Bartonian orthophragminids from the Fulra Limestone (Kutch, W India) and coeval units in Sulaiman Range, Pakistan: a synthesis of shallow benthic zone (SBZ) 17 for the Indian Subcontinent

Ercan Özcan*, Pratul Kumar Saraswati**, Ali Osman Yücel***, Nowrad Ali**** and Muhammad Hanif*****

*Faculty of Mines, Department of Geological Engineering, Istanbul Technical University (ITU), Istanbul, Turkey; **Indian Institute of Technology–Bombay, Mumbai, India; ***Department of Geology, University of Peshawar, Peshawar, Pakistan; ****National Centre of Excellence in Geology, University of Peshawar, Peshawar, Pakistan

ABSTRACT
Orthophragminids from the Bartonian Fulra Limestone in Kutch, India and the coeval units in Sulaiman Range in Pakistan suggest the establishment of a significant number of endemic species in the Indian subcontinent (Eastern Tethys). Among a total of fifteen species of Discocyclina, Orbitoclypeus and Asterocyclina, six of them appear to be confined to Indian subcontinent while seven species are common both to the peri-Mediterranean/Europe region (Western Tethys) and Indian subcontinent. Two species, Asterocyclina sireli, a four-ribbed species of possibly Indo-Pacific origin, and Orbitoclypeus haynesi that form large populations in Fulra Limestone, appear to have spread into North Africa and Turkey but not into European platforms as a response to Middle Eocene Climatic Optimum (MECO). The lack of Lutetian and Priabonian fauna in the studied sections, either due to a hiatus or unsuitable depositional environments, hampers the establishment of the actual stratigraphic ranges of the identified taxa. Our record provides us to characterize the orthophragminids in shallow benthic zone (SBZ) 17 for Eastern Tethys in detail by comparing the data from the above localities with those from the North Africa, Europe and Turkey, showing the change in diversity.

1. Introduction
Paleocene and Eocene shallow-marine deposits in Indian subcontinent were traditionally regarded to have formed under three major transgressions, Ranikot (Paleocene), Laki (early Eocene) and Kirthar (middle Eocene), the latter being the most significant one owing to deposition of highly fossiliferous beds in India and Pakistan (Eames, 1952a, 1952b; Nagappa, 1959; Nuttall, 1926). The Fulra Limestone in Kutch Basin in western India and the correlative units in Pakistan, the Pirkoh and Drazinda formations in Sulaiman Range correspond to Bartonian Kirthar transgression coeval with the Middle Eocene Climatic Optimum (MECO) (Khanolkar, Saraswati, & Rogers, 2017). The Bartonian shallow-marine deposits are exposed in Kutch, Cambay and Jaisalmer basins in western India, in the Sulaiman and Kirthar ranges in Pakistan, and in the Assam-Meghalaya regions in eastern India. Generally referred to as ‘Nummulitic limestone’, these sequences contain abundant orthophragminids that are locally more common than nummulitids (Ali et al., 2018; Özcan, Saraswati, Hanif, & Ali, 2016b; Samanta & Lahiri, 1985). Our studies on the taxonomy and paleobiogeography of orthophragminids from the Fulra Limestone and Sulaiman Range in Pakistan revealed a significant number of new species that appear to be confined to Indian subcontinent (Ali et al., 2018; Özcan et al., 2016b). This suggests a major faunal differentiation between peri-Mediterranean/Europe region (Western Tethys) and Indian subcontinent (Eastern Tethys) in the middle Eocene. As opposed to Western Tethyan orthophragminid assemblages, Discocyclina, along with subordinate Asterocyclina, is the most common group in Fulra Limestone, whereas Orbitoclypeus is represented by a single species, O. haynesi. Pirkoh and Drazinda formations from Pakistan yielded predominantly Discocyclina consisting of some new species including Discocyclina pseudodispansa Özcan, Ali & Yücel, 2018, D. sulaimanensis Özcan, Ali & Hanif, 2016, D. rakhinalensis Özcan, Ali & Yücel, 2018, D. zindapirensis Özcan, Ali & Yücel, 2018, and D. kutchensis Özcan & Saraswati, 2016, the latter one occurring also in the Fulra Limestone (Ali et al., 2018; Özcan et al., 2016b). A new morphological structure, bulges, observed at the test surface as semi-rounded to rounded thickening of the lateral layers, in D. kutchensis was introduced (Özcan et al., 2016b).
We aim to describe here in detail the orthophragminids from the Fulra Limestone to complement our findings from the Pirkoh and Drazinda formations in Pakistan (Ali et al., 2018). We make a general synthesis of Bartonian orthophragminids from the Indian subcontinent by incorporating and comparing the data from Western Tethys (Europe, north Africa and Turkey). A synthesis for shallow benthic zone (SBZ) 17 for Indian subcontinent is made in the light of new orthophragminid data from this region.

