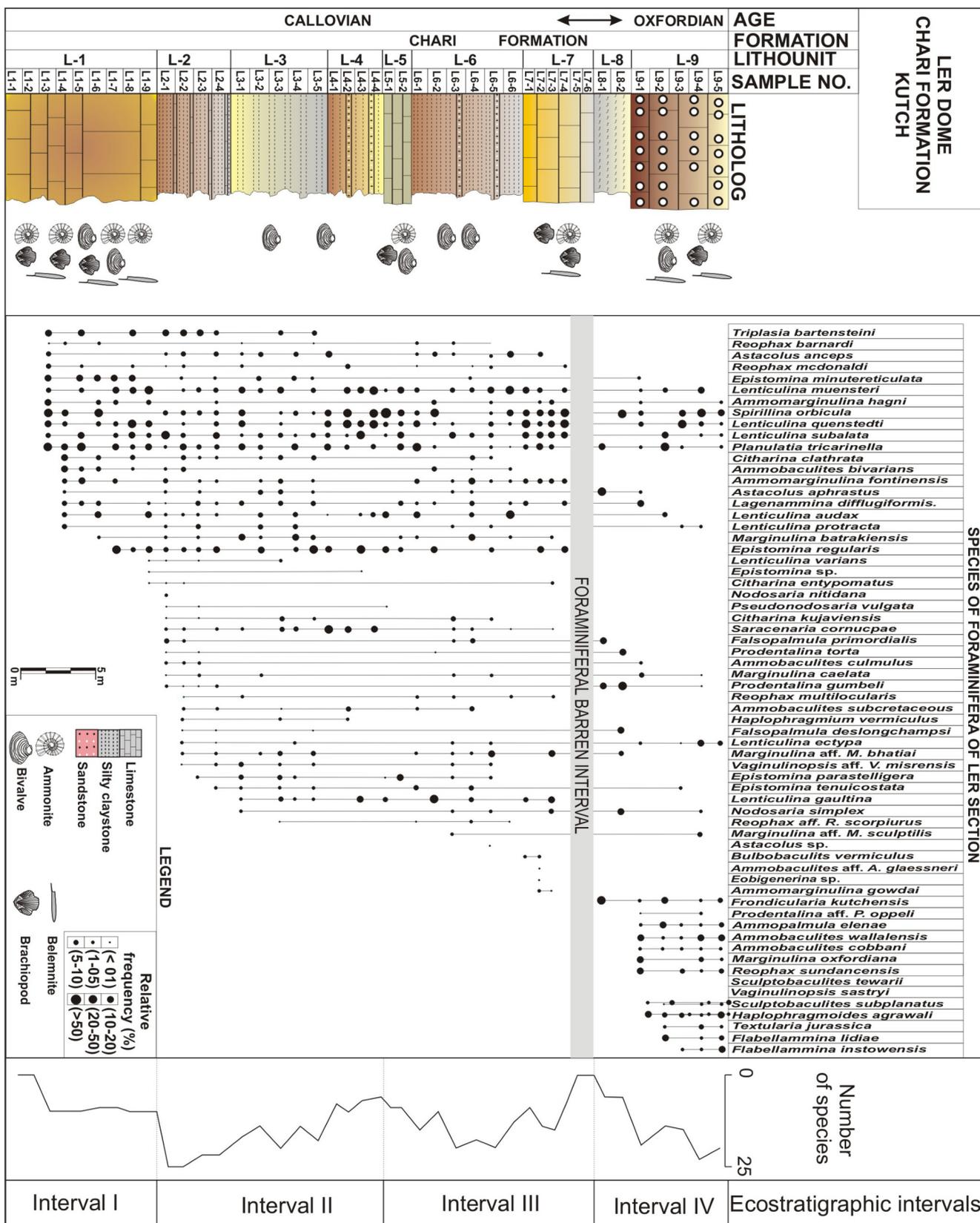
Fig. 4 - Lithological succession, stratigraphic position of studied samples, ecostratigraphic intervals for benthic foraminifera, distribution of the foraminiferal species, and number of species recorded.

Materials and methods

The study area of Ler Dome is located near Ler village, between latitudes 23°22'20" and 23°23'40" north and longitudes 69°52' 40" and 69°53'20" east. A detailed examination of sedimentary succession included special attention to lithology and the presence of fossil invertebrates. For the micropalaeontological study, a total of 43 samples were collected from a suitable section of the Middle-Upper Jurassic transition (Fig. 3) exposed on the dipping northern limb of the Ler Dome. Samples were prepared in the Micropalaeontological Laboratory of the Department of Geology, at Aligarh Muslim University (AMU), by crushing approximately 500 grams of dry sample, immersing it in water with washing soda, then boiling continuously for 46 hours. This was followed by washing using standard stainless-steel sieves with mesh openings of 60 and 120 μm, with a gentle spray of water and oven drying at 50°C. The clean dried samples were weighed and stored in plastic vials with sample numbers. Ten grams of material from each 60 and 120 μm mesh were picked under a stereozoom binocular microscope and placed in an ultrasonic micro-vibrator for further cleaning, after which microfaunal assemblage slides were prepared.

Suprageneric and generic identifications followed the classification of Loeblich & Tappan (1987), while species identification was carried in view of the literature and the Ellis & Messina Catalogue of Foraminifera (since 1940). The α-index of diversity of Fisher et al. (1953) was calculated at species level. The abundance of foraminifera, also called benthic foraminiferal number (BFN), was calculated as the number of specimens per gram. The inferred microhabitat depth of the benthic foraminifera was assigned according to Reolid et al. (2008a). Accordingly, forms living up to 1 cm below the sediment/water interface are considered to be epifaunal (*sensu* Corliss 1991), whereas shallow infauna are those living at depths between 1 and 5 cm (*sensu* Kuhnt et al. 1996), and potentially deep infauna are forms that can live deeper than 5 cm below the sea floor. The figured specimens were coated with gold and photographed using scanning electron microscopy (SEM), with a SEM Zeiss EVO-40 at the Wadia Institute of Himalayan Geology (WIHG) of Dehradun (India), and SEM JEOL model JSM-65 10LV at the University Sophisticated Instrument Facility (USIF) of the AMU. All the sample residues and specimens are stored in the micropalaeontological laboratories located in the Department of Geology of the AMU, Aligarh.

Foraminiferal composition

Benthic foraminiferal assemblages comprising 63 species from 27 genera belonging to 12 families and 4 suborders were recovered from 43 samples, though some samples were barren (Fig. 4–7). The assemblages contain mostly calcareous and secondarily agglutinated forms. The calcareous shells are largely calcitic perforate, and secondarily aragonitic. Calcareous perforate are represented by the suborder Lagenina, with the genera *Astacolus*, *Citharina*, *Falsopalmula Frondicularia*, *Lenticulina*, *Mar-*

ginulina, *Nodosaria*, *Planularia*, *Prodentalina*, *Pseudonodosaria*, *Saracenaria*, and *Vaginulinopsis*, and the suborder Spirillinina represented by the genus *Spirillina* (Fig. 8). The aragonitic forms correspond to suborder Robertinina, genus *Epistomina* (Fig. 8). The agglutinated suborder Textulariina is represented by *Ammobaculites*, *Ammomarginulina*, *Ammopalmula*, *Bulbobaculites*, *Eobigenerina*, *Flabellammina*, *Haplophragmoides*, *Haplophragmium*, *Lagenammina*, *Reophax*, *Sculptobaculites*, *Textularia*, and *Triplasia* (Fig. 9). The average foraminiferal assemblage is constituted by 50.0% of specimens of the suborder Lagenina with 32 species, 40.6% corresponding to suborder Textulariina with 26 species, 7.8% to Robertinina with 5 species, and 1.6% to suborder Spirillinina with only one species (Fig. 4).

Out of all the recovered species, 22 are described for the first time from the Indian region: *Ammobaculites bivarians*, *A. culmulus*, *A. wallalensis*, *Ammopalmula elenae*, *Bulbobaculites vermiculus*, *Citharina kujaviensis*, *Flabellammina instowensis*, *Flabellammina lidae*, *Lenticulina ectypa*, *Marginulina batrakiensis*, *Marginulina caelata*, *Marginulina* aff. *M. sculptilis*, *Nodosaria nitidana*, *Prodentalina* aff. *P. oppeli*, *P. torta*, *Pseudonodosaria vulgata*, *Reophax barnardi*, *R. mcdonaldi*, *R.* aff. *R. scorpiurus*, *Sculptobaculites subplanatus*, *Spirillina orbicular*, and *Triplasia bartensteini*. The genera *Ammomarginulina*, *Sculptobaculites*, and *Ammopalmula* are reported for the first time from the Indian subcontinent.

Systematic palaeontology

We followed the generic classification of foraminifera proposed by Loeblich & Tappan (1987). Different species within a particular genus are described in alphabetical order. The synonymies are considerably reduced. References concerning important shifts in generic names or species closely resembling ours are only cited. In order to avoid repetition, the suffix "cum syn." has been added to the references which contain satisfactory synonymies. Brief systematic discussions of the 63 species are presented within this section, their stratigraphic position located in Fig. 3, whereas selected taxa are illustrated in Fig. 5-7 with the help of SEM photomicrographs.

Order **Foraminiferida** Eichwald, 1830
Suborder **Textulariina** Delage & Hérouard, 1896
Superfamily Astrorhizacea Brady, 1881
Family Saccamminidae Brady, 1884
Subfamily Saccammininae Brady, 1884
Genus *Lagenammina* Rhumbler, 1911
Type species: *Lagenammina laguncula* Rhumbler, 1911

Lagenammina difflugiformis (Brady, 1879)

Fig. 5.1

1879 *Reophax difflugiformis* Brady, p. 51; pl. 4, fig. 3, 21a-b.
1945 *Proteonina difflugiformis* (Brady), Cushman & Ellisor, p. 545; pl.71, fig.1.
1958 *Proteonina difflugiformis* (Brady), Said & Barakat, p. 238, pl. 1, fig. 1; pl. 3, fig. 3; pl. 4, fig. 3.
1969 *Proteonina difflugiformis* (Brady), Kalantari, p. 126, pl. 16, fig. 13a-b (cum syn.).
1993 *Proteonina difflugiformis* (Brady), Pandey & Dave, p. 121, pl. 1, fig. 2.
2012 *Lagenammina difflugiformis* (Brady), Milker & Gerhard, p. 134, fig. 9.4 (cum syn.).
2012 *Lagenammina difflugiformis* (Brady), Görög et al., p. 103-104, pl. 2, fig. 1 (cum syn.).
2016 *Lagenammina difflugiformis* (Brady), Bilal et al., p. 172, text fig. 5.1.

Material: 512 specimens.

Dimensions (mm). Length 0.33–0.41, width 0.20–0.61, thickness 0.12–0.21.

Discussion. Specimens of *Lagenammina difflugiformis* found in most of the present samples are similar to the original form reported by Brady (1879) from the Recent. Specimens studied have a single chamber, rounded to ovate in section, with aperture simple, terminal, and elevated. The test is flask shaped, with an elongated and prominent neck composed by coarse grains that are strongly cemented together. This species is widespread in the North and South Atlantic and South Pacific but also reported from Jurassic rocks of different parts of the world (Gordon 1965, 1967; Bielecka & Styk, 1981; Oxford 2004; Görög et al. 2012). It was recorded from the Upper Callovian to Lower Oxfordian in Kutch, India by Pandey & Dave (1993).

Superfamily Hormosinacea Haeckel, 1894
Family Hormosinidae Haeckel, 1894
Subfamily Reophacinae Cushman, 1910
Genus *Reophax* de Montfort, 1808
Type species: *Reophax scorpiurus* de Montfort, 1808

Reophax barnardi Said & Barakat, 1958

Fig. 5.2

1958 *Reophax barnardi* Said & Barakat, p. 238, pl. 4, fig. 7.
Dimensions (mm): Length 0.21–0.69, width 0.17–0.30.

Material: 46 specimens.

Discussion. Our specimens are similar to the original forms of *Reophax barnardi* described by Said & Barakat (1958), from the Kimmeridgian of Egypt. It slightly differs from *Reophax metensis* Franke, 1936, in having a coarse finish, tapering test and indistinct sutures. It also differs from *R. scorpiurus* in having a fine-grained test wall and fewer chambers, the final chamber being less elongated.

Reophax mcdonaldi Conkin, 1961

Fig. 5.3

1958 *Reophax mcdonaldi* Conkin, p. 248, pl. 21, fig. 25–30, pl. 26, fig. 15–16.

Material: 98 specimens.

Dimensions (mm). Length 0.31–0.51, width 0.14–0.23.

Discussion. Well-preserved specimens of *Reophax* recovered from the studied material are very similar to the original forms of *Reophax mcdonaldi* Conkin, 1961, described from the Lower Cretaceous of the USA. It also closely resembles *R. tumidulus* Plummer, 1945. However, *R. mcdonaldi* has globular chambers, and a larger proloculus. The sutures of the species are indistinct in the initial chambers, whereas *R. tumidulus* possesses distinctly depressed sutures.

Reophax multilocularis Haeusler, 1890

Fig. 5.4

1890 *Reophax multilocularis* Haeusler, p. 28, pl. 3, fig. 9–11, 26.
1967 *Reophax multilocularis* Haeusler; Gordon, p. 449, pl. 1, fig. 12.
1969 *Reophax multilocularis* Haeusler; Kalantari, p. 18, pl. 7, fig. 19-21 (cum syn.).
1991 *Reophax multilocularis* Haeusler; Nagy & Johnsen, p. 19–20, pl. 2, fig. 5 (cum syn.).
1991 *Reophax multilocularis* Haeusler; Bhalla & Talib, p. 93, pl. 1, fig. 14.
2016 *Reophax multilocularis* Haeusler; Bilal et al., p. 173, text fig. 5.5.

Material: 68 specimens.

Dimensions (mm). Length 0.29–0.36, width 0.09–0.13, thickness 0.06–0.07.

Discussion. Specimens of *Reophax multilocularis* Haeusler, 1890, occurring in our material, are similar in nearly all the characters to those described by Gordon (1967) and Kalantari (1969), respectively from the Callovian of Scotland and the Bajocian and Callovian of Iran. Our forms also exhibit similarities to those figured by Neagu & Neagu (1995) from the Toarcian to Bajocian sediments of Romania, though they differ in the somewhat constricted nature of the sutures. The number of chambers in the studied specimens ranges from four to nine, considerably fewer than the original forms having 22 to 25 chambers. However, Cifelli (1959), Gordon (1967), Kalantari (1969), and Nagy & Johansen (1991) described this species with fewer chambers like the studied specimens.

Reophax aff. *R. scorpiurus* Montfort, 1936
Fig. 5.5

aff.
1808 *Reophax scorpiurus* Montfort, p. 330, tab. 162, fig. K.
1936 *Reophax scorpiurus* Montfort; Franke, p. 19, pl. 1, fig. 18.
1958 *Reophax scorpiurus* Montfort; Said & Barakat, p. 239, pl. 4, fig. 9.

Material: 19 specimens.

Dimensions (mm). Length 0.21–0.69, width 0.17–0.30.

Discussion. Few specimens of *Reophax* show affinities with *Reophax scorpiurus* Montfort, of Franke (1936), described from the Kimmeridgian of Germany and later by Said & Barakat (1958) from the same stage in Egypt. Indian forms differ slightly from the Egyptian ones, and the type specimens have more chambers and a rougher surface. They also slightly differ from *R. barnardi* Said & Barakat, 1958, in lacking of an apertural neck, while the globular chamber has more chambers (5-7) yet lesser in size, and growth of the final chamber is higher and rough.

Reophax sundancensis Loeblich & Tappan, 1950
Fig. 5.6

1950a *Reophax sundancensis* Loeblich & Tappan, p. 41, pl. 11, fig. 1.
2000 *Reophax sundancensis* Loeblich & Tappan; Gaur & Singh, p. 48, pl. 4, fig. 6.

Material: 87 specimens.

Dimensions (mm). Length 0.28–0.78, width 0.1–0.3.

Discussion. Specimens of *Reophax sundancensis* from our material are similar to those described originally by Loeblich & Tappan (1950a) from the Oxfordian rocks of North America and later by Souaya (1976) from the Kimmeridgian of Canada. However, the studied specimens differ in having slightly oblique sutures and somewhat less inflated chambers. *Reophax sundancensis* differs from *R. suevica* Franke, 1936 in having less bulbous chambers and a rougher test surface. It differs from *R. scorpiurus* Montfort, 1808 in the coarser grained and less tapering test, and the absence of an apertural neck.

Superfamily Lituolacea de Blainville, 1827
Family Haplophragmoididae Maync, 1952
Genus *Haplophragmoides* Cushman, 1910
Type species: *Nonionina canariensis* d'Orbigny, 1839

Haplophragmoides agrawali Bhalla & Abbas, 1978
Fig. 5.7

1978 *Haplophragmoides agrawali* Bhalla & Abbas, p. 168. pl. 1, fig. 3–4.

Material: 91 specimens.

Dimensions (mm). Length 0.22–0.45, width 0.24–0.42, thickness 0.09–0.14.

Discussion. Our specimens show close resemblance to those originally described by Bhalla & Abbas (1978), from the Oxfordian of Habo Hill, Kutch (India). Diagnostic features of this species include the rounded periphery, gently curved sutures and inflated chambers as well as a depressed umbilical area.

Family Lituolidae de Blainville, 1827
Subfamily Ammomarginulininae Podobina, 1978
Genus *Ammobaculites* Cushman, 1910
Type species: *Spirolina agglutinans* d'Orbigny, 1846

Ammobaculites bivarians Nagy & Seidenkrantz, 2003
Fig. 5.8

2003 *Ammobaculites bivarians* Nagy & Seidenkrantz, p. 43, pl. 12, fig. 1–10.

Material: 195 specimens.

Dimensions (mm). Length 0.26–0.48, width 0.21–0.30, thickness 0.08–0.13.

Discussion. The specimens assigned to *Ammobaculites bivarians* are similar to the type material described by Nagy & Seidenkrantz (2003), from the Toarcian of Denmark. *A. bivarians* differs from *A. agglutinans* (originally described by d'Orbigny 1846, and later emended by Bartenstein 1952) in having more depressed sutures, the larger diameter of the planispiral coil, shorter uniserial portion, and coarser wall material. This species is also closely similar to *A. alaskensis* described by Tappan (1955), from different Lower and Upper Jurassic formations of the Arctic slope of Alaska. The holotype of *A. alaskensis* (Tappan 1955, pl. 12, fig. la–b) has a larger coil of five chambers, and shorter chambers in the uniserial part and is closest to our specimens. *A. alaskensis*, however, has a larger coil, a longer uniserial portion, and smaller uniserial chambers than *A. bivarians*. This species also resembles *A. gerkei* Sharovskaja (1996), but the two species can be differentiated by the longer specimens, more inflated, and fewer chambers of *A. bivarians*.

Ammobaculites cobbani Loeblich & Tappan, 1950
Fig. 5.9

1950a *Ammobaculites cobbani* Loeblich & Tappan, p. 41, pl. 11, fig. 9–13.
1958 *Ammobaculites cobbani* Loeblich & Tappan; Said & Barakat, p. 241, pl. 1, fig. 4.
1991 *Ammobaculites cobbani* Loeblich & Tappan; Bhalla & Talib, p. 94, pl. 1, fig. 18 (cum syn.).

Material: 35 specimens.

Dimensions (mm). Length 0.54–0.74, width coiled 0.3–0.4, length of uncoiled portion, 0. 24–0.32.

Discussion. Specimens of *Ammobaculites cobbani* recovered from the studied material are similar to those described originally by Loeblich & Tappan (1950a) from the Oxfordian of South Dakota. *A. cobbani* is also somewhat similar to *A. subcretaceous* Cushman & Alexander (1930), but may be distinguished from the latter by the more regular uniserial portion, slightly larger size, but smaller size of coiled portion, distinct sutures in the coiled portion, and a more elongated aperture. *A. tyrrelli* Nauss, 1947, is similar to *A. cobbani* but slightly different, having ovate chamber; sutures are depressed and the final chamber, which is rounded, is generally larger than the original species.

