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Orthophragminids with new axial thickening structures from the Bartonian of the Indian subcontinent

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ABSTRACT

The 'axial thickening', a morphological character of certain Eocene orthophragminids refers to the thickening of the equatorial and/or lateral layers in axial directions forming radial external structures, namely the ribs. The occurrence of ribs is considered to be a diagnostic specific character of the orthophragminids in the peri-Mediterranean region and Europe (western Tethys). In the Bartonian orthophragminids of the Indian subcontinent we observe a new type of axial thickening that we name 'bulges'. The bulges are semi-rounded to rounded, localized structures on the test surface formed solely by the greater development of lateral chamberlets. These specimens, with trybliolepidine to umbilicolepidine type embryon configuration, co-occur with ribbed discocyclinids having completely different internal features. We also record another type of axial thickening of the lateral layers in notably small omphaloid tests that are characterized by a thick umbo, deeply depressed at the center such that the periphery of it forms a thick circular structure. The reported omphaloid specimens possess a small, semi-isolepidine to nephrolepidine type embryon configuration and characteristic early chambers, not comparable to any known species in the Tethys. These specimens occasionally may have incomplete and/or irregular septula, reminiscent of certain Caribbean orthophragminids. The specimens with bulges, identified in two geographically distant regions of the Indian subcontinent, possibly represent endemic foraminiferal fauna confined to the Indo-Pakistan region. We introduce two new species, *Discocyclina kutchensis* sp. nov. (characterized by bulges) and *'D'. sulaimanensis* sp. nov. (characterized by circular structures in omphaloid tests). The status of both taxa in the Tethys is discussed.

KEYWORDS **Foraminiferida. Orthophragminids. Bulges. Omphaloid tests. Indian subcontinent.**

INTRODUCTION

Orthophragminids are a group of Late Paleocene-Eocene hyaline Larger Benthic Foraminifera (LBF) characterized byadiscoid, lenticular test of semi-circular to circular outline. The test consists of an equatorial layer and two lateral layers, displaying a superficial similarity to the Late Cretaceous orbitoids and Cenozoic lepidocyclinids and miogypsinids.

A significant morphological character observed in certain orthophragminid taxa is the thickening of the equatorial and/or lateral layers in axial directions. It results from a greater development of lateral chamberlets in the lateral layers and/or axial enlargement of equatorial chambers that may be further subdivided into axially superposed chamberlets (Ferràndez-Cañadell, 1997). This leads to radial structures on the test surface, known as ribs. The various developments of the ribs may cause the test to acquire wavy, asteroidal and pentagonal shapes (Less, 1987; Ferràndez-Cañadell, 1997 and the references therein). The ribs are of importance at genus and/or species taxonomic rank. They are diagnostic specific characters in western Tethyan genera such as *Discocyclina* GÜMBEL, 1870, *Nemkovella* LESS, 1987 and *Orbitoclypeus* SILVESTRI, 1907 and a generic character in *Asterocyclina* GÜMBEL, 1870 (Less, 1987; Ferràndez-Cañadell, 1997; Özcan *et al*., 2006).

Some novel features of axial thickening in the Bartonian orthophragminids of the Indian subcontinent are reported. Two new species with distinct axial thickening from the (lower) Bartonian Fulra Limestone in Kutch (west India) and Bartonian levels of the Drazinda Formation (Fm.) in the Sulaiman Range (west Pakistan) are described. The significance of the new species in the paleobiogeography of the Tethyan orthophragminids, poorly known from the eastern Tethys and Pacific compared to those of the western Tethys, is discussed.

GEOLOGICAL SETTING

The Middle Eocene (Lutetian and Bartonian) shallow marine deposits are widely distributed in the Indian subcontinent and are characterized by the abundance of LBF, particularly of orthophragminids and nummulitids (Sen Gupta, 1963a; Samanta, 1964, 1965; Samanta and Lahiri, 1985; Weiss, 1993; Afzal *et al*., 1997). The Kutch and Cambay basins in India and the Sulaiman Range in Pakistan are the key regions to understand the development of Eastern Tethyan LBF fauna in the Indian subcontinent during the Middle Eocene (Fig. 1A). Further east of the Indo-Pakistan region, the orthophragminid record is very poor and detailed studies are lacking.

Sulaiman range

The Middle to Upper Eocene sedimentary sequence in Sulaiman range in Pakistan (Fig. 1B-C) comprises the Habib Rahi, Domanda, Pirkoh and Drazinda formations, collectively named Kirthar by Blanford (1879). The term Drazinda Shale Member of the Kirthar Fm. was introduced by Hemphill and Kidwai (1973) to replace the Upper Chocolate Clays of Eames (1952a, b), who first established a robust lithostratigraphic framework for the Eocene succession in the Sulaiman fold belt. The Drazinda Fm., more than 380 meters in thickness in Rakhi Nala (Dera Ghazi Khan), consists of dark-brown to greenish gray shale and subordinate marl and limestone beds containing abundant LBF, bivalves, bryozoans and echinoids in its lower and middle, and pale yellowish green *Pellatispira*-bearing marls in the upper part. According to Kazmi and Abbasi (2008), marine Middle to Upper Eocene sediments in the Sulaiman fold belt and their correlative units in the Kirthar belt were deposited in an epicontinental sea that transgressed the Indian subcontinent after the collision of Indian and Eurasian plates in the Early Eocene.

Previous studies suggested a Middle and late Middle Eocene age for the Drazinda Fm. based on calcareous nannofossils (Köthe *et al*., 1988) and planktonic foraminifera (Samanta, 1973; Afzal *et al*., 1997). According to Köthe *et al*. (1988), the age of this unit in the Rakhi Nala section is Middle Eocene based on the presence of the nannoplankton zones NP 16 and 17. Afzal *et al*. (1997) identified planktonic foraminifera zone P14 and dated the lower part of Drazinda Fm. (below the *Pellatispira* beds) as late Middle Eocene (Bartonian). The lower and middle portion of the Drazinda Fm. was interpreted to have been deposited in a shelf lagoon and carbonate shoal setting, while its upper part (*Pellatispira* beds) in an open marine setting (Abbas, 1999). The Drazinda Fm. is unconformably overlain by coastal deltaic to fluviatile deposits of the Oligocene Chitarwatta Fm. (Shah, 2009).

Kutch and Cambay basins

In the Kutch region the Eocene succession represents the first marine transgression following the Deccan volcanism and comprises the Naredi and Harudi formations and Fulra Limestone successively from bottom to top (Biswas, 1992) (Fig. 2A). The Fulra Limestone is a monotonous succession of white to pale yellow-brown coloured limestone, gradationally overlying the finer clastics of the Harudi Fm. Petrographically it varies from mudstones to grainstone types. It contains an abundant and diverse assemblage of orthophragminids, nummulitids, and alveolinids (Samanta and Lahiri, 1985; Samanta *et al*., 1990; Samanta, 1993; Saraswati *et al*., 2000) (Fig. 2B). The Fulra Limestone was assigned to the Shallow Benthic Zone (SBZ) 17 (early Bartonian) by Ben Ismail-Lattrache *et al*. (2013). Samanta (1970) described planktic foraminifera from the Fulra Limestone and assigned it to the *Orbulinoides beckmanni* and *Truncorotaloides rohri* zones. According to the scheme of Berggren and Pearson (2005) this unit corresponds to Zones E12 and E13. The Fulra Limestone was deposited in an inner to middle shelf environment. The water-depth and energy conditions were highly variable. The lower part, mainly comprising *Discocyclina* mudstones and planktic foraminiferal wackestones, was deposited in a low-energy, middle shelf environment. The upper part, characterized by a nummulitid-rich grainstone and a *Discocyclina* grainstone, was deposited in a high-energy depositional setting in the

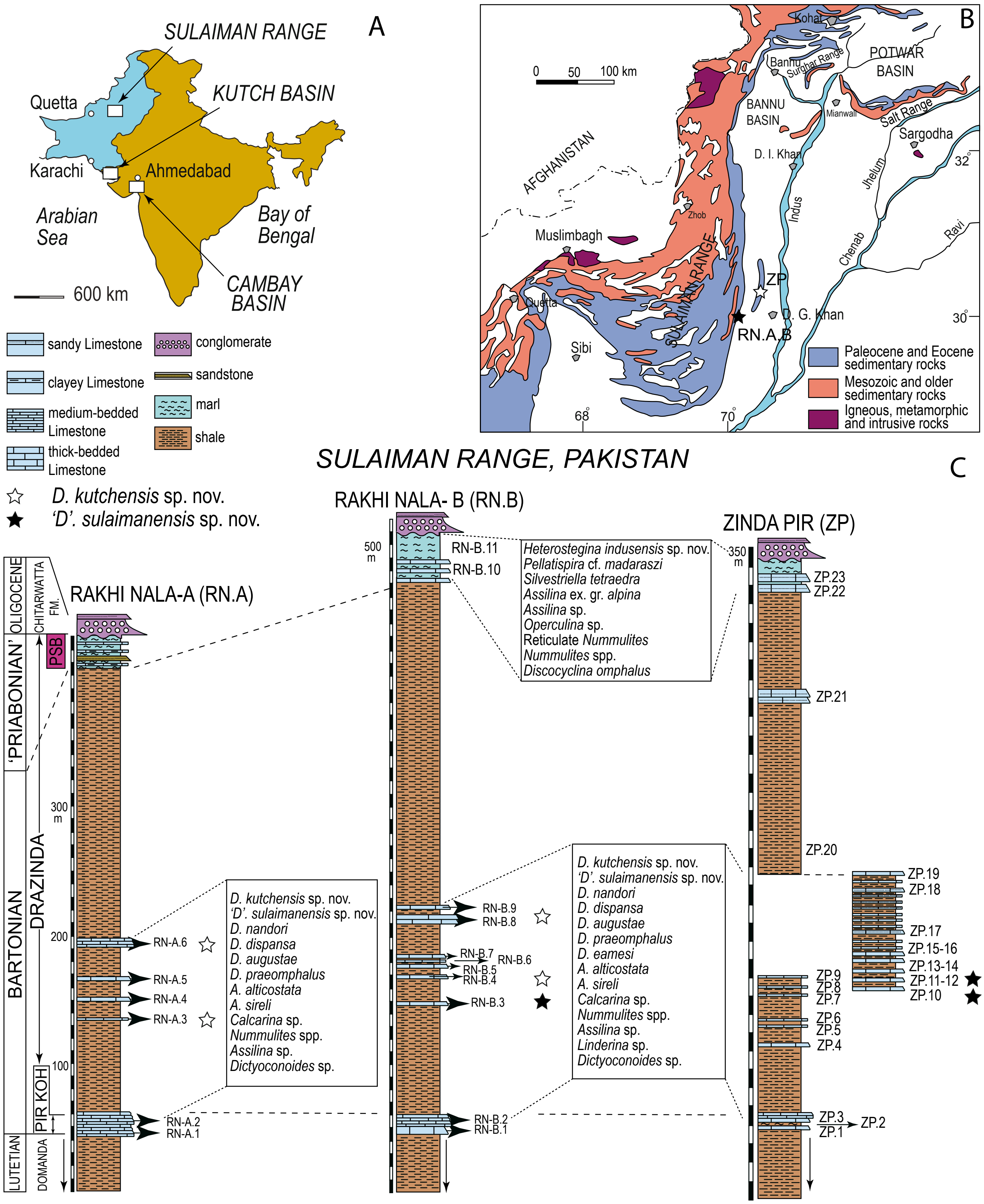

FIGURE 1. A) Location of the Sulaiman Range, Kutch and Cambay basins in Pakistan and India. B) Simplified geological map of the Sulaiman Range and position of studied sections. C) Generalised stratigraphy and the sampling points in the Drazinda Fm. Stratigraphic nomenclature is after Hemphill and Kidwai (1973). The geological map is simplified from Kazmi and Rana (1982). PSB: *'Pellatispira'* beds.

