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Bartonian orthophragminids with new endemic species from the Pirkoh and Drazinda formations in the Sulaiman Range, Indus Basin, Pakistan

Nowrad Ali^{a,c}, Ercan Özcan^b, Ali Osman Yücel^b, Muhammad Hanif^c, Syed Irfanullah Hashmi^a, Farhat Ullah^a, Muhammad Rizwan^c  and Johannes Pignatti^d

^aDepartment of Geology, University of Peshawar, Peshawar, Pakistan; ^bDepartment of Geological Engineering, Faculty of Mines, İstanbul Technical University (İTÜ), İstanbul, Turkey; ^cNational Centre of Excellence in Geology, University of Peshawar, Peshawar, Pakistan; ^dDipartimento di Scienze della Terra, Università degli Studi di Roma 'La Sapienza', Rome, Italy

ABSTRACT

The Pirkoh and Drazinda formations in the Sulaiman Range, central Pakistan, yielded assemblages of (early) Bartonian orthophragminids, characterized predominantly by discocyclinids with a significant number of species probably endemic to Indian Subcontinent. The rarity of *Asterocyclina* and the absence of *Orbitoclypeus* and *Nemkovella* are noteworthy. Ten species of *Discocyclina* Gümbel and two species of *Asterocyclina* Gümbel, referable to the Shallow Benthics Zone (SBZ) 17 are described for the first time from Pakistan. The discocyclinids, i.e. *Discocyclina praeomphalus*, *D. sulaimanensis*, *D. kutchensis*, along with the new taxa established here, *D. zindapirensis* sp. nov., *D. rakhinalaensis* sp. nov., and *D. pseudodispansa* sp. nov., seem to be confined to the Indo-Pakistani region (Eastern Tethys). The *Discocyclina dispansa*, *D. discus*, *D. nandori*, and *D. augustae* lineages known from Western Tethys are also common in the Indian Subcontinent, as are asterocyclinids, such as *Asterocyclina sireli* and *A. stellata*. The upper part of the Drazinda Formation ('*Pellatispira* beds'), referable to latest Bartonian and/or the early Priabonian, is poor in orthophragminids and is characterized by the occurrence of reticulate *Nummulites*, *Heterostegina*, *Pellatispira* and *Silvestriella*. The records of '*Lepidocyclina* of Caribbean affinity' with large embryos from the Eocene of the Indian Subcontinent correspond to misidentified *Discocyclina discus*.

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orthophragminids;
taxonomy; Sulaiman range;
Pakistan

1. Introduction

The Upper Paleocene-Eocene platform/shelf deposits along the margins of Gondwana and Laurasia, from Europe (Western Tethys) to the Indian Subcontinent and China (Eastern and Central Tethys) (Figure 1) are characterized by the widespread deposition of carbonate units with diagnostic biota. Larger benthic foraminifera (LBF), such as nummulitids, orthophragminids, alveolinids and rotaliids, constitute the dominant faunal element in these deposits (Afzal, Williams, Leng, Aldridge, & Stephenson, 2011; Hottinger, 2014; Racey, 1995; Schaub, 1981; Serra-Kiel et al., 1998; Zhang, Willems, & Ding, 2013), which are generally referred to as 'Nummulitic limestone'. The middle Eocene shallow-marine deposits with prolific development of LBF are exposed in some parts of the Indian Subcontinent: in the Sulaiman and Kirthar ranges in Pakistan, Kutch and Cambay basins in western India, and in the Assam-Meghalaya regions in eastern India (Eames, 1952a, 1952b; Nagappa, 1959; Nuttall, 1926; Özcan, Saraswati, Hanif, & Ali, 2016 and references therein; Özcan et al., 2016; Samanta, 1968; Samanta & Lahiri, 1985). In the Sulaiman Range, to the west of

Himalayas, the middle Eocene deposits, informally named 'Discocyclina beds', are known for the abundant occurrence of orthophragminids and nummulitids and also for the remains of sea cows and archaeocete whales, described from the Drazinda Formation (Gingerich, Arif, Bhatti, Anwar, & Sanders, 1997 and references therein). Although the Bartonian orthophragminids from the Kutch Basin and Assam-Meghalaya region in India have been fairly well studied at generic and species level, no thorough account of this group from Pakistan has been presented yet (Afzal, Asrar, & Naseer, 1997; Afzal, Williams, & Aldridge, 2009). Previous studies from the Bartonian Pirkoh and Bartonian-Priabonian Drazinda formations (equivalent of the obsolete Kirthar series) in the Sulaiman Range reported the occurrence of a few species of *Discocyclina* Gümbel, 1870 without any record of *Nemkovella* Less, 1987, *Orbitoclypeus* Silvestri, 1907, and *Asterocyclina* Gümbel, 1870. This is in contrast to the diverse orthophragminid assemblages from coeval deposits in the peri-Mediterranean region (Western Tethys), where more than fifteen species are known in the Bartonian (Ben Ismail-Latrache et al., 2014; Less,

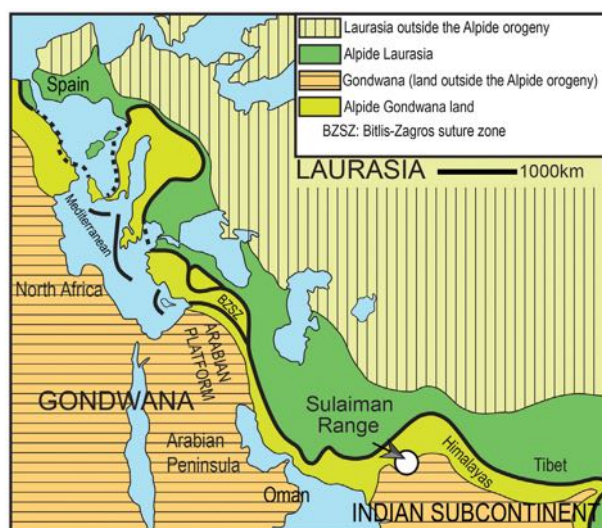


Figure 1. Tethyan mountain ranges and location of Sulaiman Range in Pakistan.

1998). The Pirkoh and Drazinda formations offer a unique opportunity to characterize the Bartonian orthophragminids from this part of Tethys that may help integrating the current shallow benthic zonation and the correlation of Tethyan shallow-marine deposits. Our aim here is to describe the orthophragminids from the Pirkoh and Drazinda formations in detail. The nummulitids and other LBF, which are in many horizons, will be published separately.

2. Geological setting and stratigraphy

The Sulaiman fold belt is a lobate structure in East Pakistan that constitutes a major part of the Lower Indus Basin to the south of the suture zone of the India-Eurasia collision (Kazmi & Rana, 1982; Shah, 2009) (Figures 1 and 2). A marine transgression in middle Eocene influenced a large area including the Lower Indus Basin, leading to the deposition of a thick sequence of shallow-marine carbonates and clastics. These deposits preserve a record of marine mammals (archaeocete whales), decapod crustaceans and abundant LBF (Afzal et al., 1997; Charbonnier et al., 2013; Gingerich, Ul-Haq, Khan, & Zalmout, 2001; Schweitzer, Feldmann, & Gingerich, 2004). The significance of the marine Bartonian and Priabonian deposits in the frame of the tectonic evolution of the region is, however, debated. 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 a post-collisional epicontinental sea. In contrast, these deposits underlying the continental Oligocene sequence have been also interpreted to record the final stages of the diachronic closure of Tethyan seaway in Priabonian times in the Lower Indus Basin (Kazmi & Abbasi, 2008).

The middle to upper Eocene sedimentary sequence in the Sulaiman Range is subdivided into the Habib Rahi, Domanda, Pirkoh and Drazinda formations, which

were collectively named as 'Kirthar' by Blanford (1879) (Figure 3). The historical development of the lithostratigraphic names applied to these units is given in Hemphill and Kidwai (1973), Kazmi and Abbasi (2008) and Shah (2009). The Domanda Formation corresponds to the Lower Chocolate beds of Eames (1952a) and consists of dark-brown and greenish-gray mudstone with subordinate brown sandstone intercalations consisting of limonitic concretions and phosphatic nodules. Bivalves and echinoids occur in some levels. The unit is well known for vertebrates, specifically for archaeocete whales (Gingerich et al., 1997, 2001), Sirenia and decapod crustaceans (Charbonnier et al., 2013; Zalmout, Ul-Haq, & Gingerich, 2003), while LBF are very sporadic and not studied at the present work. The thickness of the unit ranges from 150 to more than 300 m in the Sulaiman Range. The Pirkoh Formation is light gray to brown, thinly bedded carbonate unit containing subordinate beds of shaly limestone and dark gray marls. This unit, about 10–12 meters thick, consists of mainly nummulitids, orthophragminids, and scarce alveolinids and forms a persistent ridge in Sulaiman Range (Figure 4). The term 'Drazinda Shale Member' of the Kirthar Formation was introduced by Hemphill and Kidwai (1973) to replace the 'Upper Chocolate Clays' of Eames (1952a), who first established a robust Eocene lithostratigraphic framework for the Sulaiman fold belt. The Drazinda Formation, more than 380 and 300 m thick in Rakhi Nala and Zinda Pir respectively, consists of dark-brown to greenish-gray shale and subordinate marl and limestone beds containing LBF, bivalves, bryozoans and echinoids in its lower and middle, and pale yellowish-green *Pellatispira*-bearing marls in the upper part. Orthophragminids occur abundantly in the lower-middle part of the Drazinda Formation while upper part yields mostly nummulitids, such as *Heterostegina*, reticulate *Nummulites*, and *Pellatispira*. This unit records the final stage of an Eocene marine environment in the region and its outcrops can be traced long distances in the eastern Sulaiman fold belt. The Drazinda Formation is unconformably overlain by coastal deltaic to fluvial deposits of the Oligocene Chitarwatta Formation.

The ages of the Pirkoh and Drazinda formations were previously dated as Middle and/or late Middle and Late Eocene based on calcareous nannofossils (Köthe, Khan, & Ashraf, 1988) and planktonic foraminifera (Afzal et al., 1997; Samanta, 1973; Warraich & Nishi, 2003). According to Köthe et al. (1988), the age of Pirkoh and Drazinda formations in the Rakhi Nala section is Middle Eocene to Priabonian based on nannoplankton zones NP 15-16? in the former and 16-19/20 in the latter unit. Samanta (1973) recorded *Globorotalia crassata*/ *Truncorotaloides topilensis*, *Truncorotaloides rohani* and *Globigerina officinalis* zones in the 'Upper Kirthar' Formation in the Rakhi Nala section. Since Samanta (1973) did not follow the conventional lithostratigraphic nomenclature of lithostratigraphic unit at that time, a correlation of these

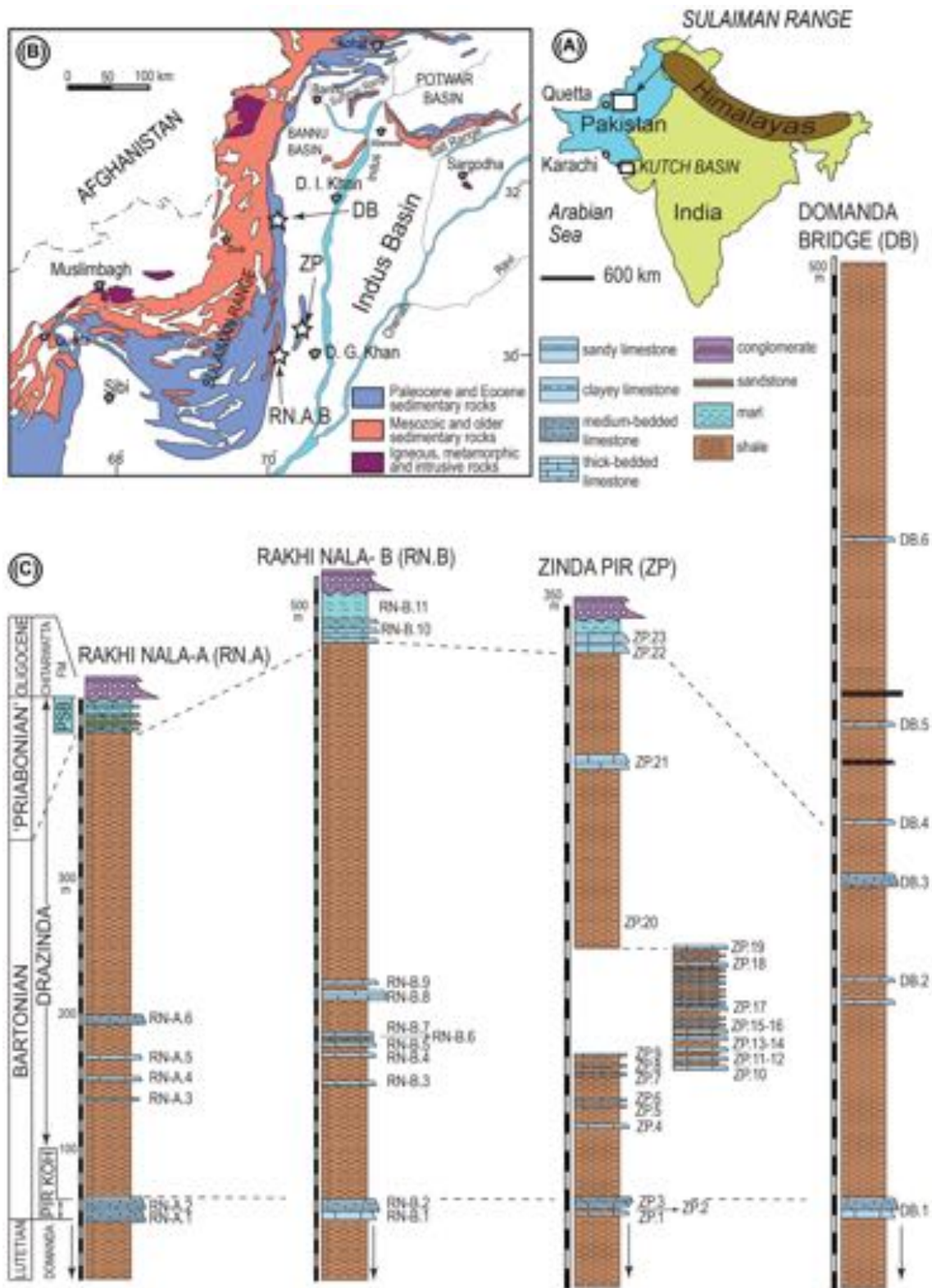


Figure 2. Location of Sulaiman Range in Pakistan to the west of Himalayas (A), simplified geological map of the Sulaiman Range and position of the studied sections (B), and generalised stratigraphic sections and sampling points in the Pirkoh and Drazinda formations (C). Geological map is simplified from Kazmi and Rana (1982). PSB: *Pellatispira* beds.

zones to the presently accepted units is not possible. Nevertheless, his data suggest late Middle to Late Eocene age for the succession in Raki Nala Section. Afzal et al. (1997) identified P12/13 and P14 planktonic foraminiferal zones in Pirkoh and Drazinda formations respectively,

suggesting a transitional Lutetian-Bartonian age for Pirkoh and (early) Bartonian for the part of the Drazinda Formation below the *Pellatispira* beds. Warraich and Nishi (2003) identified P12 in Pirkoh and P13-15 planktonic foraminiferal zones in the Drazinda Formation that

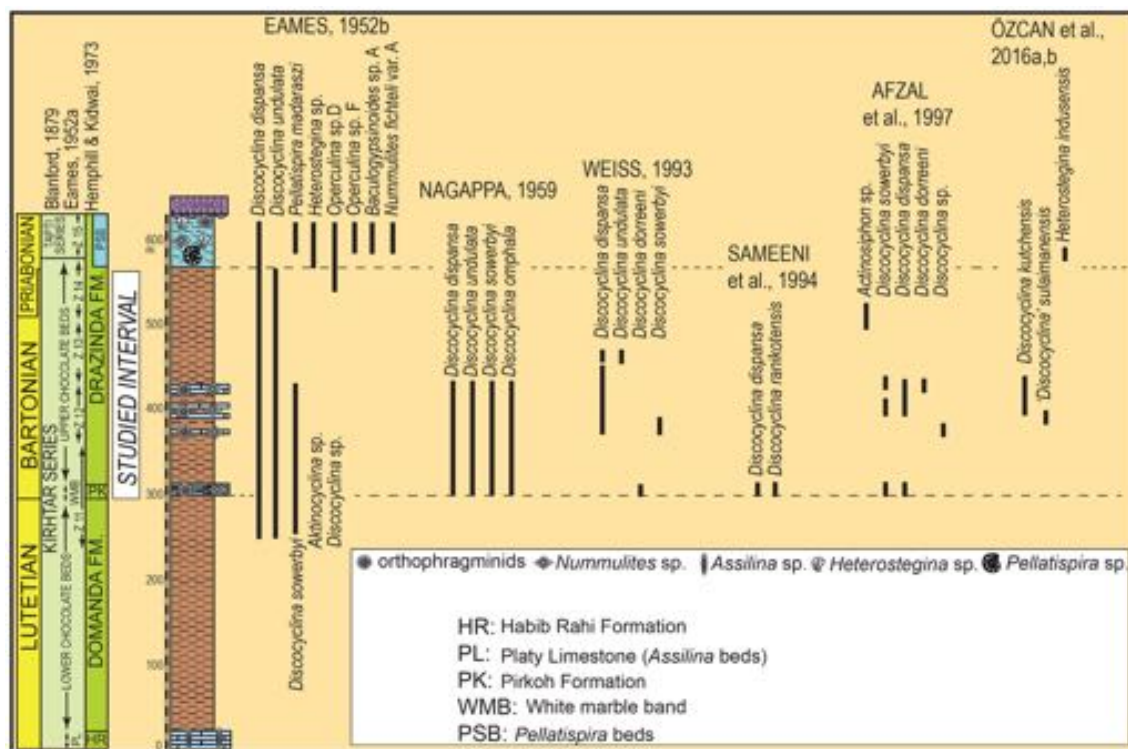


Figure 3. Generalised stratigraphy of Lutetian to Priabonian units in the Sulaiman Range with historical development of lithostratigraphic nomenclature and previous records of orthophragminids and associated LBFs. The studied interval is marked. Z refers to the 'zones' described by Eames (1952b).

suggest a Lutetian/Bartonian-Priabonian age for this part of the sequence. The upper part of the Drazinda Formation, the *Pellatispira* beds, yielded NP18-19/20 calcareous nannofossil assemblages in the Rakhi Nala section suggesting Priabonian age (Köthe et al., 1988). The Pirkoh Formation was deposited in the inner to outer shelf, and the bulk of the Drazinda Formation has been deposited in the shelf lagoon and shoal environments. The '*Pellatispira* beds' of the Drazinda Formation have been deposited in the outer shelf (Abbas, 1999).