Ammobaculites culmulus Skolnick, 1958
Fig. 5.10

1958 *Ammobaculites culmulus* Skolnick, p. 280, pl. 37, fig. 2a–d.

Material: 58 specimens.

Dimensions (mm). Length 0.68-0.94, width coiled 0.21–0.36, length of uncoiled portion, 0.12–0.22.

Discussion. Studied specimens of *A. culmulus* are similar to those described originally by Skolnick (1958) from the upper Albian of western South Dakota and Stelck & Hedinger (1983) from the Albian of northeastern British Columbia, but they have larger shells with a smaller coiling portion. This species also resembles *A. inconspicua* Cushman & Waters, 1928, in having rectilinear chambers increasing more rapidly in height with later growth, deflated final chamber, sutures that are horizontally depressed, and an absence of neck. It differs in its small coiled portion, large final chamber, sutures that are curved, and a short terminal neck.

Ammobaculites aff. *A. glaessneri* Said & Barakat, 1958
Fig. 5.11

aff.
1958 *Ammobaculites glaessneri* Said & Barakat, p. 6, pl. 4, fig. 20, 22.
2016 *Ammobaculites glaessneri* Said & Barakat, Talib et al., p. 3–4, pl. 1, fig. 6.

Material: Three specimens.

Dimensions (mm). Length of test 0.48–0.57, length of uncoiled portion 0.17–0.20, width of uncoiled portion 0.13–0.19, diameter of coiled portion 0.12–0.14.

Discussion. Only three specimens of *Ammobaculites* show affinities with *Ammobaculites glaessneri* Said & Barakat, 1958, from the Kimmeridgian of Egypt. They slightly differ in the absence of a cylindrical shape. The diameter of *A. glaessneri* is slightly larger in the early coiled part. *Ammobaculites glaessneri* differs from *A. agglutinans* in having a more flattened planispiral part and longer uniserial chamber.

Ammobaculites subcretaceous Cushman & Alexander, 1930
Fig. 5.12

1930 *Ammobaculites subcretaceous* Cushman & Alexander, p. 6, pl. 2, fig. 9–10.
1991 *Ammobaculites subcretaceous* Cushman & Alexander; Bhalla & Talib, p. 95, pl., 1, fig. 19.
1993 *Ammobaculites subcretaceous* Cushman & Alexander; Pandey & Dave, p. 123, pl. 1, fig. 6–8.

Material: 78 specimens.

Dimensions (mm). Length of test 0.59–0.64, length of uncoiled portion 0.21–0.24, width of uncoiled portion 0.15–0.22, diameter of coiled portion 0.15–0.16.

Discussion. Specimens of *Ammobaculites subcretaceous* are similar to the original species of Cushman & Alexander (1930) from the Lower Cretaceous of USA, which is also similar to those of Bhalla & Talib (1991) from the Callovian, and Pandey & Dave (1993) from the Bathonian–Oxfordian of Kutch. They differ somewhat in having more compressed and fewer chambers in the uncoiled portion and slightly oblique sutures.

Ammobaculites wallalensis Crespin, 1963
Fig. 5.13

1963 *Ammobaculites wallalensis* Crespin, p. 45–46, pl. 11, fig. 1–5.

Material: 207 specimens.

Dimensions (mm). Length 0.35–0.57, width coiled 0.17–0.21, length of uncoiled portion, 0.12–0.15.

Discussion. Specimens of *Ammobaculites wallalensis* recovered from our material are similar to those described originally by Crespin (1963) from the Upper Jurassic and Upper Cretaceous of Western Australia. This species resembles *A. fragmentaria* Cushman (1927) but differs slightly in having a large initial coiling portion and elongated uniserial portion, a globular final chamber, and the size of the chamber increases from the initial to final chambers. It also differs from *A. coprolithiformis* in having a greater number of uncoiled chambers and smaller and fewer coiled chambers.

Genus *Ammomarginulina* Wiesner, 1931
Type species: *Ammomarginulina ensis* Wiesner, 1931

Ammomarginulina fontinensis (Terquem, 1870)
Fig. 5.14

1870 *Haplophragmium fontinense* Terquem, p. 337, pl. 24, fig. 29–30a-b.

1958 *Ammobaculites fontinensis* (Terquem), Said & Barakat, p. 241, pl. 2, fig. 2; pl. 3, fig. 9.
1991 *Ammobaculites fontinensis* (Terquem), Nagy & Johansen, p. 20–21, pl. 2, fig. 3–16 (cum syn.). 1991 *Ammobaculites fontinensis* (Terquem), Bhalla & Talib, p. 95, pl. 1, fig. 11 (cum syn.).
2013 *Ammobaculites fontinensis* (Terquem), Canales & Henriques, p. 187, fig. 3.3.
2016 *Ammobaculites fontinensis* (Terquem), Bilal et al., p. 174, text fig. 5.10.

Material: 438 specimens.

Dimensions (mm). Length 0.27–0.54, width coiled 0.11–0.30, length of uncoiled portion, 0.15–0.21.

Discussion. This species was originally assigned to *Haplophragmium* by Terquem (1870) and subsequently moved to *Ammobaculites*. The genus *Ammobaculites* is rounded in cross-section, having a tightly coiled early portion, with straight sutures in the uniserial part, whereas *Ammomarginulina* is strongly compressed, with oblique sutures in its uniserial part. On this basis, the studied specimens are herein assigned to the genus *Ammomarginulina*. This species has a large number of evolute coiled chambers, the sutures are curved and the periphery lobulate. Occasional specimens of *Ammobaculites alaskensis* have an evolute coiling, but they are comparatively rare and do not have the compressed test characteristic of the *A. fontinensis*. Our specimens are similar to *Haplophragmium fontinense* described by Terquem (1870) from the Jurassic of France and later reported as *Ammobaculites fontinensis* by Said & Barakat (1958) from the Bathonian-Callovian of Egypt and Kalantari (1969) from the Bajocian of Iran.

Ammomarginulina gowdai (Bhalla & Abbas, 1978)
Fig. 5.15

1978 *Ammobaculites gowdai* Bhalla & Abbas, p. 170, pl. 2, fig. 4–6.

Material: 8 specimens.

Dimensions (mm). Length 0.24–0.56, width coiled 0.25–0.38, length of uncoiled portion, 0.13–0.19.

Discussion. Bhalla & Abbas (1978) originally assigned the species to *Ammomarginulina gowdai* in the Callovian to Oxfordian of Kutch, India. The specimens are compressed and the early planispiral portion covers nearly one half of the test chambers.

They are also similar to *Ammobaculites gaessneri* Said & Barakat (1958), although they have a smaller size, a compressed test, few chambers in the coiled portion, and rather indistinct sutures. The studied specimens also differ from *Ammobaculites imlayi* Loeblich & Tappan (1950b), having a large coiled portion, rather indistinct sutures, and a very rough surface.

Ammomarginulina hagni (Bhalla & Abbas, 1978)
Fig. 5.16

1978 *Ammobaculites hagni* Bhalla & Abbas, p. 171, pl. 3, fig. 1–3.
2016 *Ammobaculites hagni* Bhalla & Abbas; Bilal et al., p. 175, text fig. 5.12.

Material: 202 specimens.

Dimensions (mm). Length 0.31–0.42, width coiled 0.11–0.18, length of uncoiled portion 0.09–0.16.

Discussion. Specimens of *Ammomarginulina hagni* recovered from the studied material resemble those described originally by Bhalla & Abbas (1978) from the Oxfordian of Habo Hill, and by Talib et al. (2012a) from the Callovian-Oxfordian of Keera Dome, Kutch.

Genus *Sculptobaculites* Leoblich & Tappan, 1984
Type species: *Ammobaculites goodlandensis* Cushman & Alexander, 1930

Sculptobaculites subplanatus (Cushman & Deadrick, 1942)
Fig. 5.17

1942 *Ammobaculites subplanatus* Cushman & Deadrick, p. 52, pl. 9, fig. 10–11.

Material: 16 specimens.

Dimensions (mm). Length 0.26–0.48, width 0.21–0.3, thickness 0.08–0.13.

Discussion. The genus *Sculptobaculites* differs from *Ammobaculites* in the evolute to advolute coiling, depressed and excavated umbilical region, and much reduced uniserial portion, whereas *Ammobaculites* is elongated, has a large uniserial portion, and a close coiling early portion. *Sculptobaculites subplanatus* (Cushman & Deadrick, 1942) is very similar to *Ammobaculites subplanatus* originally described by from the Cretaceous of Arkansas (USA) with a similar type of coiling, large chambers, few uniserial chambers, and a strongly compressed test with a lobate periphery.

Sculptobaculites tewarii (Bhalla & Abbas, 1978)
Fig. 5.18

1978 *Haplophragmoides tewarii* Bhalla & Abbas, p. 170, pl. 2, fig. 1–2.

Material: 63 specimens.

**Dimensions** (mm). Length 0.29–0.51, width 0.26–0.54, thickness 0.09–0.15.

Discussion. Specimens of *Sculptobaculites tewarii* recovered from the studied samples are similar to those described originally by Bhalla & Abbas (1978) from the Oxfordian of Habo Hill, Kutch. This species is slightly different from *Haplophragmoides tewarii* —it does not possess a uniserial portion— but in the Ler Dome specimens a small uniserial portion is clearly seen. Coiling is evolute and the coiled portion is wide or depressed.

Subfamily **Flabellammininae** Podobina, 1978
Genus *Ammopalmula* Lindenberg, 1966
Type species: *Haplophragmium infrajurensis* Terquem, 1870

Fig. 5 - Foraminiferal species recovered from the Chari Formation, Ler Dome, Kutch Basin. 1) *Lagenammina difflugiformis* (Brady, 1879); 2) *Reophax barnardi* Said & Barakat, 1958; 3) *Reophax mcdonaldi* Conkin, 1961; 4) *Reophax multilocularis* Haeusler, 1890; 5) *Reophax* aff. *R. scorpiurus* Montfort, 1936; 6) *Reophax sundancensis* Loeblich & Tappan 1950; 7) *Haplophragmoides agrawali* Bhalla & Abbas, 1978; 8) *Ammobaculites bivarians* Nagy & Seidenkrantz, 2003; 9) *Ammobaculites cobbani* Loeblich & Tappan, 1950; 10) *Ammobaculites culmulus* Skolnick 1958; 11) *Ammobaculites* aff. *A. glaessneri* Said & Barkat, 1958; 12) *Ammobaculites subcretaceous* Cushman & Alexander, 1930; 13) *Ammobaculites wallalensis* Crespin 1963; 14) *Ammomarginulina fontinensis* (Terquem, 1870); 15) *Ammomarginulina gowdai* (Bhalla & Abbas, 1978); 16) *Ammomarginulina hagni* (Bhalla & Abbas, 1978); 17) *Sculptobaculites subplanatus* (Cushman & Deadrick, 1942); 18) *Sculptobaculites tewarii* Bhalla & Abbas 1978; 19) *Ammopalmula elenae* (Dain, 1958); 20) *Flabellammina instowensis* Wall, 1960; 21) *Flabellammina lidiae* Fursenko & Polenova, 1950; 22) *Triplasia bartensteini* Loeblich & Tappan, 1952; 23) *Bulbobaculites vermiculus* Nagy & Seidenkrantz, 2003. Scale bar = 100 μm.
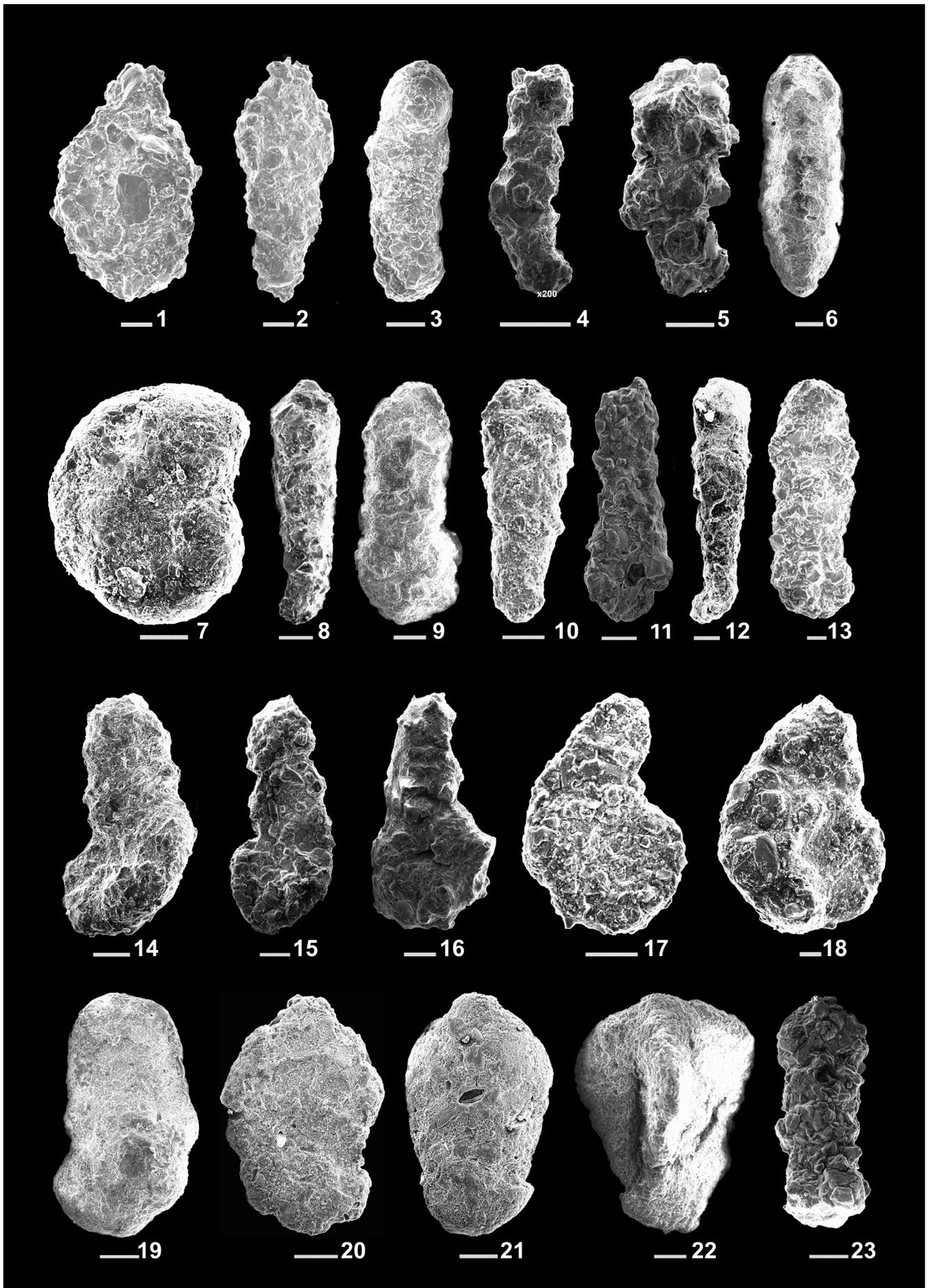
Ammopalmula elenae (Dain, 1958)
Fig. 5.19

1958 *Ammobaculites elenae* Dain, p. 13, pl. 2, fig. 4, 6.

Material: 118 specimens.

Dimensions (mm). Length 0.57–1.08, width coiled 0.32–0.6, length of uncoiled portion 0.29–0.45.

Discussion. The studied specimens show close resemblance to those originally described as *Ammobaculites elenae* by Dain (1958) from the upper Oxfordian of the USSR. *Ammopalmula elenae* is somewhat similar to *Ammobaculites suprajurassicum* but the former has broad chambers, ovate cross-section, and less elongate apertural neck, whereas the latter possesses narrower chambers, a rounded cross-section, a fairly elongate neck, and a depressed umbilical area.

Genus *Flabellammina* Cushman, 1928
Type species: *Flabellammina alexanderi* Cushman, 1928

Flabellammina instowensis Wall, 1960
Fig. 5.20

1960 *Flabellammina instowensis* Wall, p. 57–58, pl. 17, fig. 18–20.

Material: 76 specimens.

Dimensions (mm). Length 0.1–0.96, width 0.43–0.66, coiled portion 0.29–0.48, thickness 0.10–0.15.

Discussion. Studied specimens are similar to the original ones described by Wall (1960), from the upper Oxfordian of southwestern Saskatchewan, Canada, but they are smaller in size and have narrower coiling and fewer chambers. The most important features of this species are the well-developed coiled portion, arched sutures, and an elongate apertural neck.

Flabellammina lidiae Fursenko & Polenova, 1950
Fig. 5.21

1950 *Flabellammina lidiae* Fursenko & Polenova, p. 18–20, pl. 1, fig. 4–6.

Material: 64 specimens.

Dimensions (mm). Length 0.64-0.93, width 0.46-0.60, coiled portion 0.24-0.30, thickness 0.14-0.19.

Discussion. Specimens of *Flabellammina lidiae* recovered from the studied material are similar in almost all the characters to those described by Fursenko & Polenova (1950) from the Tithonian of the Emba region, former USSR. *F. alexanderi* Cushman, 1928, from the Cretaceous of the USA is fairly close to *F. lidiae* but differs in the test shape, having a highly compressed test.

Genus *Triplasia* Reuss, 1854
Type species: *Triplasia murchisoni* Cushman, 1928

Triplasia bartensteini Loeblich & Tappan, 1952
Fig. 5.22

1952 *Triplasia bartensteini* Loeblich & Tappan, p. 8, pl. 1, fig. 9.
1967 *Triplasia bartensteini* Loeblich & Tappan; Gordon, p. 450, pl. 1, fig. 19-20 (cum syn.).
2008 *Triplasia bartensteini* Loeblich & Tappan; Hamad Al-Saad, p. 8, pl. 1, fig. 6.

Material: 245 specimens.

Dimensions (mm). Length 0.42–0.81, width 0.36–0.76.

Discussion. Specimens of *Triplasia bartensteini* recovered from the studied samples are similar in almost all the characters to those described by Loeblich & Tappan (1952), from the Callovian of northwest Germany. It differs from *Triplasia variabilis* (Brady 1884) in being smaller and possessing a more flaring test, with more deeply excavated sides and more bluntly rounded angles.

Superfamily Haplophragmiacea Eimer & Fickert, 1899
Subfamily Recurvoidinae Alekseychik-Mitskevich, 1973
Family Ammobaculinidae Saidova, 1981
Genus *Bulbobaculites* Maync, 1952
Type species: *Ammobaculites lueckei* Cushman & Hedberg, 1941

Bulbobaculites vermiculus Nagy & Seidenkrantz, 2003
Fig. 5.23

2003 *Bulbobaculites vermiculus* Nagy & Seidenkrantz, p. 38–40, pl. 5, fig. 1–21.

Material: 19 specimens.

Dimensions (mm). Length of test 0.29–0.35, length of uncoiled portion 0.22–0.26, width

of uncoiled portion 0.11–0.14, diameter of coiled portion 0.01–0.15.

Discussion. A few specimens of *Bulbobaculites vermiculus* were recovered from the studied samples. They are similar to those described originally by Nagy & Seidenkrantz (2003), from the Toarcian of Denmark. However, the Indian forms differ in having a slightly larger coiled portion. The diagnostic features of this species are: smaller initial portion with streptospiral to irregular coiling, and the diameter of the first chamber of the uncoiled portion being smaller than the diameter of the coiled part.

Family Haplophragmiidae Eimer & Fickert, 1899
Genus *Haplophragmium* Reuss, 1860
Type species: *Spirolina aequalis* Roemer, 1841

Haplophragmium kutchensis Pandey & Dave, 1993

Fig. 6.1

1993 *Haplophragmium kutchensis* Pandey & Dave, p. 192, pl. 2, fig. 8–12.

Material: 26 specimens.

Dimensions (mm). Length of test 0.34, length of uncoiled portion 0.26, width of uncoiled portion 0.18, diameter of coiled portion 0.12.