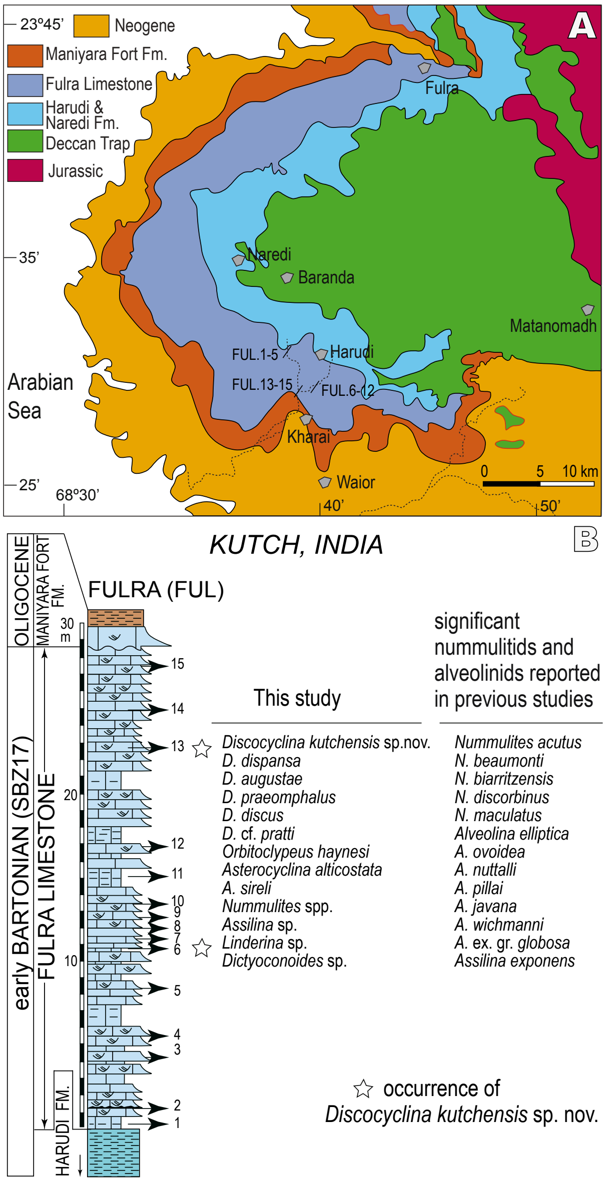

FIGURE 2. A) Simplified geological map of the western part of Kutch, west India. B) Generalised stratigraphy and the sampling points in the Fulra Limestone. Stratigraphic nomenclature and geological map are after Biswas (1992). SBZ: Shallow Benthic Zone (after Serra-Kiel *et al.*, 1998). The nummulitids and alveolinids reported in previous studies are from various sources.

inner shelf. The presence of palaeo-karsts at several levels in the upper part of the unit suggests repeated subaerial exposure (Chattoraj *et al.*, 2012). The Fulra Limestone is overlain unconformably by the Maniyara Fort Fm.

In the onshore parts of the Cambay Basin, the Eocene sediments comprise lignite and shale (Early Eocene) and calcareous shale and limestone (Middle to Late Eocene) that occur as isolated outcrops, in subsurface and in mine sections (Mukhopadhyay, 2003; Punekar and Saraswati, 2010). The Middle to Late Eocene succession named Nummulitic Limestone by Carter (1861) was subsequently renamed Amravati Fm. by Sudhakar and Basu (1973). The formation consists of foraminiferal limestone, marl and clay deposited in an inner shelf environment. It comprises several species of *Nummulites*, *Assilina* and *Pellatispira*. Mukhopadhyay (2003) reported *Orbulinoides beckmanni* and *Truncorotaloides rohri* from Amravati Fm., indicating Zones P13 (= E12, Berggren and Pearson, 2005) and P14 (= E13, Berggren and Pearson, 2005).

MATERIALS AND METHODS

The orthophragminids were systematically collected from two classical Bartonian sites in Kutch, west India, and the Sulaiman Range, west Pakistan. The samples from the Sulaiman Range correspond to the measured sections of the Drazinda Fm.: Rakhi Nala A (29°57'12.80"N, 70°06'56.80"E; 29°57'13.51"N, 70°7'1.74"E), Rakhi Nala B (29°57'25.92"N, 70°7'0.50"E; 68°40'49.23"E, 29°57'16.10"N, 70°7'11.20"E) and Zinda Pir sections (30°20'2.38"N, 70°29'32.54"E; 30°19'56.65"N, 70°29'39.48"E), west and northwest of Dera Ghazi Khan in the Punjab province (Figs. 1C, 3A-B). The samples of the Fulra Limestone were collected from three section, near Kharai and Harudi villages, 100km northwest of Bhuj, Kutch (23°30'55.97"N, 68°40'5.98"E; 23°28'45.32"N, 68°40'49.23"E) (Figs. 2, 3C). In addition, some specimens of the Middle Eocene ribbed discocyclinid, *Discocyclina nandori* from the Cambay Basin in west India were also studied. The specimens of *D. nandori*, from the Thrace Basin in Turkey (western Tethys) and a single specimen of *Proporocyclina* sp. from the Caribbean Province have been incorporated herein for comparison purposes.

Oriented thin sections of both megalospheric (A-forms) and microspheric specimens (B-forms) through the equatorial layer and the axial plane of *Discocyclina kutchensis* sp. nov., and the megalospheric forms of *'D'. sulaimanensis* sp. nov. have been prepared to observe the relation between the external structures and the equatorial and lateral layers. The microspheric forms of the latter species have not been found in the studied material. The biometric data of both species are summarized in Tables 1 and 2.

AXIAL THICKENING, ITS TAXONOMIC SIGNIFICANCE AND DEFINITION OF THE NEW TEST STRUCTURE, 'BULGES'

The test surface of the orthophragminids is either smooth or is characterized by the occurrence of ribs (Figs. 4-5). In the Tethys species, the ribs are formed in different ways in Discocyclinidae Galloway, 1928 (with genera *Discocyclina* Gümbel, 1870 and *Nemkovella* Less, 1987) and Orbitoclypeidae Brönnimann, 1945a (genera

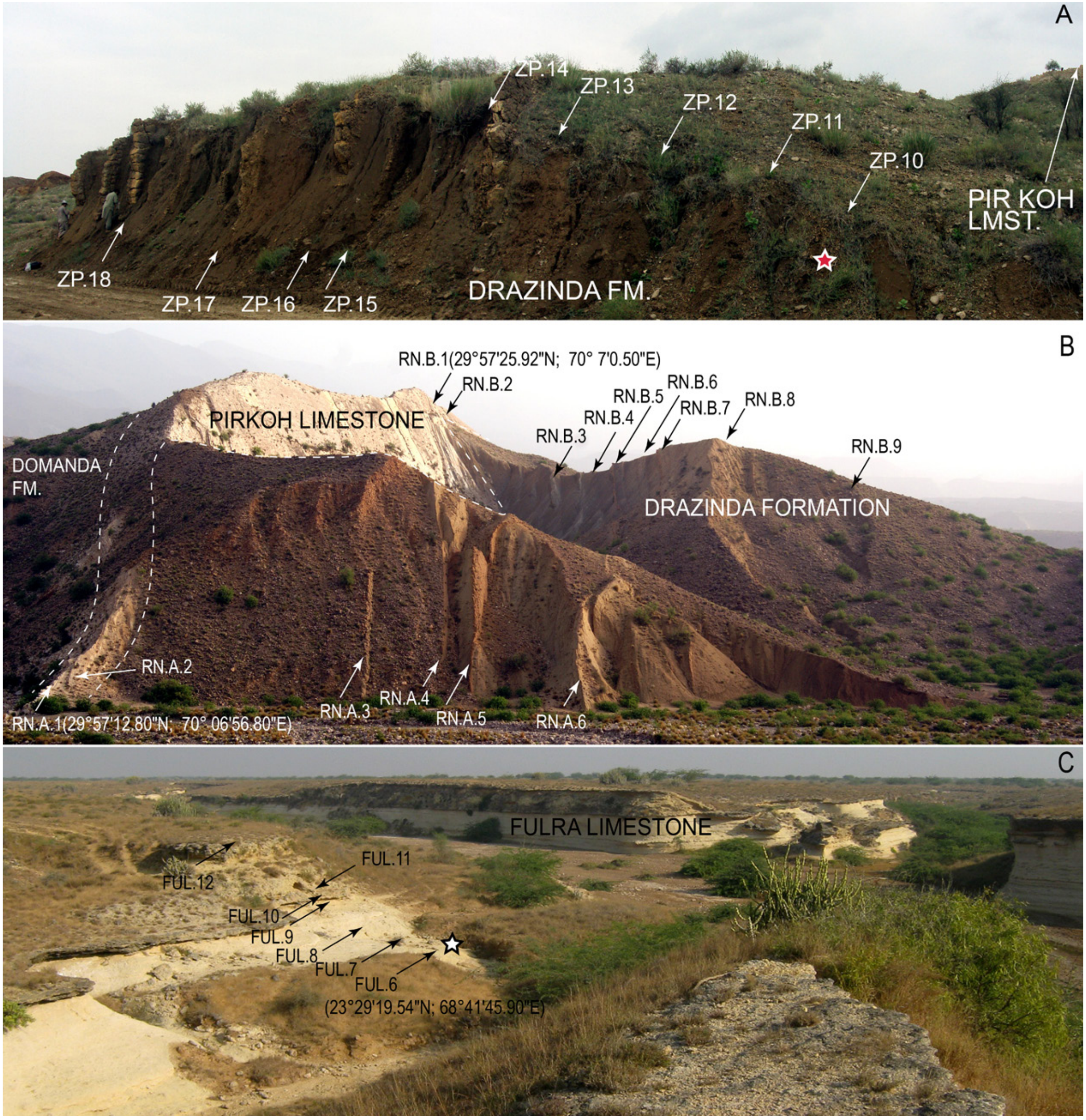

FIGURE 3. Outcrops of the Drazinda Fm. in A) Zinda Pir and B) Rakhi Nala and C) Fulra Limestone in Kutch. The samples in the Fulra Limestone correspond to the middle part of the unit, where the type-level of *D. kutchensis* sp. nov. is marked by a star (sample FUL. 6). The type-level of *'D'. sulaimanensis* sp. nov. is shown by a star (A).

Orbitoclypeus Silvestri, 1907 and *Asterocyclina* Gümbel, 1870). In Discocyclinidae, ribs are formed solely by the greater development of lateral chamberlets, whereas in Orbitoclypeidae by both the greater development of lateral chamberlets and the axial enlargement of the equatorial layer. Occasionally, the ribs may bifurcate close to the periphery of the test (Less, 1987).

Previous illustrations of Tethyan orthophragminids reveal that the ribs, starting to develop either at early or later stages of test growth, are always continuous linear structures radially developed from the central or near-central part of the test (Nuttall, 1926; Brönnimann, 1945b; Tewari, 1949; Less, 1987; Ferràndez-Cañadell, 1997). In general, two types of ribbed orthophragminid taxa have been recognized in the fossil record: forms with five ribs, and forms with numerous ribs. Specimens with four, six and more ribs, however, also occur in the Western Tethyan and the Caribbean provinces (Cushman, 1917, 1919; Brönnimann, 1951; Cole and Gravel, 1952; Caudri, 1975, 1996; Less, 1987). As a consequence, Tethyan ribbed orthophragminid taxa were assigned to two genera, *Asterocyclina* Gümbel, 1870 for the specimens with five-ribs

TABLE 1. Statistical data of *D. kutchensis* sp. nov. The measurements (in microns) and counts are P and D: outer diameter of the protoconch and deuteroconch perpendicular to their common axis; A: number of adauxiliary chamberlets; H and W: height and width of the adauxiliary chamberlets; n0.5: number of annuli within a 0.5 mm distance measured from the deuteroconch along the axis of the embryon; and h and w: height and width of the equatorial chamberlets around the peripheral part of the equatorial layer. N denotes the number of specimens studied in the sample

		Outer cross diameter of the embryon				Adauxiliary chamberlets			Equatorial chamberlets		
		Deuteroconch (D)		Protoconch (P)		number (A)	Height (H)	Width (W)	annuli/0.5mm (n0.5)	height (h)	Width (W)
Sample	N	range	mean±s.e	range	mean	range	range	range	range	range	range
FUL.6	34	275-610	411.0±14.6	105-250	169.4	27-47	70-110	25-50	5-6	75-100	25
FUL.13	6	310-460	423.3±21.0	150-200	177.5		80-120	25-45	5-6	80-120	25-30
RN.A.3	3	440-500	473.3±14.4	170-200	186.7	38-50	90-140	30-45	5	100-110	20-35
RN.A.6	3	440-515	477.5±26.5	175-230	202.5		100-110	30-35	6	100-135	30-35

and *Actinocyclina* (GÜMBEL, 1870) for the specimens with numerous ribs (Nuttall, 1926; Tewari, 1949; Schweighauser, 1953; Bieda, 1963; Portnaya, 1974). However, the presence of ribs in some species of *Discocyclina* GÜMBEL, 1870, *Orbitoclypeus* SILVESTRI, 1907 and *Nemkovella* LESS, 1987 as shown by Less (1987) and Ferràndez-Cañadell (1997) indicate that the ribs occur in all western Tethyan genera, implying that these features are of specific rank in the aforementioned genera, but a genus-rank character in *Asterocyclina*. The present orthophragminid systematics follows the characters of the microspheric juvenarium (B- forms) and the stolons connecting the chamberlets and the successive annuli rather than ribs (Brönnimann, 1945a; Less, 1987; Ferràndez-Cañadell and Serra-Kiel, 1992; Ferràndez-Cañadell, 1998). At present, the genus *Actinocyclina*, with numerous ribs, is considered invalid as its generotype *Actinocyclina radians* (GÜMBEL, 1870) has proven to belong to *Discocyclina* (Less, 1987; Ferràndez-Cañadell, 1997), although this species is still incorrectly adopted for orthophragminids with numerous ribs.