3. Previous records of orthophragminids in Pirkoh and Drazinda formations

Although orthophragminids have been reported from the Pirkoh and Drazinda formations, only few species have been illustrated (Afzal et al., 1997; Nagappa, 1959; Sameeni, Ahsan, & Baloch, 1994; Weiss, 1993). The discocyclinids were identified as *Discocyclina dispansa*, *D. sowerbyi*, *D. undulata*, *D. omphala*, *D. dorreini* while asterocyclinids were not reported (Figure 3). The presence of *Actinosiphon*, a Caribbean species, was also reported from the Drazinda Formation (Afzal et al., 1997). Some orthophragminids with various axial thickening structures, *Discocyclina kutchenensis* Özcan and Saraswati 2016 and *D. sulaimanensis* Özcan, Ali, Hanif, 2016, were recently described from the Fulra Limestone in Kutch, India and Drazinda Formation in Sulaiman Range (Özcan et al., 2016). The *Heterostegina* in the upper part of the Drazinda

Formation (*Pellatispira* beds) is represented by an endemic species, *Heterostegina indusensis* Özcan, Ali, Hanif (Özcan et al., 2016), suggesting the polyphyletic origin of the genus. The Western Tethyan *Heterostegina* lineages, such as *H. armenica* (Grigoryan), *H. reticulata* Rüttimeyer and *H. gracilis* Herb, were not found in the Drazinda Formation.

4. Materials and methods

The Pirkoh and Drazinda formations have been sampled in three different outcrop areas, Rakhi Nala, Zinda Pir and Domanda Bridge, in the Sulaiman Range to provide the widest coverage of the orthophragminids (Figures 2 and 5). The Rakhi Nala A (29°57'12.80"N, 70°06'56.80"E; 29°57'13.51"N, 70°7'1.74"E), and 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) sections are from the same area west of Dera Ghazi Khan in the Punjab province. The Zinda Pir section (30°20'2.38"N, 70°29'32.54"E; 30°19'56.65"N, 70°29'39.48"E), located in the Zinda Pir anticline, is ca. 55 km north-east of the Rakhi Nala section. The Domanda Section (31°35'0.19"N, 70°11'40.31"E; 31°35'14.43"N; 70°11'28.78"E) is located in the north-west of both Rakhi Nala and Zinda Pir sections, and is about 73 km west of Dera Ismail Khan in the Federally Administered Tribal Areas (FATA).

Specimens extracted from the shale, marl and limestone beds were studied for their external features, features in the equatorial layer and axial sections.

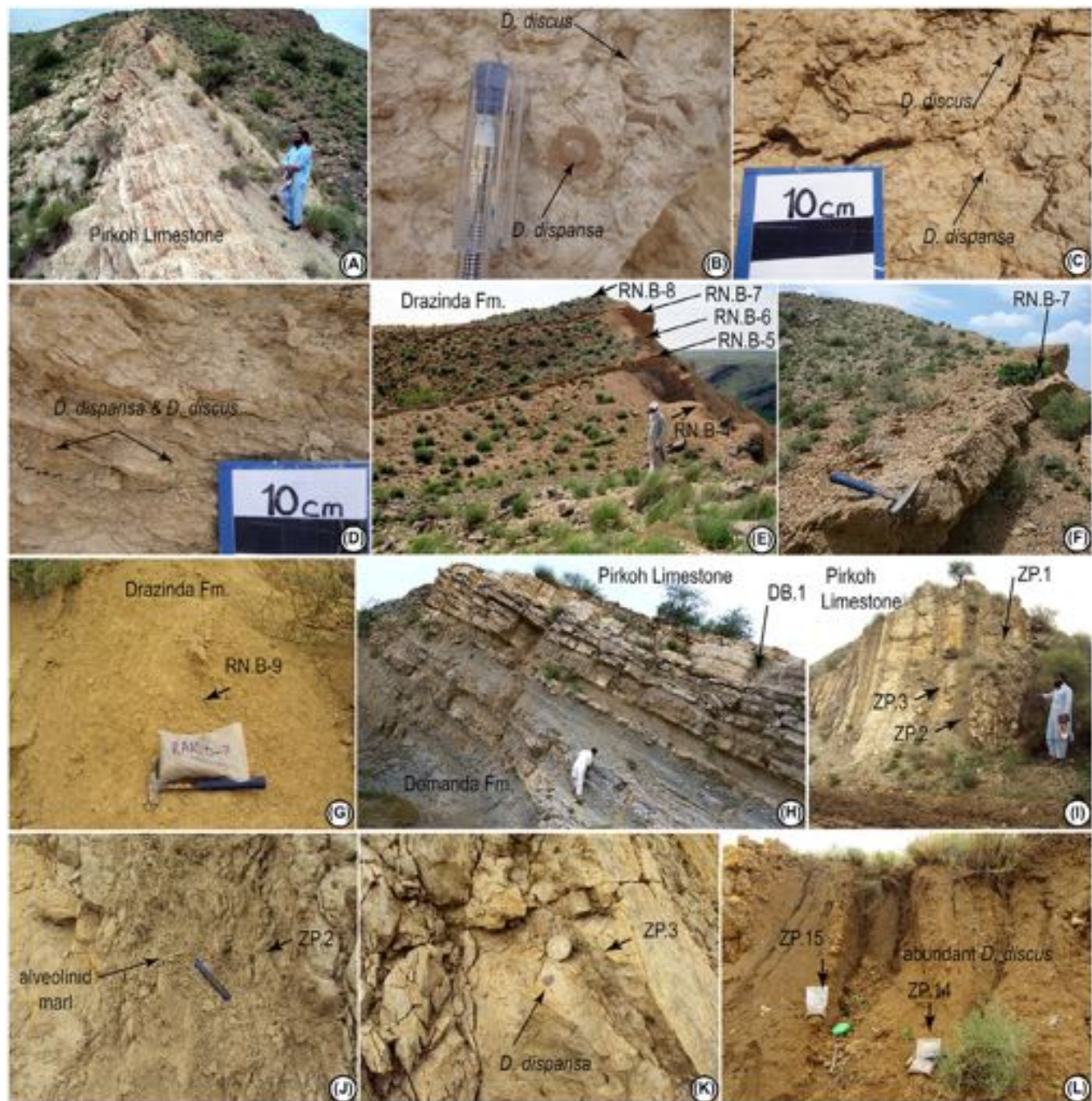


Figure 4. Field aspects of Pirkoh and Drazinda formations. Pirkoh Formation in Rakhi Nala A (A, B), Domanda (H) and Zinda Pir section (I–K), and Drazinda Formation in Rakhi Nala A (C; sample RN.A.4, D; sample RN.A.6), Rakhi Nala B (E–G) and Zinda Pir section (L).

The oriented sections of megalospheric and (partly) microspheric specimens (A and B-forms respectively) have been prepared through their equatorial layers because the most important taxonomic and evolutionary parameters are observed in this part of the test (Ferrández-Cañadell, 1998; Less, 1987; Neumann, 1958; Portnaya, 1974). The biometric measurements and counts were carried out on equatorial sections of the megalospheric specimens (Less, 1987, 1998). Eight measurements (in μm) and counts and some qualitative data were used to characterize the taxa (Figure 6, Table 1). These measurements 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 embryo; and h and w, height and width of the equatorial chamberlets around the peripheral part of the equatorial layer. Finally, axial sections of megalospheric and microspheric forms have been prepared in order to facilitate specific recognition in rock thin sections.

5. Distribution of orthophragminids in the Pirkoh and Drazinda formations

Orthophragminids in the Pirkoh and Drazinda formations are represented by *Discocyclina* and sparse *Asterocyclina* whereas *Orbitoclypeus* and *Nemkovella*



Figure 5. Sample localities in Zinda Pir (A), Rakhi Nala (B) and Domanda Bridge (C) sections.

were not recorded (Figures 7 and 8). The Pirkoh Formation yielded only discocyclinids, represented by *D. dispansa* (Sowerby, 1840), *D. discus* (Rütimeyer, 1850), *D. praeomphalus* Samanta & Lahiri, 1985 accompanied by *Dictyoconoides*, *Nummulites*, *Assilina*, *Operculina*, *Linderina* and alveolinids, found only in one level (sample ZP.2) in the Zinda Pir section. Orthophragminids in the Drazinda Formation are more diverse and are characterized by *D. dispansa* (Sowerby, 1840), *D. discus* (Rütimeyer, 1850), *D. praeomphalus* Samanta & Lahiri, 1985; *D. augustae* Weijden, 1940; '*D.*' *sulaimanensis* Özcan, Ali & Hanif, 2016, *D. kutchensis* Özcan & Saraswati, 2016, *D. nandori* Less, 1987; *D. pseudodispansa* sp. nov., *D. rakhinalaensis* sp. nov., *D. zindapiensis* sp. nov., *Asterocyclina sireli* Özcan & Less, 2006, and *A. stellata* (d' Archiac, 1846). The associated LBF are represented by *Nummulites* sp., *Assilina* sp., *Operculina* sp., *Calcarina* sp., and *Linderina* sp. The Pellatispira-beds in the upper part of the Drazinda Formation contain scarce unidentified *Discocyclina* and other LBF, such as *Pellatispira*, reticulate *Nummulites*, *Heterostegina*, *Silvestriella*, and *Operculina*.

6. Systematic paleontology

Order Foraminiferida Eichwald, 1830

Family Discocyclinidae Galloway, 1928

Genus *Discocyclina* Gümbel, 1870

Type-species: *Orbitolites pratti* Michelin, 1846

***Discocyclina dispansa* (Sowerby, 1840)**

(Figures 9, 12, 15, 17)

1840 *Lycophris dispansus* n. sp., Sowerby, p. 327, pl. 24, figs. 16, 16a–b.

1926 *Discocyclina undulata* sp. nov., Nuttall, p. 160–151, pl. 7, figs. 8–9, pl. 8, fig. 5.

Diagnosis. *Discocyclina dispansa* is a small to large sized, 'flat to saddle' shaped, unribbed form. The small to medium-sized megalospheric embryo is semi-nephrolepidine in the earliest representatives of its lineage (e.g. *D. d. broennimanni* and *D. d. taurica*) and is trybliolepidine in the phylogenetically advanced members. The adauxiliary chamberlets are moderately wide and high, and of the 'archiaci' type. The equatorial chamberlets are also moderately wide and high. This species includes six subspecies in Western Tethys: *D. d. broennimanni* Less, 1987 (Dmean < 160 µm); *D. d. taurica* Less, 1987

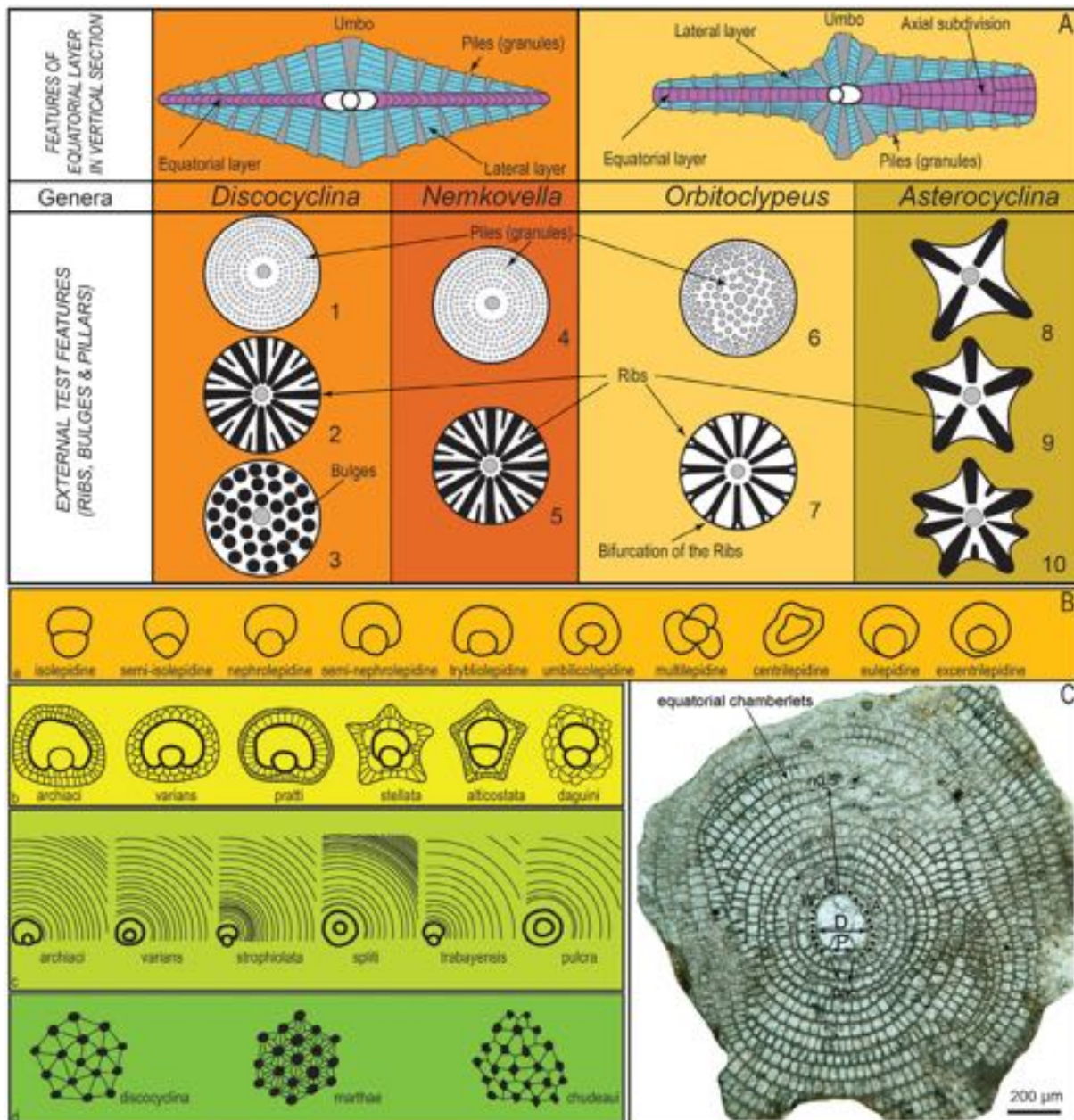


Figure 6. General test features in Tethyan orthophragminid genera (A) (after Ferràndez-Cañadell, 1997; Less, 1987; Özcan et al., 2016), qualitative parameters (B): a- types of embryo configurations, b- types of the adauxiliary chamberlets, c- different growth patterns of the equatorial annuli, d- types of granules and lateral chamberlets on the test surface, and parameters used in the morphometric description of orthophragminids as illustrated in *D. pseudodispansa* sp. nov. from sample RN.B9–79 (C). pac: principal auxiliary chamberlets.

(Dmean = 160–230 µm); *D. d. hungarica* Kecskeméti, 1959 (Dmean = 230–290 µm); *D. d. sella* (d' Archiac, 1850) (Dmean = 290–400 µm); *D. d. dispansa* (Sowerby, 1840) (Dmean = 400–520 µm); and *D. d. umbilicata* (Deprat, 1905) (Dmean > 520 µm) (Less, 1998).

Remarks. *Discocyclina dispansa*, one of the most common orthophragminid species in the middle Eocene of the Sulaiman Range and the Indian Subcontinent, was first described from the Fulra Limestone in Kutch Basin, India (Sowerby, 1840). At its type-locality, the species is invariably characterized by flat and thick forms (unpublished data of Ercan Özcan) (Figure 12). In the Sulaiman Range, the species is represented by flat forms with a

thick umbo, surrounded by a thin flange. The equatorial layer consists of a large trybliolepidine-type embryo (ranging in diameter from 399 to 664 µm in average), high equatorial chamberlets in the early stage (Figures 9, 12, 15, 17), followed by lower and narrower ones in the gerontic stage of development (Figure 17). In axial sections, the embryo is about 225 (protoconch) to 250 (deuteroconch) µm in height (Figure 12). The equatorial layer is about 30–35 µm thick. The lateral chambers are wide (180–320 µm) and high (50–90 µm). It appears that in the Western Tethys, saddle-shaped and flat forms exhibiting the 'similar' embryonic configuration and development of equatorial chambers appear to have

Table 1. Statistical data of orthophragminids from the Pirkoh and Drazinda formations. For the illustration and explanation of the parameters see Figure 6C. N denotes the number of specimens studied in the sample.