Discussion. Specimens of *Haplophragmium kutchensis* found in our material resemble those specimens described originally by Pandey & Dave (1993) from the Lower Cretaceous (Neocomian) of the Kutch region. Our forms exhibit a less prominent streptospiral coil than the original forms and fewer chambers in the uniserial portion.

Superfamily Spiroplectamminacea Cuhman, 1927
Family Spiroplectamminidae Cushman, 1927
Subfamily Spiroplectammininae Cushman, 1927
Genus *Eobigenerina* Cetean et al., 2008
Type species: *Bigenerina variabilis* Vašíček, 1947

Eobigenerina sp.

Fig. 6.2

2008 *Eobigenerina* Cetean, Setoyama, Kaminski, Neagu, Bubík, Filipescu & Tyszka, 2008, p. 6.

Material: Two specimens.

Description. Test is small, elongate, compressed, slightly curved, early portion biserial comprising at least one-third the length of the adult test, later becoming uniserial; twelve chambers in biserial portion, initially only slightly inflated, later more inflated, enlarging gradually in size; uniserial portion with two chambers, strongly inflated, nearly globular; sutures distinct, initially flush, later depressed, with oblique to long axis of test; median sutures simple, zigzag, flush in early portion, slightly depressed later; periphery slightly lobate; aperture indistinct, apparently terminal and rounded; wall solid, noncanaliculate, particles finely agglutinated in organic material; surface smooth. Aperture terminal, small and rounded, on a collar or short neck.

Dimensions (mm). Length 0.36–0.42, width 0.09–0.12, thickness 0.06–0.80.

Discussion. Two specimens of *Eobigenerina* were obtained from the studied samples. Differs from *Bigenerina* in having a solid, noncanaliculate wall that is insoluble in acid, and from *Aaptotoichus* in having a well-developed biserial part, an apertural neck, and a finely agglutinated test wall. Numerous Mesozoic species originally described as *Bigenerina* possess a solid noncalcareous wall and should be transferred to this genus. Recorded from Upper Jurassic (Tithonian) to Upper Cretaceous of Australia; North Atlantic; Barents Sea; Alpine-Carpathian region: Romania, Poland, Czech Republica and Austria (see Cetean et al. 2008).

Superfamily Textulariacea Ehrenberg, 1838
Family Textulariidae Ehrenberg, 1838
Subfamily Textulariinae Ehrenberg, 1838
Genus *Textularia* Defrance, 1824
Type species: *Textularia sagittula* Defrance in de Blainville, 1824

Textularia jurassica Gümbel, 1862

Fig. 6.3

1862 *Textularia jurassica* Gümbel, p. 228, pl. 4, fig. 17a-b.
1967 *Textularia jurassica* Gümbel; Gordon, 1967, p. 450, pl. 1, fig. 11.
1991 *Textularia jurassica* Gümbel; Bhalla & Talib, p. 96, pl. 1, fig. 6;
2016 *Textularia jurassica* Gümbel, Bilal et al., p. 176, text fig. 5.17.

Material: 40 specimens.

Dimensions (mm). Length 0.23–0.39, width 0.05–0.09, thickness 0.06.

Discussion. The studied specimens favourably resemble the form described by Gümbel (1862)

from the Oxfordian of Germany. Later a number of authors reported it from Bathonian to Tithonian in different parts of the world including India (e.g. Bhallar & Talib 1991; Bilal et al. 2016). *Textularia pugiunculus* (Schwager) described by Gordon (1965) is regarded as a variant of this species by Coleman (1981).

Suborder **Spirillinina** Hohenegger & Piller, 1975
Family Spirillinidae Reuss & Fritsch, 1861
Genus *Spirillina* Ehrenberg, 1843

Type species: *Spirillina vivipara* Ehrenberg, 1843

Spirillina orbicula Terquem & Berthelin, 1875

Fig. 6.4

1875 *Spirillina orbicula* Terquem & Berthelin, p. 17, pl. 1, fig. 12a–c.
2013 *Spirillina orbicula* Terquem & Berthelin; Canales & Henriques, p. 187, fig. 3.8.

Material: 1633 specimens.

Dimensions (mm). Major diameter 0.15–0.24, minor diameter 0.30–0.22, thickness 0.04–0.09.

Discussion. The studied specimens are similar to those described by Terquem & Berthelin (1875), from the Lower Jurassic of France, also similar to specimens reported by Canales & Henriques (2013) from the Bajocian of Portugal, and by Figueiredo et al. (2014) from the Toarcian to Aalenian of Portugal. This species differs from *Spirillina polygyrata* due to its small spherical proloculus. Our specimens slightly differ from *Spirillina numismalis* Terquem & Berthelin, 1875, having constant tube diameter and likewise differ from *Spirillina gracilis* Terquem, 1886, but have a similar perforate surface and small prolocular.

Suborder **Lagenina** Delage & Hérouard, 1896
Superfamily Robuloidacea Reiss, 1963
Family Ichthyolariidae Loeblich & Tappan, 1986
Genus *Prodentalina* Norling, 1968

Type species: *Dentalina terquemi* d'Orbigny, 1850

Prodentalina guembeli (Schwager, 1865)

Fig. 6.5

1865 *Dentalina guembeli* Schwager, p. 101, pl. 2, fig. 20.
2013 *Prodentalina guembeli* (Schwager), Canales & Henriques, p. 187.
2016 *Prodentalina guembeli* (Schwager), Bilal et al., p. 177, text fig. 5.20.

Material: 74 specimens.

Dimensions (mm). Length 0.42–0.45, width 0.09–0.12.

Discussion. Ler Dome specimens are similar to the type material. It is an extremely variable species, however, and exhibits a wide range of morphological overlap. Different authors —including Gordon (1965), Bhalla & Abbas (1978) and Bhalla & Talib (1991)— proposed that different species, *viz.*, *P. guembeli* Schwager (1865), *Dentalina communis* d'Orbigny (1826) and *D. pseudocommunis* Franke, (1936) are perhaps morphovarients of the same species.

Prodentalina aff. *L. oppeli* (Schwager, 1865)

Fig. 6.6

aff.
1865 *Dentalina oppeli* Schwagar, p. 95, pl. 3, fig. 16–17.

Material: 7 specimens.

Dimensions (mm). Length 0.36, width 0.07.

Discussion. A few broken specimens of *Prodentalina* from the studied material exhibit affinity with the specimens of *Dentalina oppeli* originally described by Schwager (1865) from the Oxfordian of Germany and by Espitalié & Sigal (1963) from the Oxfordian to Kimmerdgian of Madagascar.

Prodentalina torta (Terquem, 1858)

Fig. 6.7

1858 *Dentalina torta* Terquem, p. 599, pl. 2, fig. 6.
1958 *Dentalina torta* Terquem; Said & Barakat, p. 254, pl. 5, fig. 4 (cum syn.).
1969 *Dentalina torta* Terquem; Kalantari, p. 68–69, pl. 4, fig. 25 (cum syn.).

Material: 21 specimens.

Dimensions (mm). Length 0.31–0.54, width 0.06–0.09.

Discussion. Our specimens fit well with *Prodentalina torta* (Terquem 1858) reported originally from the Lower Jurassic of France. This species somewhat resembles *Dentalina vetustissima* d'Orbigny, 1850, but differs in being more slender and in having oblique sutures as compared to the nearly horizontal sutures of the latter. Furthermore, *D. vetustissima* has a circular section and is larger in size, while the studied species has ovate cross-section and is smaller in size.

Genus: *Falsopalmula* Bartenstein, 1948

Type species: *Flabellina tenuistriata* Franke, 1936

Falsopalmula aff. *F. deslongchampsi* (Terquem, 1864)

Fig. 6.8

aff.
1864 *Flabellina deslongchampsi* (Terquem), p. 216, pl. 10, fig. 13.
1960 *Falsopalmula deslongchampsi* (Terquem); Lutze, p. 464, pl. 32, fig. 15.
1969 *Neoflabellina deslongchampsi* (Terquem); Kalantari, p. 90-91, pl. 3, fig. 19-20 (cum syn.).
2012 *Citharinella deslongchampsi* (Terquem); Quilty, p. 188, fig. 3.23 (cum syn.).
2014 *Palmula deslongchampsi* (Terquem); Copestake & Johnson, p. 224, pl. 11, fig. 32, 37.
2017 *Falsopalmula deslongchampsi* (Terquem); Talib et al., p. 7, fig. 6J.

Materials: 82 specimens.

Dimensions (mm). Length 0.25–0.36, width 0.12–0.21, thickness 0.04–0.06.

Discussion. This species was originally assigned to the generic name *Flabellina*. Bartenstein, 1948b, replaced it with *Neoflabellina* on the basis that the former was already in use for a molluscan genus. Bartenstein (1948a) further stated that *Neoflabellina* was not known to occur before the Cretaceous and also differs in morphological features, possessing a coarse perforate test. *Falsopalmula* has a planispirally coiled early chamber in an astacoline coiling, the suture slightly depressed in a later stage, and ranges from Lower to Middle Jurassic, whereas *Palmula* has astacoline nature in only the megalospheric generation, sutures are flush, and occurs in Palaeocene to middle Miocene sediments (Loeblich & Tappan 1987). Few well-preserved specimens of *Falsopalmula* aff. *F. deslongchampsi* (Terquem 1863) are recorded from the studied samples and show a close resemblance to the forms described by Barnard (1952) from the Oxford clay (middle Callovian to lower Oxfordian) of England. The species is characterised by a small rounded proloculus, a lobate margin, and depressed sutures.

Falsopalmula primordialis (Terquem, 1869)

Fig. 6.9

1869 *Flabellina primordialis* Terquem, p. 221, pl. 23, fig. 19–24.
2017 *Falsopalmula primordialis* (Terquem); Talib et al., p. 7, fig. 6K.

Material: 135 specimens.

Dimensions (mm). Length 0.48–0.60, width 0.21–0.32, thickness 0.08–0.17.

Discussion. Well-preserved specimens of *Falsopalmula* are recorded, showing close similarity to *Flabellina primordialis* Terquem, 1869. The specimens also show similarities with material described by Kalantari (1969) from the Bajocian of Iran. This species somewhat resembles *Frondicularia involuta* Terquem, 1866, but differs in its astacoline coiling of the initial end, having three compressed chambers followed by five symmetrically chevron-shaped chambers. *F. primordialis* has distinct and depressed sutures and a small globular proloculus.

Superfamily Nodosariacea Ehrenberg, 1838
Family Nodosariidae Ehrenberg, 1838
Subfamily Nodosariinae Ehrenberg, 1838
Genus *Nodosaria* Lamarck, 1816

Type species: *Nautilus radicula* Linne, 1758

Nodosaria nitidana Brand, 1937

Fig. 6.10

1937 *Nodosaria nitidana* Brand; p. 44, pl. 3, fig. 22b.
1958 *Nodosaria nitidana* Brand; Said & Barakat, p. 255, pl. 5, fig. 2 (cum syn.).

Material: 17 specimens.

Dimensions (mm). Length 0.53–0.9, width of upper portion 0.25–0.42, width of lower portion 0.09.

Discussion. Some poorly preserved and broken specimens of this species are recorded. They are similar to those described originally by Bartenstein & Brand (1937) from the Lower Jurassic of France and Germany, as well as by Said & Barakat (1958) from the Kimmeridgian of Egypt.

Nodosaria simplex (Terquem, 1858)

Fig. 6.11

1858 *Dentalina simplex* Terquem, p. 599, pl. 2, fig. 5a–b.
1958 *Nodosaria simplex* (Terquem), Said & Barakat, p. 255, pl. 2, fig. 29; pl. 5, fig. 9.
1984 *Nodosaria simplex* (Terquem), Leckie, p. 682, pl. 5, fig. 128.
2009 *Nodosaria simplex* (Terquem), Gaur & Talib, p. 237, pl. 2, fig.7 (cum syn.).

Material: 88 specimens.

Dimensions (mm). Length 0.21–0.27, width 0.09–0.10.

Discussion. Our specimens closely resemble

the forms described by Said & Barakat (1958). The most similar features of the studied specimens are the presence of four to five uniseral chambers in a rectilinear series, rounded cross-section, and depressed and horizontal sutures. This species can be distinguished from *Nodosaria dolioligera* (Schwager, 1865) in being much more regular in its growth; but its final chamber is more elongated than in the studied specimens, the chamber being higher than it is wide, and presenting longitudinal costae.

Genus *Pseudonodosaria* Boomgaart, 1949
Type species: *Glandulina discreta* Reuss, 1850

Pseudonodosaria vulgata (Bornemann, 1854)
Fig. 6.12

1854 *Glandulina vulgata* Bornemann, p. 31, pl. 2, fig. 1a-b–2a-b.
1991 *Pseudonodosaria vulgata* (Bornemann), Nagy & Johansen, p. 25, pl. 5, fig. 17-18.
2013 *Pseudonodosaria vulgata* (Bornemann), Canales & Henriques, p. 190, fig. 3.21.
2015 *Pseudonodosaria vulgata* (Bornemann), Ramírez & Herrero, p. 329, fig. 3.18, (cum syn.).

Material: 9 specimens.

Dimensions (mm). Length 0.30, width 0.16.
Discussion. Specimens of *Pseudonodosaria vulgata* (Bornemann 1854) recovered from the Ler Dome area exhibit similarities to those described by Nagy & Johansen (1991) from the Jurassic of the North Sea. These authors (*op. cit.*) indicated that the species shows an extremely wide range of variation. The studied forms are also similar in overall characters to those figured by Gordon (1967) from the Callovian of Scotland.

Subfamily Frondiculariinae Reuss, 1860
Genus *Frondicularia* Defrance, 1826
Type species: *Renulina complanata* Defrance, in de Blainvilla, 1824

Frondicularia kutchensis Bhalla & Abbas, 1978
Fig. 6.13

1978 *Frondicularia kutchensis* Bhalla & Abbas, p. 178, pl. 7, fig. 2–3.
2009 *Frondicularia kutchensis* Bhalla & Abbas; Gaur & Talib, p. 237, pl. 2, fig. 10 (cum syn.).

Material: 121 specimens.

Dimensions (mm). Maximum length 0.39–0.57, maximum width 0.12–0.18, thickness 0.04–0.06.

Discussion. Bhalla & Abbas (1978) originally described *Frondicularia kutchensis* from the Callovian to Oxfordian of Kutch, which is similar to the studied specimens. A considerable range of variation in the shape and size of the test as well as number of chambers is exhibited by this species.

Family Vaginulinidae Reuss, 1860
Subfamily Lenticulininae Chapman, Parr & Collins, 1934
Genus *Lenticulina* Lamarck, 1804
Type species: *Lenticulina rotulatus* Lamarck, 1804

Lenticulina audax Loeblich & Tappan, 1950b
Fig. 6.14

1950b *Lenticulina audax* Loeblich & Tappan, p. 43, pl. 11, fig. 18a–21b.
1969 *Lenticulina audax* Loeblich & Tappan; Kalantari, p. 34, pl. 11, fig. 30-33a-b (cum syn.).
2001 *Lenticulina audax* Loeblich & Tappan; Kottachchi, pl. 23, fig. 3.
2016 *Lenticulina audax* Loeblich & Tappan; Bilal et al., p. 178, text fig. 6.3.

Material: 597 specimens.

Dimensions (mm). Length 0.5–0.63, width 0.42–0.6, thickness 0.21–0.35.
Discussion. The studied specimens of *Lenticulina audax* are similar to the specimens originally reported from the Oxfordian of the USA by Loeblich & Tappan (1950b). *Lenticulina audax* is fur-

Fig. 6 - Foraminiferal species recovered from the Chari Formation, Ler Dome, Kutch Basin. 1) *Haplophragmium kutchensis* Pandey & Dave, 1993; 2) *Eobigenerina* sp.; 3) *Textularia jurassica* Gümbel, 1862; 4) *Spirillina polygyrata* Gümbel, 1862; 5) *Prodentalina guembeli* (Schwager, 1865); 6) *Prodentalina* aff. *L. oppeli* (Schwager, 1865); 7) *Prodentalina torta* Terquem, 1858; 8) *Falsopalmula* aff. *F. deslongchampsi* (Terquem, 1864); 9) *Falsopalmula primordialis* (Terquem, 1869); 10) *Nodosaria nitidana* Brand, 1937; 11) *Nodosaria simplex* (Terquem, 1858); 12) *Pseudonodosaria vulgata* (Bornemann, 1854); 13) *Frondicularia kutchensis* Bhalla & Abbas, 1978; 14) *Lenticulina audax* Loeblich & Tappan, 1950; 15) *Lenticulina ectypa* (Loeblich & Tappan 1950b); 16) *Lenticulina gaultina* (Berthelin 1880); 17) *Lenticulina muensteri* (Roemer, 1839); 18) *Lenticulina protracta* (Bornemann 1854); 19) *Lenticulina quenstedti* (Gümbel, 1862); 20) *Lenticulina subalata* (Reuss, 1854). 21) *Lentculina varians* Loeblich & Tappan, 1950. Scale bar = 100 μm.
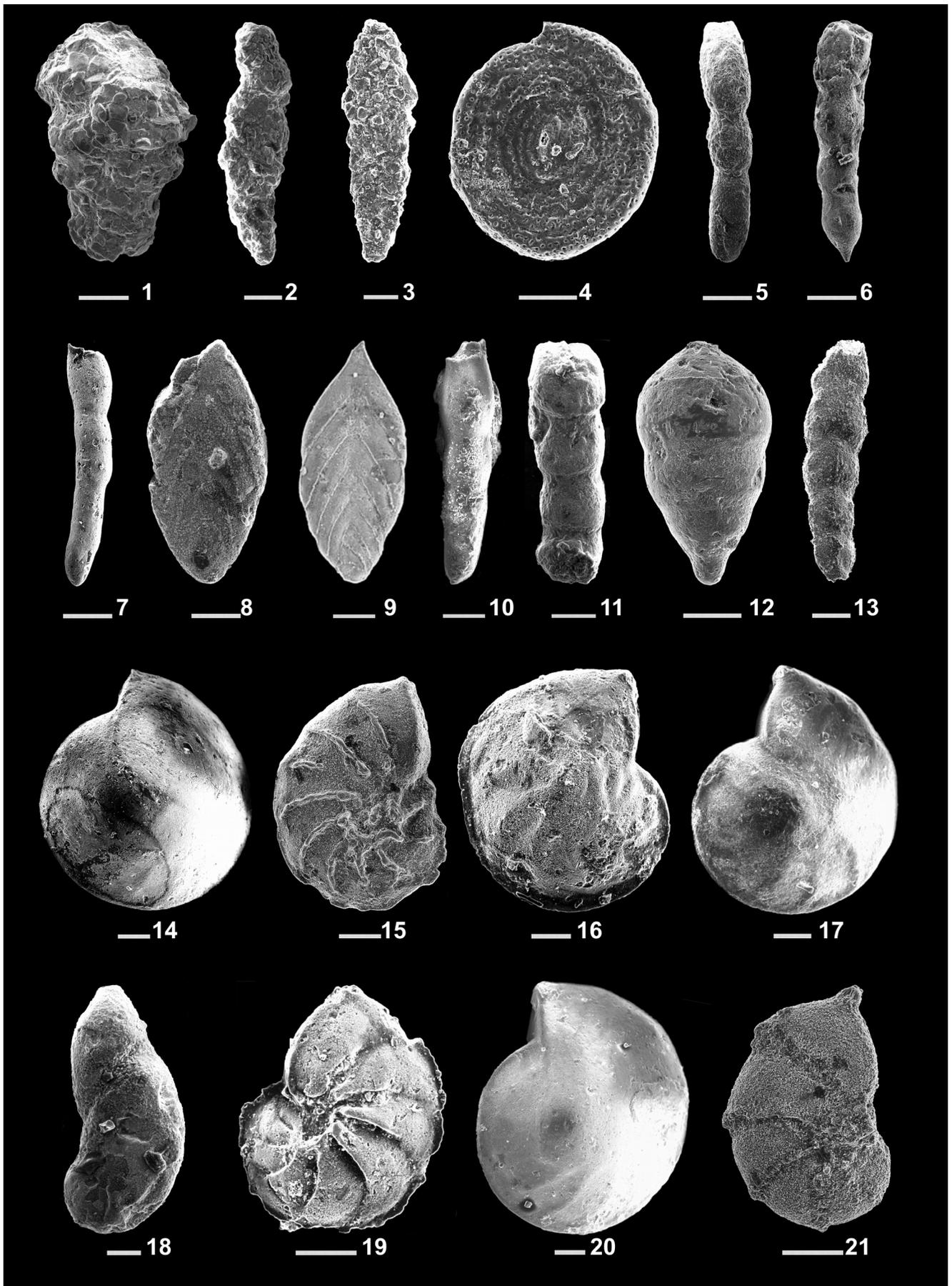
thermore similar to *Cristellaria diademeta* (Berthelin 1880), except in being approximately one-third larger and having twice the number of chambers in the final whorl. *Cristellaria gualtina* (Berthelin 1880) resembles *L. audex* in size as well as the number of chambers in the final whorl, but differs in the thickness of the umbo. *Cristallaria helios* (Terquem 1870) is approximately one half the size of *L. audax* and possesses limbate sutures, while *Cristallaria mamillaris* (Terquem 1870) differs in being nearly twice as large and in possessing fewer chambers in the final volution (Loeblich & Tappan 1950a).