The term 'bulges' is introduced here for the semi-rounded to rounded, localized thickenings, homogenously distributed over the orthophragminid test surface. These structures are about 250–350 microns in diameter, 100–150 microns in height and 100–300 microns apart from each other, and form an uneven test surface. Internally, the bulges consist of lateral chamberlets and coarse piles of up to 100 microns in diameter at its center, surrounded by smaller piles (25–50 microns in diameter), forming a circular pattern. These piles are semi-circular to polygonal in shape in transversal sections. The lateral surfaces of the bulges are rather sharp. The axial sections show no variation in the thickness of the equatorial layer adjacent to the bulges and inter-bulge areas. This implies that bulges are formed solely by the thickening of the lateral layers. Although bulges and ribs are easily distinguished from each other by their characteristic external shapes, distinction of both structures may not be possible in axial sections.

BARTONIAN ORTHOPHRAGMINIDS EXHIBITING AXIAL THICKENING (RIBS) AND OMPHALOID TESTS IN THE INDIAN SUBCONTINENT

In earlier studies from the Indo-Pakistan region, the orthophragminids with numerous ribs were assigned to genus *Actinocyclina* GÜMBEL, 1870 (Nuttall, 1926; Tewari, 1949; Sen Gupta, 1959). Nuttall (1926) erected *Actinocyclina alticostata* from the Fulra Limestone (middle Kirthar series of the author) for the specimens displaying numerous (8-12) ribs. Sen Gupta (1963b) reassigned these specimens to genus *Asterocyclina* considering the increase in the thickness of the equatorial layer and noted that this was the only orthophragminid species with numerous ribs in India. Samanta and Lahiri (1985) followed this taxonomic concept and identified this species as the only asterocyclinid in the Fulra Limestone. Recently, Ben Ismail-Lattrache (2013) and Özcan and Saraswati (2014) reported another species, *Asterocyclina sireli*, with predominantly four ribs from the Fulra Limestone (Figs. 4B.8, 5G-H). This species also displays four ribs at its type locality in Turkey (Özcan *et al*., 2006). Tewari (1949) illustrated a single specimen with numerous ribs, assigning it to genus *Actinocyclina* GÜMBEL, 1870, from the Cambay Basin. We show herein that these forms belong, in fact, to *Discocyclina nandori* LESS, a common species in the

TABLE 2. Statistical data of *'D'.sulaimanensis* sp. nov. See Table 1 for nomenclature

		Outer cross diameter of the embryon				Adauxiliary chamberlets			Equatorial chamberlets		
		Deuteroconch (D)		Protoconch (P)		number (A)	Height (H)	Width (W)	annuli/0.5mm (n0.5)	height (h)	Width (W)
Sample	N	range	mean±s.e	range	mean	range	range	range	range	range	range
ZP.10	10	55-65	60.0±1.41	40-45	42.78	0-1	10-15	40-55	18-20	50-65	20-35
ZP.11	7	50-70	60.0±2.47	35-45	41.43	0-1	15	45-50	18-19	50-65	25-30
ZP.12	20	55-75	64.9±1.23	35-50	42.00	0-3	10-20	40-55	18-21	60-80	20-25
RN.B.3	1	45.0		35.0		0	10	40	19?	50-60	20-30

	Discocyclinidae	Orbitoclypeidae	A
Genera	Discocyclina & Nemkovella	Orbitoclypeus	Asterocyclina
Test surface	With or without ribs	With or without ribs	Always with ribs
Ribs	Ribs are small and numerous (up to more than 20; increasing in number through ontogeny.	Ribs are few (6 to 9), number constant through ontogeny, sometimes bifurcated.	Ribs are always 5, number constant through ontogeny.
Annuli & test outline	Always circular	Circular, wavy, incipient asteroidal	Stellate to pentagonal
Mode of Rib formation	Ribs are constructed exclusively from lateral layers	Ribs are constructed from lateral layers, but with slight axial enlargement of annuli	Ribs are constructed from both lateral layers and axial enlargement of annuli
Axial subdivision of annuli	Not present	Not present	Axial subdivision of annuli

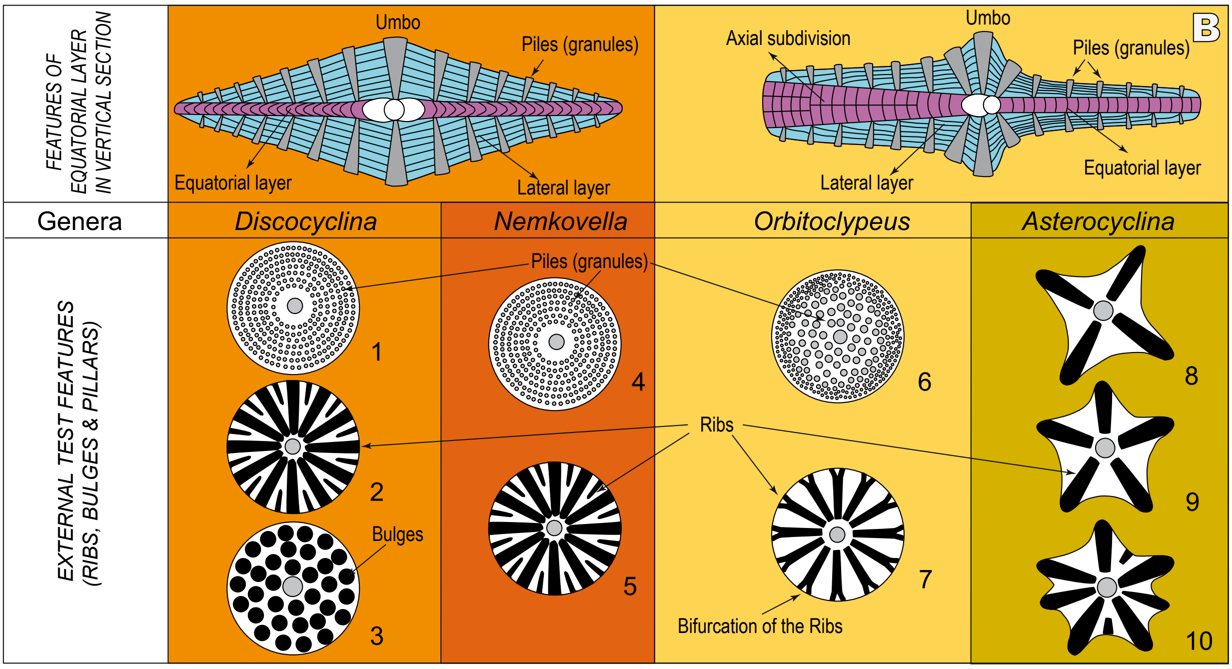

FIGURE 4. A) Ribs and their general features in Tethyan orthophragminid genera after Ferràndez-Cañadell (1997). B) The 'bulges', introduced in present study and ribs and their variation in Tethyan orthophragminids. The genus *'Actinocyclina'*, characterized solely by the presence of numerous ribs, is considered an invalid genus after Ferràndez-Cañadell (1997). 1, 4, 6: specimens with smooth tests. 2: ribbed *Discocyclina* (*e.g. D. nandori, D. radians*). 3: *Discocyclina* with bulges (*e.g. D. kutchensis* sp. nov.). 5: ribbed *Nemkovella* (*e.g. N. rota*). 7: ribbed *Orbitoclypeus* (*e.g. O. furcatus*). 8: four-ribbed *Asterocyclina* (*e.g. A. sireli*). 9: five-ribbed *Asterocyclina* (*e.g. A. stella*). 10: *Asterocyclina* with commonly numerous ribs (*e.g. A. alticostata* and *A. schweighauseri)*.

Middle Eocene of western Tethys (Özcan *et al*., 2010). This species also occurs in the Drazinda Fm. where is associated with the specimens displaying bulges. Thus, Bartonian ribbed species in the Indian subcontinent are represented by *Discocyclina nandori*, *Asterocyclina alticostata*, and *Asterocyclina sireli*.

Previous studies recurrently mention the presence of large, flat to saddle-shaped species of genus *Discocyclina* GÜMBEL, 1870 (*e.g. D. dispansa, D. sowerby, D. undulata, D. omphalus, D. praeomphalus*) in the Indian subcontinent. *D. omphalus* (Fritsch, 1875), was described firstfrom Borneo and was considered to be a common Pacific species, and *D. praeomphalus* SAMANTA and LAHIRI, 1985, that was described first from the Fulra Limestone in west India, possess a test feature characterized by a central depression at the umbonal zone of its saddle-shaped test. The orthophragminids with such test features do not occur in the western Tethys.

SYSTEMATIC PALEONTOLOGY

Order: Foraminiferida EICHWALD, 1830
Family: Discocyclinidae GALLOWAY, 1928

GENUS ***Discocyclina*** GÜMBEL, 1870

Type species. *Orbitolites pratti* MICHELIN, 1846
Discocyclina kutchensis sp. nov. ÖZCAN AND SARASWATI
Figs.5L; 6A-I; 7A; 8A-D; 9; 10A-D

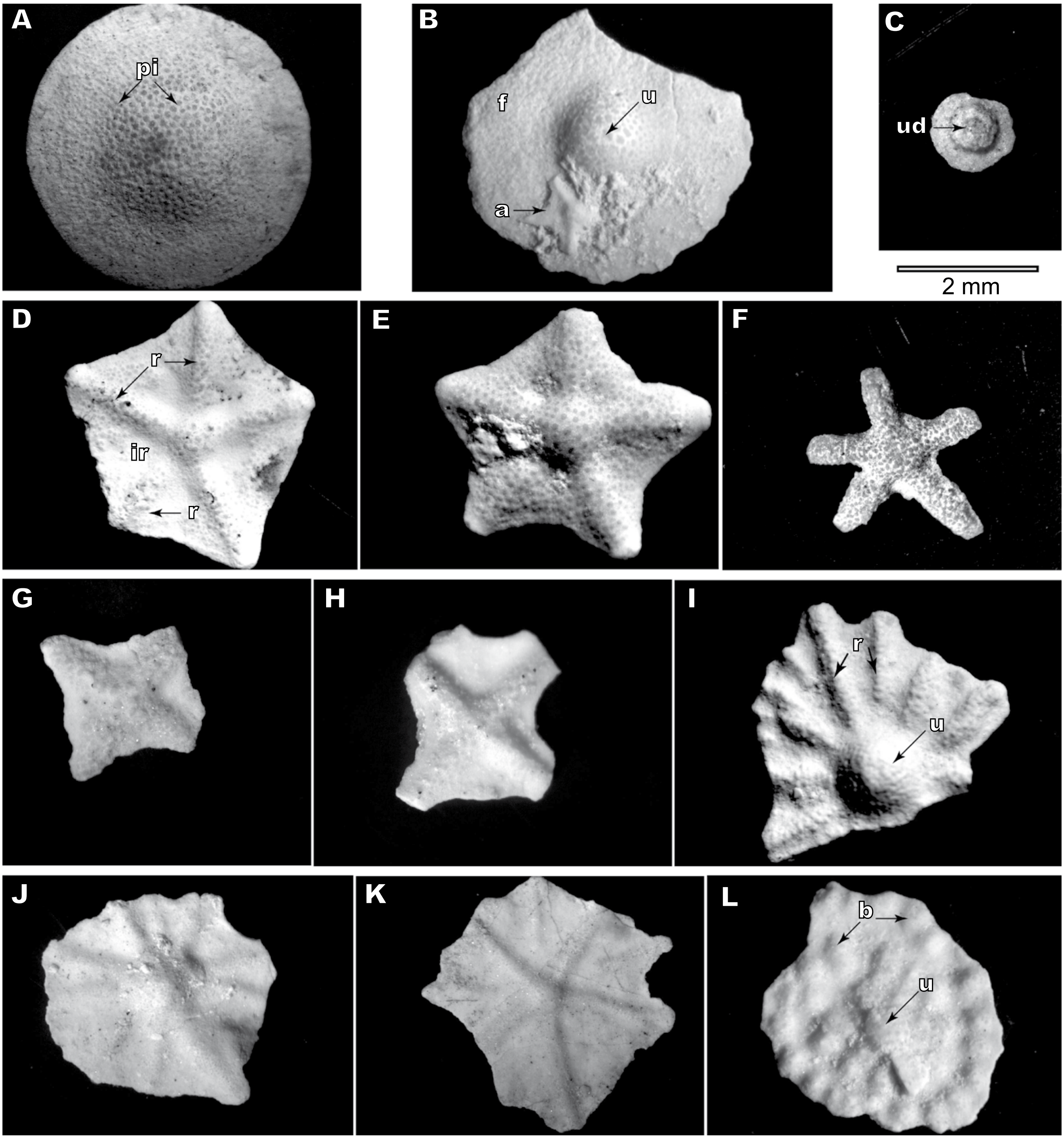

FIGURE 5. External test features in Tethyan orthophragminids; A–C) the smooth tests, D–K) test with ribs and L) with 'bulges'. A–B) smooth tests with a central umbo and piles; note half broken test of *Asterocyclina* sp. sticking on the broken test of *Discocyclina dispansa*. A) *Discocyclina spliti* Butterlin and Chorowicz, Ayrıdam, central Turkey, early Lutetian. B) *D. dispansa* (Sowerby), Fulra Limestone, Kutch, west India, early Bartonian. C) Test with a prominent central depression in the umboof *'D'.sulaimanensis* sp. nov., Drazinda Fm., Sulaiman Range, west Pakistan, Bartonian. D)pentagonal and E) pentagonal to asteroidal tests of five-ribbed *Asterocyclina* with well-developed inter-rib areas, *A. stellata* (d'Archiac), Soğucak Fm., Şamlar, north-west Turkey, late Bartonian. F) asteroidal test of five-ribbed *Asterocyclina* with deeply incised inter-rib areas, Soğucak Fm., Gökçeada, north-west Turkey, early Bartonian. G–H) almost tetragonal tests of four-ribbed *A. sireli* Özcan and Less, Fulra Limestone, Kutch, west India, early Bartonian. I) Numerous ribs in *D. radians* (d'Archiac), Soğucak Fm., Şamlar, north-west Turkey, late Bartonian. J–K) Numerous ribs in *A. alticostata* (Nuttall), Fulra Limestone, Kutch, west India, early Bartonian. L: bulges in *D. kutchensis* Özcan and Saraswati, Fulra Limestone, Kutch, west India, early Bartonian. a: *Asterocyclina* sp., b: bulges, f: flange, ir: inter-rib areas, pi: piles, r: ribs, u: umbo, ud: umbonal depression.