		Outer cross diameter of the embryo				Adauxiliary chamberlets			Equatorial chamberlets			
		Deuteroconch		Protoconch		Number	Height	Width	Annu- li/0.5mm	Height	Width	
		D		P		A	H	w	n0.5	h	w	
Sample	N	Range	Mean ± s.e	Range	Mean	Range	Range	Range	Range	Range	Range	Species
DB-1	34	270–545	399.4 ± 9.84	120–210	161.1	26–37	40–125	25–55	7–11	40–110	25–50	
DB-3	10	390–700	516.5 ± 27.8	165–290	195.0	29–52	70–100	25–45	7–8	50–125	30–50	
ZP-3	2	385–490	437.5 ± 37.1	130–140	135.0		45–55	30–40	10	45–55	30–40	
ZP-4	17	360–820	478.8 ± 29.9	130–350	169.1	38–42	70–90	25–50	6–8	45–60	30–40	
ZP-5	1		470.0		130.0	40	60–75	25–45	6	80–85	25–45	
ZP-6	4	410–480	447.5 ± 12.03	115–220	161.2	36–43	50–75	20–40	7	50–60	25–40	
ZP-7	3	370–465	411.6 ± 22.89	150–200	166.6		50–100	25–35	7	55–75	30–40	
ZP-10	1		370.0									
RN.A-2	16	350–900	529.6 ± 34.18	100–350	195.3	32–38	60–90	25–45	5–10	50–100	25–40	D. dispansa
RN.A3	8	355–490	413.7 ± 18.2	110–200	157.7	27–37	35–70	20–60	6–10	45–65	20–45	
RN.A6	15	520–795	663.6 ± 20.36	150–310	240.6	41–47	15–135	30–60	4.5–7	35–75	25–45	
RN.B1	2	455–460	457.5 ± 1.7	140–215	177.5	30	25–90	30–50	7–9	50–70	25–35	
RN.B2	11	345–480	418.1 ± 12.6	125–230	179.0	30–38	40–75	30–55	5–10	35–100	20–45	
RN.B4	5	320–555	436.0 ± 33.2	140–180	162.0	30–40	45–70	25–45	5–8	50–85	20–40	
RN.B6	1		420.0		180.0	40	40–80	20–50	8–9	35–85	20–45	
RN.B7	4	400–490	432.5 ± 17.4	150–195	170.0	34–38	45–85	25–45	6–8	50–80	25–30	
RN.B8	10	400–750	586.0 ± 36.5	175–300	227.7		75–110	36–60	6–11	30–85	35–45	
RN.B9	11	300–570	470.9 ± 23.68	130–270	183.0	33–36	45–75	25–45	7–9	60–90	25–40	
RN.A3	31	170–320	252.3 ± 7.36	75–175	106.2	19–35	20–65	20–50	8–15	45–125	25–40	
RN.A6	2	250–250	250.0 ± 0.0		105.0	24	20–55	20–40	12–13	80–85	30–35	
RN.B6	12	170–360	277.5 ± 17.6	80–180	124.1	32–34	45–80	25–50	8–13	40–100	20–45	
RN.B7	2	210–260	235.0 ± 16.6	85–135	110.0	19	35–60	20–30	8–11	30–90	20–40	
RN.B9	3	180–200	190.0 ± 4.71	80–90	83.3	15	30–45	25–30	13–14	60–100	30–35	D. pseu-
ZP-4	2	215–260	237.5 ± 15.9	70–130	100.0		30–35	30–45	11	30	25	dodis-
ZP-8	1		200.0		85.0							pansa sp.
ZP-9	12	200–290	246.2 ± 8.9	70–110	92.1	20–29	25–45	30–45	9–13	55–65	25–45	nov.
ZP-10	3	190–255	223.3 ± 15.3	65–100	81.6	19–20	35–45	25–40	10–12	100–130	25–50	
ZP-12	3	190–280	233.3 ± 21.7	80–120	95.0	19	40–55	25	9–11	45–50	25–35	
DB-3	7	220–300	255.0 ± 9.95	110–140	125.0	22–29	35–65	25–35	12–16	55–90	25–30	
RN.A1	1		240.0		115.0	16			13			
RN.A6	11	240–325	281.3 ± 7.36	100–140	123.5	22–26	30–65	25–35	10–13	50–85	25–35	D. praeom-
RN.B3	1		215.0		105.0							phalus
RN.B8	4	270–300	287.5 ± 6.5	110–145	131.7	28	35–70	25–50	10–12	25–80	20–35	
RN.A3	7	160–220	184.3 ± 7.98	70–100	82.9	14–15	20–45	20–40	14–16	50–80	20–35	
RN.A6	5	160–200	178.0 ± 6.72	75–95	82.5	20	35–45	25–30	14–17	35–85	20–35	D. augustae
RN.B3	1		185.0		75.0							
RN.B8	5	140–205	169.0 ± 9.53	70–80	76.0				15–16	55–60	25–30	
DB-3	12	850–1575	1257.5 ± 46.3	410–700	565.0		120–165	35–85	4–5	55–90	25–50	
RN.A2	1		1275.0		400.0		140–150	60–90	4	85–90	40–50	
RN.B3	4	680–1690	1292.0 ± 189				80–105	50–90	4–5			D. discus
RN.B5	3	1150–1825	1591.6 ± 180.4						4			
RN.B8	4	1150–1625	1343.7 ± 87.4	250–820	535.0		140–160	50–60	4–5	130–150	40–60	
ZP-14	8	930–1350	1211.2 ± 41.3		500.0		90–150	50–90	4–6			
RN.A3	3	440–500	473.3 ± 14.4	170–200	186.6	40–52	100–110	30–35	5			
RN.A5	1											
RN.A6	2	440–515	477.5 ± 26.5	175–230	202.5		100–110	30–35	6	100–135	30–35	D. kutch-
RN.B3	1		560.0		200.0	53	100–110	40–45	6	120–125	25–35	ensis
RN.B5	2	560–630	595.0 ± 24.7		260.0							
RN.B8	2	360–430	395.0 ± 24.7	130–200	165.0		100–120	30–45	7	100–115	30–35	
RN.B9	14	140–205	168.5 ± 4.3	70–100	83.9	12–19	25–50	25–35	13	75–100	20–40	D. nandori
RN.B3	1		260.0		100.0							D. cf.
												nandori
ZP-5	1		55.0		40.0							
ZP-10	10	55–65	60.0 ± 1.41	40–45	42.7	0–1	10–15	40–55	18–20	50–65	20–35	
ZP-11	7	50–70	60.0 ± 2.47	35–45	41.4	0–1	15	45–50	18–19	50–65	25–30	D. su-
ZP-12	20	55–75	64.9 ± 1.23	35–50	42.0	0–3	10–20	40–55	18–21	60–80	20–25	laiman-
RN.B3	1		45.0		35.0	0	10	40	19?	50–60	20–30	ensis
RN.B9	16	60–80	70.0 ± 1.82	30–50	44.0	4–5	15–20	30	17–20	50–70	25–40	D. zinda-
												pirensis
												sp.nov.
RN.B9	7	75–120	102.8 ± 5.04	55–75	64.2	9–13	20–25	25–35	14–18	65–85	20–30	D. rakhinal-
												aensis sp.
												nov.
RN.A3	1		110.0		70.0	2						Asterocycli-
												na sireli

(Continued)

Table 1. (Continued).

Sample	N	Outer cross diameter of the embryo		Auxiliary chamberlets			Equatorial chamberlets			Species
		Deuteroconch		Protoconch		Number	Height	Width	Annuli/0.5mm	
		D		P		A	H	w	n0.5	
		Range	Mean \pm s.e	Range	Mean	Range	Range	Range	Range	
RN.B3	1	120–125	122.5 \pm 1.7	70–80	75.0					
RN.B8	2									
RN.B8	1									
RN.B3	1									
			220.0		190.0					<i>Asterocyclina stellata</i>

been lumped under this species (Less, 1987; Özcan, Less, Báldi-Beke, Kollányi, & Kertész, 2006). The notable overlaps in the ranges of some subspecies such as *D. dispansa hungarica* and *D. dispansa sella* in the Lutetian and Bartonian (Zakrevskaya, Beniamovsky, Less, & Báldi-Beke, 2011), and *D. dispansa sella* and *D. dispansa dispansa* in the Bartonian (Less, Özcan, & Okay, 2011) also may suggest lumping of forms with similar internal features. Based on biometry, this species is represented by *D. d. dispansa* (Sowerby, 1840) and *D. d. umbilicata* (Deprat, 1905) in our material. We think that a revision of this group is necessary and a taxonomic distinction between the flat and saddle discocyclinids might be possible and hence, we here do not apply the subspecies concept to *D. dispansa* in the Sulaiman Range.

Discocyclina undulata was described for thick, flat discocyclinid specimens with a prominent umbo and a large embryo, about 440–770 μ m in diameter, from the 'lower part of middle Kirthar series' in Sulaiman Range (east of Garmaf) in Pakistan (Nuttall, 1926). The species was named after the irregularly curved lateral chamberlet walls. Nuttall reported about 14 cycles of equatorial chambers in 1 mm distance from the embryo, which corresponds to 7 cycles in 0.5 mm distance. Samanta (1969) studied the type-material and observed that embryo is characterized by a small protoconch and large deuteroconch exhibiting eulipidine-type configuration (this author also considers *D. dispansa* embryo as of eulipidine-type). Samanta also noted that in the middle part of the equatorial chamber cycles the annuli is narrower than the earlier ones. The axial sections illustrated by Nuttall show a great resemblance to that of *D. dispansa* and *D. pseudodispansa* (Figure 12 specimens ZP.4-24, ZP.4-21). We conclude that *D. undulata* is a junior synonym of *D. dispansa* based on (a) the similarities of test features, (b) embryo diameters, (c) number of equatorial chamber cycles within 0.5 mm distance from the embryo and, (d) narrowing of the annular chambers in the middle part of the equatorial layer.

***Discocyclina pseudodispansa* sp. nov. Özcan, Ali & Yücel**

(Figures 9, 12, 15, 16)

Diagnosis. Flat test, small-to medium-sized, strongly inflated with a thick umbo. The small embryo consists of a rounded to nearly-rounded protoconch and

larger deuteroconch displaying semi-nephrolepidine to trybliolepidine type configuration in equatorial sections. The annuli are typically narrow, presenting 'archiaci' type growth pattern. The piles are coarser in the umbonal part, compared to flange. Moderately high and wide lateral chamberlets are arranged in irregular rows.

Derivation of the name. After the similarity of test shape and axial sections to *D. dispansa*.

Holotype. Specimen RN.A3-10, a megalospheric form (Figure 15).

Paratypes. Specimens illustrated in Figures 9 and 12.

Type locality. Rakhi Nala, Dera Ghazi Khan, Punjab, Pakistan.

Type level. Bartonian, lower-middle part of the Drazinda Formation, about 50 km west of Dera Ghazi Khan, Punjab.

Material. Megalospheric and microspheric specimens from samples Rakhi Nala and Zinda Pir sections.

Geographic and stratigraphic distribution. As yet, only known from the Bartonian of Pakistan.

Repository. The holotype and a single paratype (RN.A3-58), marked by TTM.PI-2017/1 and TTM.PI-2017/2 respectively, are deposited in Natural History Museum in General Directorate of Mineral Research and Exploration of Turkey, Ankara.

Description

External features. The test is typically flat, small to medium sized (1.35–6.8 mm in diameter) with a thick umbo, surrounded by a narrow, thin flange (Figure 12). The thickness of the test varies between 600 and 2100 μ m. The piles are relatively larger along the rims of the umbo (80–160 μ m) compared to those in the flanges (50 μ m), and are evenly distributed over the test surface.

Internal features. The embryo is small to moderately large, with average protoconch and deuteroconch diameters ranging between 81.6 and 106.2 and 190 and 252.3 μ m respectively (Table 1). It exhibits semi-nephrolepidine to trybliolepidine configuration. The equatorial layer consists of low chambers (annuli), circular or near circular in outline. The chamberlets are typically square in shape, while those around the periphery may occasionally reach up to 130 μ m and are rectangular in shape.

Axial section. The embryo is about 140 (protoconch) to 170 (deuteroconch) μ m in height (Figure 12). The equatorial layer is about 25–30 μ m thick in the early

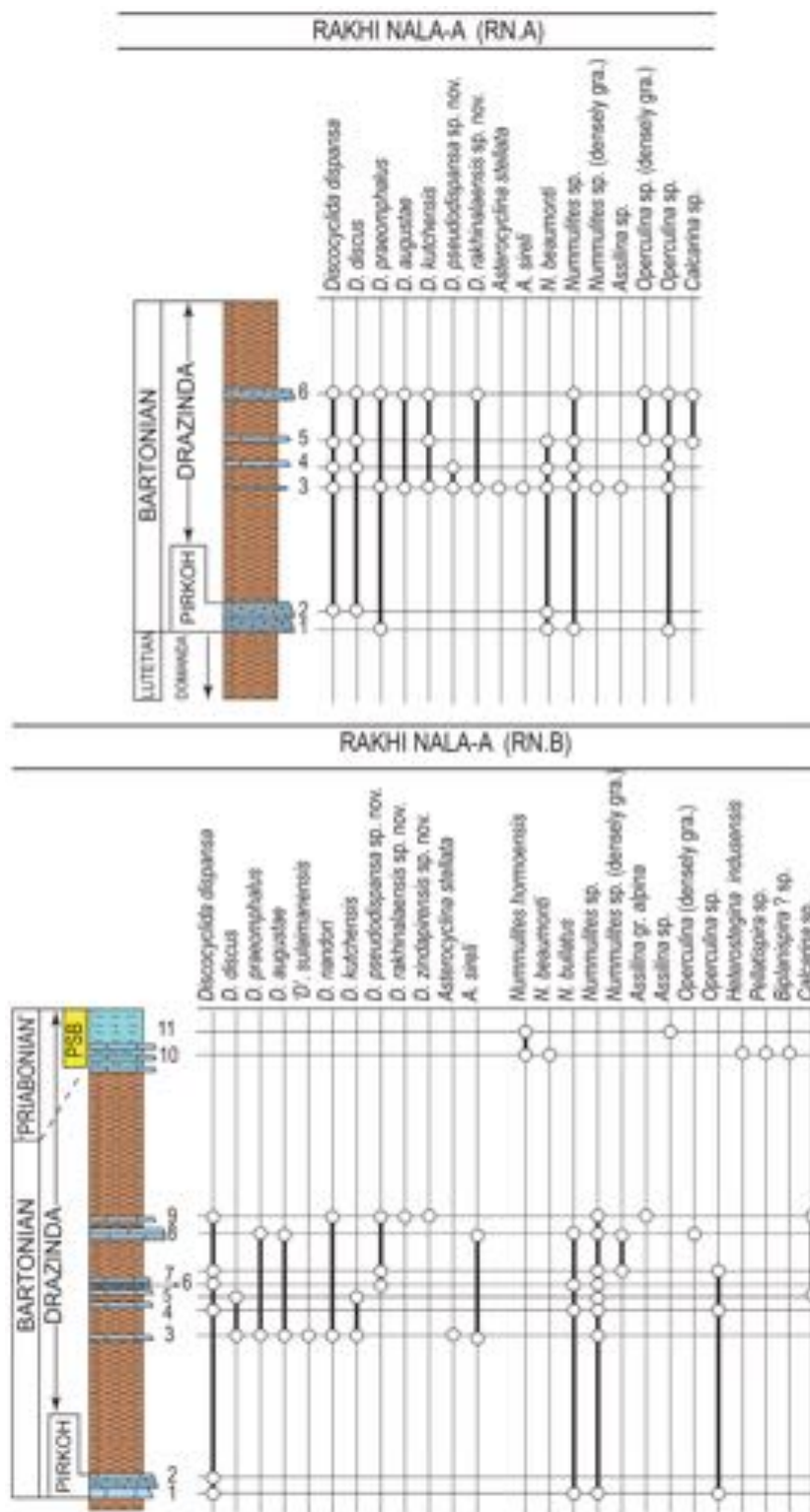


Figure 7. Distribution of orthophragminids and associated LBF taxa in the Rakhi Nala A and B sections.

stage and becomes 45–50 μm thick at the periphery. The lateral chambers are wide (180–250 μm) and high (50–85 μm).

Microspheric generation. The microspheric forms are common and display a typical discocyclinid juvenarium (Figure 11).

Remarks. *D. pseudodispersa* sp. nov., a common species in the Sulaiman Range, could be easily confused with *D. dispersa* on the basis of external characters.

This species, however, differs from *D. dispersa* in having a much smaller embryo and tighter early chambers (compare the n0.5 parameters of both species in Table 1). The axial sections of both species are also similar to each other in terms of development of lateral chamberlets and their size (Figure 12). In equatorial sections, some of the specimens exhibiting semi-nephrolepidine type of embryo may also be confused with *D. augustae*. The axial sections of both species are totally different as the

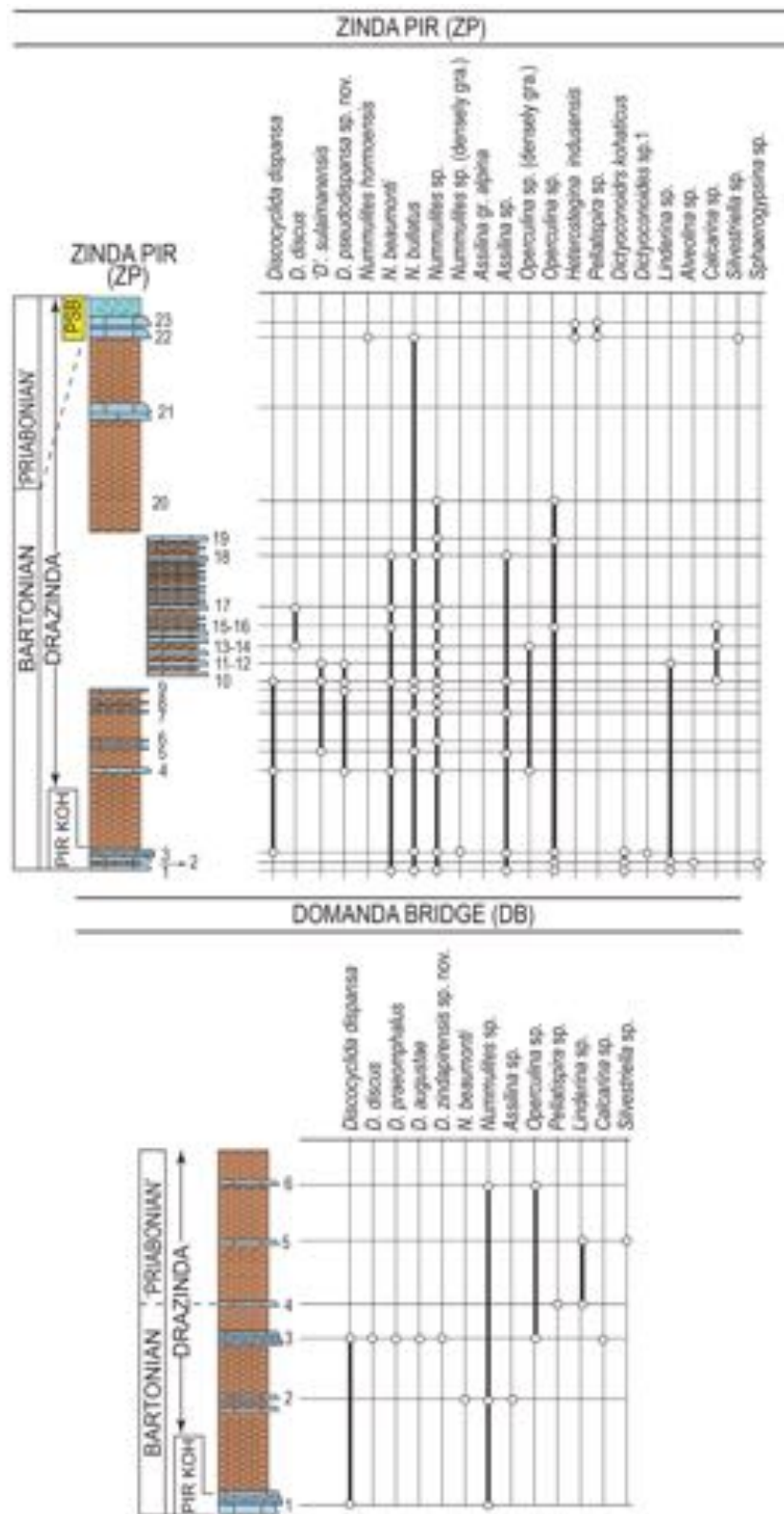


Figure 8. Distribution of orthophragminids and associated LBF taxa in the Zinda Pir and Domanda Bridge sections.

lateral chamberlets in *D. augustae* are very low (slit-like) and small in size.

'Discocyclina' sulaimanensis Özcan, Ali & Hanif, 2016

(Figures 9, 12, 13, 18–20)

2016 '*Discocyclina*' *sulaimanensis* sp. nov. Özcan, Ali, Hanif, p. 274–277, figs. 11–15, 16A–C.