Lenticulina ectypa (Loeblich & Tappan, 1950b)
Fig. 6.15

1950b *Astacolus ectypa* Loeblich & Tappan, p. 179, pl. 1, fig. 10.
1981 *Lenticulina ectypa* (Loeblich & Tappan); Barnard et al., p. 412, pl. 2, fig. 19.
1981 *Lenticulina ectypa* (Loeblich & Tappan); Shipp & Murray, p. 138, pl. 6.3.3, fig. 7–10 (cum syn.).
2001 *Lenticulina ectypa* (Loeblich & Tappan); Nagy et al., pl. 2, fig. 5

Material: 52 specimens.

Dimensions (mm). Major diameter 0.24–0.40, minor diameter 0.16–0.30, thickness 0.07–0.15.

Discussion. Well-preserved specimens of *Lenticulina ectypa* were recovered from the Kutch material. Our specimens are similar to those described by Loeblich & Tappan (1950b) from the Oxfordian of USA and show little variation in size and shape of the test. Most of the specimens are closely coiled. This species resembles *L. quenstedti* but differs in having a deep recess posterior to the rib in each chamber and generally having a large central area.

Lenticulina gaultina (Berthelin, 1880)
Fig. 6.16

1880 *Cristellaria gaultina* Berthelin, p. 49, pl. 3, fig. 15–19.
1991 *Lenticulina gaultina* (Berthelin); Bhalla & Talib, p. 99, pl. II, fig. 9 (cum syn.).
1965 *Lenticulina gaultina* (Berthelin); Neagu, p. 10, pl. 3, fig. 1-2 (cum syn.).
1987 *Lenticulina gaultina* (Berthelin); Williamson, p. 58, pl. 1, fig. 18-19.
1991 *Lenticulina gaultina* (Berthelin); Bhalla & Talib, p. 99, pl. II, fig. 9 (cum syn.).

Material: 350 specimens.

Dimensions (mm). Length 0.51–0.60, width 0.28–0.49, thickness 0.15–0.29.

Discussion. It is similar to *L. audax* but possesses a prominently raised umbonal region. The test shows signs of uncoiling in the last one or two chambers in many of the studied specimens. This species is widespread throughout the section of the Chari Formation in the study area. In the Indian region, this species is described by Bhalla & Talib (1991) from the Callovian of Jhurio Hill, Kutch, and by Gaur & Singh (2000) from the Oxfordian of Nara Dome, Kutch.

Lenticulina muensteri (Roemer, 1839)
Fig. 6.17

1839 *Robulina muensteri* Roemer, p. 48, pl. 20, fig. 29a–b.
1935 *Cristellaria muensteri* (Roemer); Macfadyen, p. 13, pl. 1, fig. 10a–b (cum syn.).
1958 *Lenticulina muensteri* (Roemer); Said & Barakat, p. 248, pl. 1, fig. 10; pl. 3, fig. 25; pl. 4, fig. 35 (cum syn.).
2013 *Lenticulina muensteri* (Roemer); Canales & Henriques, p. 191, fig. 4.4.
2016 *Lenticulina muensteri* (Roemer); Bilal et al., p. 179, text fig. 6.6.

Material: 1182 specimens.

Dimensions (mm). Length 0.48–1.31, width 0.42–1.01, thickness 0.24–0.46.

Discussion. Originally described as *Robulina muensteri* by Roemer (1839) from the Lower Cretaceous of Germany, this species is widespread and abundant throughout the studied section. Barnard & Ship (1981) noted that *L. muensteri* shows slight variation in size and shape of the test and is commonly found with *L. subalata* (Reuss 1863), which has a markedly raised central boss and ribs unlike the smoother *L. muensteri*. The most characteristic features of this species are its tightly coiled spiral test, distinctly raised boss, and slightly limbate sutures. The test shows uncoiling in the last one or two chambers in many of the specimens.

Lenticulina protracta (Bornemann, 1854)
Fig. 6.18

1854 *Cristellaria protracta* Bornemenn, p. 39, pl. 4, fig. 27a,b.
1969 *Planularia protracta* (Bornemann); Kalantari, p. 54, pl. 3, fig. 9a–11b.
2013 *Planularia protracta* (Bornemann); Canales & Henriques, p. 195, fig. 5.6.
2015 *Planularia protracta* (Bornemann); Ramírez & Herrero, p. 334, fig. 4.17 (cum syn.).
1981 *Lenticulina protracta* (Bornemann); Barnard, Cordey & Shipp, p. 413–414, pl. 2, fig. 22.
2016 *Lenticulina protracta* (Bornemann); Talib et al., p. 6–7, pl. 6, fig. 5.

Material: 218 specimens.

Dimensions (mm). Major diameter 0.30–0.36, minor diameter 0.12–0.18, thickness 0.06–0.09.

Discussion. Well-preserved specimens of *Lenticulina protracta* (Bornemann 1854) were recovered from the Kutch material, being similar to those described from the Callovian of England by Barnard et al. (1981) and Medd (1983), and from Russia by Ustinovaa & Tesakovab (2015). The specimens fall well within the variation range of this species.

Lenticulina quenstedti (Gümbel, 1862)
Fig. 6.19

1862 *Cristellaria quenstedti* Gümbel, p. 226, pl. 4, fig. 2a-b.
2009 *Lenticulina quenstedti* (Gümbel); Gaur & Talib, p. 238, pl. 2, fig. 14.
2011 *Lenticulina quenstedti* (Gümbel); Quilty, p. 187, fig. 3.11.
2013 *Lenticulina quenstedti* (Gümbel); Canales & Henriques, p. 191, fig. 4.6.
2016 *Lenticulina quenstedti* (Guembel); Bilal et al., p. 180, text fig. 6.8.

Material: 1198 specimens.

Dimensions (mm). Major diameter 0.36–0.58, minor diameter 0.24–0.38, thickness 0.14–0.21.

Discussion. Well-preserved specimens of the long ranging species *Lenticulina quenstedti* (Gümbel 1862) recovered from the samples are similar to the original forms described by Gümbel (1862) from the Oxfordian of Germany. This species has a long ranging record from the Toarcian to Lower Cretaceous and displays markedly raised sutures and a well-developed keel. The studied forms show a clear umbilical ring as figured by Bhalla & Abbas (1978), Bhalla & Talib (1985a, 1991) and Pandey & Dave (1993) from the Jurassic sediments of Kutch, and Coleman (1981) from Dorset, England. A detailed study on the variability of *L. quenstedti* was carried out by Barnard et al. (1981) and Bhalla & Talib (1985c). However, our specimens show little variation in test morphology.

Lenticulina subalata (Reuss, 1854)
Fig. 6.20

1854 *Cristellaria subalata* Reuss, p. 68, pl. 25, fig. 13.
2009 *Lenticulina subalata* (Reuss); Gaur & Talib, p. 238, pl. 2, fig. 15.
2016 *Lenticulina subalata* (Reuss); Bilal et al., p. 180, text fig. 6.9.

Material: 1135 specimens.

Dimensions (mm). Major diameter 0.59–0.78, minor diameter 0.38–0.72, thickness 0.36–0.48.

Discussion. *Lenticulina subalata* (Reuss 1854) was originally described from the Cretaceous of Germany and is found throughout the studied section. This species shows a wide range of variation in size and shape of the test. Our specimens are identical to those described throughout the Jurassic as well as Lower Cretaceous by a number of authors. This species differs from *L. muensteri* (Roemer 1839) in having the suture radiating from a non-elevated central disc, and in having more distinct, thinner and less thickened sutures. In the Indian region, Bhalla & Abbas (1975) carried out a detailed variation study of this species, observing that some of the species of *Lenticulina* erected by previous workers are in fact different morphovarients of *L. subalata*.

Lenticulina varians (Bornemann, 1854)
Fig. 6.21

1854 *Cristellaria varians* Bornemann, pl. 4, fig. 32–34, p. 41.
2014 *Lenticulina varians* (Bornemann), Al-Hussein, pl. 5, fig. 10a-b, p. 76 (cum syn.).

Material: 16 specimens.

Dimension (mm). Major diameter 0.31–0.65, minor diameter 0.23–0.45, thickness 0.13–0.22.

Discussion. The specimens are more or less similar to the original species *Cristellaria varians* (Bornemann 1854) described by Barnard (1952) from the Lower Jurassic of England. The specimens are also similar to those of Kalantari (1969) from the Jurassic of Iran. In the Jurassic sediments of Kutch, Bhalla & Abbas (1978), Bhalla & Talib (1991) and Alhussein (2014) have reported similar types of forms. However, in the recorded specimens the periphery is more lobate and each chamber overlaps the preceding one, forming node-like structures at the periphery.

Genus *Saracenaria* Defrance, 1824
Type species: *Saracenaria italica* Defrance, 1824

Saracenaria cornucopiae (Schwager, 1865)
Fig. 7.1

1865 *Cristellaria (Saracenaria) cornucopiae* Schwager, p. 181, pl. 5, fig. 7.
1991 *Saracenaria cornucopiae* (Schwager); Bhalla & Talib, p. 101, pl. III, fig. 14-15 (cum syn.).
2013 *Saracenaria cornucopiae* (Schwager); Canales & Henriques, p. 191, fig. 4.7.

Material: 333 specimens.

Dimensions (mm). Length 0.32–0.74, width 0.11–0.26, thickness 0.09–0.19.

Discussion. Our specimens of *Saracenaria cornucopiae* (Schwager 1865) are similar to the type material from the Oxfordian of Germany as well as to specimens described by Kalantari (1969) from the Lower Cretaceous of Iran. This is a highly variable species which shows variations not only in the shape and size of the test but also in the number of chambers.

Subfamily Marginulininae Wedekind, 1937
Genus *Astacolus* de Montfort, 1808

Type species: *Astacolus crepidulatus* de Montfort, 1808

Astacolus anceps (Terquem, 1870)

Fig. 7.2

1870 *Cristellaria anceps* Terquem, p. 428, pl. 9, fig. 11–21.
1967 *Planularia anceps* (Terquem); Gordon, p. 452, pl. 4, fig. 15-20 (cum syn.).
2009 *Astacolus anceps* (Terquem); Gaur & Talib, p. 239, pl. 2, fig. 21 (cum syn.).
2016 *Astacolus anceps* (Terquem); Bilal et al., p. 182, text fig. 6.12.

Material: 414 specimens.

Dimensions (mm). Length 0.22–0.36, width 0.10–0.24, thickness 0.04–0.11.

Discussion. Studied specimens are similar to the originally described *Astacolus anceps* (Terquem 1870) from the Bathonian of France. In the Indian region this species is reported by Subbotina et al. (1960), Bhalla & Abbas (1978), Kalia & Chowdhary (1983), Bhalla & Talib (1991), Pandey & Dave (1993) and Gaur & Talib (2009). The Indian forms from the Jurassic deposits of Kutch and Rajasthan differ in having slightly depressed sutures in later stage, like the Iranian specimens described by Kalantari (1969).

Astacolus aphrastus Loeblich & Tappan, 1950

Fig. 7.3

1950 *Astacolus aphrastus* Loeblich & Tappan, p. 45, pl. 12, fig. 1–4.

Material: 201 specimens.

Dimensions (mm). Length 0.38–0.57, width 0.18–0.36, thickness 0.11–0.18.

Discussion. A large number of well-preserved specimens of *Astacolus aphrastus* Loeblich & Tappan, 1950, originally described from the Oxfordian of the USA, are found in the studied sediments. The specimens are identical to the American form as well as the Indian forms described by Subbotina et al. (1960), Bhalla & Abbas (1978), Kalia & Chowdhary (1983), Bhalla & Talib (1991) and Pandey & Dave (1993). Gaur & Talib (2009) reported *A. aphrastus* from the Jurassic deposits of Kutch with features included within the variation range of this species.

Astacolus sp.

Fig. 7.4

Material: 2 specimens.

Dimensions (mm). Length 0.63, width 0.33, thickness 0.09.

Description. Test medium, compressed, elongate, early portion coiled, later portion uncoiled; coiled portion with five chambers, enlarging gradually as added; uncoiled portion with three chambers, tending to reach proloculus, increasing gradually in size, broader than high; sutures distinct, nearly flush in early portion, depressed in later part, oblique to axis of coiling, with thin broken ribs, giving a beaded appearance; periphery slightly lobate; aperture indistinct, appears to be radiate, at dorsal angle; wall calcareous; surface smooth.

Discussion. Two specimens of *Astacolus* were recovered from the studied material, which could not be assigned to any known species of the genus. However, they show some resemblance to *Astacolus filosa*, described by Said & Barakat (1958) from the Jurassic of Egypt but having flush sutures in the early portion and a smaller number of chambers in the coiled portion. The beaded ribs along the sutures are the characteristic feature of this species, unlike *A. filosa* figured by Said & Barakat (1958). We refrain from assigning it a species name because we have only two specimens.

Genus *Marginulina* d'Orbigny, 1826

Type species: *Marginulina raphanus* d'Orbigny, 1826

Marginulina batrakiensis (Mjatliuk, 1939)

Fig. 7.5

1939 *Cristellaria batrakiensis* Mjatliuk, p. 61, pl. 4, fig. 52–53.
1967 *Marginulina batrakiensis* (Mjatliuk); Gordon, p. 452, pl. 4, fig. 24–25 (cum syn.).
2016 *Marginulina batrakiensis* (Mjatliuk); Bilal et al., p. 182, text fig. 6.14.

Material: 238 specimens.

Dimensions (mm). Length 0.13–0.19, width 0.03–0.05, thickness 0.03–0.06.

Discussion. Our specimens are similar to the original specimens of *Cristellaria batrakiensis* Mjatliuk, 1939 from the Middle Callovian of the former USSR. On the basis of generic character, Gordon (1967) suggested the new generic combination *Marginulina batrakiensis* for specimens from the Callovian of Brora in Scotland. *Marginulina batrakiensis* resembles *Cristellaria reticulata* Schwager, 1867, but differs markedly in the test sculpture and the arrangement of initial chambers. In the Indian region, Kalia & Chowdhary (1983) reported this species from the Callovian of Kuldhar of Rajasthan. The studied specimens are similar to those from Scotland, South Dakota and Rajasthan.

Marginulina aff. *M. bhatiai* (Bhalla & Talib, 1985b)
Fig. 7.6

aff.
1985b *Vaginulina bhatiai* Bhalla & Talib, p. 150–151, pl. 1, fig. 10–18.
2009 *Marginulina bhatiai* Bhalla & Talib; Gaur & Talib p. 241, pl. 3, fig. 6–7.

Material: 211 specimens.

Dimensions (mm). Length 0.16–0.36, width 0.07–0.18, thickness 0.04–0.09.

Discussion. This species was first described by Bhalla & Talib (1985b) from Jhurio Hill (India), followed by Bhalla & Talib (1991), Talib & Bhalla (2006), Talib et al. (2007), and Gaur & Talib (2009) from the Callovian of Kutch mainland. This species is also similar to the *Astacolus calliopsis* Tappan, 1955, but this species has fewer chambers, which are more inflated in the portion of the test and a larger inflated final chamber tending to reach the proloculus. The final chamber is about twice the height of the previous one. On either side of the test occur uninterrupted longitudinal costae. *Marginulina bhatiai* is also similar to *Astacolus aphrastus* Loeblich & Tappan, 1950a, but the *M. bhatiai* has a more prominent dorsal keel, and distinctly ornamented costae.

Marginulina caelata Loeblich & Tappan, 1950
Fig. 7.7

1950 *Marginulina caelata* Loeblich & Tappan, p. 46, pl. 12, fig. 10a-b.
2016 *Marginulina caelata* Loeblich & Tappan; Bilal et al., p. 184, text fig. 6.15.

Material: 91 specimens.

Dimensions (mm). Maximum length 0.21, maximum width 0.09, thickness 0.07.

Discussion. A solitary specimen of *Marginulina caelata* was found in our material, similar in all characters to those described originally by Loeblich & Tappan (1950a) from the Oxfordian of North America and Espitalié & Sigal (1963) from the Bathonian to Callovian of Madagascar. However, the Kutch form has a smaller apertural neck than the North American forms, and its surface is ornamented with numerous very fine uninterrupted raised ribs forming a reticulate pattern.

Marginulina oxfordiana Gordon, 1965
Fig. 7.8

1965 *Marginulina oxfordiana* Gordon, p. 842, text-fig. 6, fig. 28–31.
1991 *Marginulina oxfordiana* Gordon; Bhalla & Talib, p. 101, pl. III, fig. 16-17.

Material: 39 specimens.

Dimensions (mm). Maximum length 0.27–0.36, maximum width 0.08–0.12, thickness 0.06–0.77.

Discussion. Specimens of *Marginulina oxfordiana* in the studied samples resemble those described originally by Gordon (1965) from the Oxfordian of England, but have fewer chambers. The studied specimens are similar to those described by Bhalla & Talib (1991) from the Oxfordian sediments of Kutch.

Marginulina aff. *M. sculptilis* (Schwager, 1865)
Fig. 7.9

aff.
1865 *Cristellaria sculptilis* Schwager, p. 129, pl. 6, fig. 10.
1965 *Marginulina sculptilis* (Schwager); Gordon, p. 842-843, text-fig. 6, fig. 23–25 (cum syn.).

Material: 24 specimens.

Dimensions (mm). Maximum length 0.27–0.33, maximum width 0.08, thickness 0.10.

Discussion. Few specimens, having affinity with *Marginulina sculptilis* (Schwager 1865), were recovered from the samples. Our specimens somewhat resemble those described by Gordon (1965) from the Oxfordian of England; they differ in having a larger number and finer longitudinal costae and chambers tending to reach the proloculus. However, as mentioned by Gordon, (1965) ornamentation is highly variable in these forms.

Genus *Vaginulinopsis* Silvestri, 1904

Type species: *Vaginulina soluta* Silvestri var: *carinata* Silvestri, 1898

Vaginulinopsis aff. *V. misrensis* Said & Barakat, 1958

Fig. 7.10

aff.
1958 *Vaginulinopsis misrensis* Said & Barakat, p. 251-252, pl. 5, fig. 7a–c, 21a-b.
2009 *Vaginulina misrensis* (Said & Barakat); Gaur & Talib, p. 242, pl. 3, fig. 17-18.

Material: 117 specimens.

Dimensions (mm). Maximum length 0.27, maximum width 0.10, thickness 0.06.

Discussion. Well-preserved specimens of *Vaginulinopsis misrensis* found in the Kutch material somewhat resemble those described originally by Said & Barakat (1958) from the Kimmeridgian of Egypt. Our forms resemble the Egyptian specimens in most of the characters, but differ in having a faint keel, fewer chambers in the uncoiled portion, and thick sutures.

Vaginulinopsis sastryi (Bhalla & Talib, 1985b)

Fig. 7.11

1985b *Marginulina sastryi* Bhalla & Talib, p. 149-150, pl. 1, fig. 1–9; fig. 1.