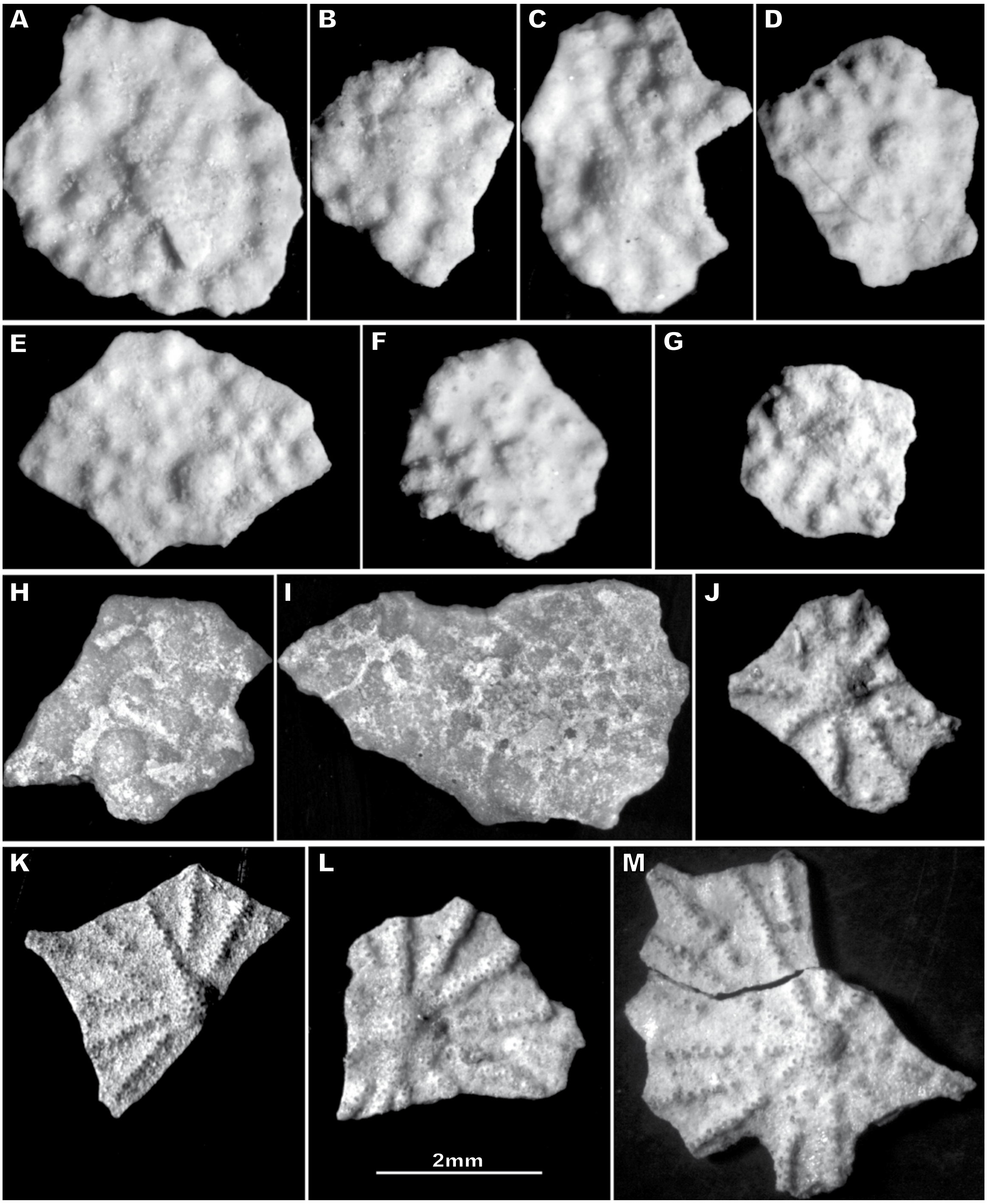

FIGURE 6. A–I) Bulges in *Discocyclina kutchensis* sp. nov. Özcan and Saraswati and J–M) ribs in *D. nandori* Less. A and H microspheric, the others megalospheric forms. The specimen FUL.6-86 (figured in E) is the holotype of *D. kutchensis* sp. nov. (see Fig. 9 for the equatorial section of the same specimen). A–G) Fulra Limestone, Kutch, west India, early Bartonian, SBZ 17. A) FUL.6-53, B) FUL.6-51, C) FUL.6-56, D) FUL.6-58, E) FUL.6-86, F) FUL.6-45, G) FUL.6-85. H–I) Drazinda Fm., Sulaiman Range, West Pakistan, early Bartonian, SBZ 17. H) RN.A.6-1, I) RN.A.6-2. J–M) Amravati Fm., Cambay Basin, west India, Middle Eocene. J) 178.5-13, K) 178.5-6, L) 178.5-14, M) 178.5-10.

Diagnosis. Medium sized (2 to 6mm), flat forms with numerous bulges. The bulges, uniformly distributed over the test surface, are semi-rounded and rounded in shape and range in size between 250 and 350µm. The embryon is large, with an average diameter of the deuteroconch ranging between 410 and 478µm, trybliolepidine to rarely umbilicolepidine in configuration. The equatorial chambers are typically

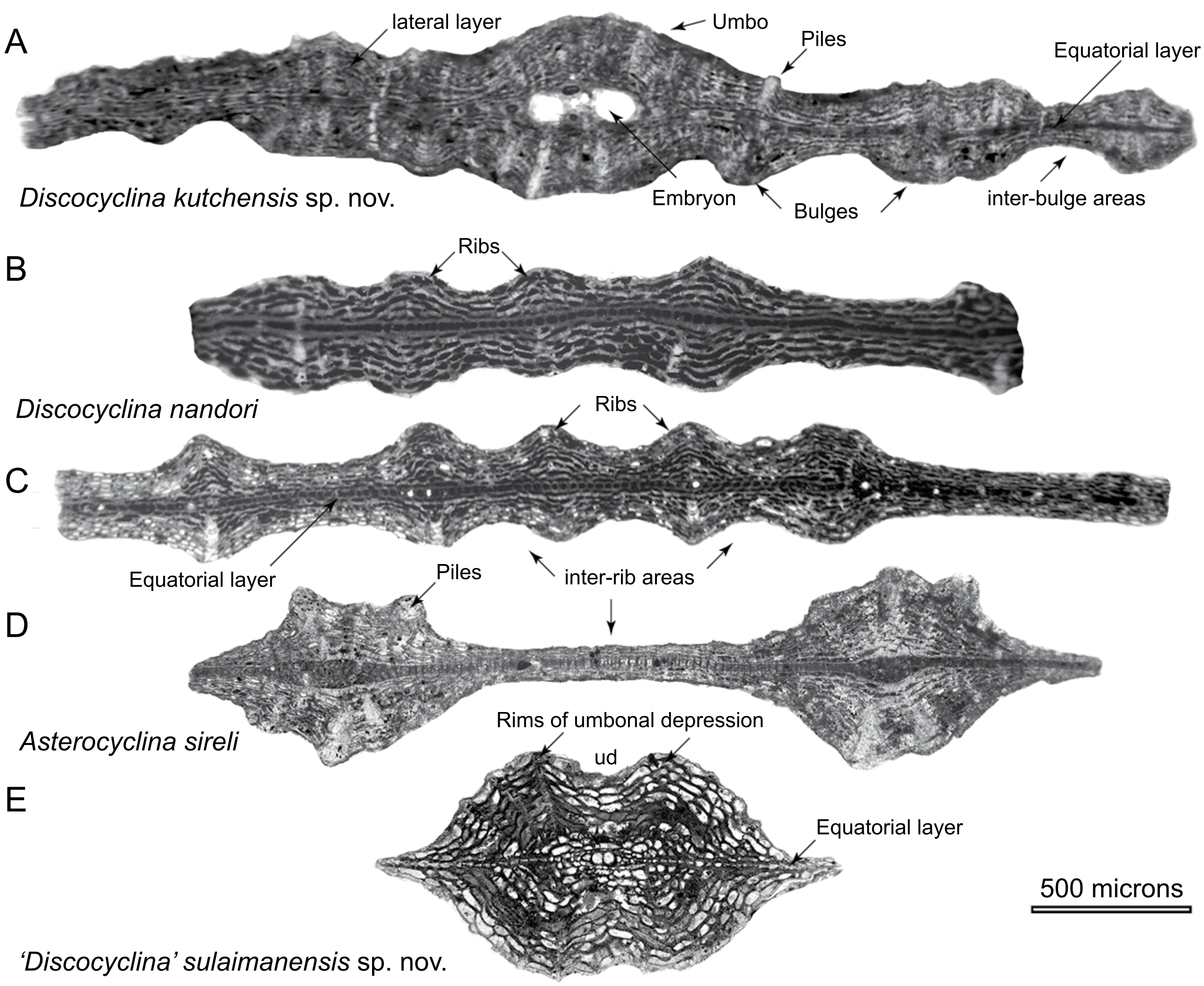

FIGURE 7. Axial sections comparing the bulges in A) *D. kutchensis* sp. nov., B-C) the ribs in *D. nandori* and D) *Asterocyclina sireli* and E) thickening of lateral layers in *'Discocyclina' sulaimanensis* sp.nov. The external view of the specimen in (E) is illustrated in Figure 5C note that axial thickening of equatorial layer in ribs is also incorporated by the axial subdivision of equatorial chambers in *A. sireli.* A) Fulra Limestone, Kutch, west India, early Bartonian, SBZ 17, FUL.6-127. B-C) Amravati Fm., Cambay Basin, west India, Middle Eocene, B) 178.5-2, C) 178.5-1. D) Fulra Limestone, Kutch, west India, early Bartonian, SBZ 17, FUL .8-1. E) Drazinda Fm., Sulaiman Range, west Pakistan, Bartonian, ZP.12-8.

high, narrow and are nearly circular in shape, and the chamberlet sare rectangular.

Derivation of name. Named after the Kutch district, west India, where the Fulra Limestone containing this species has extensive outcrops.

Holotype. The specimen FUL.6-86, a megalospheric form (Fig. 6E: TTM.P.İ-2016/21). The equatorial section of this specimen is illustrated in Figure 8B.

Paratypes. Specimens illustrated in Figures 6A-D, F-I; 8C-D; 9; 10A-D

Fig. 6A: TTM.P.İ-2016/24, Fig. 6B:TTM.P.İ-2016/23, Fig. 6C: TTM.P.İ-2016/25, Fig. 6D: TTM.P.İ-2016/26, Fig. 6F: TTM.P.İ-2016/22, Fig. 6G: TTM.P.İ-2016/29, Fig. 6H: TTM.P.İ-2016/31, Fig. 6I: TTM.P.İ-2016/32, Fig. 8C: TTM.P.İ-2016/30, Fig. 8D: TTM.P.İ-2016/23, Figs. 10A-B:TTM.P.İ-2016/24, Fig. 10C: TTM.P.İ-2016/27, Fig. 10D: TTM.P.İ-2016/28.

Type locality. Kutch District, Gujarat, north of Kharai village (23º29'20.19"N-68º41'45.90"E).

Type level. Middle part of the Fulra Limestone, sample FUL.6, about 2.3km NNE of Kharai village (Fig. 3C).

Material. 107 megalospheric and microspheric specimens sectioned for the equatorial, axial and tangential sections.

Geographic and stratigraphic distribution. This species is known from the early Bartonian of west Pakistan and west India (eastern Tethys).