Diagnosis. The omphaloid test is of small size, strongly inflated with a thick centrally- depressed umbo and an elevated ring-like structure. The small embryo consists of a rounded to nearly rounded protoconch and semi-rounded slightly larger deutoconch displaying a semi-isolepidine or nephrolepidine type configuration in equatorial sections. The pre-annular stage is

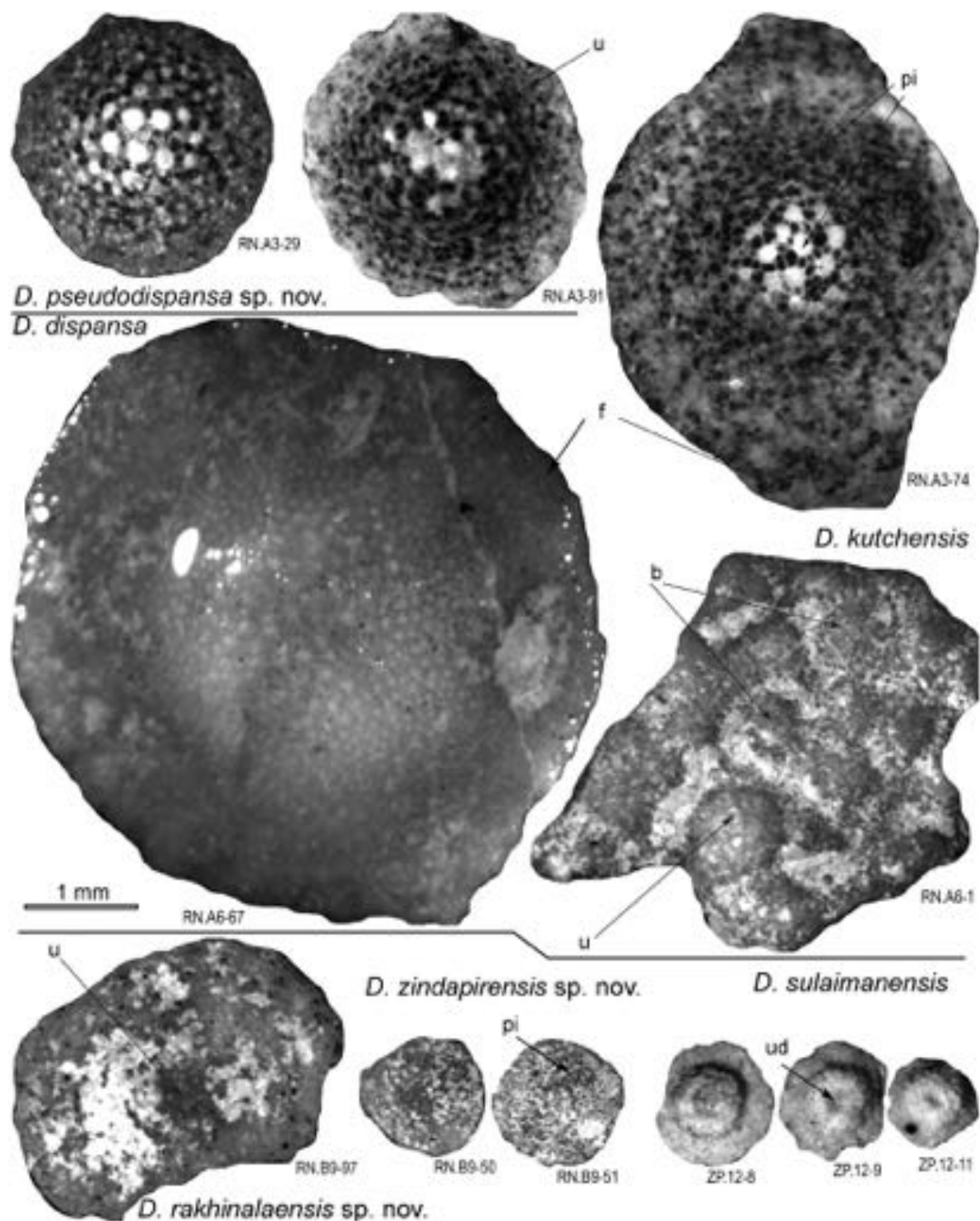


Figure 9. External test features of *Discocyclusina pseudodispersa* sp. nov., *D. dispersa*, *D. kutchensis*, *D. rakhinalaensis* sp. nov., *D. zindapirensis* sp. nov. and *D. sulaimanensis* from the Drazinda Formation. Specimen RN.A6-1 is the paratype of *D. kutchensis* (Özcan et al., 2016). b: bulges, f: flange, pi: piles, u: umbo, ud: umbonal depression.

characterized by notably large auxiliary chambers, elongated parallel to the common axis of embryonic chambers, and only few (commonly single) isolated adauxiliary chamberlets. The annuli are typically narrow in the early, and high in the late stage, and present a 'trabayensis' type growth pattern. The septula are occasionally irregular and/or incomplete and partly in alignment in successive annuli. The equatorial chamberlets display annular and radial stolons, the former one being 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.

Remarks. '*D. sulaimanensis*' has a small test (700–1300 µm diameter), small embryo (deuteroconch diameter varying 50 to 75 µm), two large auxiliary chamberlets and few adauxiliary chamberlets. It differs from other omphaloid taxa from the Tethyan and Caribbean

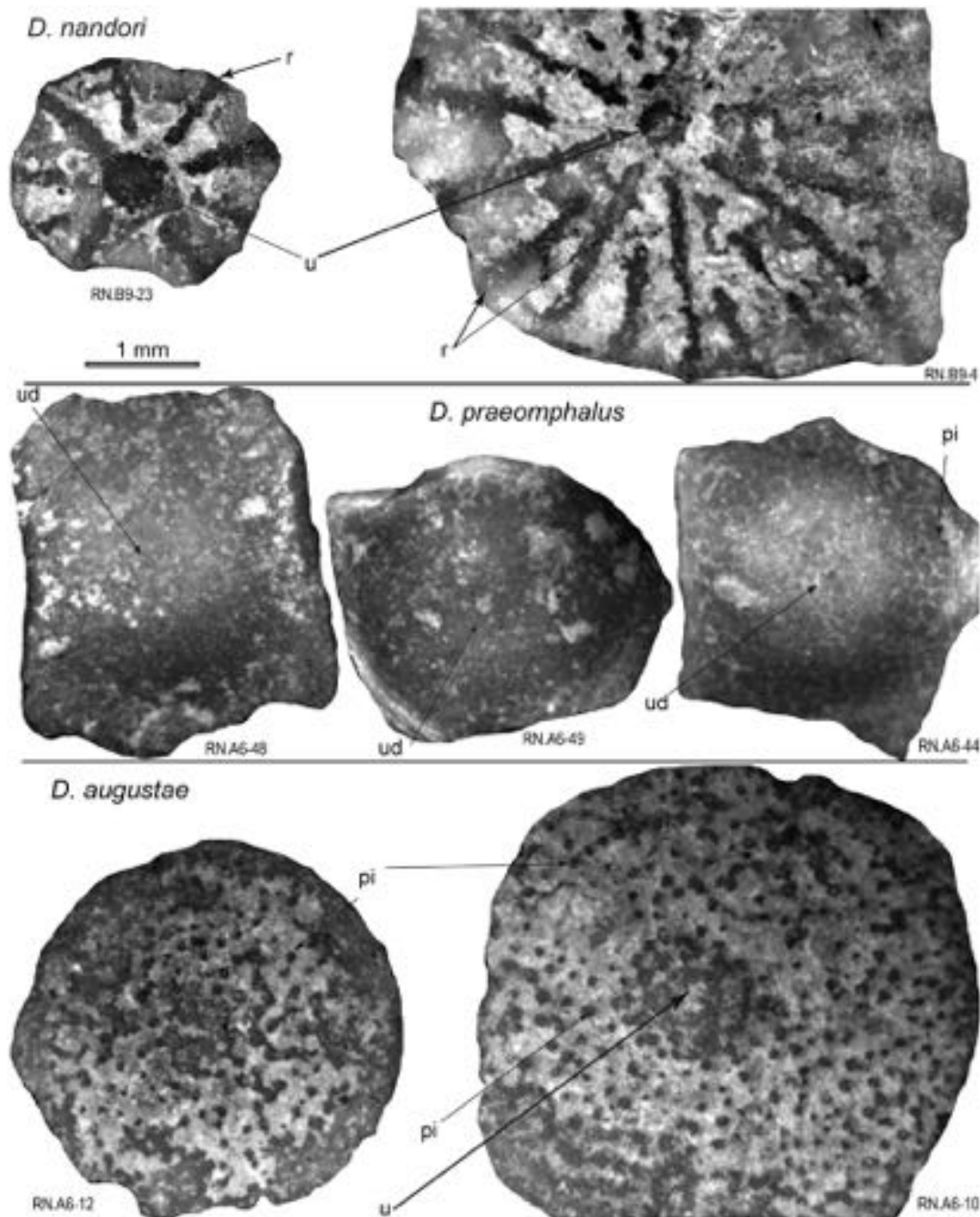


Figure 10. External test features of *Discocyclusina nandori*, *D. praeomphalus*, and *D. augustae* from the Drazinda Formation. pi: piles, u: umbo, ud: umbonal depression, r: ribs.

provinces in having a much smaller flat test, a more pronounced umbonal depression (Figures 9, 12 and 13), a smaller embryo (Figures 18 and 19), and a completely different development of early chambers (Figure 20) (Özcan et al., 2016). It shows some resemblance to some Caribbean orthophragminids, such as species of *Proporocyclusina* Vaughan and Cole, 1941, in having irregular and/or incomplete septula in the early chambers. Such irregular/incomplete septula have never been recorded in Western Tethys and have a generic-level significance in the classification of Caribbean orthophragminids. Septula are absent in *Athecocyclusina* (Vaughan,

1929) and incomplete and/or irregular in *Proporocyclusina* (Caudri, 1996). As yet, the species is known only from the Sulaiman Range.

***Discocyclusina rakhinalaensis* sp. nov. Özcan, Ali & Yücel**

(Figures 9, 12, 13, 18–20)

Diagnosis. Test of small size, discoid, with a thick umbo. The small embryo consists of a rounded to nearly rounded protoconch and semi-rounded slightly larger deutoconch displaying a semi-isolepidine or nephrolepidine type configuration in equatorial sections. The adauxiliary chamberlets are of archiaci-type.

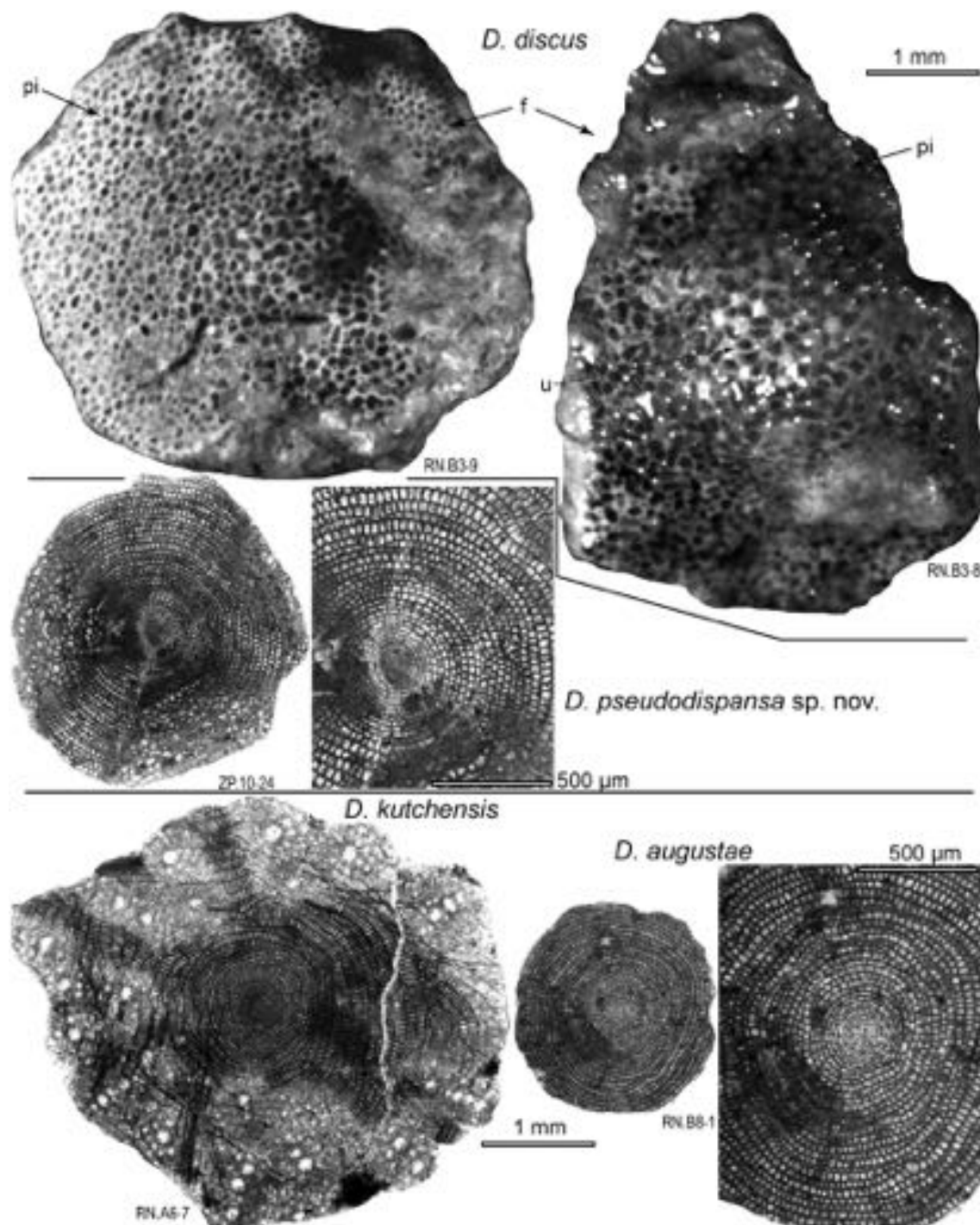


Figure 11. External test features of *Discocyclus discus*, and equatorial sections of microspheric forms of *D. pseudodispersa* sp. nov., *D. kutchensis* and *D. augustae* from the Drazinda Formation. pi: piles, u: umbo, f: flange.

The annuli are typically narrow in the early, and high in the later stages, and present a 'trabayensis' type growth pattern. The equatorial chamberlets are square in shape in the early stage and rectangular in the later stages. The piles are coarser in the umbonal part, compared to flange. Moderately high and wide lateral chamberlets are arranged in regular rows.

Derivation of the name. Named after Rakhi Nala in the Sulaiman Range, the type-locality of the species.

Holotype. Specimen RN.B9-75, a megalospheric form (Figures 18, 20).

Paratypes. Specimens illustrated in Figures 12 and 18.

Type locality. Rakhi Nala, Dera Ghazi Khan, Punjab, Pakistan.

Type level. Bartonian, lower-middle part of the Drazinda Formation, about 50 km west of Dera Ghazi Khan, Punjab.

Material. Megalospheric specimens from section Rakhi Nala B.

Geographic and stratigraphic distribution. Known as yet only from the Bartonian of Pakistan.

Repository. The holotype and a single paratype (RN.B9-85), marked by TTM.PI-2017/3 and TTM.PI-2017/4 respectively, are deposited in Natural History Museum in

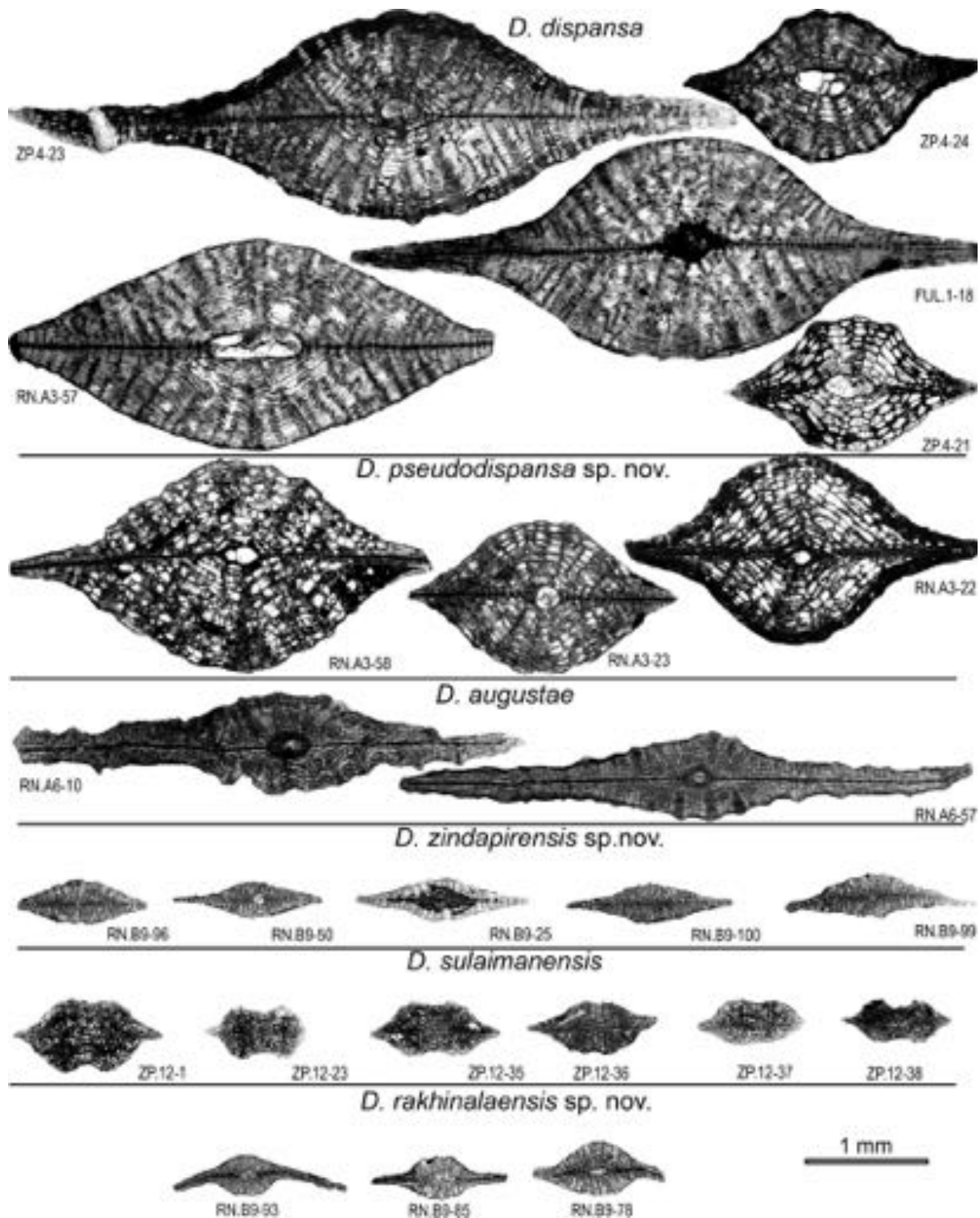


Figure 12. Axial sections of *Discocyclusina dispansa*, *D. pseudodispansa* sp. nov., *D. augustae*, *D. zindapirensis* sp. nov., *D. sulaimanensis*, and *D. rakhinalaensis* sp. nov. from the Drazinda Formation. The axial section of *D. dispansa* (specimen FUL1-18) from the Fulra Limestone at its type-locality in Kutch Basin (India) is also illustrated for comparison.