Material: 67 specimens.

Dimensions (mm). Length 0.21–0.36, width 0.08–0.12, thickness 0.09–0.14.

Discussion. This species was first described by Bhalla & Talib (1985b) from the Oxfordian of Jhurio Hill, Kutch. We assign this species to *Vaginulinopsis* due to the absence of longitudinal costae and tight coiling in early chambers, with a prominent dorsal keel. Our species is similar to *Marginulina psila* Tappan, 1955, but differs in being nearly half of its size and in having slightly more inflated chambers, including a greatly inflated final chamber that is nearly twice the size of the previous one. It is also similar to *Marginulina caelata* Loeblich & Tappan, 1950a, but differs in having a smooth test and possessing a less prominent aperture neck.

Subfamily Vaginulininae Reuss, 1860
Genus *Citharina* d'Orbigny, 1839

Type species: *Vaginulina* (*Citharina*) *strigillata* Reuss, 1846

Citharina clathrata (Terquem, 1864)

Fig. 7.12

1864 *Marginulina longuemari* var. *clathrata* Terquem, p. 402, pl. 8, fig. 16, 19a-b.
2009 *Citharina clathrata* (Terquem); Gaur & Talib, p. 241, pl. 3, fig. 11 (cum syn.).
2015 *Citharina clathrata* (Terquem); Ramírez & Herrero, p. 332, fig. 4.10 (cum syn.).
2016 *Citharina clathrata* (Terquem); Bilal et al., p. 186, text fig. 6.20.

Material: 294 specimens.

Dimensions (mm). Length 0.29–0.45, width 0.16–0.27, thickness 0.08–0.13.

Discussion. The studied specimens are similar to the original forms of Terquem (1864) and to those later described from Jurassic sediments of India, the Middle-East, and Europe (Said & Barakat 1958; Kalantari, 1969; Bhalla & Talib 1991; Gaur & Talib 2009; Ramírez & Herrero 2015). However, the studied specimens have fewer longitudinal costae as compared to the type specimens. Bhalla & Abbas (1978) remarked that this species is highly variable in test shape, ornamentation, chamber arrangement and proloculus diameter.

Citharina entypomatus Loeblich & Tappan, 1950

Fig. 7.13

1950 *Citharina entypomatus* Loeblich & Tappan, p. 57, pl. 15, fig. 1–12.

Material: 15 specimens.

Dimensions (mm). Length 0.56–0.85, width 0.25–0.32, thickness 0.09–0.15.

Discussion. This species is closely similar to *Citharina entypomatus* as originally described by Loeblich & Tappan, 1950, from the Oxfordian of USA. Our species differs from *Marginulina flabelloides* Terquem 1868, in being less flabellate, in having a more curved dorsal margin, in possessing many more ribs and in the absence of globular/ovate proloculus. It is slightly larger than *Marginulina condita* Terquem 1868, and has less depressed sutures. Its test shape is less triangular than *Marginulina tumida* Terquem 1868.

Citharina kujaviensis Bielecka & Pozaryski, 1954

Fig. 7.14

1954 *Vaginulina kujaviensis* Bielecka & Pozaryski, p. 46, pl. 6, fig. 28a-b.
1975 *Citharina kujaviensis* (Bielecka & Pozaryski); Bielecka, p. 324, pl. 5, fig. 3-4.

Material: 90 specimens.

Dimensions (mm). Length 0.35–0.96, width 0.16–0.21, thickness 0.05–0.06.

Discussion. Our specimens are similar to *Citharina kujaviensis* described by Bielecka & Pozaryski (1954) from the Tithonian to Lower Cretaceous of Poland. Specimens with 6–7 chambers and 7–8 ribs were found in the material of the Ler Dome of Kutch, India. Our specimens are also similar to *Vaginulina cetra* Lalicker, 1950, but slightly differ in their depressed sutures, the regular distribution of the costae on the sides of the test, and half of the width. *Citharina kujaviensis* differs from *C. intumencens* (Reuss) in being smaller in size and having fewer chambers, and fine and straight longitudinal ribs as compared to the wavy ribs of the latter. It also differs from *Vaginulina lancea* Lalicker, 1950, in the regular distribution of costae, the absence of sharp edges, and narrower chambers.

Genus *Planularia* Defrance, 1826

Type species: *Peneroplis auris* Defrance in de Blainville, 1824

Planularia tricarinella (Reuss, 1863)

Fig. 7.15

1863 *Cristellaria (tricarinella) tricarinella* Reuss, p. 68, pl. 7, fig. 9; pl. 12, fig. 2–4.
2009 *Lenticulina tricarinella* (Reuss); Gaur & Talib, p. 238, pl. 2, fig. 16 (cum syn.).

Material: 1067 specimens.

Dimensions (mm). Length 0.42–0.95, width 0.35–0.53, thickness 0.24–0.47.

Discussion. *Planularia tricarinella* is frequently found in the studied material. This species was first described by Reuss (1863) from the Lower Cretaceous of North Germany and is further known from many Jurassic localities around the world. *Planularia tricarinella* (Reuss) shows wide variation in size and shape of the test as well as number of chambers comprising the coiled and uncoiled portion. The variation of this species has been discussed in detail by Bhalla & Abbas (1978).

Suborder **Robertinina** Loeblich & Tappan, 1984
Superfamily Ceratobuliminacea Cushman, 1927
Family Epistominidae Wedekind, 1937
Subfamily Epistomininae Wedekind, 1937
Genus *Epistomina* Terquem, 1883
Type species: *Epistomina regularis* Terquem, 1883

Epistomina minutereticulata Espitalié & Sigal, 1963

Fig. 7.16a, 16b

1963 *Epistomina minutereticulata* Espitalié & Sigal, p. 66, pl. 31, fig. 3-4.
1993 *Epistomina minutereticulata* Espitalié & Sigal; Pandey & Dave, p. 142–143, pl. 20, fig. 8–9; pl. 21, fig. 1.
2016 *Epistomina minutereticulata* Espitalié & Sigal; Bilal et al., p. 187, text fig. 7.6a-b.

Material: 371 specimens.

Dimensions (mm). Major diameter 0.31–0.43, minor diameter 0.28–0.40, thickness 0.18–0.25.

Discussion. Specimens of *Epistomina minutereticulata* are abundant in our material and similar to those described originally from the Callovian to Oxfordian of Madagascar (Espitalié & Sigal 1963), the Callovian of Tanzania (Karega 1992), and the Oxfordian of Russia (Ustinova 2009). The studied specimens resemble those described by Singh (1977) from the Callovian to Oxfordian and Pandey & Dave (1993) from the Oxfordian of Kutch, India. The fine reticulation on both sides is the main distinguishing feature of this species.

Epistomina parastelligera (Hofker, 1954)

Fig. 7.17a, 17b

1954 *Brotzenia parastelligera* Hofker, p. 88, text-fig. 4–6.
1958 *Epistomina parastelligera* (Hofker); Said & Barakat, p. 267, pl. 3, fig. 43; pl. 5, fig. 35a–c; fig. 35a–c;
1967 *Epistomina parastelligera* (Hofker); Gordon, p. 458, pl. 4, fig 32.
2001 *Epistomina parastelligera* (Hofker); Nagy et al., pl. 2, fig. 17-18 .

Material: 192 specimens.

Dimensions (mm). Major diameter 0.24, minor diameter 0.19, thickness 0.09.

Discussion. Well-preserved specimens of *Epistomina parastelligera* (Hofker 1954), originally reported from Callovian of Germany, were found in the studied samples, resembling those described by Said & Barakat (1958) and Kalantari (1969) from the Callovian sediments of Egypt and Iran, respectively. Olszewska & Wieczorek (1998) reported this species from the Callovian-Oxfordian of southern Poland that exhibit fairly raised sutures on the dorsal side, unlike the studied form. In the Indian region, Mandwal & Singh (1999) described this species from the Bathonian of Jhurio Dome, Kutch Region.

Epistomina regularis Terquem, 1883

Fig. 7.18a, b

1883 *Epistomina regularis* Terquem, p. 379, pl. 44, fig. 1-3.

Material: 961 specimens.

Dimensions (mm). Length 0.28–0.39, width 0.28–0.39, thickness 0.09–0.12.

Discussion. Our specimens are similar to *Epistomina regularis* as originally described by Terquem (1883) from the Oxfordian of France, and are also similar in overall characters to those reported from the Jurassic rocks of Dorset, England (Coleman 1981) and from the Bathonian to Callovian of Canada and North Europe (Williamson & Stam 1988). However, they differ in having a very convex dorsal and slightly flatter surface on the ventral side. The main character of this species is pitting or an irregular pattern of ridges on the umbilical side that distinguishes it from the smoother *E. mosquensis*, which possesses a sharp collar in the centre of the ventral side (Williamson & Stam 1988). Most authors have reported this species from Bathonian strata in different parts of the world.

### *Epistomina tenuicostata* Bartenstein & Brand, 1951

Fig. 7.19a, 19b

1951 *Epistomina tenuicostata* Bartenstein & Brand, p. 327, pl. 12A, fig. 325a–c.
1969 *Brotzenia tenuicostata* Bartenstein & Brand; Kalantari, p. 169–170, pl. 15, fig. 1–4a–c.
1988 *Epistomina tenuicostata* (Bartenstein & Brand); Williamson & Stam, p. 146, pl. 4, fig. 3, 6. 2011 *Epistomina tenuicostata* (Bartenstein & Brand); Quilty, p. 189–191, fig. 4.9 (cum syn.).

Material: 99 specimens.

Dimensions (mm). Major diameter 0.29–0.33, minor diameter 0.28–0.31, thickness 0.22–0.27.

Discussion. The studied specimens of *Epistomina tenuicostata* are similar to those described from the Middle Jurassic of Germany (Bartenstein & Brand 1951) and from the Oxfordian of England (Gordon 1965). The characteristic feature of this species is the nature of the last chamber on the ventral side, which overlaps a part of the umbilical area.

Epistomina sp.

Fig. 7.20a, 20b

Material: 4 specimens.

Description. Test small, trochospiral, biconvex, almost circular in outline, three whorls with seven chambers visible in the final whorl; chambers of dorsal side trapezoidal, increasing gradually in size as added; chambers of ventral side, triangular; dorsal sutures distinct, limbate, slightly raised, curved, making a small reticulation on initial whorl; ventral sutures limbate, straight, very slightly raised, converging at centre, pitted near umbilical area; periphery acute, distinctly keeled; aperture areal, oblique, oval, secondary apertures slit-like; wall calcareous; surface smooth.

Dimensions (mm). Major diameter 0.38, minor diameter 0.37, thickness 0.20.

Discussion. A few specimens of *Epistomina* were obtained from the Kutch material. These could not be compared with any described species of the genus.

Fig. 7 - Foraminiferal species recovered from the Chari Formation, Ler Dome, Kutch Basin. 1) *Saracenaria cornucopiae* (Schwager, 1865); 2) *Astacolus anceps* (Terquem, 1870); 3) *Astacolus aphrastus* Loeblich & Tappan, 1950; 4) *Astacolus* sp.; 5) *Marginulina batrakiensis* (Mjatliuk, 1939); 6) *Marginulina* aff. *M. bhatiai* (Bhalla & Talib, 1991); 7) *Marginulina caelata* Loeblich & Tappan, 1950; 8) *Marginulina oxfordiana* Gordon, 1965; 9) *Marginulina* aff. *M. sculptilis* (Schwager), 1865; 10) *Vaginulinopsis* aff. *V. misrensis* Said & Barakat, 1958; 11) *Vaginulinopsis sastryi* (Bhalla & Talib, 1991); 12) *Citharina clathrata* (Terquem, 1864); 13) *Citharina entypomatus* Loeblich & Tappan, 1950; 14) *Citharina kujaviensis* Bielecka & Pozaryski 1954; 15) *Planularia tricarinella* (Reuss, 1863); 16) a, b. *Epistomina minutereticulata* Espitalié & Sigal, 1963; 17) a, b. *Epistomina parastelligera* (Hofker, 1954); 18) a, b. *Epistomina regularis* Terquem, 1883; 19) a, b. *Epistomina tenuicostata* Bartenstein & Brand, 1951; 20) a, b. *Epistomina* sp. Scale bar = 100 μm.
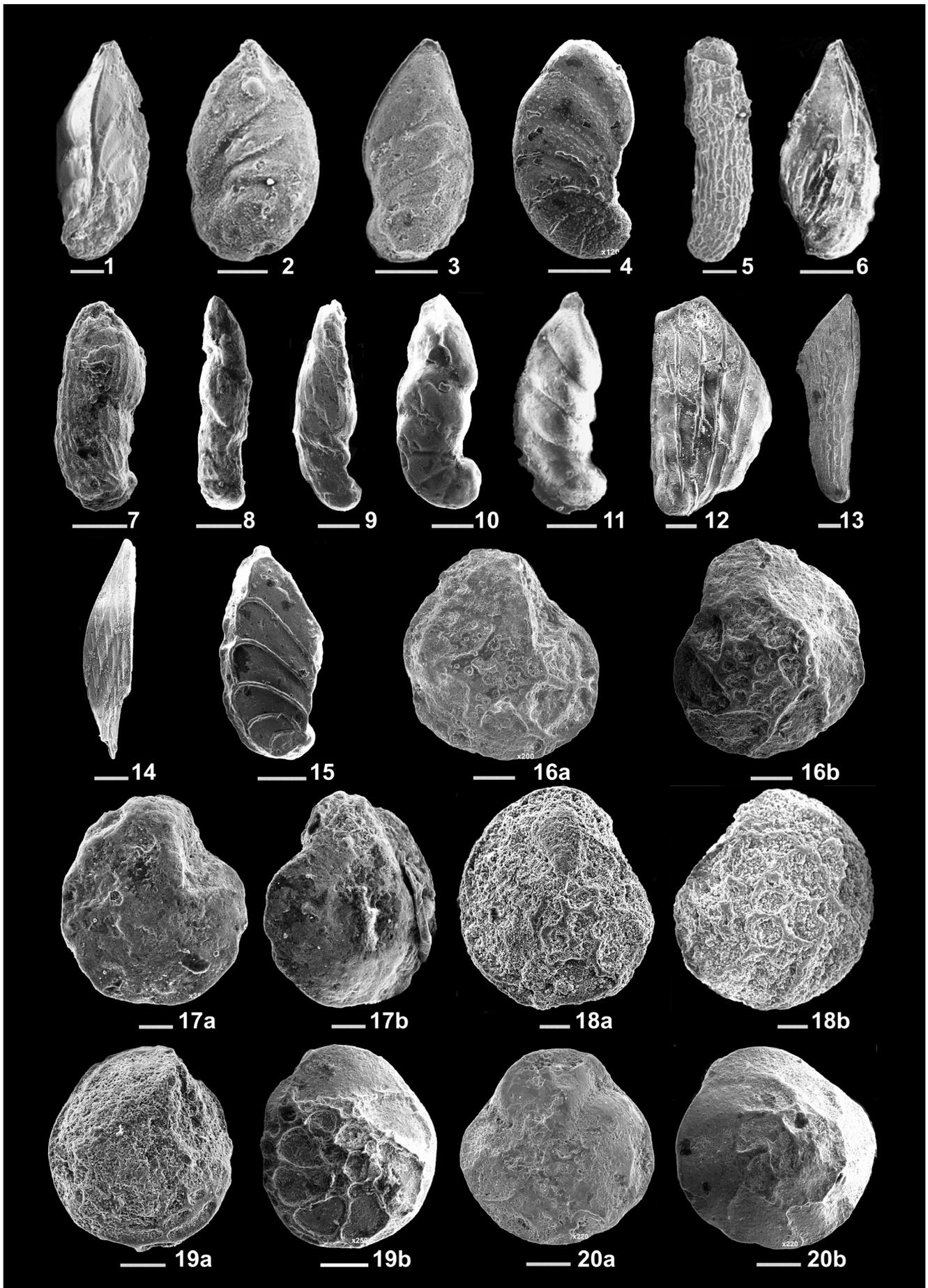
STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERAL ASSEMBLAGES

According to the stratigraphic changes in the composition of foraminiferal assemblages (Fig. 8–11), different ecostratigraphic intervals can be recognised in the studied section.

The first foraminiferal ecostratigraphic interval corresponds to lithological unit 1. The foraminiferal assemblage is characterised by a relatively low diversity (α-index < 2.5) and low abundance (around 30 specimens/g) (Fig. 10). Epifaunal forms present an initial increase in percentage and abundance, mainly marked by high values of *Epistomina* and *Lagenammina* with a subsequent diminution toward the top of the ecostratigraphic interval (Fig. 8-9). The potential deep infaunal forms (capable of living deeper than 5 cm below the sea floor) show the opposite trend of the epifaunal ones (Fig. 10, 11), and are represented primarily by *Lenticulina* (Fig. 8). The highest values of *Lenticulina* occur at the boundary between lithological units 1 and 2. Toward the top of lithological unit 1, the abundance of foraminifera (mainly epifaunal and shallow infaunal forms) decreases, whereas potential deep infaunal forms increase (Fig. 10).

The second foraminiferal ecostratigraphic interval includes lithological units 2, 3 and 4. The assemblages are characterised by higher diversity (reaching α-index > 6 in the lower part) and abundance (BFN ranging from 40 to 60 specimens/g in the lower part) than in lithological unit 1 (Fig. 10). The α-index describes an initially abrupt increase with respect to the previous ecostratigraphic interval and a subsequent decrease, with the lowest values at the top of the ecostratigraphic interval (Fig. 10). The highest values of diversity occur in lithological unit 2 and the lowest in lithological unit 4. A total of 21 species appear at the base of this ecostratigraphic interval, corresponding to epifauna (*Epistomina parastelligera* and *E. tenuicostata*), shallow infaunal forms (*Ammobaculites culmulus*, *A. subcretaceous*, *Citharina entypomatus*, *C. kujaviensis*, *Falsopalmula deslongchampsi*, *F. primordialis*, *Haplophragmium kutchensis*, *Marginulina bhatiai*, *M. caelata*, *Nodosaria nitidana*, *Prodentalina guembeli*, *P. torta*, *Pseudonodosaria vulgata*, *Saracenaria cornucopae*, and *Vaginulinopsis nusrensis*), and inferred deep infaunal forms (*Reophax multilocularis*, *Lenticulina ectypa* and *L. varians*) (Fig. 4, 8-9). The abrupt increase in the abundance of foraminifera at the base

of the second ecostratigraphic interval is mainly related to shallow infaunal forms, but these foraminifera decrease in abundance toward the top, with the lowest values found at the boundary with the third ecostratigraphic interval (Fig. 10-11). Considering the proportion of the components in the foraminiferal assemblages, they are dominated by potential deep infaunal forms (ranging from 23–82%, commonly more than 45%), mainly corresponding to the genus *Lenticulina* (Fig. 8, 11). Shallow infauna (average 23%) and epifauna (average 28%) are well represented (Fig. 11). The proportions of both epifauna and shallow infauna abruptly decrease at the top of this ecostratigraphic interval.

The third ecostratigraphic interval includes lithological units 5, 6 and 7. The diversity is characterised by a cycle of increased-decreased diversity, with the highest values corresponding to the grey to yellowish shales and sandstones of lithological unit 6 (Fig. 10). The abundance of foraminifera increases, newly related to shallow infaunal forms of the suborder Lagenina (Fig. 8, 10). The top of this ecostratigraphic interval is located in the last meter of the limestones constituting lithological unit 7, and is characterised by a barren interval for foraminifera (Fig. 11). *Lenticulina*, a potential deep infaunal form, dominates the assemblage with the highest values recorded at the base of the calcareous lithological units, the limestones of lithological units 5 (82%) and 7 (71%) (Fig. 8). The proportions of shallow infauna describe the opposite trend: the highest values (35%) are found in the grey to yellowish shales and sandstones of lithological unit 6 (Fig. 11). Again, diversity is mainly related to the shallow infaunal forms such as *Ammomarginulina*, *Ammobaculites*, *Marginulina*, *Astacolus* and *Planularia*. Epifaunal forms keep constant values (average 23%, Fig. 11).