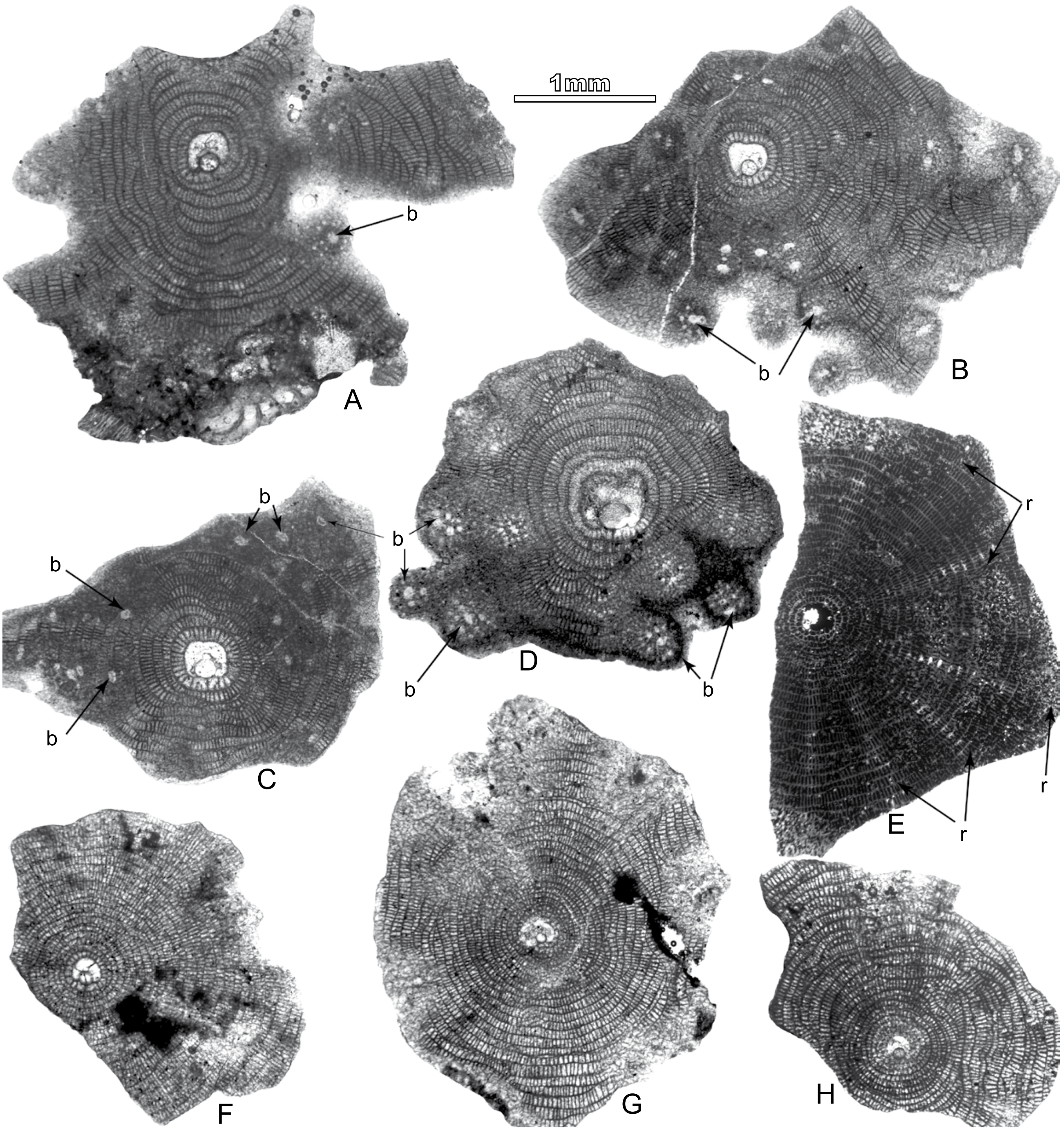

FIGURE 8. A-D) Sections through the equatorial layer of *D. kutchensis* sp. nov . Özcan and Saraswati, E-H) *D. nandori* Less. The specimen FUL.6-86 (B) is the equatorial section of the holotype of *D. kutchensis* sp. nov. illustrated in Figure 6E. Note that bulges (b) are exposed in B, C and D, where the section is off-centered. The position of the ribs (r) with respect to the equatorial layer in *D. nandori* is shown in E. A-D) Fulra Limestone, Kutch, west India, early Bartonian, SBZ 17. A) FUL.13-145, B) FUL.6-86, C) FUL.6-132, D) FUL.6-51, E) Amravati Fm., Cambay Basin, west India, Middle Eocene, 178.5-6. F-G) Drazinda Fm., Sulaiman Range, West Pakistan, early Bartonian, SBZ 17. F) RN.B.9-18, G) RN.B.9-20. H) Soğucak Fm., Thrace Basin, North-west Turkey, early Bartonian, SBZ 17, GIZ.12-56. b: bulges, r: ribs.

Repository. The holotype and paratypes, marked by TTM.P.İ-2016, are deposited in the Natural History Museum in the General Directorate of Mineral Research and Exploration of Turkey, Ankara.

Description. ***External features***. The discoidal test is almost flat with a well-marke dumbo with a diameter of 500–800μm. The test surface contains numerous bulges and pillars uniformly distributed. Bulges are semi-rounded

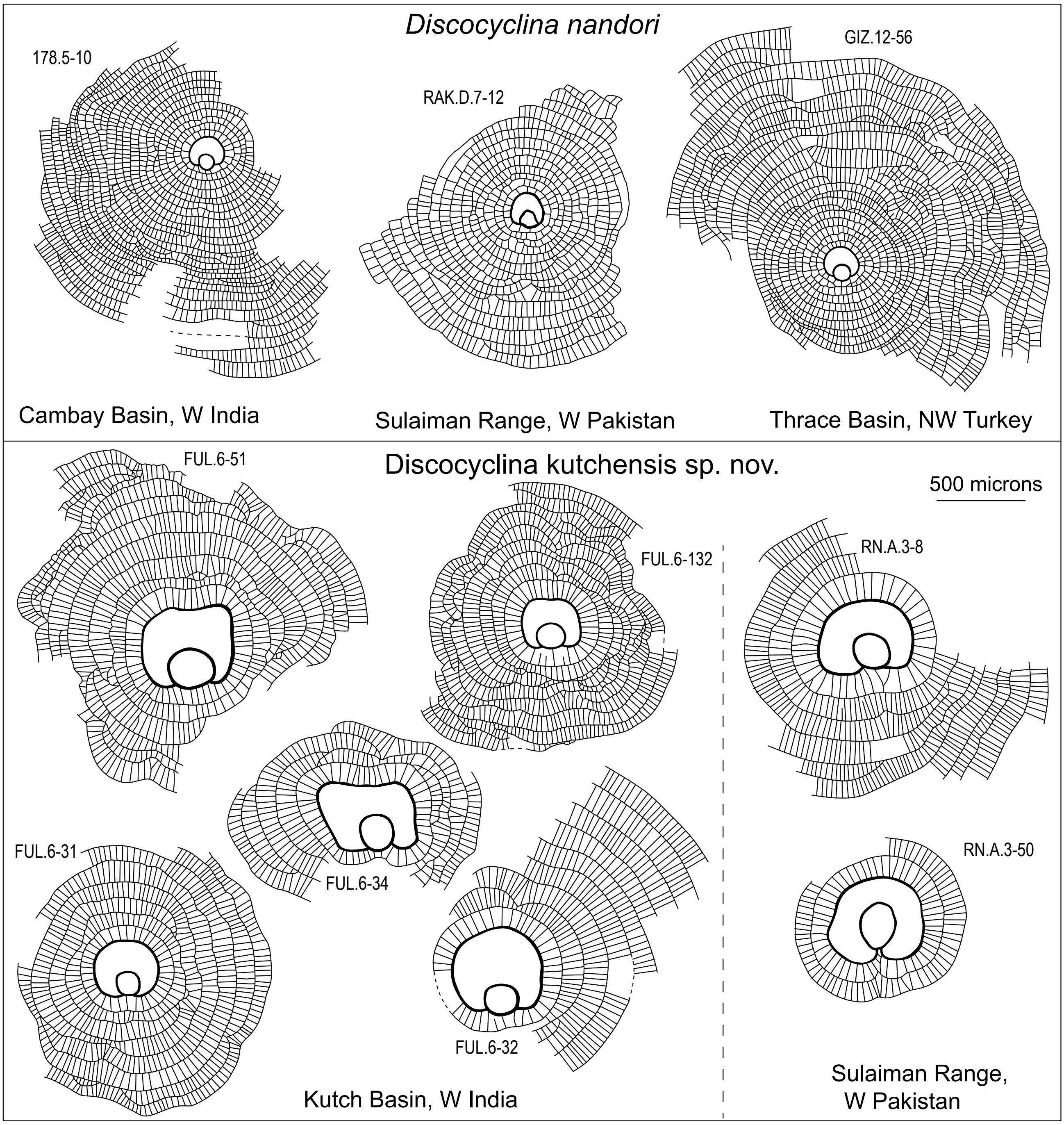

FIGURE 9. Comparison of the embryons and development of annuli and equatorial chamberlets in *D. nandori* and *D. kutchensis* sp. nov. Note that the bulges and ribs do not develop any wavy pattern in the annuli.

to rounded in shape, ranging from 250 to 350μm in diameter. Externally, the bulges are characterized by few central piles, about 70–80μm across, in megalospheric forms and about 90–110μm across in microspheric forms. The central piles are surrounded by smaller ones, varying in size from 25 to 50μm, arranged in circles (Figs. 8B-D; 10A-D). The piles are characteristically polygonal in shape.

Internal features. The embryon is large with an average protoconch and deuteroconch diameters ranging between 169μm and 203μm and 410μm and 478μm respectively (Table 1), commonly trybliolepidine and rarely umbilicolepidine in configuration. The equatorial layer consists of high chambers (annuli), about 100μm in size, circular or near circular in outline. No wavy pattern is observed. Incomplete chambers are common. The chamberlets are typically rectangular in shape.

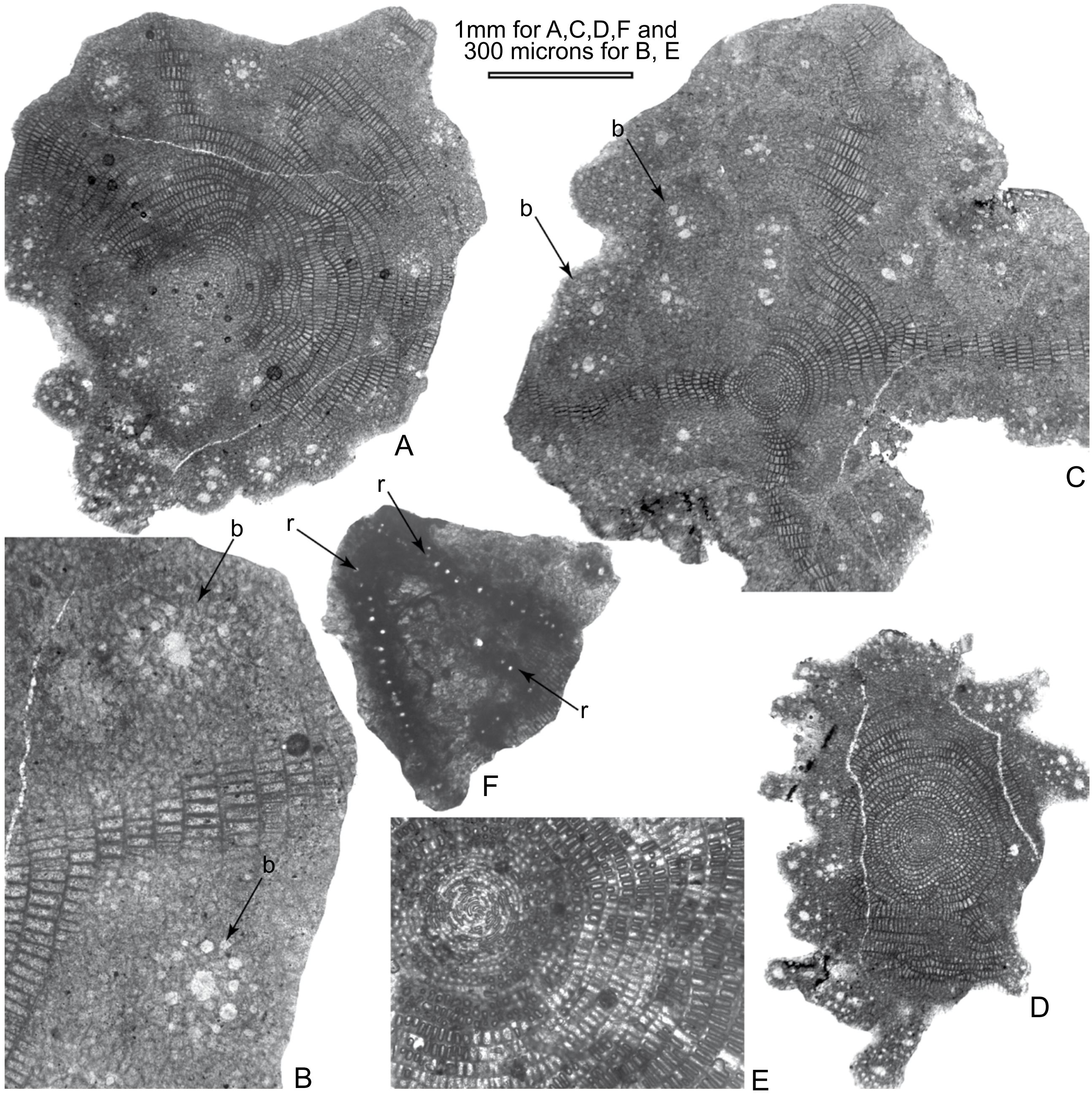

FIGURE 10. A-D) Microspheric forms of *Discocyclina kutchensis* sp. nov. ÖZCAN AND SARASWATI and E-F) *D. nandori* LESS showing discocyclinid type juvanarium and development of bulges and ribs. A-D) Fulra Limestone, Kutch, West India, early Bartonian, SBZ 17. A-B) FUL.6-53, C) FUL.6-59, D) FUL.6-61. E-F) Amravati Fm., Cambay Basin, west India, Middle Eocene, E: 178.5-8, F: 178.5-16. b: bulges, r: ribs.