General Directorate of Mineral Research and Exploration of Turkey, Ankara.

Description

External features. The test is typically small (980–3250 µm in diameter) with a thick umbo, surrounded by a narrow, thin flange (Figures 12 and 13). The thickness of the test varies between 350 and 450 µm. The piles are relatively larger along the rims of the umbo (50 µm)

compared to those in the flanges (20 µm), and are evenly distributed over the test surface.

Internal features. The embryo is small with average protoconch and deuteroconch diameters of 64.2 and 102.8 µm respectively (Table 1). It exhibits semi-isolepidine or nephrolepidine type configuration. The archiaci-type adauxiliary chamberlets are low and narrow and their number ranges between 9 and 13. The

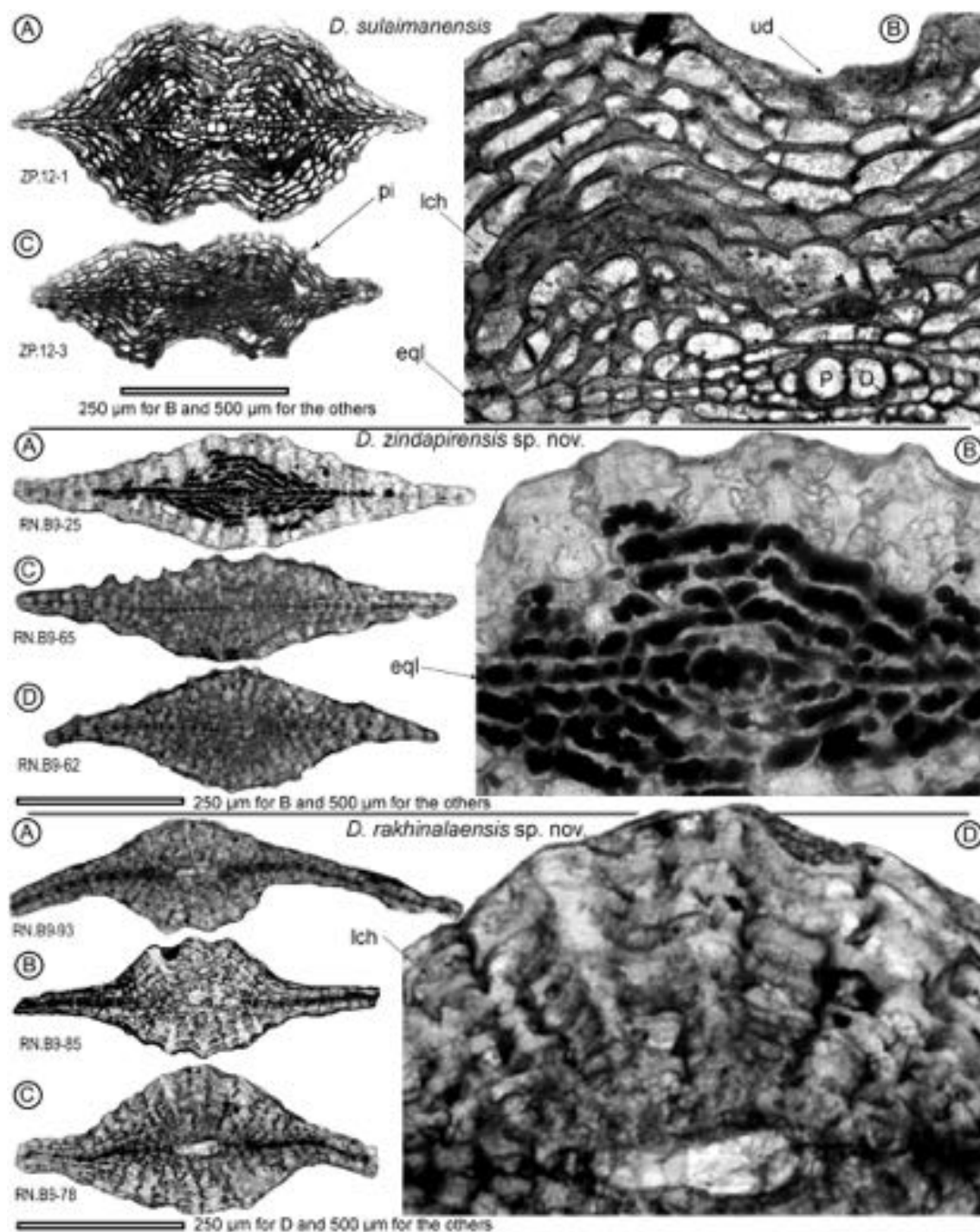


Figure 13. Comparison of the axial sections of *Discocyclus sulaimanensis*, *D. zindapirensis* sp. nov. and *D. rakhinalaensis* sp. nov. from the Drazinda Formation. P: protoconch, D: deutoconch, pi: piles, lch: lateral chamberlets, eqi: equatorial layer, ud: umbonal depression.

equatorial layer consists of low chambers (annuli), circular or near circular in outline. The chamberlets are typically square in shape, progressively become higher, and those around the periphery may occasionally reach up to 85 µm and are rectangular in shape.

Axial section. The embryo is about 55–60 µm in height (Figure 13). The equatorial layer is about 20–25 µm in thickness and it maintains throughout the ontogeny. The lateral chambers are 55–60 µm wide and 15–25 µm high.

Microspheric generation. The microspheric form is not known.

Remarks. *D. rakhinalaensis*, a rare species in the Sulaiman Range, is close to *D. augustae* in having a similar type of embryo and development of equatorial chambers. It differs from the latter by its small test size, general test features in axial sections and small embryo. This species differs from *D. trabayensis* of the peri-Mediterranean region in the type of adauxiliary chamberlets and much smaller embryo.

***Discocyclus zindapirensis* sp. nov.** Özcan, Ali & Yücel

(Figures 9, 12, 13, 18–20)

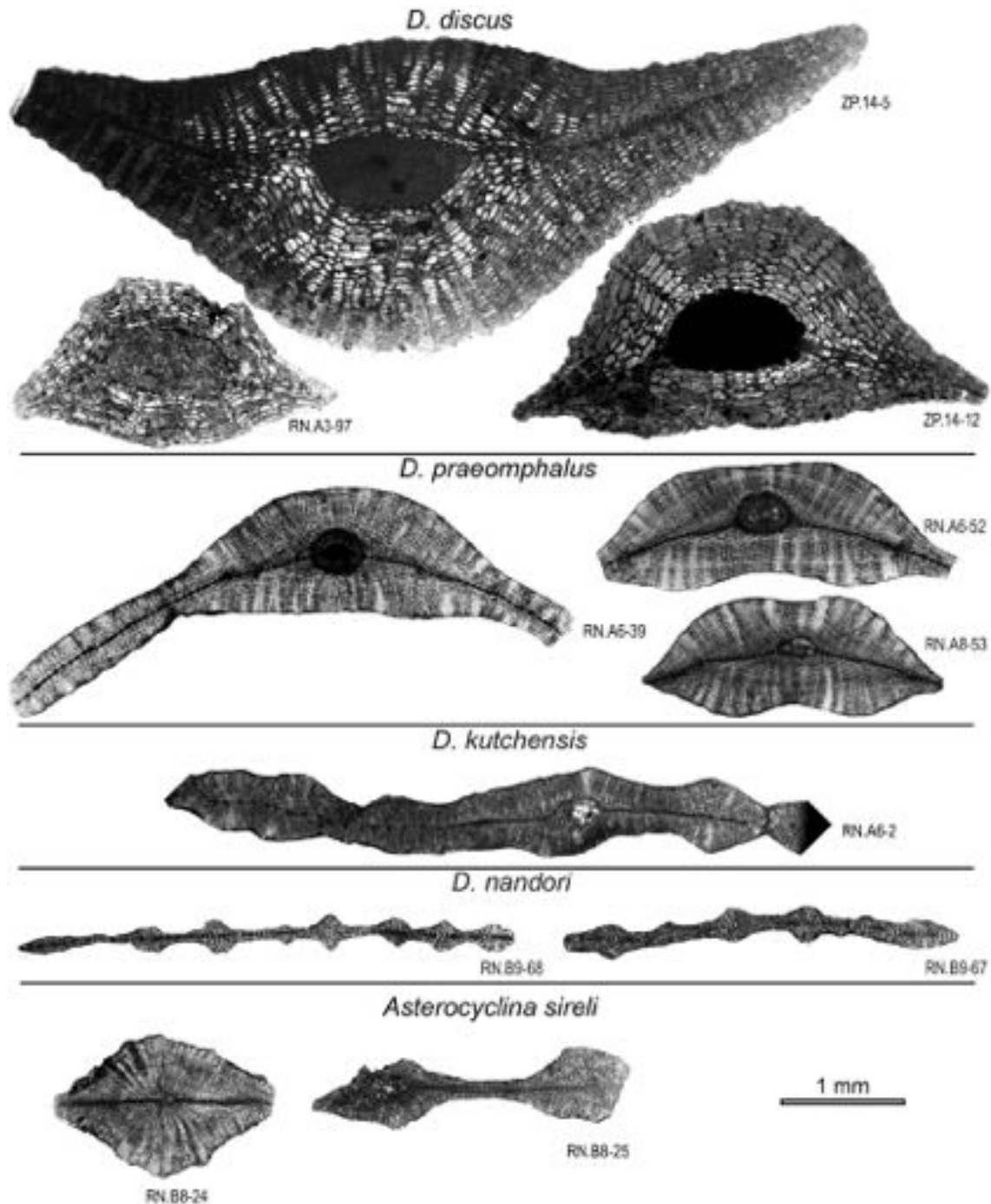


Figure 14. Axial sections of *Discocyclina discus*, *D. praeomphalus*, *D. kutchensis*, *D. nandori* and *A. sireli* from the Drazinda Formation.

Diagnosis. Test of small size, flat, lenticular. The small embryo consists of a rounded to nearly-rounded protoconch and a sub-rounded slightly larger deutoconch displaying a semi-isolepidine to nephrolepidine type configuration in equatorial sections. The annuli are typically narrow in the early, and high in the later stages, and present a 'trabayensis' type growth pattern. The equatorial chamberlets are square in shape in the early stage and rectangular in the later stages. The piles are of uniform size. Moderately high and wide lateral chamberlets are arranged in regular rows.

Derivation of the name. After Zinda Pir anticline in Sulaiman Range.

Holotype. Specimen RN.B9-102, a megalospheric form (Figures 19 and 20).

Paratypes. Specimens illustrated in Figures 12 and 13.

Type locality. Rakhi Nala, Dera Ghazi Khan, Punjab, Pakistan.

Type level. Bartonian, lower-middle part of the Drazinda Formation, about 50 km west of Dera Ghazi Khan, Punjab.

Material. Megalospheric specimens from Rakhi Nala section.

Geographic and stratigraphic distribution. Known as yet only from the Bartonian of Pakistan.

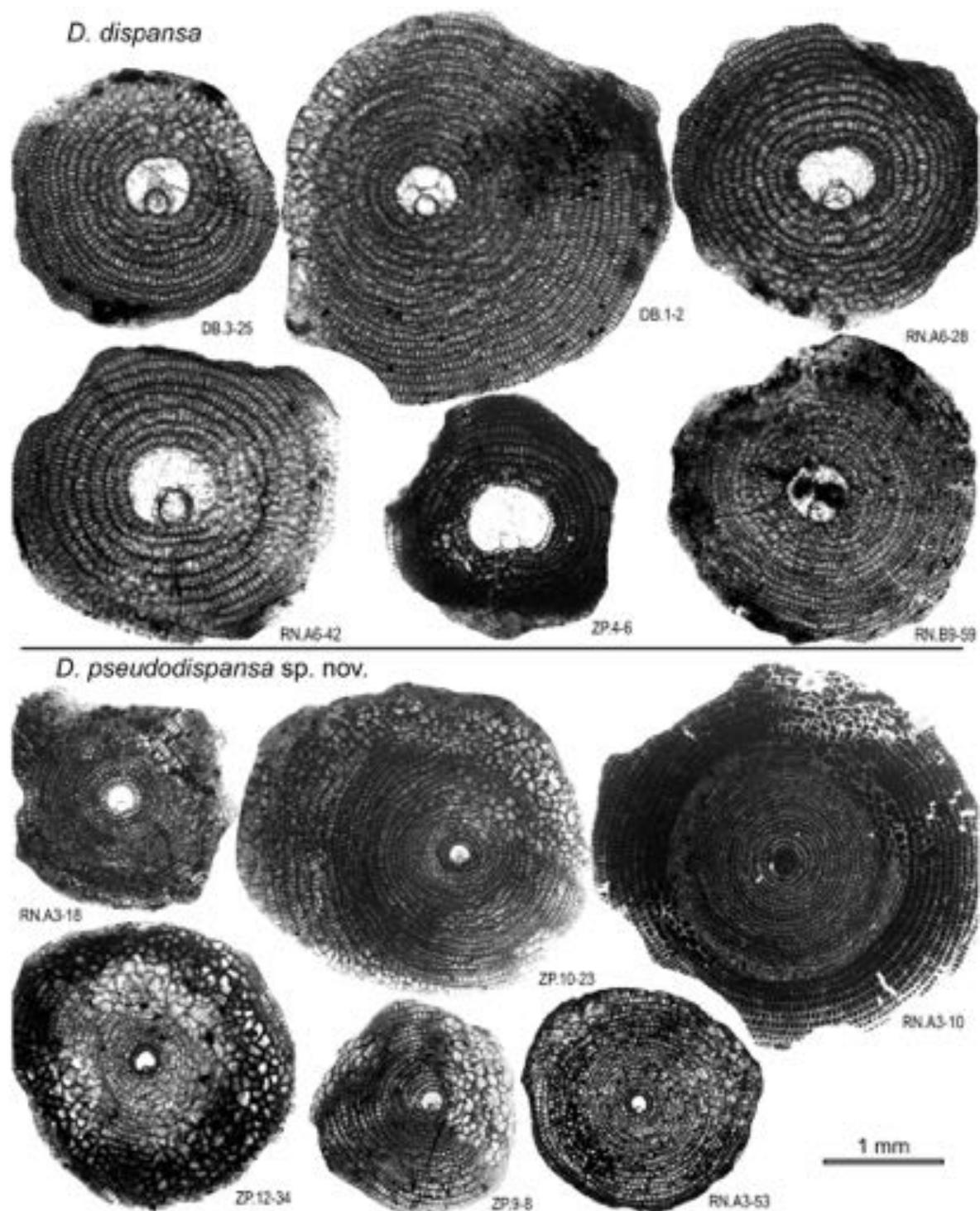


Figure 15. Equatorial sections of *Discocyclusa dispana*, and *D. pseudodispana* sp. nov. from the Pirkoh and Drazinda formations.

Repository. The holotype and a single paratype (RN. B9-100), marked by TTM.PI-2017/5 and TTM.PI-2017/6 respectively, are deposited in Natural History Museum in General Directorate of Mineral Research and Exploration of Turkey, Ankara.

Description

External features. The test is typically small (1.15–1.5 mm in diameter), flat and slightly biconvex (Figures 12 and 13). The thickness of the test varies between 225 and 370 μm . The piles are relatively small (30–35 μm), uniformly distributed over the test surface.

Internal features. The embryo is small with average protoconch and deuteroconch diameters of 44.0 and 70.0 μm respectively (Table 1). It exhibits semi-isolepidine or nephrolepidine type configuration. The adauxiliary chambers are low and narrow and their number ranges between 4 and 5. The equatorial layer consists of low chambers (annuli), circular or near circular in outline. The chamberlets are typically square in shape, progressively become higher, and those around the periphery may occasionally reach up to 70 μm and are rectangular in shape.

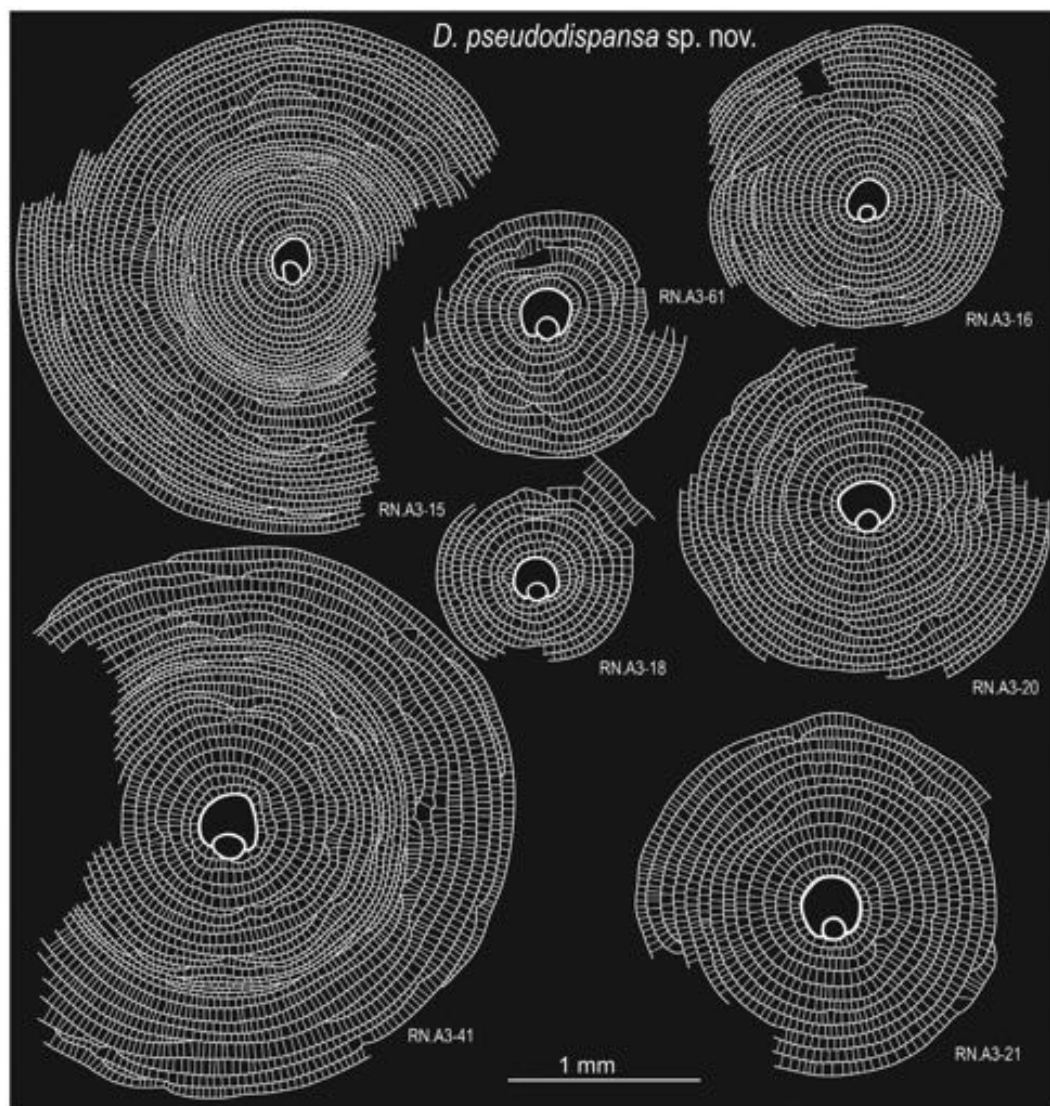


Figure 16. Equatorial sections of *Discocyclus pseudodispansa* sp. nov. from the Drazinda Formation.