The fourth ecostratigraphic interval comprises the silty claystone of lithological unit 8 and the ferruginous oolithic limestones of lithological unit 8 (Dhosa Oolite Member). The foraminiferal assemblages are characterised by a progressive increase in diversity from the barren interval that constitutes the top of lithological unit 7 (Fig. 10). However, many genera are not recovered until the base of the Dhosa Oolite Member (e.g., *Ammobaculites*, *Ammomarginulina*, *Epistomina*, *Haplophragmoides*, *Lagenammina*, *Lenticulina*, and *Reophax*; Fig. 8-9). The agglutinated foraminifera are absent from litholo-
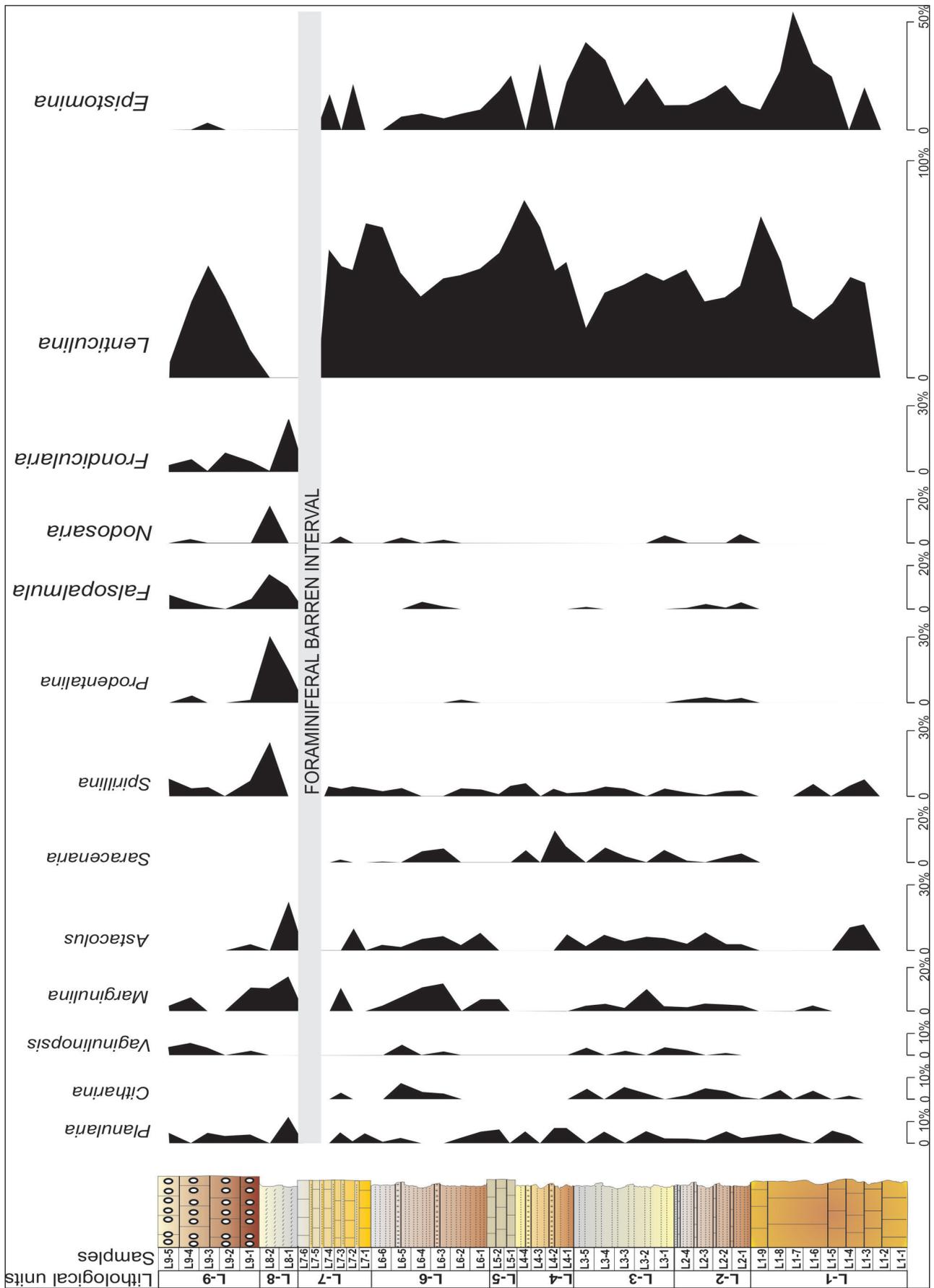
Fig. 8 - Ecostratigraphic distribution of the proportions of calcareous foraminifera in the upper part of the Chari Formation.
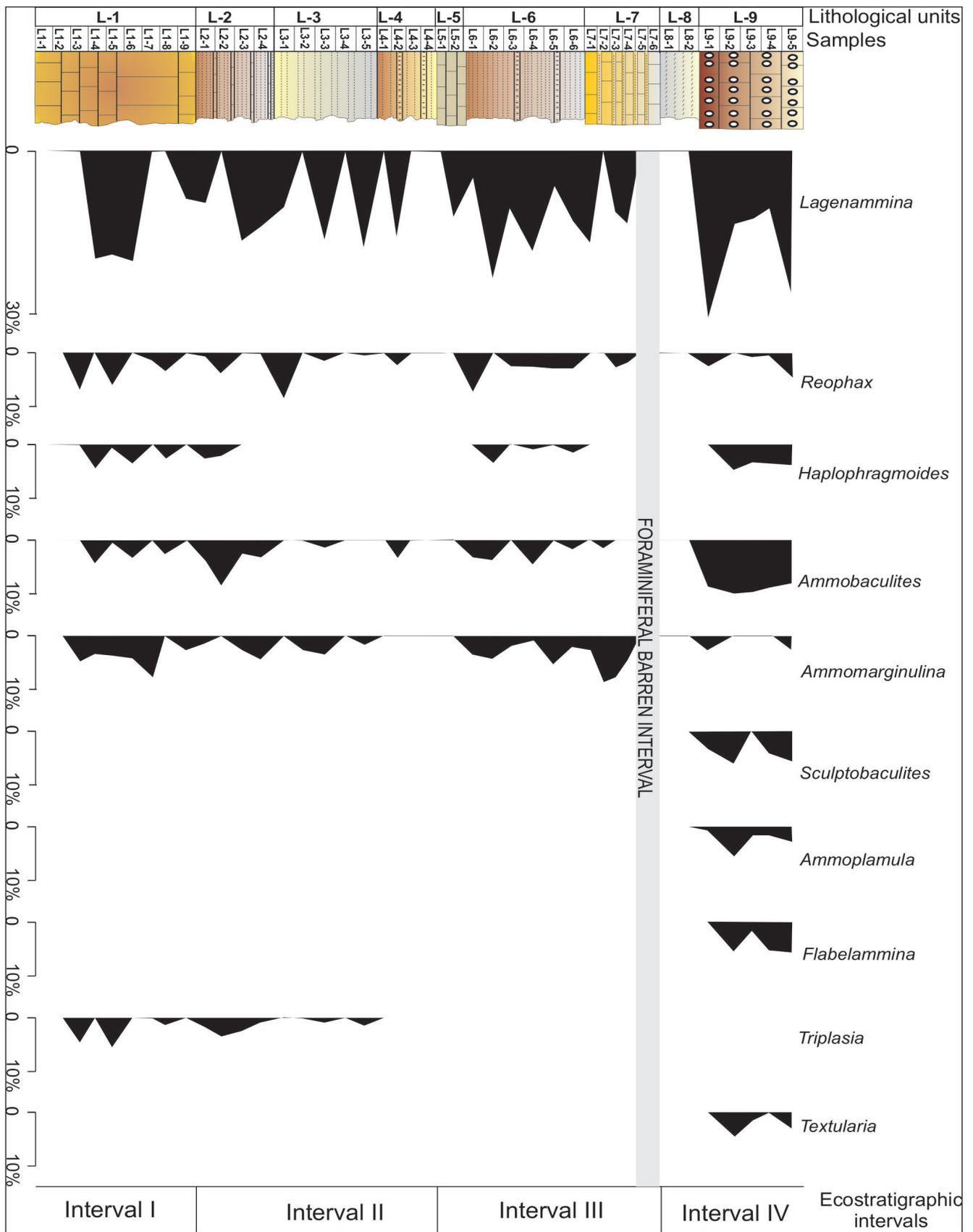
Fig. 9 - Ecostratigraphic distribution of the proportions of agglutinated foraminifera in the upper part of the Chari Formation.
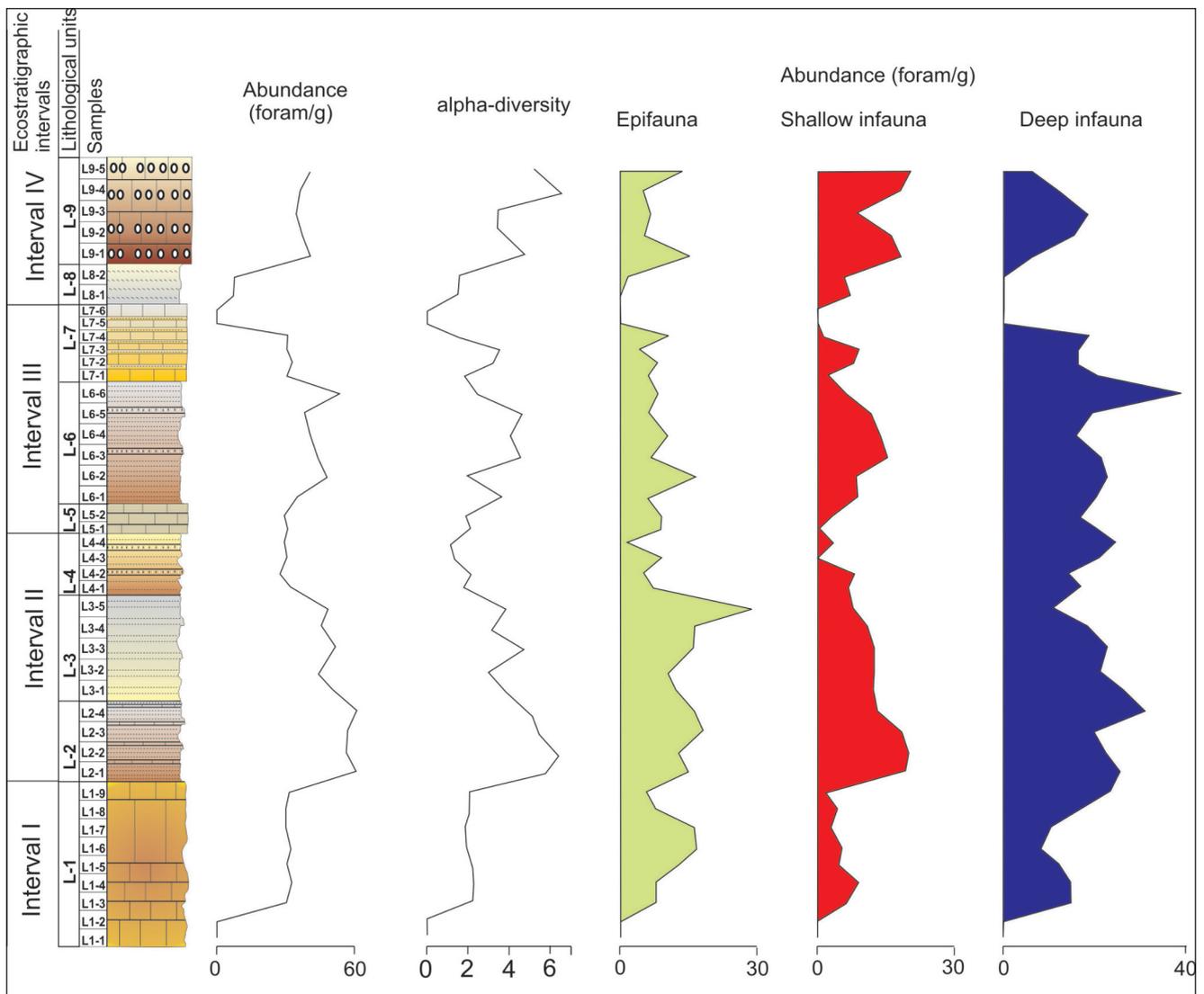
Fig. 10 - Ecostratigraphic changes in the total abundance of foraminifera and diversity, and abundance of foraminifera according to the inferred life style (microhabitat depth).

gical unit 8 (Fig. 9). These silty claystones are dominated by shallow infaunal forms (locally reaching 100%, Fig. 11) of the suborder Lagenina, such as *Astacolus*, *Falsopalmula*, *Frondicularia*, *Marginulina*, *Planularia*, and *Prodentalina* (Fig. 8). However, some genera such as *Citharina* and *Saracenaria* are not recovered in the fourth ecostratigraphic interval (Fig. 4, 8). New genera appear in the Dhosa Oolite Member, corresponding to agglutinated forms: *Ammopalmula*, *Flabellammina*, *Scultobaculites*, and *Textularia* (Fig. 4, 8). With respect to microhabitat, the fourth ecostratigraphic interval is characterised by the dominance of shallow infaunal forms with the highest values after the foraminiferal barren interval (Fig. 10-11). Epifauna recovers in the upper part of the silty claystones, giving values from 14% to 38%, dominated by *Lagenammina* and *Spirillina*, with a scarce record

of *Epistomina*. The deep infaunal forms are primarily represented by *Lenticulina* and secondarily by *Reophax* and *Textularia* (Fig. 8-9). They show a peak in the middle part of the Dhosa Oolite Member (reaching 54%). Regarding the genus *Lenticulina*, generally dominant in the studied section, within the Dhosa Oolite Member it is represented mainly by *L. quenstedti*, and some species previously recorded are not recovered, as *L. ectypa* and *L. gaultina*.

INTERPRETATION

Age of the foraminiferal assemblages

According to the record of ammonites in the studied section, as well as previous works (Krishna & Ojha 1996; Prasad 1998; Jain & Pandey 2000;
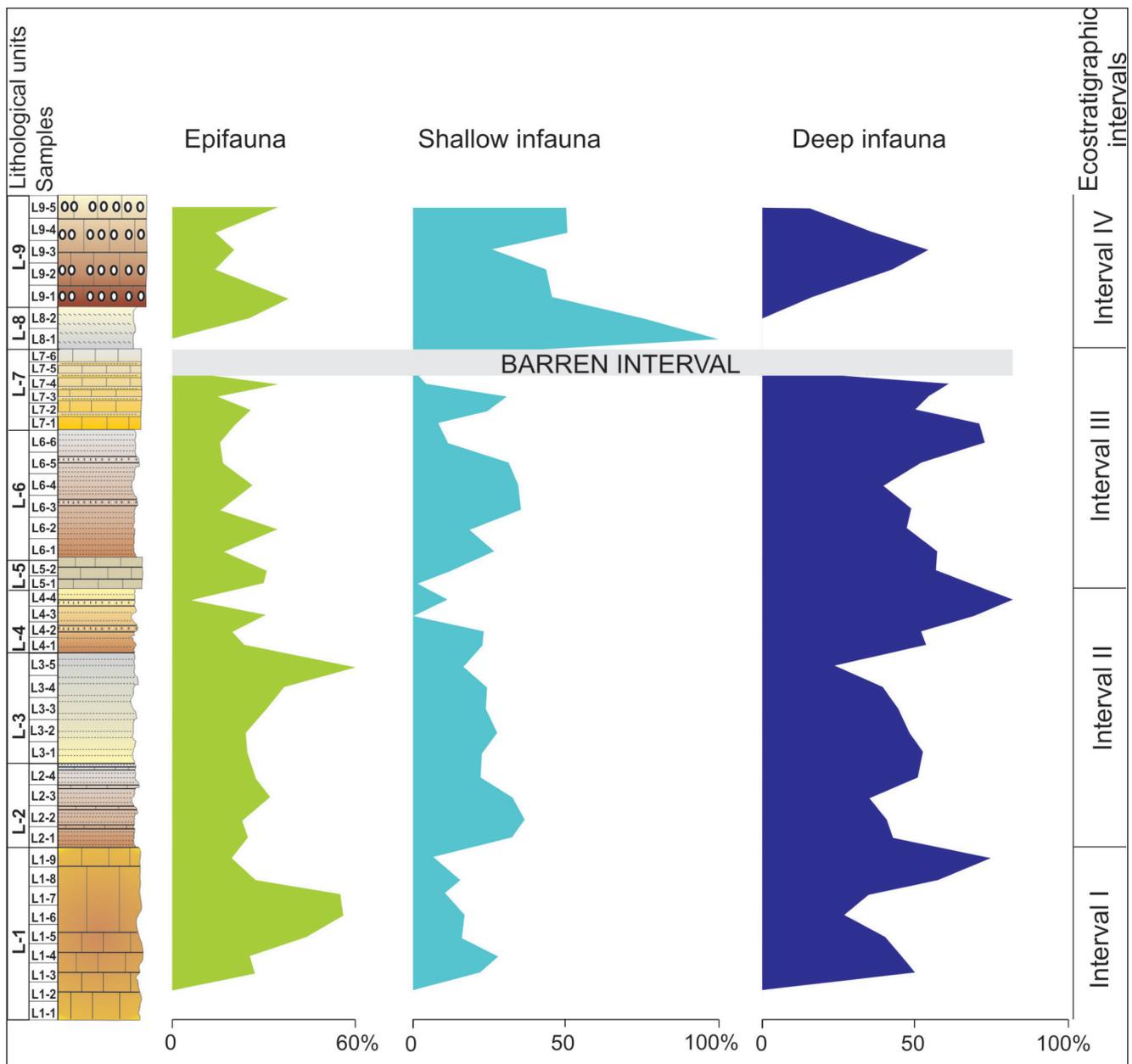
Fig. 11 - Variations in the composition of the foraminiferal assemblages (%) according to microhabitat depth in the sediment, compared with the ecostratigrahic intervals.

Pandey et al. 2012) involving the Chari Formation, the Dhosa Sandstone Mb is assigned to the Callovian, whereas the Dhosa Oolite Member is assigned to the lower Oxfordian (Fürsich 1998; Fürsich et al. 2001; Alberti et al. 2013). In the upper Callovian, hectoceratins (e.g. *Hecticoceras*), aspidoceratids (e.g. *Peltoceras* and *Metapeltoceras*) and perisphinctids (*Obtusocostites* and *Hubertoceras*) are recorded (Fürsich et al. 2013). The Dhosa Oolite Member is characterised by its record of typical Oxfordian periphinctids (*Perisphinctes subevolutus*), aspidoceratids (*Peltoceratoides arduennensis*), and mayaitids (Pandey et al.