Axial section. The embryon is about 100-110μm in height and slightly compressed at the site of proloculus. The equatorial layer is about 25-35μm in thickness and it maintains throughout the ontogeny. No thickening of the equatorial layer at the proximity of the bulges is observed (Fig. 7A).

Microspheric generation. Microspheric forms are common and display a typical discocyclinid juvenarium (Fig. 10 A-D).

Remarks. *D. kutchensis* sp. nov. and *Asterocyclina alticostata* with numerous ribs are associated in the Fulra Limestone and Drazinda Fm. Unlike many *Asterocyclina* species, *Asterocyclina alticostata* develops numerous ribs and externally may be confused with the Tethyan ribbed *Discocyclina* and *Orbitoclypeus* (Fig. 4B.10). We have observed that *A. alticostata* commonly builds up more than five ribs, but two specimens in the Fulra Limestone display up to ten ribs. In this unit, nine out of fifty-four specimens that were identified showed five ribs, while the other show more than five ribs. This may explains why Nuttall (1926) assigned these specimens to *Actinocyclina* and not to *Asterocyclina* in the original description of the species.

The occurrence of *D. kutchensis* sp. nov. in two widely separated regions of the Indian subcontinent suggests that bulges are not an ecologically determined character. Similar morpho-structures have not been recorded in comparatively well-studied western Tethys orthophragminids, where ribbed discocyclinids are represented by *D. radians* and *D. nandori*. The new species is associated with *D. nandori* in the Sulaiman Range, whereas in Fulra Limestone, *D. nandori* does not occur. Internally, *D. kutchensis* sp. nov. is very similar to *D. radians*, not recorded in eastern Tethys, in terms of embryon configuration, dimensions, development of equatorial chambers and shape. Tewari (1949) provided an external picture of a ribbed specimen with about more than twenty ribs from the Cambay Basin and assigned this specimen to *Actinocyclina* cf. *crassicostata* Douville. Our present study from the Cambay Basin reveals that such many ribbed specimens may belong to *D. nandori* Less.

'Discocyclina' sulaimanensis sp. nov. Özcan, Ali and Hanif
(Figs. 11-15; 16A-C)

Diagnosis. Test of small-sized, strongly inflated with a thick centrally-depressed umbo and an elevated ring-like structure. The small embryon consists of a rounded to nearly-rounded protoconch and semi-rounded slightly larger deuteroconch displaying a semi-isolepidine or nephrolepidine type configuration in equatorial sections. The pre-annular stage is characterized by notably large auxiliary chambers, elongated parallel to the common axis of embryonic chambers, and only few (commonly single) isolated adauxiliary chambers. The annuli are typically narrow in the early, and high in the late stage, and present a 'trabayensis' type growth pattern. The septulum are occasionally irregular and/or incomplete and partly in alignment in successive annuli. The equatorial chamberlets display annular and radial stolons, the former ones situated both on the proximal and distal side of the septulum. The piles (pillars) are coarser in the umbonal part, compared to flange. Moderately high and wide lateral chamberlets are arranged in irregular rows.

Derivation of name. Named after the Sulaiman Mountains, west Pakistan, where the Drazinda Formation is widely exposed in the Zinda Pir anticline.

Holotype. Specimen ZP.12-8, a megalospheric form (Fig. 11A;TTM.P.İ-2016/3).

Paratypes. Specimens illustrated in Figures 11B-C; 12A-E; 13A-E; 14; 15A, C-F; 16A-C; Fig. 11B: TTM.P.İ-2016/7, Fig. 11C: TTM.P.İ-2016/8, Figs. 12A-B: TTM.P.İ-2016/4, Fig. 12C: TTM.P.İ-2016/11, Fig. 12D: TTM.P.İ-2016/5, Fig. 12E: TTM.P.İ-2016/12, Fig. 13A: TTM.P.İ-2016/7, Fig. 13B: TTM.P.İ-2016/9, Fig. 13C: TTM.P.İ-2016/20, Fig. 13D: TTM.P.İ-2016/6, Fig. 13E: TTM.P.İ-2016/16, Fig. 15A: TTM.P.İ-2016/15, Fig. 15C: TTM.P.İ-2016/16, Fig. 15D: TTM.P.İ-2016/19, Fig. 15E:

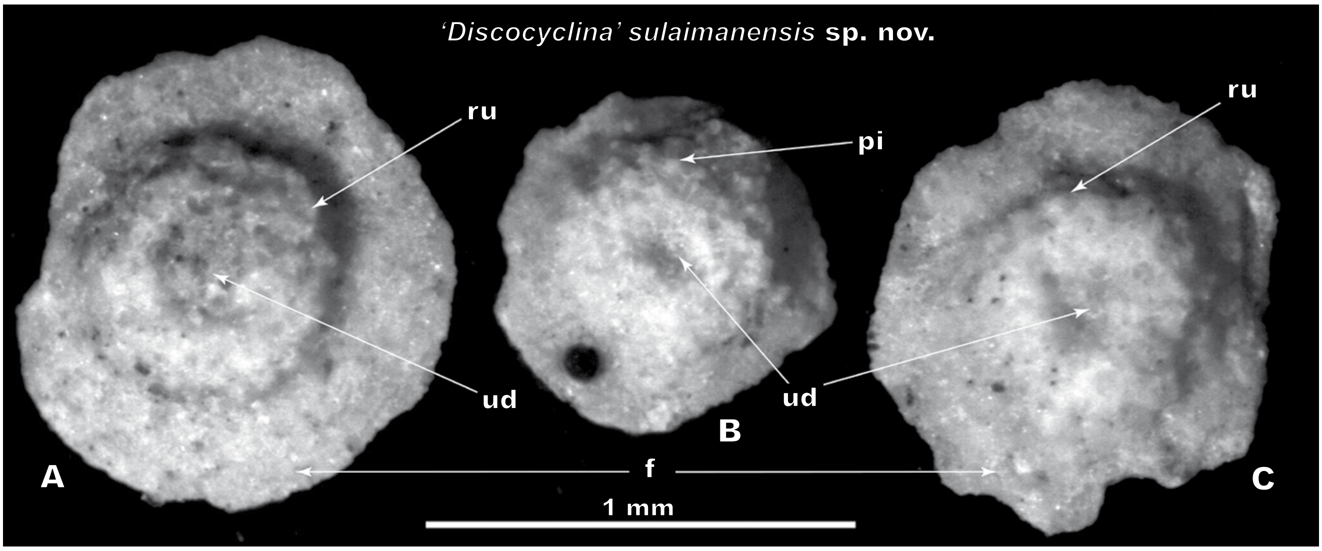

FIGURE 11. External views of *'D'. sulaimanensis* sp. nov. Note that the test of *D. sulaimanensis* sp. nov. is strongly inflated at the umbo (u), with a typical central depression (cd), u: umbo, ud: umbonal depression, ru: rim of umbo, pi: piles, f: flange. A) ZP.12-8, B) ZP.12-9 (see Fig. 13A for the equatorial section of this specimen), C) ZP.12-11, D) RN.B.9-50, E) RN.B.9-51.

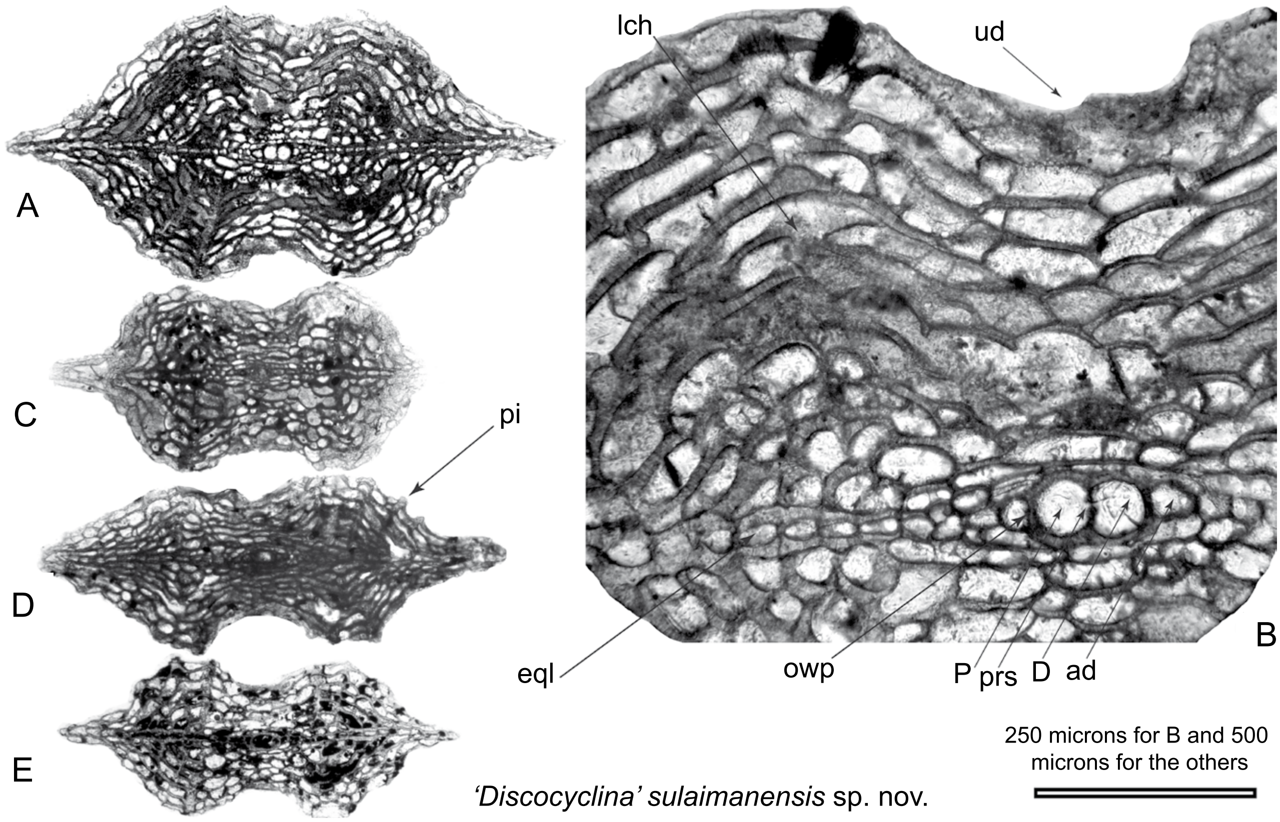

FIGURE 12. A-E) Axial sections of '*D'. sulaimanensis* sp. nov.. The protoconchal stolon (prs) in the center of the wall separating the protoconch and deutroconch is visible (B).Note that the proximal wall of the equatorial chamberlet placed directly on the outer wall of the protoconch (owp) is flattened and the equatorial chamberlets are sharply narrowing at their distal sides. The thickenings of the test are reminiscent of the axial thickening in ribs. A–B) ZP.12-1, C) ZP.12-23, D) ZP.12-3, E) ZP.12-24. P: protoconch, D: deuteroconch, ad: adauxiliary chamberlet, eql: equatorial layer, lch: lateral chamberlets, owp: outer wall of the protoconch, prs: protoconchal stolon, pi: piles, ud: umbonal depression.

TTM.P.İ-2016/14, Fig. 15F: TTM.P.İ-2016/17, Fig. 16A: TTM.P.İ-2016/10, Fig. 16B: TTM.P.İ-2016/13, Fig. 16C: TTM.P.İ-2016/18.

Type locality. Zinda Pir anticline, Dera Ghazi Khan, Punjab, west Pakistan.

Type level. Bartonian, lower-middle part of the Drazinda Fm., about 35km north-west of Dera Ghazi Khan, Punjab (Fig. 3A).

Material. 53 megalospheric specimens from samples ZP.10, 11, 12, RN.B.3 sectioned to obtain equatorial and axial sections.

Geographic and stratigraphic distribution. This species is only known from the early Bartonian of west Pakistan (eastern Tethys).