Axial section. The embryo is about 40 µm in height (Figure 13). The equatorial layer is about 25–35 µm thick throughout the ontogeny. The lateral chambers are 50–55 µm wide and 15–20 µm high.

Microspheric generation. The microspheric form is not known.

Remarks. *D. zindapiensis*, differs from *D. rakhinalaensis* in the shape of the test with distinct umbo, in having a smaller embryo, and few number of adauxiliary chamberlets. This species differs from *D. trabayensis* of the peri-Mediterranean region in the type of adauxiliary chamberlets and the smaller embryo.

***Discocyclus kutchensis* Özcan & Saraswati, 2016**
(Figures 9, 11, 14, 22, 23)

2016 *Discocyclus kutchensis* sp. nov. Özcan & Saraswati, pp. 267–274, figs 5L, 6A–I, 7A, 8A–D, 9, 10A–D.

Diagnosis. Medium sized (2 to 6 mm), 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 350 µm. The embryo is large, with an average diameter of the deuteroconch

ranging between 410 and 478 µm, tryblielepidine to umbilicolepidine in configuration. The adauxiliary chamberlets (37–53 in number) are high and archiaci-type. The equatorial chambers are typically high, narrow and rectangular in shape.

Remarks. This species, originally described from the Fulra Limestone in Kutch Basin in India, differs from all other orthophragminids in Tethys by having the bulges uniformly distributed on the test surface. The bulges are semi-rounded to rounded, localized thickenings, homogeneously distributed over the test surface (Özcan et al., 2016). These structures are about 250–350 µm in diameter, 100–150 µm high and 100–300 µm apart from each other, and form an uneven test surface. Internally, the bulges consist of lateral chamberlets and coarse piles of up to 100 µm in diameter at its center, surrounded by smaller piles (25–50 µm 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

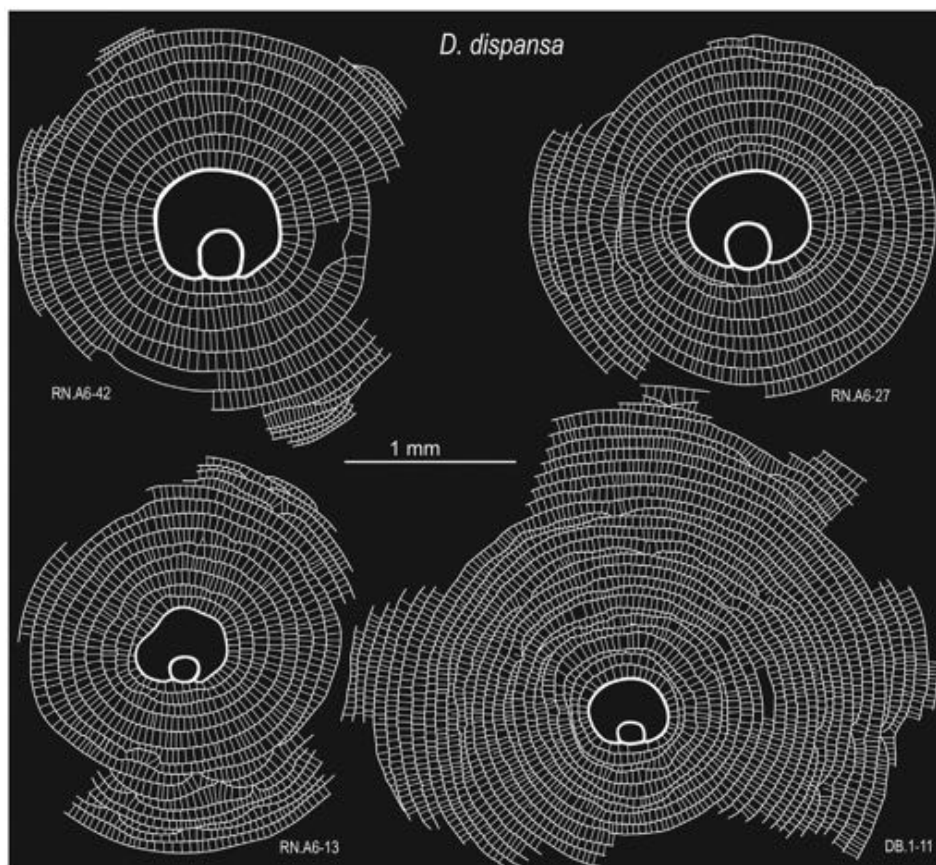


Figure 17. Equatorial sections of *Discocyclina dispansa* from the Pirkoh and Drazinda formations. Note that high early annuli are followed by lower and narrower ones. The sections do not illustrate the complete ontogeny.

equatorial layer adjacent to the bulges and inter-bulge areas. This implies that bulges are formed solely by the thickenings in the lateral layers (Figure 14). Although bulges and ribs are easily distinguished from each other externally, a distinction between these structures is virtually impossible from axial sections. *D. kutchensis* is known from the Fulra Limestone in India and from the Drazinda Formation in the Sulaiman Range (Özcan et al., 2016).

***Discocyclina praeomphalus* Samanta & Lahiri, 1985**
(Figures 10, 14, 23, 24)

1985 *Discocyclina praeomphalus* n. sp. Samanta & Lahiri, p. 272–275. pl. 5, figs. 1–6, text figures 5–7, 12.

Diagnosis. *Discocyclina praeomphalus* is a medium sized (2.4–4 mm), saddle shaped, unribbed form with a slight depression at the center of the test. The megaspheric embryo (average 255.0–287.5 µm in diameter) exhibits semi-nephrolepidine to trybliolepidine type configuration. The adauxiliary chamberlets (16–29 in number) are moderately wide and high, and of the ‘archiaci’ type. The equatorial chamberlets are low and narrow in the early stage and are rectangular in shape in the later stages. The lateral chambers are typically low, numerous and not aligned in regular rows.

Remarks. This saddle-shaped, omphaloid species, first described from the Bartonian Fulra Limestone of the Kutch Basin, India (Samanta & Lahiri, 1985), is recorded

here for the first time from Pakistan. It differs externally from other orthophragminids from the Drazinda Formation by its characteristic saddle shape and the central depression of the test (Figures 10 and 14). ‘*D. sulaimanensis*’, the other omphaloid species from the Drazinda Formation, has a flat and smaller test than that of *D. praeomphalus*. The axial sections of *D. praeomphalus* are easily differentiated from that of the saddle-shaped *D. discus* in having very low (slit-like) chamberlets (Figure 14). This is a common discocyclinid in the middle Eocene of the Indian Subcontinent.

***Discocyclina augustae* van der Weijden, 1940**
(Figures 10, 11, 12, 21)

1940 *Discocyclina augustae* n. sp. van der Weijden, p. 23–26, pl. 1, figs. 4, 5, 7, 8; pl. 2, figs. 1, 2, 11.

Diagnosis. *Discocyclina augustae* is an unribbed form having a very small to small, semi-iso- to nephrolepidine embryo, narrow and low, ‘archiaci’ type adauxiliary chamberlets and also narrow and relatively low equatorial chamberlets mostly with ‘strophiolata’ type growth pattern. This species includes four subspecies in Western Tethys: *D. a. sourbetensis* Less, 1987 (Dmean < 145 µm); *D. a. atlantica* Less, 1987 (Dmean = 145–180 µm); *D. a. olivanae* (Almela & Rios, 1942) (Dmean = 180–225 µm); *D. a. augustae* van der Weijden, 1940 (Dmean > 225 µm).

Remarks. *Discocyclina augustae*, recorded here for the first time from Pakistan, is easily differentiated externally by

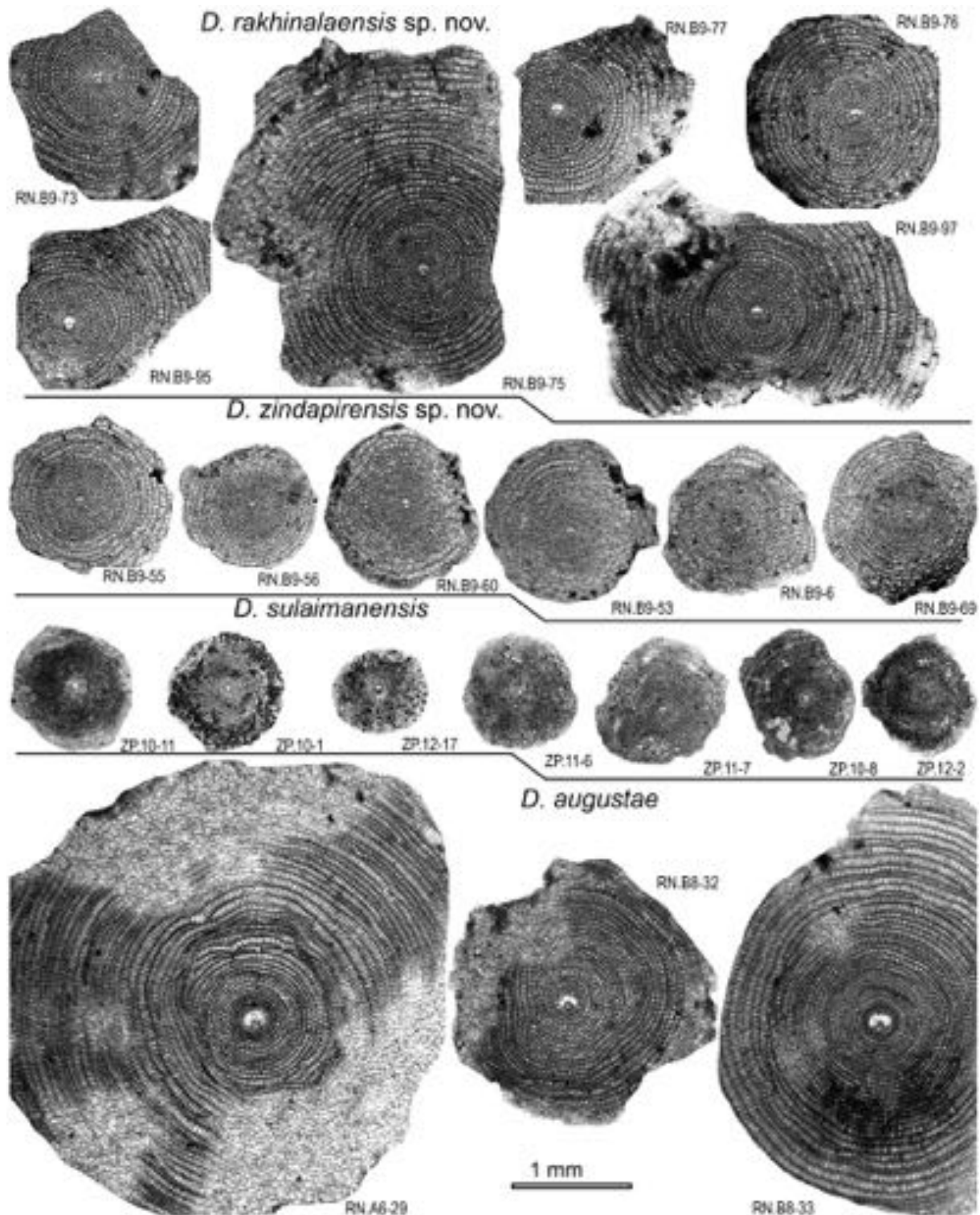


Figure 18. Equatorial sections of *Discocyclus rakhinalaensis* sp. nov., *D. zindapirensis* sp. nov. and *D. sulaimanensis* and *D. augustae* from the Drazinda Formation.

its flat test with small central umbo and uniformly distributed piles (Figure 10). It can be, however, easily confused with *D. pseudodispansa* sp. nov. in equatorial sections, whereas their axial sections are completely different (see the comparison in Figure 12). This species has a much larger embryo than that of *D. rakhinalaensis* sp. nov. In the studied material, *D. augustae* is represented by transitional stages between *D. a. atlantica* and *D. a. olivanae*, according to the evolutionary scheme of the genus in the Western Tethys.

***Discocyclus nandori* Less, 1987**

(Figures 10, 14, 22, 23)

1987 *Discocyclus nandori* n. sp. Less, p. 169–170, pl. 16, figs. 8–12, text-figures 27y–z.

Diagnosis. *Discocyclus nandori* is a ribbed form with a small, semi-nephro- to trybliolepidine embryo (less than 200 µm), rather few, moderately wide and average-sized, 'pratti' type adauxiliary chamberlets and narrow equatorial chamberlets with 'trabayensis–pulchra'

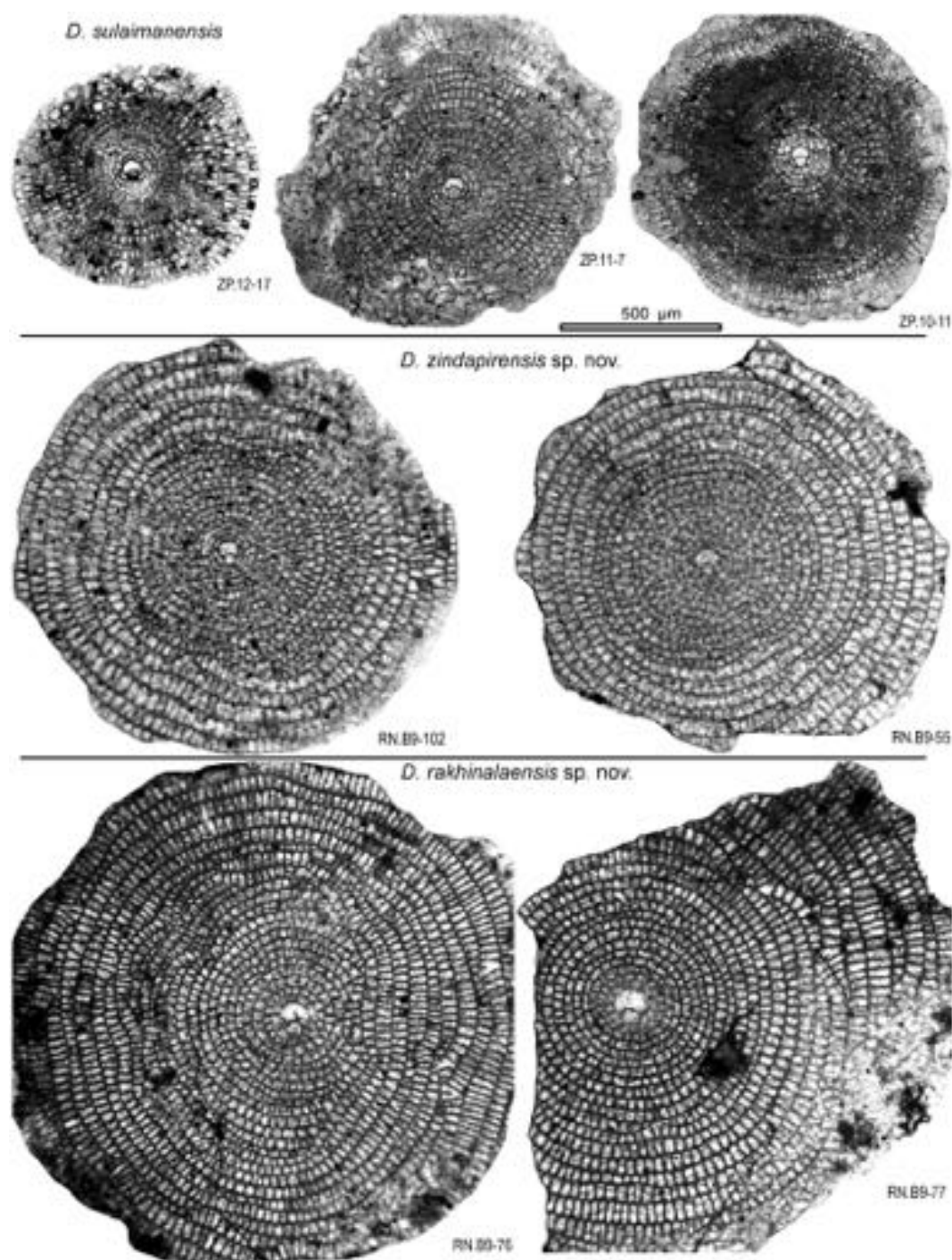


Figure 19. Comparison of embryo and equatorial chamberlets in *Discocyclina rakhinalaensis* sp. nov., *D. zindapirensis* sp. nov. and '*D.* *sulaimanensis*' from the Drazinda Formation.

type growth pattern. The equatorial chambers are low near the embryo and high at the peripheries.

Remarks. *D. nandori*, first recorded from the Amravati Formation in Cambay Basin in India by Özcan et al. (2016), is the only ribbed discocyclinid in the Sulaiman Range. *D. nandori* has a moderately small protoconch (70–100 µm) and deutoconch (140–205 µm), exhibiting semi-nephrolepidine type (rarely trybliolepidine-type) configuration (Figures 22 and 23). The equatorial chamberlets are low and narrow in the early stage and rectangular in the later stages of development. The assignment of ribbed specimens to *Actinocyclus* from the Sulaiman

Range by Eames (1952b) and the Cambay Basin by Tewari (1949) is invalid after Less (1987) and Ferrández-Cañadell (1997), since the microspheric forms of these specimens have a typical discocyclinid juvenarium and also, in axial sections, their equatorial layer shows no enlargement in the ribs (Özcan et al., 2016).

***Discocyclina discus* (Rütimeyer, 1850)**

(Figures 11, 14, 24 and 25)

1850 *Orbitolites discus* n. sp. Rütimeyer, p. 116, pl. 5, figs. 70–71, 78, 80–81.

1926 *Discocyclina sowerbyi* nom. nov., Nuttall, p. 149–150, pl. 3, figs. 1–3.