2012). Collections throughout the Kutch Mainland indicate that Dhosa Oolite Member was deposited during the early Oxfordian —more precisely, the Cordatum Zone, in view of the record of the index taxon *Peltoceratoides* (Alberti et al. 2011). This record allows us to compare the age of the foraminiferal assemblages deduced from literature with the age indicated by the ammonoid assemblages. Jurassic benthic foraminifera have been locally used for dating Jurassic rocks in different parts of the world, only sometimes attaining a time resolution comparable with that of ammonites (Herrero et al.
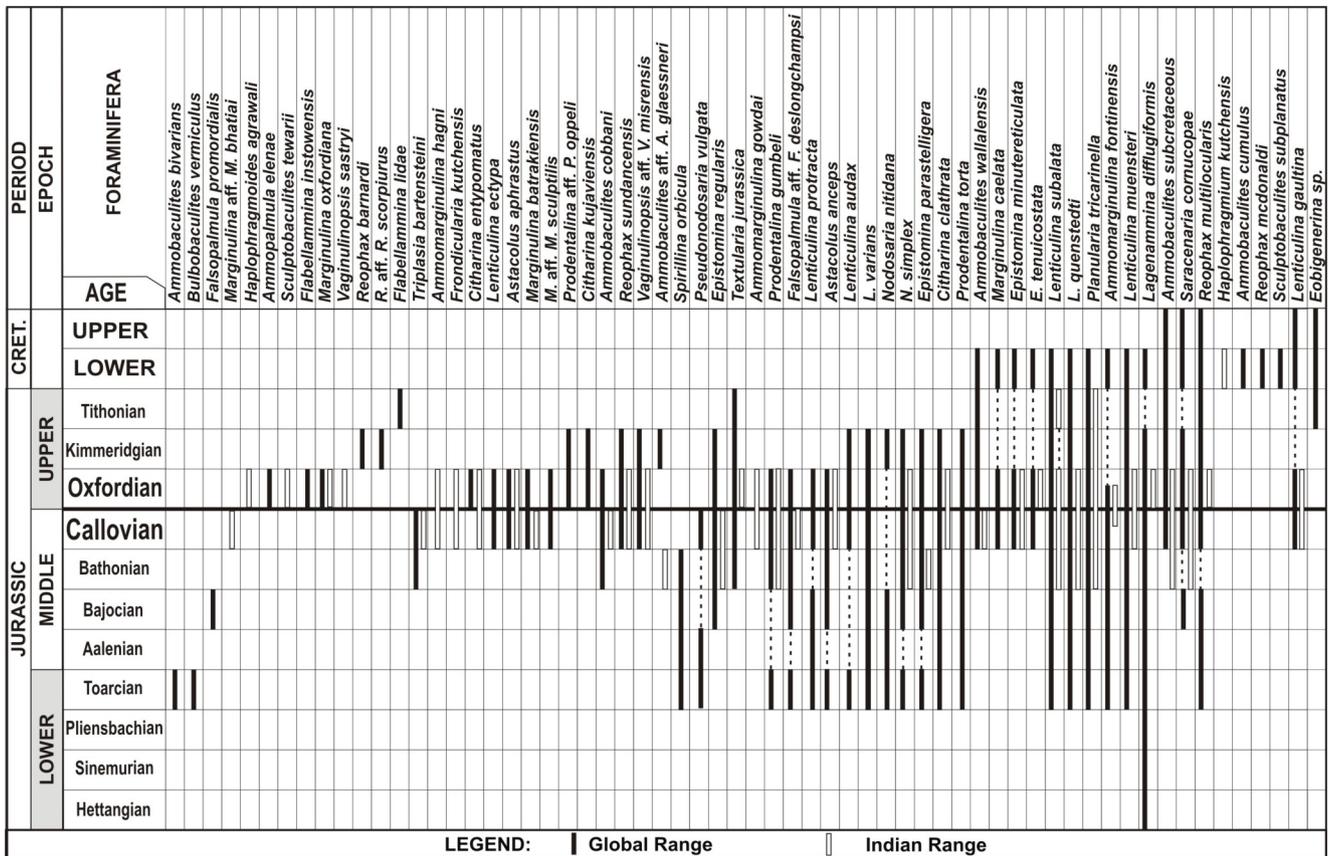
LEGEND: ▮ Global Range   ▯ Indian Range

Fig. 12 - Known global and Indian ranges of foraminifera from the Chari Formation.

1996; Canales & Henriques 2008; Bejjaji et al. 2010; Quilty 2011; Kiselev et al. 2013; Copestake & Johnson 2014; Silva et al. 2014; Hughes 2018). Notwithstanding, they appear to be somewhat unreliable for the precise dating of Jurassic sediments within the Indian region. Larger benthic foraminifera were not found, and therefore the biostratigraphic scheme devised for the Middle-East (Hughes, 2018) cannot be applied here. Talib & Gaur (2008) used benthic foraminifera to define the Bathonian/Callovian and the Callovian/Oxfordian boundary at the Jumara Dome. Most of the Jurassic foraminiferal species recorded in the Indian region are rather long-ranging, while index benthic and planktic forms are rare or absent (Bielecka & Pozaryski 1954; Gordon 1965; Bhalla & Abbas 1976; Coleman et al. 1981; Kalia & Chowdhury 1983; Bhalla & Talib 1985, 1991; Bilal et al. 2016; Talib et al. 2016, 2017; Farahani et al. 2018). It is therefore desirable to establish the Jurassic foraminiferal species of biostratigraphic significance in the Indian region, and an attempt to do so is put forth in this study. Still, it is clear that the distribution of benthic foraminifera is strongly controlled by environmental factors. The Jurassic biostratigraphy based on benthic foraminifera is far less reliable than the ammonite biostratigraphy. For this reason, here the age of the members interpreted from ammonites by previous authors is used for checking the stratigraphic range of the different foraminifera taxa identified in the Ler Dome.

The Jurassic foraminiferal assemblages from Ler Dome contain a number of well-known species that have been reported from Middle and Upper Jurassic sediments in many parts of the world, including India (Fig. 12). Fortunately, some relatively short-ranging species restricted to a single stage of the Jurassic elsewhere, as well as in India (Fig. 12), are identified in the studied assemblages and could be employed for age determination of these rocks. They include *Ammobaculites bivarians*, *Ammobaculites culmulus*, *Ammopalmula elenae*, *Bulbobaculites vermiculus*, *Falsopalmula primordialis*, *Flabellammina instowensis*, *Flabellammina lidae*, *Marginulina oxfordiana*, *Reophax barnardi*, *Reophax* aff. *R. scorpiurus*, *Reophax mcdonaldi*, and *Sculptobaculites subplanatus*, which are globally restricted to a single stage, whereas *Haplophragmium*

kutchensis, *Haplophragmoides agrawali*, *Marginulina* aff. *M. bhatiai*, *Marginulina oxfordiana*, *Sculptobaculites tewarii*, and *Vaginulinaopsis sastryi* are restricted to a single stage and occur only in the Indian region.

Some species have longer global ranges but are restricted to a single stage of Jurassic in the Indian region: *Ammobaculites cobbani*, *Ammobaculites* aff. *A. glaessneri*, *Ammomarginulina fontinensis*, *Ammobaculites wallalensis*, *Citharina entypomatus*, *Epistomina parastelligera*, *Epistomina tenuicostata Falsopalmula* aff. *F. deslongchampsi*, *Lagenammina difflugiformis*, *Marginulina batrakiensis*, *Reophax multilocularis*, *Textularia jurassica*, and *Triplasia bartensteini*.

Other species of the studied foraminiferal assemblages that are globally restricted to two stages of the Jurassic period, are also restricted to two stages only in the Indian region: *Ammobaculites gowdai, Ammomarginulina hagni, Astacolus anceps, Astacolus aphrastus, Citharina clathrata, Citharina entypomatus, Epistomina minutereticulata, Epistomina regularis, Frondicularia kutchensis, Lenticulina gaultina, Lenticulina muensteri, Reophax sundancensis* and *Vaginulinopsis* aff. *V. misrensis*.

Ammobaculites bivarians was found in the Toarcian of Denmark (Nagy & Seidenkraantz 2003). *Bulbobaculites vermiculus* was reported from the Toarcian of Denmark and Norway (Nagy & Seidenkraantz 2003; Nagy & Berge 2008; Nagy et al. 2010, 2011; Hess et al. 2014). *Falsopalmula primordialis* was recorded from the Bajocian of France (Terquem 1869, 1870), and Iran (Kalantari 1969). *Eobigenerina* sp. is a cosmopolitan deep-water agglutinated form recorded from Tithonian to Upper Cretaceous (Cetean et al. 2008). *Ammopalmula elenae, Flabellammina instowensis, Marginulina oxfordiana* and *Citharina entypomatus* were reported from the Oxfordian of different parts of the world (Loeblich & Tappan 1950; Eicher 1955; Dain 1958; Wall 1960; Gordon 1965; Fortunato 1982; Eicher 2010). *Reophax barnardi, R.* aff. *R. scorpiurus*, and *Ammobaculites* aff. *A. glaessneri* were reported from the Kimmeridgian of different parts of the world (Franke 1936; Said & Barakat 1958; Kalantari 1969; Aalug et al. 2007). *Flabellammina lidae* was recorded from the Tithonian of Russia by Fursenko & Polenova (1950), whereas three of the species (*Ammobaculites culmulus, Reophax mcdonaldi*, and *Sculptobaculites subplanatus*) were globally restricted to the Lower Cretaceous (Skolnick 1958; Conkin 1961; Stelck 1983). This constitutes the first record of these species in the Middle Jurassic, be-

cause they are recovered below the Dhosa Oolite Member.

In the Indian region, *Marginulina* aff. *M. bhatiai* was described from the Callovian of Kutch, India (Talib & Bhalla 2006; Talib et al. 2007; Gaur & Talib 2009), while *Haplophragmoides agrawali, Sculptobaculites tewarii* and *Vaginulinaopsis sastryi* were recorded only in the Oxfordian of Kutch (Bhalla & Abbas 1978; Bhalla & Talib 1985, 1991) and *Haplophragmium kutchensis* from the Lower Cretaceous rocks of Kutch (Pandey & Dave 1993).

Species restricted within two stages include *Triplasia bartensteini*, recorded from the Bathonian of England and the Middle-East by Cifelli (1960) and Saad (2008), as well as the Callovian of Germany and Scotland, respectively by Loeblich & Tappan (1952) and Gordon (1967); but in the Indian region it is restricted to the Callovian (Gaur & Singh 2000; Gaur & Talib 2009; Talib et al. 2012a). *Lenticulina ectypa* was reported from the Callovian of England and Scotland by Barnard et al. (1981) and Nagy et al. (2001), respectively, as well as from the Oxfordian of South Dakota USA and France by Loeblich & Tappan (1950) and Oxford (2004). *Astacolus aphrastus* was reported from the Callovian of the Indian region by Bhalla & Abbas (1978), Pandey & Dave (1993), Kalia & Chowdhary (1983), Gaur & Talib (2009) and Talib et al. (2012a); as well as from the Oxfordian of South Dakota (USA) and Canada by Loeblich & Tappan (1950) and Tingley & Sawyer (2015) respectively. *Marginulina batrakiensis* was reported from the Callovian of the USSR (Mjatliuk 1939), Scotland (Gordon 1967), England (Barnard et al. 1981), and Germany (Franz & Knott 2012) and from the Oxfordian of France by Oxford (2004). *Marginulina sculptilis* was reported from the Callovian of Canada by Sauaya (1979) and the Oxfordian of Germany and England by Schwagar (1865) and Gordon (1965), respectively. *Prodentalina* aff. *L. oppeli* was reported from the Oxfordian of Germany by Schwagar (1865) and the Kimmeridgian of Madagascar by Espitalié & Sigal (1936). *Citharina kujaviensis* was described from the Kimmeridgian and Tithonian of Poland by Bielecka & Pozaryski (1954) and Bielecka (1975).

In the Indian region (Fig. 12), some of the species are restricted to two stages. *Ammomarginulina hagni* was reported from the Oxfordian by Bhalla & Abbas (1978) and later from the Callovian-Oxfordian stages by Talib et al. (2012a). *Frondicularia*

kutchensis was reported in the Oxfordian by Bhalla & Abbas (1978), Gaur & Singh (2000) and Talib et al. (2012a), and later from the Callovian-Oxfordian by Talib & Faisal (2013) and Gaur & Talib (2009). *Ammobaculites gowdai* and *Citharina entypomatus* were both recorded from the Callovian-Oxfordian by Bhalla & Abbas (1978), Talib et al. (2007), Talib & Gaur (2008), Gaur & Talib (2009) and Talib et al. (2012a, 2014).

Epistomina regularis, *Astacolus anceps*, *Citharina clathrata*, *Epistomina minutereticulata*, *Lenticulina muensteri*, and *Lenticulina gaultina* have longer global ranges but are restricted to only two stages in the Indian region. *Epistomina regularis* globally ranges from Bajocian to Kimmeridgian (Terquem 1883; Gordon 1965; Bielecka & Styk 1981; Williamson 1987; Williamson & Stam 1988; Smolen 2012), yet in the Kutch Basin it ranges from Bathonian to Callovian (Pandey & Dave 1993; Mandwal & Singh 1999; Talib et al. 2012a; Jain & Garg 2014). *Astacolus anceps* was reported from the Callovian of Kutch by Bhalla & Talib (1991), Pandey & Dave (1993), Gaur & Singh (2000), Talib & Bhalla (2006), Talib et al. (2007), Gaur & Talib (2009), and Rajasthan (India) by Kalia & Chowdhary (1983); and from the Oxfordian of the same region by Subbotina et al. (1960), Bhalla & Abbas (1978), and Talib et al. (2012a); and globally recorded from the Toarcian to Oxfordian (e.g. Terquem 1870; Kalantari 1969; Kottachchi 2001). *Citharina clathrata* was reported from the Callovian of Kutch by Bhalla & Talib (1991), Gaur & Singh (2000), Talib & Bhalla (2006), Talib et al. (2007), Gaur & Talib (2009), and Talib et al. (2012a), and from the Oxfordian of the same region by Bhalla & Abbas (1978). *Citharina clathrata* was globally reported from Toarcian to Kimmeridgian by Terquem (1864), Said & Barakat (1958), Kalantari (1969), and Canales & Henriques (2008). *Epistomina minutereticulata* was reported in the Kutch Basin from the Oxfordian by Pandey & Dave (1993) and Callovian to Oxfordian by Singh (1977), and globally reported from the Callovian to Lower Cretaceous by Espitalié & Sigal (1963), Jansa (1993), Karega (1992), and Ustinova (2009). *Lenticulina muensteri* has been reported in the Kutch Basin and Rajasthan from the Callovian by Talib et al. (2012a) and Kalia & Chowdhary (1983) and from the Oxfordian of Kutch by Bhalla & Abbas (1978) and Gaur & Singh (2000). *Lenticulina gaultina* was identified in the Kuth Basin from the Callovian by Bhalla & Abbas (1991) and

Talib & Bhalla (2006), and from the Oxfordian by Gaur & Singh (2000), while it is globally reported from the Cretaceous by various authors (e.g. Berthelin 1880; Williamson 1987; Gebhardt 2004).

Reophax sundancensis has been globally identified from the Callovian to Kimmeridgian (Loeblich & Tappan 1950a; Souaya 1976), but in the Indian region it has been reported from Callovian to Oxfordian (Gaur & Singh, 2000). *Vaginulinopsis* aff. *V. misrensis* globally ranges from Callovian to Kimmeridgian, though in the Indian region it has been reported from Callovian to Oxfordian (Gaur & Talib 2009; Talib et al. 2012a). *Ammobaculites cobbani* has a global range from Bathonian to Oxfordian (Loeblich & Tappan 1950a; Eicher 1955; Souaya 1976; Saad 2008; Tingley & Sawyer 2015), while in the Indian region it is restricted to Callovian (Bhalla & Talib 1991; Talib & Bhalla 2006).

Textularia jurassica is globally a long-ranging species from Bathonian to Tithonian (Seibold & Seibold 1960; Medd 1983; Giusberti & Coccioni 2003), whereas in the Indian region, it is restricted to Oxfordian (Bhalla & Talib 1991; Talib & Bhalla 2006). *Falsopalmula* aff. *F. deslongchampsi* is globally long ranging from Toarcian to Oxfordian (e.g. Kalantari 1969; Coleman et al. 1981; Ustinova 2009; Smolen 2012), yet in India, it is restricted exclusively to the Callovian (Jain & Garg 2014). *Ammobaculites wallalensis* has a global range of Callovian to Lower Cretaceous (Crespin 1963) but it is recorded from only the Callovian in the Indian region (Jain & Garg 2014). *Epistomina minutereticulata* has a global occurrence in the Callovian and Lower Cretaceous (Espitalié & Sigal 1963; Karega 1992; Jansa 1993; Ustinova 2009), but in the Indian region it is reported only from the Callovian and Oxfordian (Pandey & Dave 1993; Singh 1977). *Epistomina tenuicostata* has global occurrence in the Callovian and the Lower Cretaceous (Williamson & Stam 1988; Oxford 2004; Franz & Knott 2012); in the Indian region it was reported only from the Oxfordian (Gaur & Singh 2000). *Ammomarginulina fontinensis* has a global range from Toarcian to Lower Cretaceous (Bielecka 1975; Bielecka & Styk 1981; Canales & Henriques 2008; Smolen 2012; Ustinovaa & Tesakovab 2015), but in the Indian region it was recorded only from the Callovian (Bhalla & Talib 1991; Talib & Bhalla 2006). *Lagenammina difflugiformis*, though having a longer global range from Hettangian to Lower Cretaceous (Said & Barakat 1958; Gordon 1965,

1967; Oxford et al. 2004; Görög et al. 2012), is restricted to just the Oxfordian in the Indian region (Jain & Garg 2014). *Lenticulina muensteri*, *Ammobaculites subcretaceous*, *Saracenaria cornucopae* and *Lenticulina gaultina* are globally long-ranging, reaching up to the Cretaceous, while in the Indian region they are recorded from Callovian to Oxfordian strata. *Reophax multilocularis* has a global range from Toarcian to Upper Cretaceous (Gordon 1967; Nagy & Johansen 1991; Neagu & Neagu 1995) but in the Indian region it was recorded only from the Callovian (Bhalla & Talib 1991).

In light of the above indications, it is clear that most of the Jurassic foraminiferal species in the analysed assemblages (Fig. 12) are quite long-ranging and that the assemblages are scarce in short-ranging marker species. Nonetheless, 31 species do show restricted ranges confined to a single stage, either globally or in the Indian region. Of these, 10 species are restricted to the Oxfordian (4 globally and 8 in the Indian region); 7 species are restricted to the Callovian (1 globally and 6 in the Indian region); 1 restricted to the Bathonian in the Indian region; and 2 globally to the Toarcian. A total of 20 species show restricted ranges within two stages either globally or in the Indian region. Of these, 16 species are restricted to the Callovian and the Oxfordian (4 globally and 13 in the Indian region), whereas 2 are globally restricted to the Bathonian and the Callovian, and 2 are restricted to the Oxfordian and the Kimmeridgian. Most of the above-mentioned species are confined to the Callovian and the Oxfordian. Therefore, the presence of these species in the foraminiferal assemblages allows us to assign a Callovian to Oxfordian age to the studied section of the Chari Formation exposed in Ler Dome, Kutch. This interpretation agrees with previous studies based on ammonite faunas (e.g. Fürisch et al. 2001; Alberti et al. 2011, 2013).

Palaeoecological remarks and ecostratigraphy

Numerous palaeoecological studies have employed foraminiferal assemblages as a tool for interpreting different environmental parameters with significant accuracy, including those of the Jurassic period (Tyszka 1994; Valchev 2003; Reolid & Nagy 2008; Reolid et al. 2008a, 2012a; Nikitenko et al. 2013; Bilal et al. 2016; Rita et al. 2016; Talib et al. 2016, 2017; Farahani et al. 2018; among others).

These include test abundance (foraminifera per gram), richness (number of species), composition of assemblages (according to taxonomic groups, type of test or morphogroups), and α-diversity index. The foraminiferal assemblages of the Upper Chari Formation in the Ler Dome are generally rich in number of specimens and species.