Repository. The holotype and paratypes, marked by TTM.P.İ-2016, are deposited in the Natural History Museum in the General Directorate of Mineral Research and Exploration of Turkey, Ankara.

Description. ***External morphology***. The test is small (700–1300μm in diameter) with a thick umbo, sharply demarcated and surrounded by a narrow, thin flange (Fig. 11A-C). The thickness of the test (350 to 610μm at the rims and 230 to 510μm in the depressed portion of the umbo) shows a remarkable variation because of greater development of lateral chamberlets at the rims (Fig. 12A-E). The piles are relatively larger in the rims of the umbo (40–50μm), compared to those in the flanges (15–20μm), and are evenly distributed over the test surface

Internal characters. The embryon is bilocular with a rounded to nearly- rounded protoconch and slightly larger deuteroconch exhibiting a semi-isolepidine or nephrolepidine- type embryonic configuration in the equatorial sections. The embryon is small, with protoconch and deuteroconch diameters varying from 35 to 50 and 50 to 75μm, respectively (Table 2). The embryonic chambers are connected by a single, centrally located stolon on the protoconchal wall (Figs. 12B; 14: specimen ZP.10–5). The development of the chambers in the equatorial layer is differentiated into two stages in regard to the formation of the

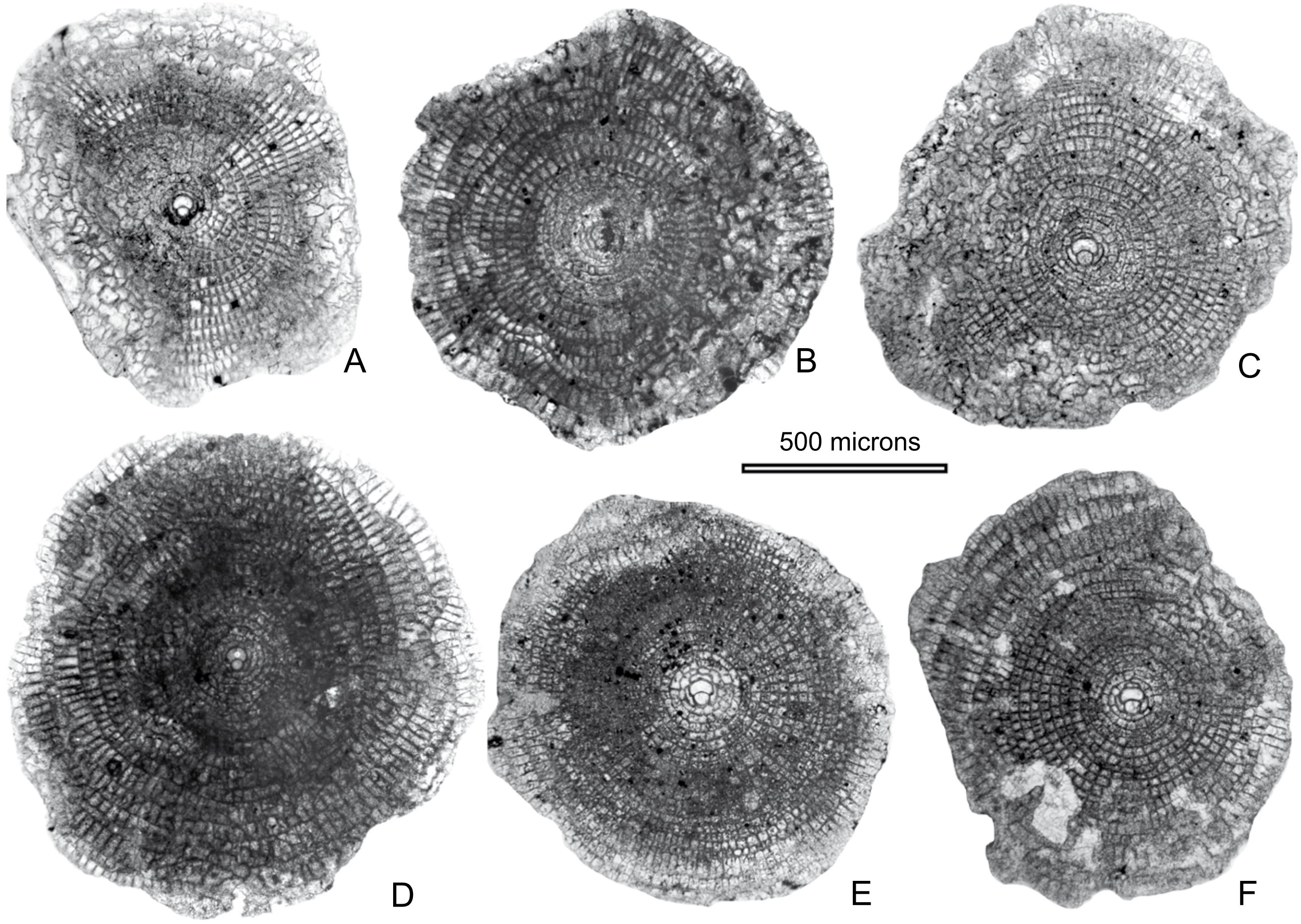

FIGURE 13. Equatorial sections of *'D'. sulaimanensis* sp. nov. A) ZP.12-9, B) ZP.12-16, C) ZP.11-7, D) ZP.12-6, E) ZP.10-11, F) ZP.10-8.

first annular chamber. The pre-annular stage includes both auxiliary and adauxiliary chambers with their characteristic shapes and various types of chamber arrangement in the equatorial layer. The annular stage includes typical annular chambers. Two large auxiliary chamberlets at the junction of the protoconch and deuteroconch are easily marked by being tangentially elongated. These chambers, along with adauxiliary chamberlets, differ from the later chamberlets in having greater tangential diameter (45–80µm) and arcuate distal sides (Figs. 14-16). The number of adauxiliary chamberlets, their shapes and relation to the auxiliary and succeeding annular chambers are variable. In some specimens, a complete or incomplete annular chamber may be formed in the next step after the auxiliary chamberlets in the absence of any single, prominent adauxiliary chamberlets (Fig. 14: specimen ZP.11-4, ZP. 10-5; Fig. 15D). Most specimens possess a single, tangentially elongated adauxiliary chamberlets (Fig. 14; 15A-C, F), while in some, a few adauxiliary chamberlets were noted (Fig. 15E). A spiral development between these and auxiliary chamberlets is not recorded. The first annulus is usually formed after this stage (3rd growth stage), but occasionally it may be formed at 4th stage (Fig. 14: specimen ZP.11-4). The annuli are regular and circular in outline. The chamberlets are narrow, square in shape in the early stage, and high and rectangular in the late stage, and present a 'trabayensis' type growth pattern. The septulum in the peri-embryonic annular chambers is often irregular and/or incomplete (Figs. 14-16) and more regular in the later chambers. The septula in the successive chambers usually appear to be aligned (Figs. 13; 15). Some kind of rounded structures in the form of 'dots' or 'commas', possibly corresponding to the thickened parts of the septulum, are observed in some specimens (Figs. 14-16). The septulum in the later chambers is more regular and straight, and usually alternating in the successive annuli (Fig. 16C). Both annular and radial stolons connecting the chamberlets of the same annulus and the successive chambers are observed in equatorial sections. The annular stolons are situated both on the proximal and distal sides of the septulum (Fig. 16B-C).

Axial section. The test forms a central depression that occupies a significant portion of the umbo. The embryon

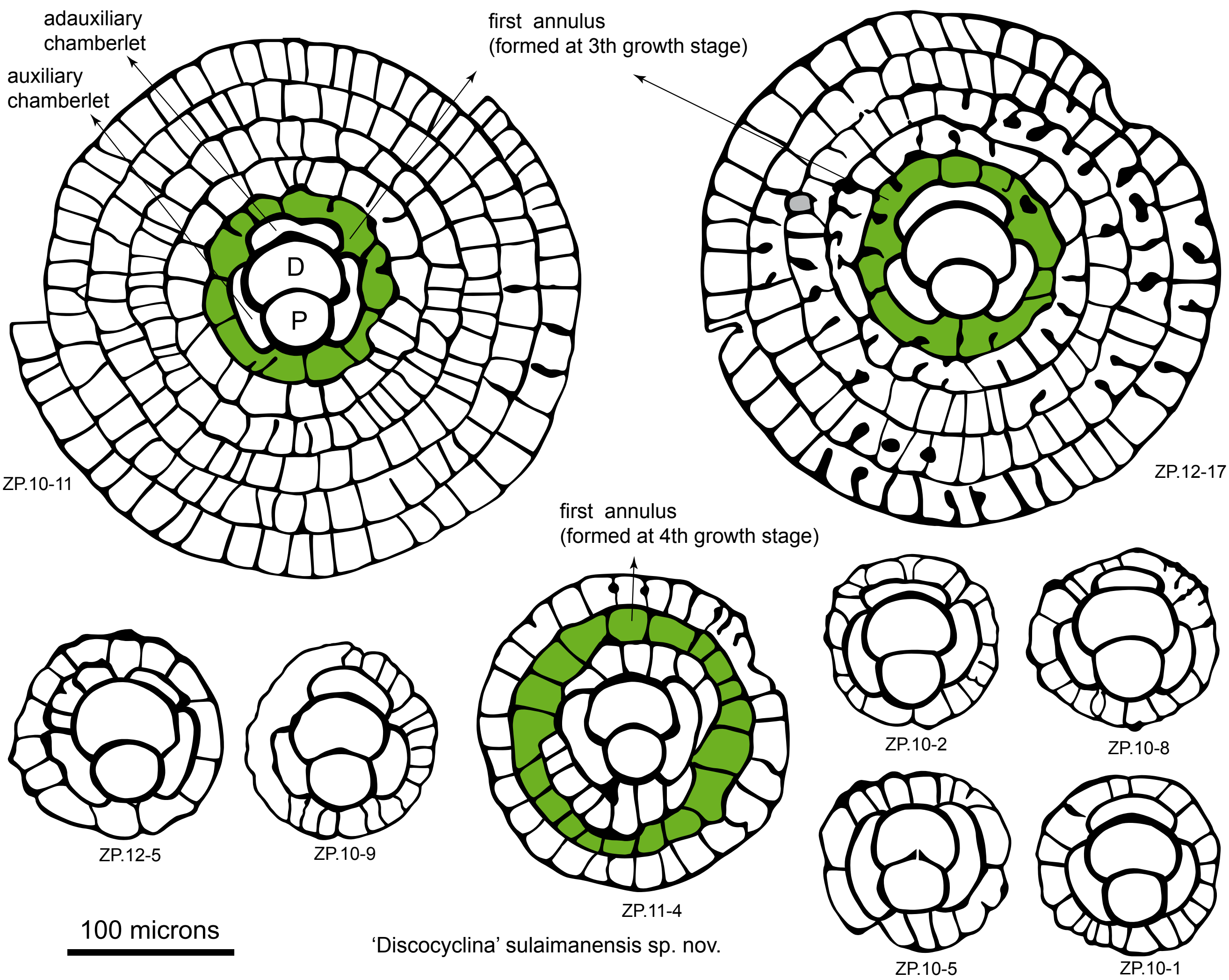

FIGURE 14. The embryon and development of annuli and equatorial chamberlets in *'D'. sulaimanensis* sp. nov.

is small, with a flat protoconchal wall with respect to the equatorial layer at its proximal side (Fig. 12B). The equatorial layer is thin, 25-35µm including the wall. The thickness of these chambers, however, is about 10-15µm excluding the wall. The lateral chambers are significantly large and wide and do not form a regular pattern.

Remarks. '*D*'. *sulaimanensis* differs from other omphaloid taxa from the Tethyan and Caribbean Provinces (*e.g. Discocyclina omphalus, D. praeomphalus, Proporocyclina penonensis* and *Stenocyclina advena*) in having a much smaller flat test, a more pronounced umbonal depression, a smaller embryon, and a completely different development of early chambers. The early chamber arrangement of this species belongs to new type since the few Tethyan species possessing axially elongated auxiliary chamberlets and few isolated adauxiliary chamberlets (*e.g. Nemkovella daguini*) also develop spiral chambers between the auxiliary and adauxiliary chamberlets before the onset of annular growth (Özcan *et al.*, 2006). However such chambers are not observed in the new species and usually an annular chamber with typical square-rectangular chamberlets are formed immediately following the adauxiliary chamberlets.