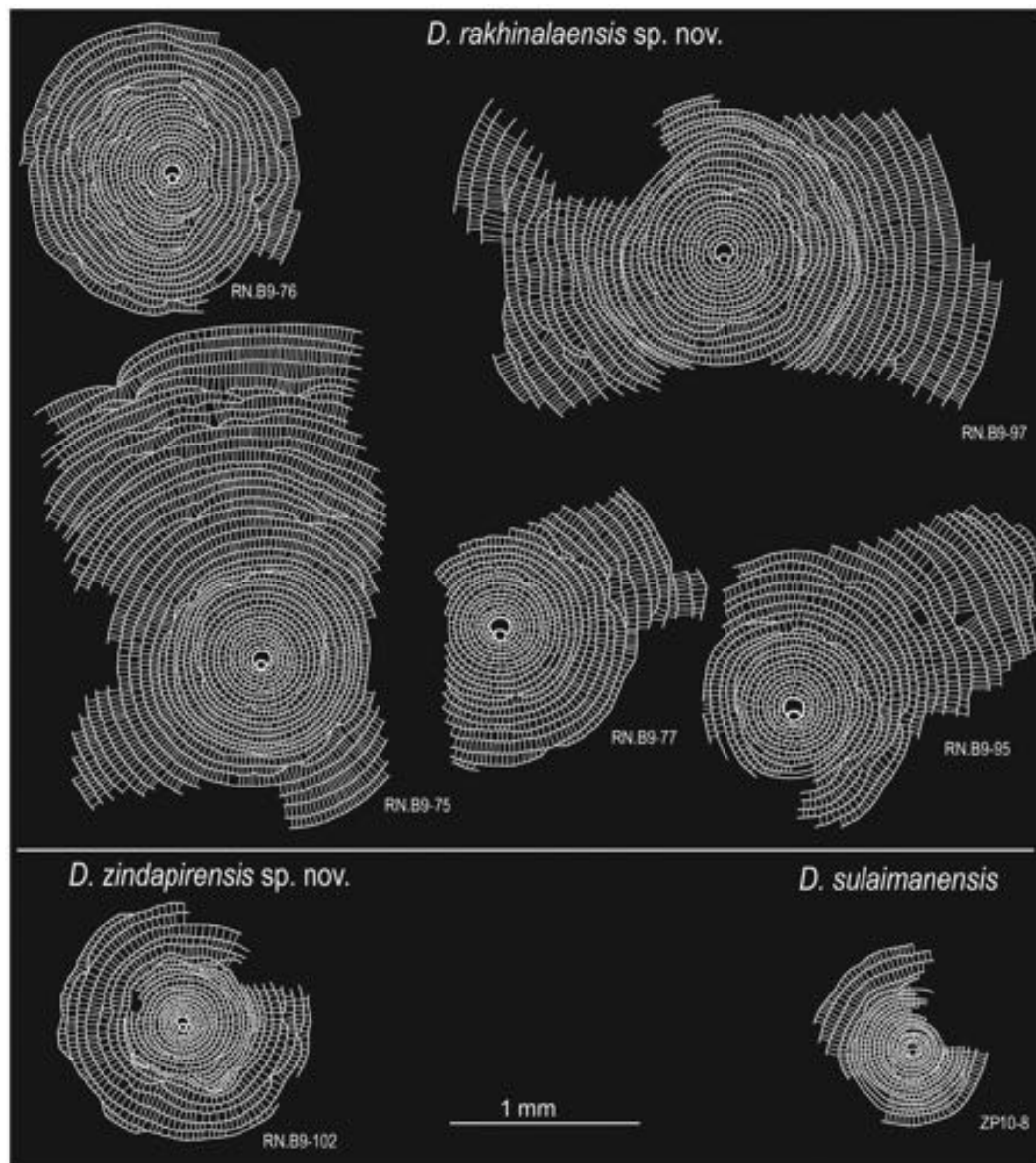


Figure 20. Comparison of embryo and equatorial chamberlets in *Discocyclina rakhinalaensis* sp. nov., *D. zindapirensis* sp. nov. and 'D'. *sulaimanensis* from the Drazinda Formation.

2010 *Lepidocyclina* sp. (*L. pustulosa*), Matsumaru & Sarma, p. 550, pl. 3, fig 11.

Diagnosis. *Discocyclina discus* is an unribbed form with a giant, mostly umbilicolepidine (rarely also tryblio- or excentrilepidine) embryo, numerous, wide and high, 'archiaci' or transitional 'archiaci-pratti' type adauxiliary chamberlets and wide and high equatorial chamberlets with 'archiaci' or transitional 'archiaci-pulcra' type growth pattern. This species includes two subspecies in Western Tethys: *D. d. discus* (Rütimeyer, 1850) (Dmean < 1350 µm) and *D. d. dudarensis* Less, 1987 (Dmean > 1350 µm).

Remarks. *D. discus*, previously reported from the Drazinda Formation in the Sulaiman Range as *D. sowerbyi*, is distinguished from other orthophragminids by its thick, saddle-shaped test and its large embryo with irregular wall. *D. praeomphalus*, another saddle-shaped species, is much smaller and thinner than *D. discus*. In addition, the equatorial chambers of *D. discus* are much

higher than those of *D. praeomphalus* (Figure 24). Our data show that the thick, saddle-like forms described as *Discocyclina sowerbyi* (Nuttall, 1926) by Nuttall (1926) and Sen Gupta (1963) from the type locality of *Lycophris ephippium* of Sowerby (1840) in the Kutch Basin, present the same morphological features as *D. discus* (Rütimeyer, 1850). Nuttall (1926) proposed the specific name 'sowerbyi' to replace 'ephippium', which was pre-occupied by another species. We maintain that *D. sowerbyi*, widely recorded from the middle Eocene of the Indian Subcontinent, is a junior synonym of *D. discus*. Matsumaru and Sarma (2010) illustrated an axial section of a saddle-shaped specimen with a large and thick embryo from the late Eocene of Meghalaya (NE India) and identified it as a Caribbean *Lepidocyclina* sp. (*L. pustulosa*) without any illustration and description of the equatorial layer (Pl. 3, Figure 11). This was interpreted to be the first record of the genus in Meghalaya and significant

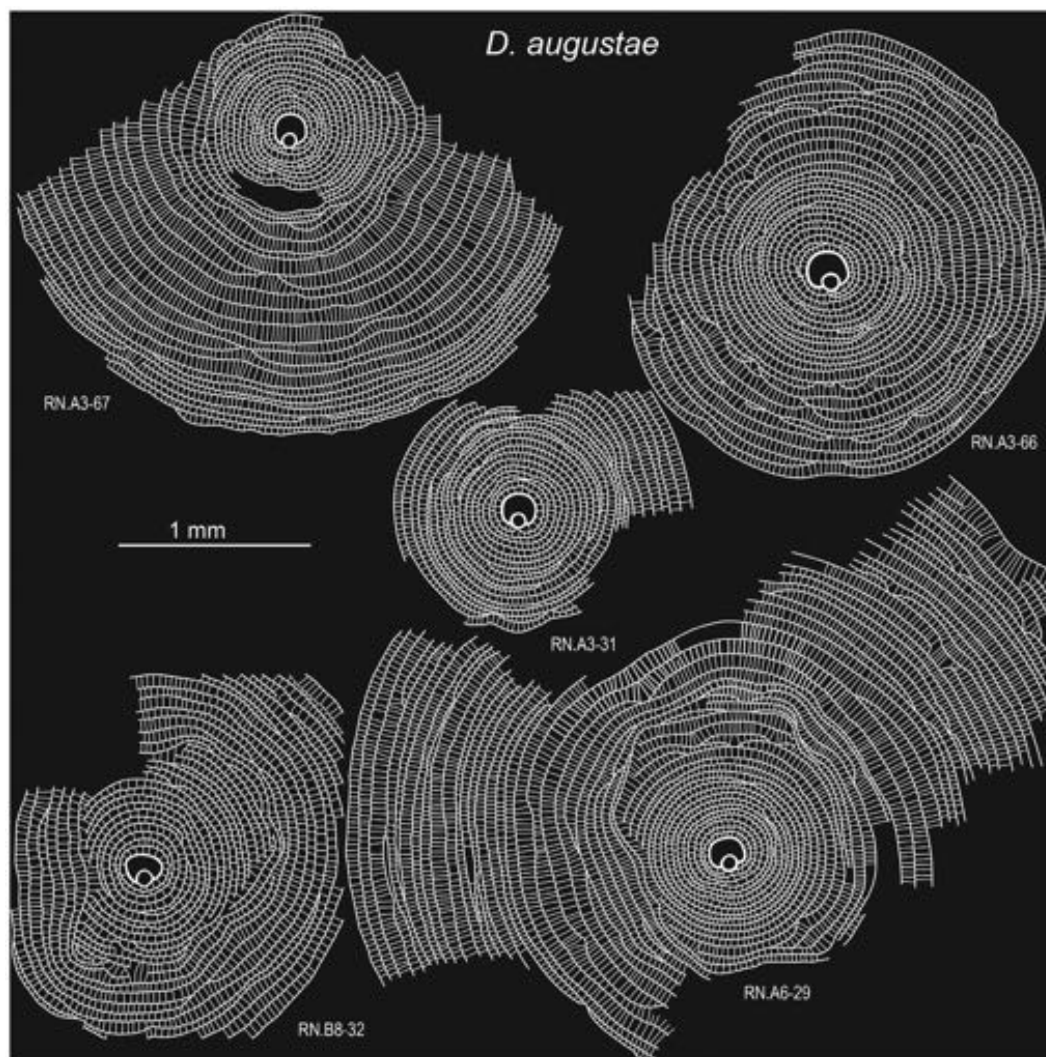


Figure 21. Embryon and equatorial chamberlets in *Discocyclus augustae* in the Drazinda Formation.

for the occurrence of Caribbean lepidocyclinids in the Eocene of Indian Subcontinent. In our opinion, the illustrated axial section has the same morphological features of *D. discus* in having a large embryo, high and wide lateral chamberlets and saddle-shaped test (compare the axial section of the so-called *Lepidocyclus* with *D. discus* illustrated in Pl. 14), and cannot be referred to the genus *Lepidocyclus*.

Family Orbitoclypeidae Brönnimann 1946

Genus *Asterocyclus* Gümbel, 1870

Type species *Asterocyclus stellata* (d' Archiac, 1846)

***Asterocyclus sireli* Özcan & Less, 2006**

(Figure 14, 26)

2006 *Asterocyclus sireli* n. sp. Özcan & Less, pl. 3, fig. 32; pl. 4, figs. 1–3; pl. 5, figs. 1–5; text-figure 12.

Diagnosis. Medium to large, flat forms with mostly four radial ribs and 'marthae' type rosette. The embryo is small, iso- to nephrolepidine. The deuterocoel wall corresponding to the position of the successive stage of the developing rib is mostly depressed. The adauxiliary chamberlets are few (2–4) in number, low and

moderately wide. The equatorial annuli are arranged usually in four rays.

Remarks. This species, recorded here for the first time from Pakistan, was first introduced from the Upper Lutetian of the Sivas Basin (Turkey) for asterocyclinid specimens displaying mostly four ribs and an embryo different from contemporaneous asterocyclinids in Western Tethys (Özcan et al., 2006). It was later recorded from the Bartonian Reineche Limestone in Tunisia and the Fulra Limestone in India (Ben Ismail-Lattrache et al., 2014). In its type material (sample ALM.6) from Sivas, twenty-two specimens out of twenty-five have four ribs. In lower Bartonian Reineche Limestone in Tunisia, only three specimens out of twenty-three specimens have five ribs. In the Fulra Limestone, only one out of seventy-nine specimens has five ribs and in the Drazinda Formation all specimens are with four ribs. The consistent occurrence of four ribs and the wide geographic range of this feature support that *A. sireli* is essentially a four-ribbed species. In contrast to its common occurrence in the Fulra Limestone, *A. sireli* is very rare in the Drazinda Formation.

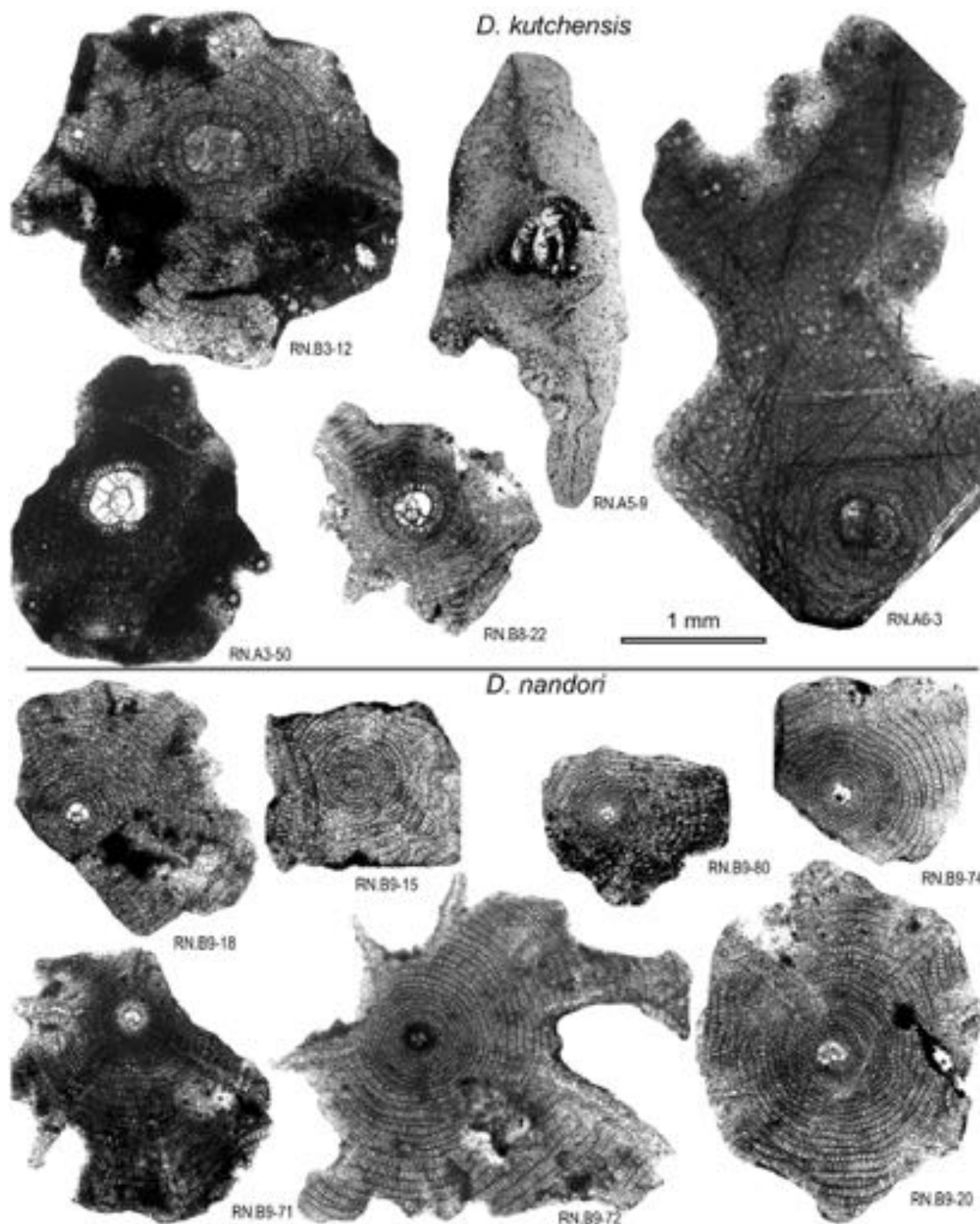


Figure 22. Equatorial sections of *Discocyclina kutchensis* and *D. nandori* from the Drazinda Formation.

A detailed description of this species from India is given in Ben Ismail-Lattrache et al. (2014).

***Asterocyclina stellata* (d' Archiac, 1846)**

(Figure 26)

Diagnosis. *Asterocyclina stellata* is a star-shaped form usually with five rays and 'marthae' type rosette. It has a small semi-iso- to nephrolepidine-type embryo, few, wide and low, 'stellata' type adauxiliary chamberlets and also narrow and low equatorial chamberlets arranged into asteroidal annuli with 'strophiolata' type growth

pattern. This species includes four subspecies in Western Tethys: *A. s. adourensis* Less, 1987 (Dmean < 150 µm); *A. s. stellata* (d' Archiac, 1846) (Dmean = 150–190 µm); *A. s. stellaris* (Brünner, 1848 in Rütimeyer, 1850) (Dmean = 190–240 µm); *A. s. buekkensis* Less, 1987 (Dmean > 240 µm).

Remarks. *A. stellata*, recorded here for the first time from Pakistan, is very sporadic. In the Indian Subcontinent, this species has been previously recorded by Samanta (1965) only from the Priabonian of Assam (India) as *A.*

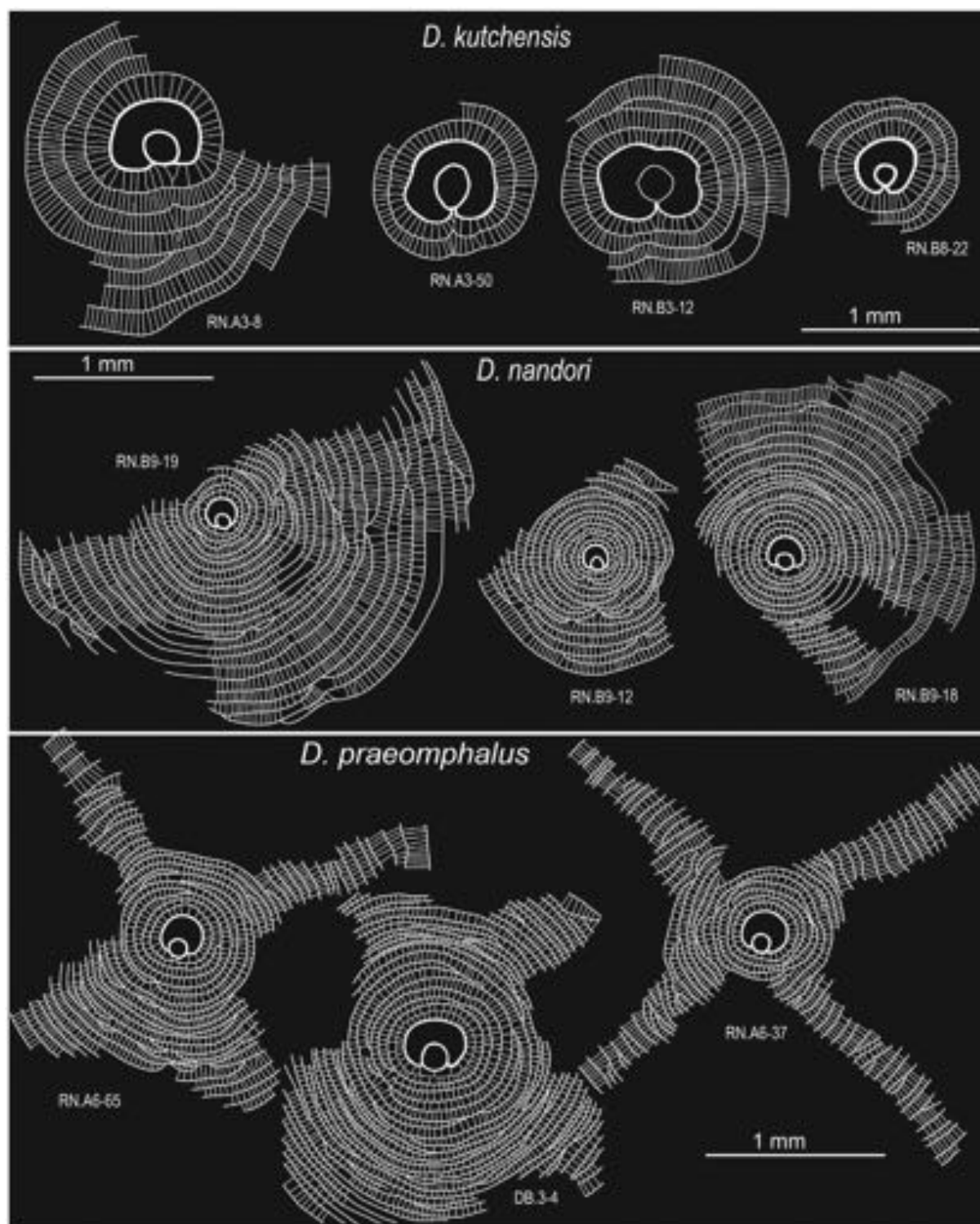


Figure 23. Comparison of embryo and equatorial chamberlets in *Discocyclus kutchensis*, *D. nandori* and *D. praeomphalus* from the Drazinda Formation.

matanzensis Cole. A subspecies designation is not possible because of the rare specimens in the studied material.