The abundance of foraminifera or benthic foraminiferal number (BFN) is a useful proxy to estimate the oxygenation degree and the availability of trophic resources at the sea floor (Jorissen et al. 1995; Ghoorchaei et al. 2012; Bilal et al. 2016; Talib et al. 2016, 2017). According to the TROX model proposed by Jorissen et al. (1995) and applied to Jurassic assemblages by Olóriz et al. (2012), the oxygenation, trophic resources and competition among species controls the distribution and abundance of benthic foraminifera in the different microhabitats within the sediment (from epifaunal to deep infaunal). In oxygen-depleted environments, the BFN generally decreases (e.g. Coccioni & Galeotti 1993; Friedrich et al. 2003; Ghoorchaei et al. 2012). An excellent example is shown by the foraminiferal assemblages during the Toarcian Oceanic Anoxic Event, when diversity and abundance clearly decrease (Reolid et al. 2012a, 2019a, b; Nikitenko et al. 2013; Rita et al. 2016). In contrast, under aerobic conditions, a higher BFN is observed with increasing organic matter flux to the sea floor and low sedimentation rate (Bernhard 1986; Koutsoukos et al. 1990; Jorissen et al. 1992, 1995; Olóriz et al. 2003; Friedrich & Hemleben 2007; Reolid et al. 2008a, b; Smolen 2012; Ghoorchaei et al. 2012). However, the blooms of some species may be related to opportunist behaviour during survival or recolonization phases of biotic crises (e.g. Nikitenko et al. 2013; Reolid et al. 2014a, 2019a, b; Rita et al. 2016). Oxygen availability and organic matter are narrowly related due to increasing organic matter flux, and its oxidation leads to oxygen consumption on the sea floor; hence oxygen depleted condition affects the benthic foraminiferal abundance. The high abundance of benthic foraminifera throughout the studied section, together with the record of benthic macroinvertebrates, indicate well-oxygenated bottom waters, and in particular the availability of labile organic matter (quantity and quality). Fontanier et al. (2002) indicated that in benthic foraminiferal assemblages, oxygenation appears to be a less important controlling factor

than the quantity and quality of food particles. In this sense, analyses on recent foraminiferal assemblages show that short-term anoxic conditions do not have a direct lethal impact for the majority of foraminiferal taxa (Alve & Bernhard 1995; Langlet et al. 2013).

Calcareous species are dominant, corresponding mainly to suborder Lagenina. The absence of vagile porcellaneous forms (e.g. Family Nautiloculinidae) in the studied assemblages rules out proximity to the shallow environment of the inner shelf (Valchev 2003; Koutsoukos et al. 1990; Smolen 2012). Typical genera of shallow environments of the family Involutinidae (e.g. *Trocholina* and *Involutina*), or agglutinated families Pfenderinidae (e.g. *Pseudopfenderina* and *Kurnubia*), Valvulinidae (e.g. *Valvulina*), Hauranidae (e.g. *Alveosepta*, *Anchispirocyclina*, *Palaeocyclammina*), and Everticyclamminidae (e.g. *Everticyclammina*) are not recorded in the studied section. This is congruent with the record of ammonites and belemnites indicating a hemipelagic environment —open marine with normal salinity conditions (Seidenkrantz et al. 1993; Nagy et al. 1995, 2010; Nagy & Seidenkrantz 2003; Olóriz et al. 2006, 2012; Nagy & Berge 2008).

The stratigraphic fluctuations of the different features of the studied foraminiferal assemblages, such as composition of the foraminiferal assemblages, diversity and abundance, are interpreted in the context of the ecostratigraphy (stratigraphy of ecosystems; see Olóriz et al. 2012). Following the ecostratigraphic approach, the sedimentary successions record information about the environmental changes that control the fossil communities, thus making it possible to to identify bioevents (Boucot 1986) and long-term ecological dynamics (Olóriz 2000; Olóriz et al. 2012). Valuable contributions concerning ecostratigraphic changes in Jurassic foraminiferal assemblages and sea-level fluctuations have been published recently (e.g. Nikitenko et al. 2013; Rita et al. 2016; Colpaert et al. 2017; Farahani et al. 2018). Relative sea-level changes control the ecospace and force changes in detrital/nutrient input that directly affect the benthic foraminiferal assemblages, marking ecostratigraphic trends (e.g. Bouhamdi et al. 2001; Olóriz et al. 2003; Reolid & Nagy 2008; Reolid et al 2010, 2019b; Farahani et al. 2018). Changes in the foraminiferal assemblages occurring in different ecostratigraphic intervals may be interpreted according to environmental fluctuations (sedimentation rate, nutrient availability, oxygenation and distality gradient).

First ecostratigraphic interval. The first foraminiferal ecostratigraphic interval, corresponding to lithological unit 1, shows a good tiering with foraminiferal assemblages represented by epifaunal, shallow infaunal and potential deep infaunal forms (Olóriz et al. 2003, 2012; Reolid et al. 2008a-b; Fig. 11). This interval points to a well-oxygenated environment, as confirmed by the record of abundant and diverse benthic macroinvertebrates (brachiopods and bivalves). The genus *Epistomina* shows a high percentage (reaching 54% of the assemblage; Fig. 8), which may be related to an open marine environment, e.g. outer shelf, as this genus has been related to hemipelagic conditions and sea-level rise (Samson 2001; Oxford et al. 2002; Olóriz et al. 2003; Colpaert et al. 2016). This is compatible with the record of ammonites in lithological unit 1 (Fig. 4). This ecostratigraphic interval also features relatively low diversity (α-index < 2.5) and low abundance of foraminifera (BFN ranges from 30 to 32 specimens/g; Fig. 10), which is indicative of a low availability of trophic resources for benthic foraminifera. The dominance of opportunist forms such as *Epistomina* and *Lenticulina* (Reolid et al. 2008a) confirms the restriction of trophic resources (Fig. 8, 13). Most likely the distality of the Ler Dome depocenter with high sea-level reduced the input of labile organic matter, mainly phytodetritus (as observed in the sieved samples). The abundance of specialists (such as *Ammobaculites*, *Ammomarginulina*, *Astacolus*, *Lagenammina*, *Marginulina*, *Planularia* and *Spirillina*) decreases at the top of the interval (Fig. 13), probably indicating adverse conditions. This explains the increased proportion of opportunists at the top of the first interval.

Second ecostratigraphic interval. The second foraminiferal ecostratigraphic interval includes lithological units 2, 3 and 4, characterised by shale lithofacies, representing more terrigenous input to the basin in comparison with lithological unit 1 of the first ecostratigraphic interval. The decrease of *Epistomina* (Fig. 8) as well as ammonoids (Fig. 4) is congruent with a diminution of ecospace and the lesser distality for the Ler Dome depocenter (Fig. 13). The increase of terrigenous material is consistent with a regressive trend, and an increase of abundance

and diversity of benthic foraminifera (Fig. 13) due to the influx of phytodetritus from shallow areas and emerged areas (similar to examples from the Callovian of Scotland, described by Reolid & Nagy 2008).

The beginning of the second foraminiferal ecostratigraphic interval is characterised by an abrupt change of lithofacies, foraminiferal diversity (α-index > 6) and the decrease of proportion of the opportunistic form *Lenticulina* (Tyszka 1994; Reolid 2008, 2014). This change is coincident with the increased abundance of foraminifera, both opportunist and specialist forms, from the base of the second ecostratigraphic interval (Fig. 13). The increase in abundance of specialist forms —principally shallow infaunal forms— is abrupt at the base of the second ecostratigraphic interval (Fig. 10). The greater diversity is related to the increment of specialists (Fig. 13). Among the opportunists, *Lenticulina* is the dominant genus (Fig. 8) and is adapted to microhabitats ranging from epifaunal to deep infaunal (Tyszka 1994; Reolid et al. 2008a-b; Olóriz et al. 2012; Hjalmarsdottir et al. 2018), being an active deposit-feeder to grazing omnivore. Many species appear in this ecostratigraphic interval due to the influx of organic matter in association with the increase of input from proximal areas in the shelf and emerged land. The new species largely correspond to suborder Lagenina. The shallow infaunal forms of Lagenina recorded here are commonly flattened and elongated forms with active deposit feeding and grazing omnivore trophic habits (genera *Astacolus*, *Citharina*, *Falsopalmula*, *Marginulina*, *Nodosaria*, *Planularia*, *Prodentalina*, *Saracenaria* and *Vaginulinopsis*). Most of the species of these genera are unornamented tests, suggesting a normal level of dissolved oxygen (Bernhard 1986; Reolid et al. 2008b, 2012a, 2014b). These taxa are responsible for the increase in diversity values.

After the initial increase of the α-index and BFN there is a decrease, the lowest values found at the end of the ecostratigraphic interval. The abundance of specialists decreases (principally shallow infaunal forms), whereas the opportunists maintain high abundance. The top of this ecostratigraphic interval is marked by a severe decrease in diversity and the proportion of epifauna and shallow infauna, and the consequent increase of opportunists, mainly potential deep infaunal *Lenticulina*. This upper part reflects a deterioration of the environmental conditions at the sea bottom for benthic foraminifera, probably tied to increasing terrigenous input, as inferred from the presence of sandstone layers in lithological unit 4.

Third ecostratigraphic interval. The third ecostratigraphic interval, which includes lithological units 5, 6 and 7, begins with fossiliferous limestones that include brachiopods, bivalves and ammonoids. The increase in fossil macroinvertebrates and (mainly) ammonites would indicate an increase of the ecospace (Olóriz et al. 2012), related to the higher depth in the water column, but also a more pelagic character. The presence of carbonates and the decrease in siliciclastics confirm a diminution of terrigenous input, likely related to a higher distance to emerged land for the sediments represented in the Ler Dome area. This context is compatible with a transgression in the Kutch Basin at the beginning of the third ecostratigraphic interval (Fig. 13). The diversity of foraminiferal assemblages and the abundance of foraminifera are characterised by a cycle of increase-decrease in diversity, with the highest values corresponding to the grey to yellowish shales and sandstones of lithological unit 6. The greater abundance involves specialist forms (mainly shallow infauna) and not opportunist ones (Fig. 13). This is again related to the increased input of trophic resources after the transgression. But the diversity decreases again at the top, in relation to a new carbonate interval —the fossiliferous limestones of lithological unit 6— when the record of abundant ammonoids indicates a new sea-level rise. The opportunist forms are mainly represented by the genus *Lenticulina*, and the proportion is the opposite of the diversity trends. Therefore, *Lenticulina* dominates the assemblage with the highest values recorded at the base of the calcareous lithological units (lithological units 5 with 82% and 7 with 71%). The proportions of shallow infauna describe the opposite trend: the highest values (35%) are found in the grey to yellowish shales and sandstones of lithological unit 6 (Fig. 11). The diversity is largely related to the shallow infaunal forms such as *Ammomarginulina*, *Ammobaculites*, *Marginulina*, *Astacolus* and *Planularia*. These data allow us to interpret a good tiering in the foraminiferal assemblages, particularly during the most terrigenous interval, and there were not restricted conditions regarding oxygenation or trophic resources.
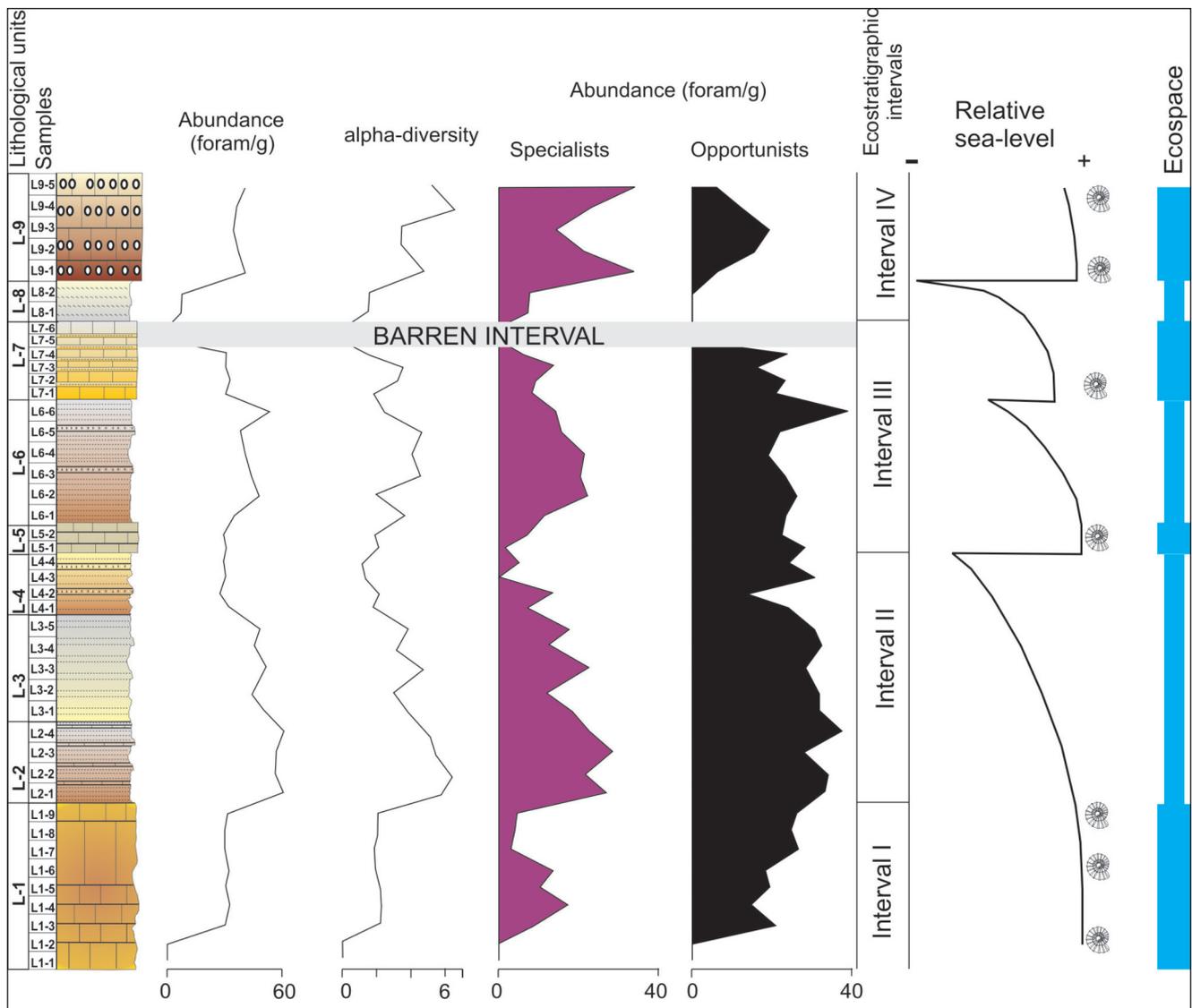
Fig. 13 - Foraminiferal stratigraphic distribution of studied samples (abundance of foraminifera, diversity, distribution of specialist vs opportunist forms), ecostratigraphic intervals, relative sea-level changes with distribution of ammonite-rich intervals, and inferred fluctuations in the ecospace.

The presence of ammonites in the fossiliferous limestones of lithological unit 7 is again interpreted as marking an increase in ecospace and distance to emerged areas, within a context of a relative sea-level rise. In parallel to the decrease in terrigenous input, the reduction of organic matter input could explain the lower diversity of shallow infaunal forms. However, the top of this ecostratigraphic interval, located in the last meter of the limestones, is characterised by a barren interval for foraminifera. It is not clear if the environmental features were more unfavourable for living foraminifera or for preserving the shells.

Fourth ecostratigraphic interval. The fourth ecostratigraphic interval begins with the return to terrigenous sedimentation (the silty claystone of lithological unit 8). The foraminiferal assemblages show a progressive increase in diversity from the barren interval that constitutes the top of lithological unit 7 (Fig. 13).

Analysis of foraminiferal assemblages from lithological unit 8 discards a taphonomic explanation for the barren interval characterising the top of the limestones. The reasons are: a) An absence of agglutinated foraminifera after the barren interval; b) Many genera of foraminifera are not recovered until the base of the Dhosa Oolite Member (e.g. *Ammobaculites*, *Ammomarginulina*, *Epistomina*, *Haplophragmoides*, *Lagenammina*, *Lenticulina*, and *Reophax*); and c) Some genera such as *Citharina* and *Saracenaria* are not recovered after the barren interval during

the fourth ecostratigraphic interval. Therefore, the barren interval is related to adverse conditions with a low recovery observed in lithological unit 8, and with increasing abundances of shallow infaunal forms —lately epifaunal forms and finally potential deep infaunal ones.

The silty claystones are dominated by specialists (Fig. 13) of the shallow infaunal microhabitat (Fig. 10-11) corresponding to the suborder Lagenina (*Astacolus*, *Falsopalmula*, *Frondicularia*, *Marginulina*, *Nodosaria*, *Planularia* and *Prodentalina*, Fig. 8), which is related to the increase in phytodetritus input. New genera appearing in the Dhosa Oolite Member are consistent to agglutinated forms (*Ammopalmula*, *Flabellammina*, *Sculptobaculites*, and *Textularia*) and *Frondicularia*. Epifaunal forms are recovered in the upper part of the silty claystones (mainly *Lagenammina* and *Spirillina*, and secondarily *Epistomina*). The deep infaunal forms are recovered in the Dhosa Oolite Member (primarily represented by *Lenticulina* and secondarily by *Reophax* and *Textularia*). The Dhosa Oolite Member presents good tiering and includes foraminifera from epifaunal to deep infaunal microhabitats; this may be interpreted as unrestricted conditions for oxygen availability and trophic resources.

The Dhosa Oolite Member presents a high content in fossil macroinvertebrates, mainly ammonites (Fig. 13), as well as ferruginous ooids and concretions typically interpreted as related to rapid sea-level rise. This kind of ferruginous oolithic limestone has been also recorded in the Callovian/Oxfordian boundary in the western Tethys (e.g., Gygi 1981; Soussi & M'Rabet 1991; Collin et al. 2005; Olóriz et al. 2008; Reolid et al. 2008c; Reolid & Abad 2019) and interpreted as related to a transgressive interval after an unconformity. The Dhosa Oolite Member, recorded across the Kutch Mainland for more than 100 km, dates back to the early Oxfordian (Ramkumar et al. 2013).

Consequently, the siliclastic units, in some cases showing upward-coarsening sequences (commonly from claystones to sandstones), represent upward-shallowing trends related to highstand and sea-level fall (Fig. 13). The fossiliferous intervals are the expression of the following deepening phase, the increase in ammmonoids indicating a hemipelagic environment. The low sedimentation rate caused relative enrichment of the skeletal remains of macroinvertebrates. The presence of iron ooids in the Dhosa Oolite Member furthermore indicates reworking during the transgression (Fig. 13). The base of the fossiliferous limestone lithological units is a transgressive surface, included in the Dhosa Oolite Member. A similar model has been proposed for the ferruginous oolithic limestone of the Oxfordian from the Prebetic (South Spain; Reolid et al. 2008c; Reolid & Abad 2019).

Such highly asymmetric transgressive-regressive cycles (most of the sediment thickness corresponding to the highstand and lowstand) can also be observed in the sandy units of the Goradongar Formation (Bathonian), the Katrol Formation (Kimmeridgian), and the Umia Formation (Tithonian) (see Fürsich & Pandey 2003; Fürsich et al. 2013). The transgressive-regressive cycles governed organic matter input into the Ler Dome area, and subsequently affected the foraminiferal assemblages (diversity, abundance and microhabitat tiering within the sediment).

CONCLUSIONS

Ecostratigraphic analysis of the foraminiferal assemblages of the upper part of the Chari Formation, Ler Dome of Kutch Basin, leads us to interpret different environmental parameters. Fluctuations in the abundance of foraminifera, diversity, and the content of specialist forms were related mainly to the availability of labile organic matter at the sea floor. Fluctuations in the trophic resources were related to changes in the type of sedimentation, ranging from carbonates to siltstones and sandstones.

A relatively high input of food resources, probably phytodetritus, was related to siliciclastic lithofacies commonly linked to increased abundance and diversity of foraminifera, including specialist forms. This occurred during regressive phases. Some upward-coarsening sequences from claystones-siltstones to sandstones are interpreted as upward-shallowing trends developed during the highstand or sea-level fall.

The input of food resources derived from emerged areas and shallow environments decreased during the transgressive phases when carbonates rich in ammonoid moulds were deposited, indicating hemipelagic conditions. The decrease of trophic resources for benthic foraminifera is evidenced

by their diminution in abundance and diversity. The specialist forms were more sensitive to the scarcity of food resources.

The carbonate intervals, more fossiliferous, represent the deepening phase with low sedimentation rate and common cephalopods (ammonoids and belemnites), which indicate a hemipelagic environment. The base of the fossiliferous limestones is therefore a transgressive surface. As a result, the studied stratigraphic interval of the Chari Formation represents highly asymmetric transgressive-regressive cycles, where most of the sediment thickness corresponds to the highstand and lowstand. The transgressive-regressive cycles controlled the organic matter input in the Ler Dome area, and subsequently affected diversity, abundance and microhabitat tiering within the sediment of the foraminiferal assemblages.

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