STATUS OF THE NEW SPECIES IN THE TETHYS AND BIOGEOGRAPHIC INFERENCE

The bulges represent the axial thickening in the lateral layers in a similar way to what it has been reported in the ribbed species of Discocyclinidae (*e.g. D. radians* (Gümbel, 1870), *D. nandori* Less, 1987 and *Nemkovella rota* Ferràndez-Cañadell, 1997). Nevertheless, bulges are rounded to semi-rounded structures, differentiated from the ribs by their distinct surface expressions, also forming an uneven test surface. All specimens with bulges have similar internal characteristics, such as a similar type of

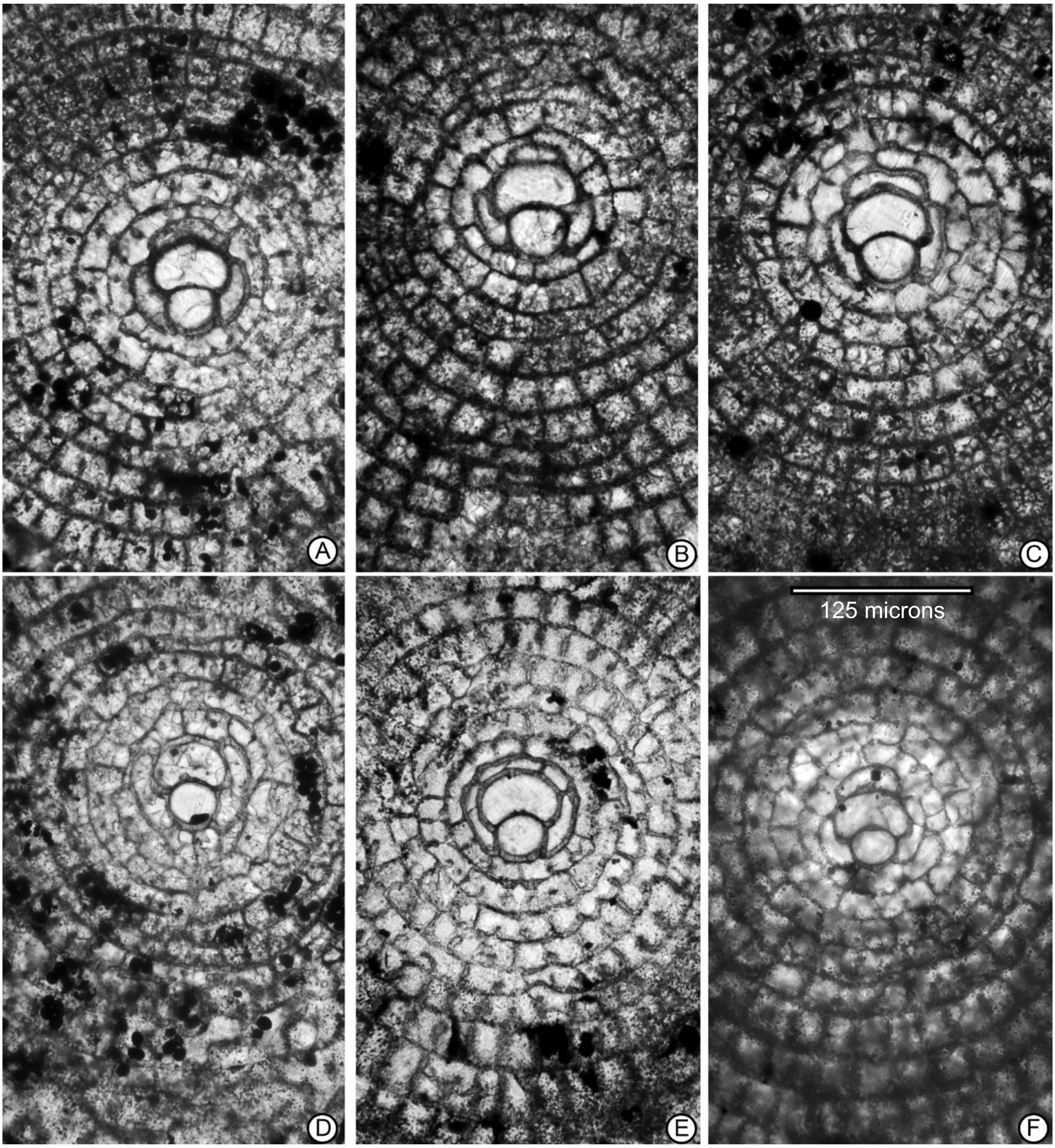

FIGURE 15. Close-up view of the embryon and early chambers in *'D'. sulaimanensis* sp. nov. A) ZP.10-1, B) ZP.10-8, C) ZP.10-11, D) ZP.11-4, E) ZP.12-31, F) ZP.11-1.

embryonic configuration and equatorial chambers (narrow, and axially elongated), suggesting that they represent a single homogenous population and species. Ribs are considered significant structures at species-level in western Tethyan taxa. We hypothesize that bulges are also a specific character independent from ecological parameters. Their occurrence in specimens from two widely separated regions of the Indian subcontinent suggests that this feature could be genetically determined. The exclusive occurrence of the new species with bulges, *Discocyclina kutchensis*, in the Indian subcontinent is of significance for the paleobiogeography of the orthophragminids exhibiting axial thickening. The orthophragminids further east of the Indian subcontinent have not been studied

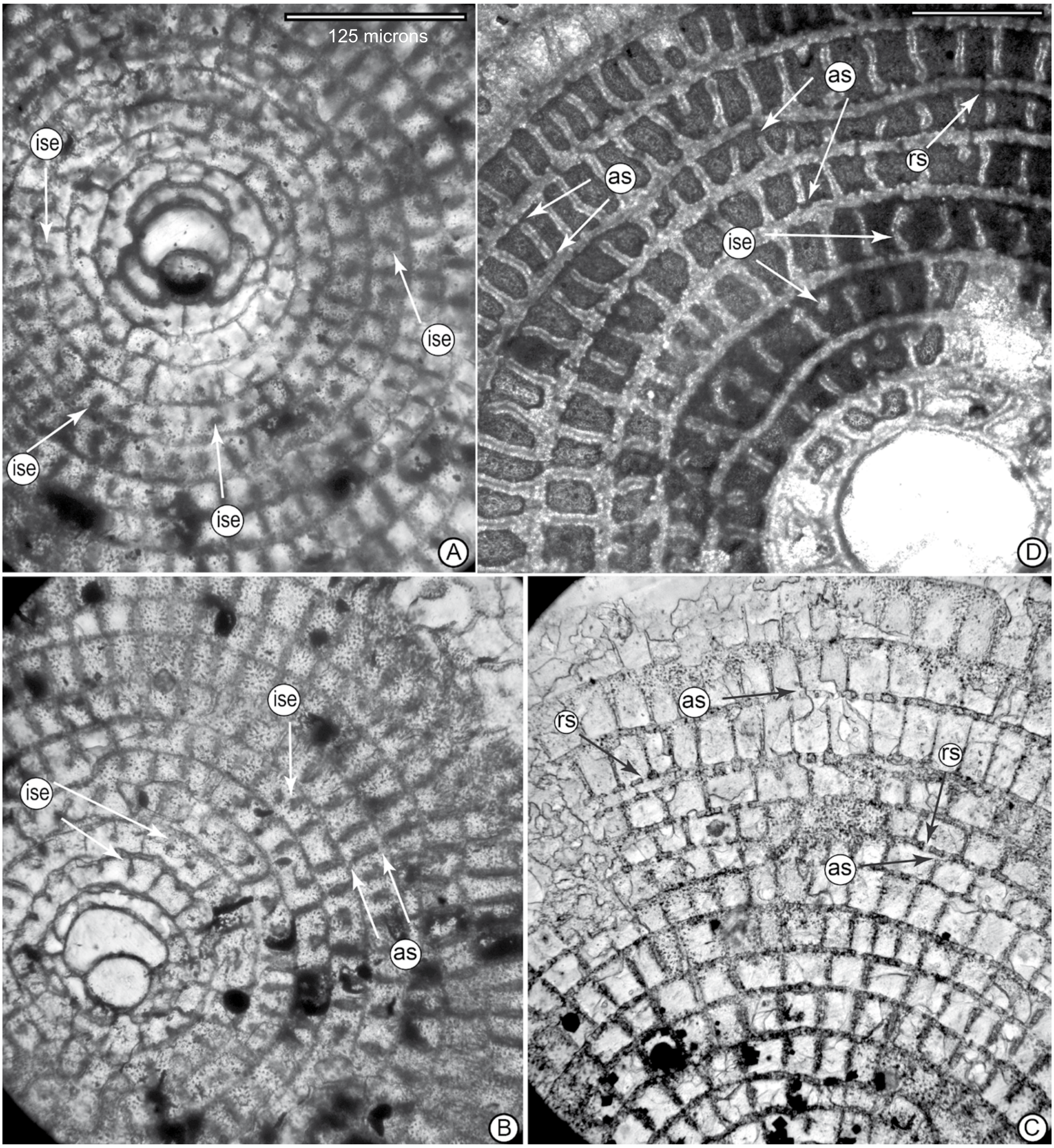

FIGURE 16. A–C) The equatorial sections of *'D'. sulaimanensis* sp. nov. and D) *Proporocyclina* sp. from (late?) Middle Eocene of Jamaica, Caribbean Province. A) ZP.12-17, B) ZP.12-28, C) ZP.11-2, D) 2044-17: 'Chapelton' Fm., Bamboo region, north Jamaica. The incomplete and/or irregular septulum (ise) is commonly observed in the first several annuli of *'D'. sulaimanensis* sp. nov. and in genus *Proporocyclina*. The radial and annular stolons in *'D'. sulaimanensis* sp. nov. are shown (B-C). ise: incomplete/irregular septulum, as: annular stolon, rs: radial stolon.

systematically and therefore our paleobiogeographic conclusions are provisional.

Omphaloid specimens occur both in the eastern Tethys and Caribbean provinces and are represented by large tests, while in eastern Tethys, they are also commonly saddle-shaped (Cole and Gravell, 1952; Samanta, 1964). These forms display trybliolepidine to- umblicolepidine large embryons and numerous adauxiliary chamberlets. In spite of general thickening of the test near the depressed central part, in axial sections, these forms do not reveal any localised thickening that could be confused with ribs and bulges. The new omphaloid species, '*Discocyclina*' *sulaimanensis* sp. nov., has a characteristic small test, a small embryon and a new type of early chamber arrangement that makes it different from any omphaloid species in the Tethys and Caribbean region. It shows some resemblance to certain Caribbean taxa, such as the species of the genus *Proporocyclina* VAUGHAN AND COLE, 1941, in having an irregular and/or incomplete septulum in the early chambers. Such irregular/incomplete septulum has not been recorded in the western Tethys, while these characters have a generic-level significance in the classification of Caribbean orthophragminids. Septula are absent in *Athecocyclina* (Vaughan, 1929) and they are incomplete and/or irregular in *Proporocyclina* (Caudri, 1996) (Fig. 16D). The omphaloid specimens from the Drazinda Fm. deserve a new status based on their peculiar early chambers before the beginning of the annular stage and also other external and internal features. In the absence of microspheric specimens, a proper generic assignment is not possible. We provisionally assigned these forms to '*Discocyclina*' based on the presence of annular stolons and rectangular chamberlets, the former feature being only seen in the Tethyan species of the genus *Discocyclina*.

CONCLUSIONS

i) The Bartonian orthophragminids of the Indian subcontinent (eastern Tethys) are characterized by various types of axial thickenings in the test not described previously. Among them, a group of specimens possesses localized, rounded to semi-rounded external structures, regularly distributed over the uneven test surface. These structures, named 'bulges', are formed solely by the greater development of lateral chamberlets and thus, their differentiation from each other is not straightforward in the axial sections. The discocyclinids with bulges, assigned to *D. kutchensis* sp. nov. after the discocyclinid juvenarium of the microspheric forms, are associated with the ribbed species *D. nandori* in the Drazinda Fm. in Pakistan, while the latter species has not been recorded in Fulra Limestone in India. *D. nandori* occurs abundantly in Amravati Fm. (age equivalent of the Fulra Limestone and lower part of the Drazinda Fm.) in Cambay Basin in India. The occurrences of specimens with bulges in two paleogeographically distant parts of the Tethys suggest that bulges are a specific character but not an ecologically induced feature.

ii) The Bartonian orthophragminids in the Sulaiman Range include some omphaloid specimens with notably small, thick tests, deeply depressed in the central part of the umbo. Externally, these omphaloid specimens differ from other similar forms in the Tethys and Caribbean Province in having a more pronounced central depression and its prominent ring-like thickening in the depressed portion of the test. Although this structure is easy to recognize externally, it is observed as the thickening of the lateral layers in the axial sections, which may be easily confused with bulges and ribs. These specimens, with small semi-isolepidine to nephrolepidine embryon consistently develop axially elongated auxiliary chamberlets and reveal a variable arrangement of the early chambers/chamberlets before the onset of annular chambers. Incomplete to irregular septula, a feature observed in some Caribbean genera/species, occur in some of the early chambers. In the absence of microspheric forms, a generic assignment is not possible, however, based on the presence of annular stolons, these specimens are loosely assigned to '*Discocyclina*' and a new species, '*D*'. *sulaimanensis* sp. nov. is erected.

iii) The new orthophragminid test structures and species are significant for the paleobiogeography of the Bartonian orthophragminids since they appear to be confined to the Indian subcontinent (eastern Tethys). Our record suggests that incomplete/irregular septula is not a feature confined to certain species of the Caribbean Province. As the composition of the Eocene orthophragminids in the Pacific domain is poorly known, and specific studies on Pacific orthophragminid are lacking, a synthesis covering regions further east of the Indian subcontinent is not possible yet.

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