6. Conclusions

The Bartonian orthophragminids in the Pirkoh and Drazinda formations are represented by two Tethyan genera, *Discocyclus* Gümbel, 1870 and *Asterocyclus*

Gümbel, 1870. The former is very common and the latter is sporadic. The morphological variation in the orthophragminid test, ranging from small, flat to large saddle-shaped forms, is high, providing a helpful criterion for the identifications. We observed that these externally distinct types also possess distinctive morphological features in the lateral layers (as observed in axial sections) and the equatorial layer. The correlation in the external

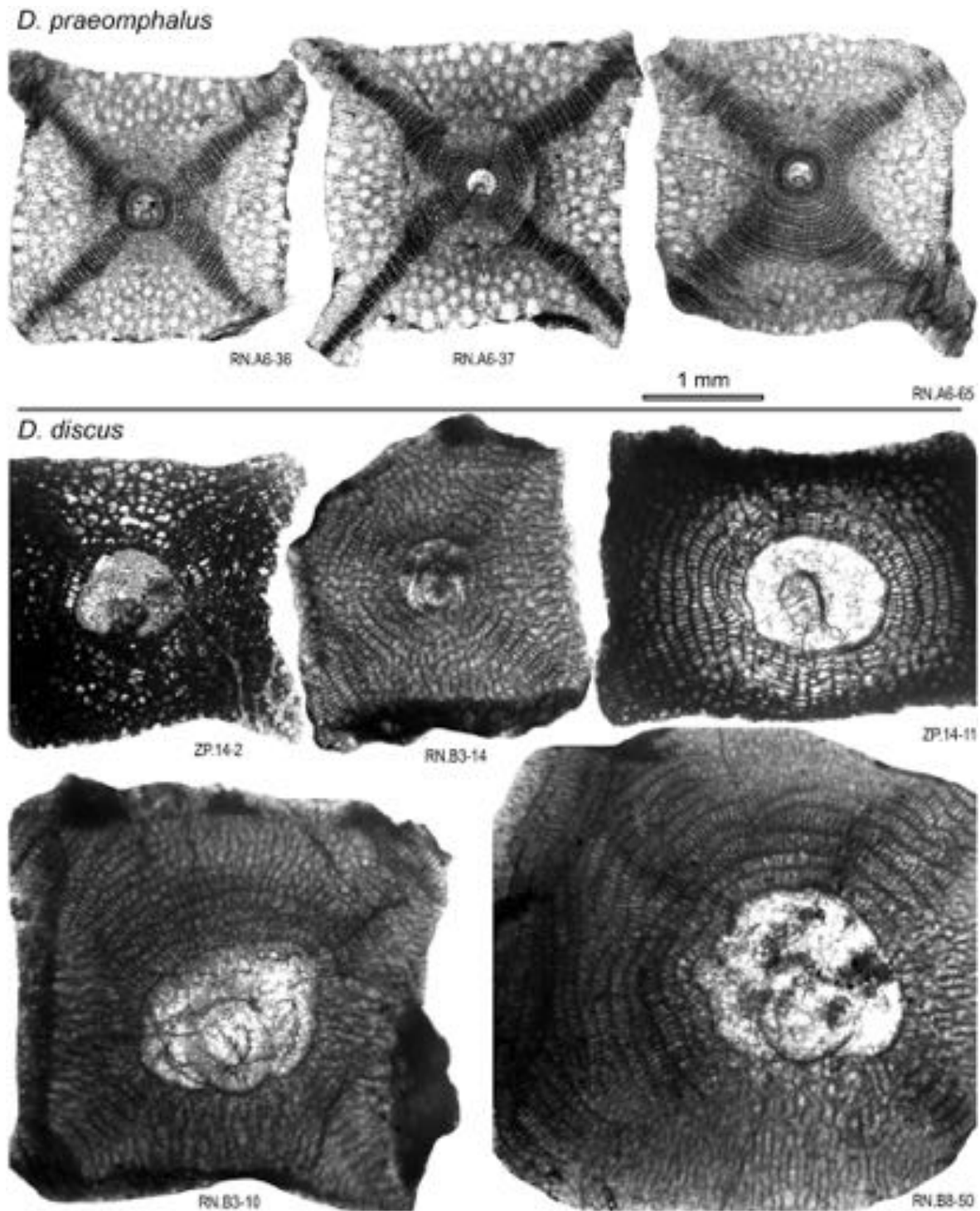


Figure 24. Embryon and equatorial chamberlets in *Discocyclus praeomphalus* and *D. discus* from the Drazinda Formation.

and internal test features in the equatorial layer is also supported by the biometry (e.g. *D. discus* with a large and *D. praeomphalus* with a comparatively smaller embryo). A key for the identification of orthophragminids in the Pirkoh and Drazinda formations based on test shape (flat versus saddle-shaped), and test surface characteristics (ribs, bulges, umbonal depressions) and test size (small versus large) is shown in Figure 27.

The saddle-shaped specimens are represented either by large, robust tests with large trybliolepidine-to umbilicolepidine-type embryo (*D. discus*) or comparatively

small tests with omphaloid structure, characterized by the central depression on either side of the test with small, semi-nephrolepidine/trybliolepidine-type embryo (*D. praeomphalus*) (Figure 27). The flat specimens are categorised into four groups as smooth tests (*Discocyclus rakhinalaensis* sp. nov., *D. zindapirensis* sp. nov., *D. dispansa*, *D. pseudodispansa*, *D. augustae*), test with ribs (*D. nandori*, *Asterocyclus stellata*, *A. sireli*), test with bulges (*Discocyclus kutchensis*), and omphaloid tests (*D. sulaimanensis*). The flat tests with smooth surface further can be categorised as small tests (<3 mm) or large

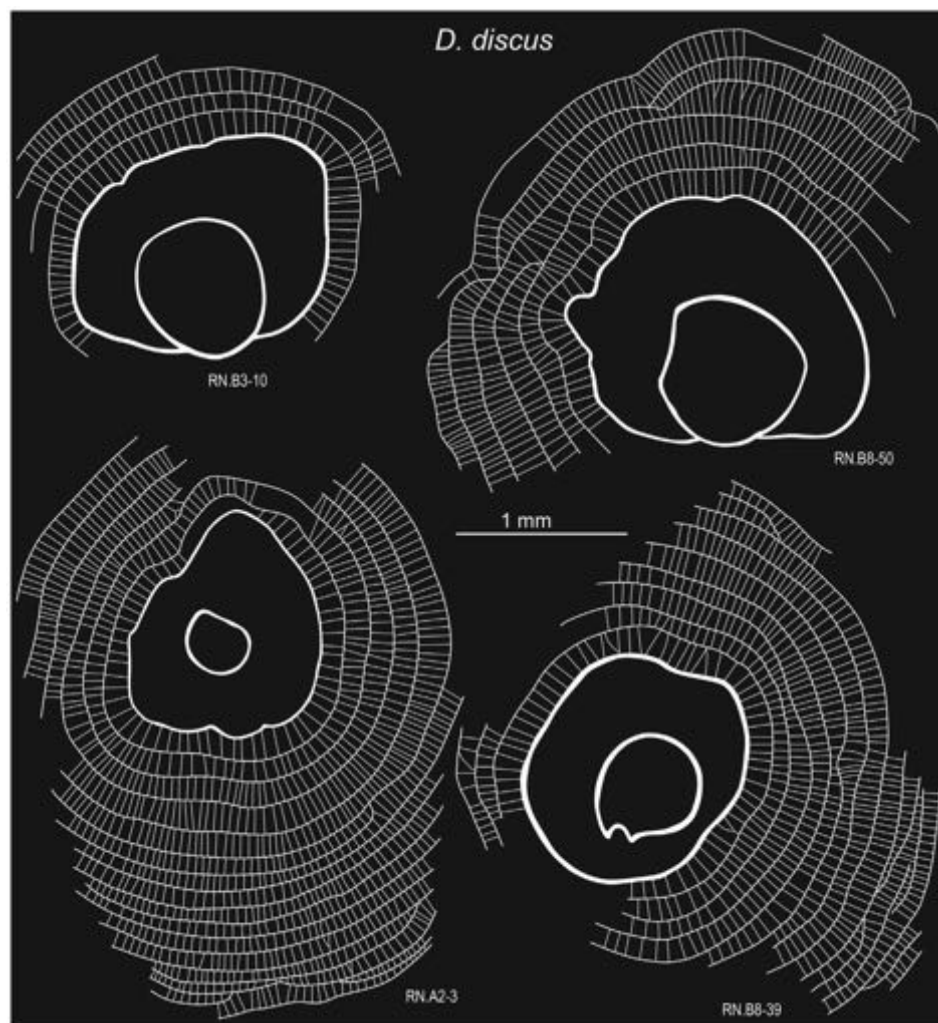


Figure 25. Embryo and equatorial chamberlets in *Discocyclus discus* from the Pirkoh and Drazinda formations.

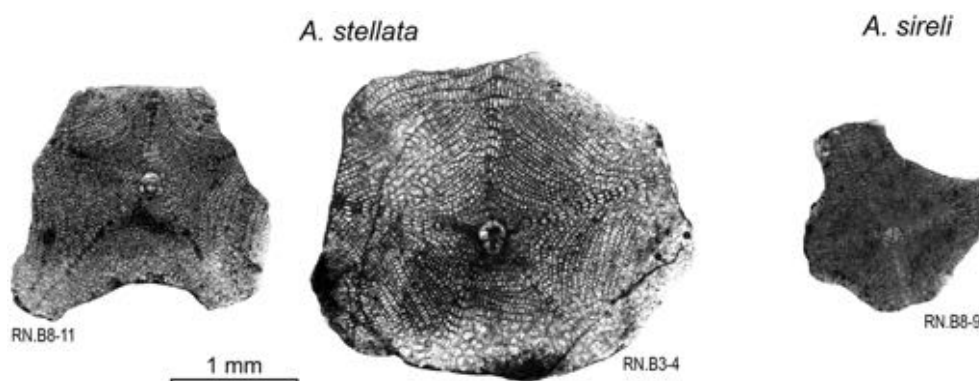


Figure 26. Comparison of embryo and equatorial chamberlets in *Asterocyclina stellata* and *A. sireli* from the Drazinda Formation.

tests (>3 mm) with various embryonic configurations. It is possible that some species, such as *D. pseudodispansa* and *D. augustae*, may be confused in the equatorial sections, although the external test shapes and test features in axial sections of both species are completely different. We also conclude that *D. dispansa*, characterized only by flat forms at its type-locality in Kutch Basin in India, is also represented invariably by flat specimens in Sulaiman Range. In Western Tethys, saddle-shaped and flat forms exhibiting ‘similar’ embryonic configuration and development of

equatorial chambers appear to have been lumped under this species (Less, 1987; Özcan et al., 2006). The notable overlaps in the stratigraphic ranges of some subspecies of this species (Less et al., 2011; Zakrevskaya et al., 2011), also prompt the re-evaluation of this group in Western Tethys.

Our data suggest that a significant number of ortho-phragminid species from the Sulaiman Range, such as *D. praeomphalus*, *D. sulaimanensis*, *D. kutchensis*, and newly described *D. rakhinalaensis*, *D. zindapirensis* and *D. pseudispansa*, are endemic to Indian Subcontinent.

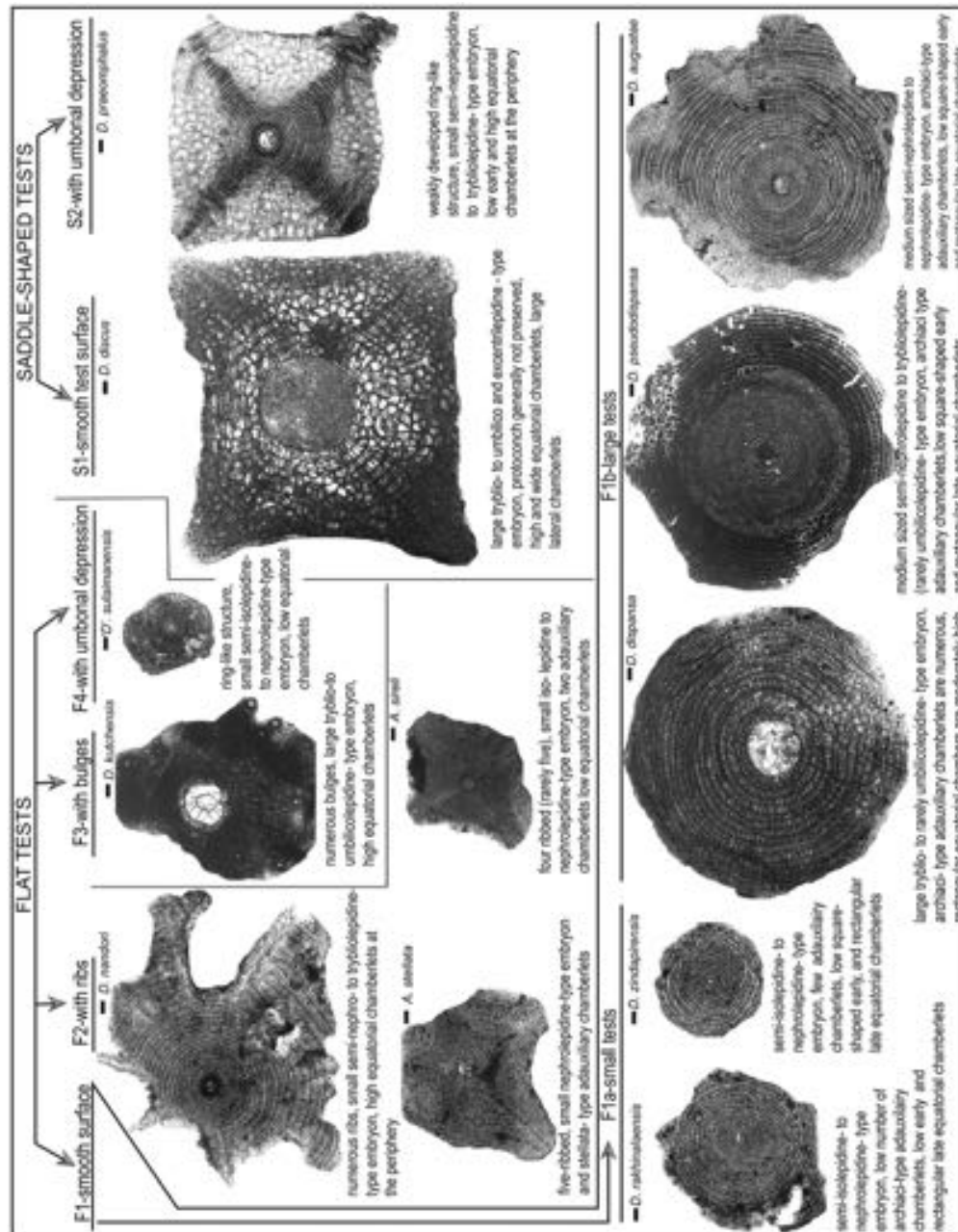


Figure 27. Identification chart of orthophragminids from the Sulaiman Range based on external test shape and corresponding equatorial sections. The flat orthophragminids are categorized into four groups based on test surface features (e.g. ribs, bulges, and central depression of the test). The flat specimens with smooth test surface are further categorized as 'small' (<3 mm) and 'large' (>3 mm). The saddle-shaped tests are subdivided into two categories as 'smooth tests' and tests with 'umbonal depression'. This categorisation does not reflect a taxonomical hierarchical classification.

A. sireli, common in eastern part of Western Tethys (e.g. Turkey), north Africa, and India, was not reported from central and western Europe. This implies a remarkable differentiation of orthophragminid taxa between the Indian Subcontinent and the peri-Mediterranean region already in (early) Bartonian times. The Ypresian and Lutetian orthophragminids from the Indian Subcontinent are poorly known. We encourage further research in Lutetian assemblages in Pakistan to evaluate the possible ancestral stocks of Bartonian orthophragminids and their relations to those in Western Tethys. This will help assessing whether some orthophragminid lineages in the Indian Subcontinent have independently developed during much of the Eocene or it followed a faunal differentiation period in Tethys that led to development of some endemic taxa. Our data are consistent with previous recent works (Ben İsmail-Latrache et al., 2014; Özcan & Saraswati, 2014) postulating that generic and specific diversity of orthophragminids shows a longitudinal decline eastward from the peri-Mediterranean region. This relies on the fact that the common middle Eocene *Orbitoclypeus* and *Nemkovella* lineages have not been recorded in Pakistan. The number of asterocyclinid lineages may also show a decline eastward of the peri-Mediterranean region. We do not confirm the occurrence of *Actinosiphon*, a Paleocene Caribbean genus, and *D. ranikotensis*, early Eocene species endemic to Indian Subcontinent (Özcan, Hanif, Ali, & Yücel, 2015), in the Pirkoh and Drazinda formations.

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ORCID

Muhammad Rizwan  <http://orcid.org/0000-0002-2242-9727>

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