2. Geological setting and stratigraphy

2.1. Kutch Basin

In Kutch the Eocene succession represents the first marine transgression following the Deccan volcanism and consists of Naredi and Harudi formations and Fulra Limestone (Biswas, 1992; Saraswati, Khanolkar, & Banerjee, 2017) (Figure 1(A), (B)). The Fulra Limestone conformably overlying the Harudi Formation is interpreted to have been deposited in a warm, oligotrophic sea during the globally recognized warming period called Middle Eocene Climatic Optimum (MECO) (Khanolkar et al., 2017). It comprises exclusively of shallow marine carbonates consisting of various fossil groups including planktonic foraminifera at its lower part (Khanolkar et al., 2017; Samanta, 1970, 1993; Samanta, Bandopadhyay, & Lahiri, 1990; Samanta & Lahiri, 1985; Saraswati, Patra, & Banerjee, 2000; Saraswati et al., 2017; Sen Gupta, 1963a, 1963b). The unit is characterized by six facies, as orthophragminid mudstone (sample FUL1, Figure 2(A)), orthophragminid wackestone-mudstone alternation, orthophragminid wackestone-packstone alternation, nummulitic grainstone, nummulitic wackestone-packstone alternation, and Alveolina wackestone-packstone alternation (samples FUL2–15) corresponding to various depositional settings on a carbonate ramp (Figures 1(C), 2(C)–(E)) (Banerjee, Khanolkar, & Saraswati, 2017). These facies indicate a depositional spectrum ranging from bar-lagoon to mid-ramp depositional setting. Orthophragminid mudstone in the lower part of the Fulra succession contains planktonic foraminifera including Orbutiloides beckmanni and records the deepest bathymetry, up to 60 m, corresponding to mid-ramp setting. The cross-stratified Nummulitic grainstone beds, with slightly convex-up geometry and common palaeokarst surfaces, represent a high-energy deposit in inner-ramp setting (Banerjee et al., 2017; Chattoraj, Sarkar, Chakraborty, Banerjee, & Saraswati, 2012). These beds record the shallowest deposits in the ramp indicating low-relief bars in shoal environment. Nummulitic wackestone-packstone alternation forms a shoal flank environment. Orthophragminid wackestone-packstone alternation and orthophragminid wackestone-mudstone alternations form more distally. The repetition of above facies record repeated phases of shallowing and deepening. The Fulra Limestone is overlain unconformably by the Maniyara Fort Formation.

The age of the Fulra Limestone is firmly constrained as Bartonian by the occurrence of key planktonic species identified at its lower part and in the upper part of the underlying Harudi Formation (see Saraswati et al., 2017 for details). Samanta (1970) described planktic
foraminifera from the Fulra Limestone and assigned it to the *Orbulinoides beckmanni* and *Truncorotaloides (Acarinina) rohri* zones. Saraswati, Khanolkar, Raju, Dutta, and Banerjee (2014) identified *Orbulinoides beckmanni, Acarinina rohni, A. topilensis, Streptochilus martini, Pseudohastigerina micra*, and *Jenkinsina columbiana* in

Figure 2. Field aspects of the Fulra Limestone: Transition from Harudi Formation to the Fulra Limestone (A, B), the lower beds of the Fulra Limestone (sample FUL1) with planktonic foraminifera and LBF (B), close-up view of sample FUL6 with predominantly Discocyclina discus and *D. dispansa* (C), a shallowing upward cycle with transition from wackestones-packstone alternation (FUL6–10) to grainstone facies (FUL11–12) in the middle part of the unit (D), the upper carbonates of the Fulra Limestone of predominantly grainstone facies (E).
shale beds immediately below the Harudi Formation—Fulra Limestone boundary and assigned P13 Zone to this level. According to the scheme of Berggren and Pearson (2005) the unit corresponds to the Zones E12 and E13. The Fulra Limestone was assigned to shallow benthic zone (SBZ) 17 based on orthophragminids (Ben Ismail-Lattrache et al., 2014; Özcan et al., 2016b) and benthic foraminiferal assemblages supplemented by the planktonic foraminifera (Khanolkar et al., 2017).

2.2. Sulaiman range

The Middle to Upper Eocene sedimentary sequence in Sulaiman Range in Pakistan consists of Habib Rahi, Domanda, Pirkoh and Drazinda formations that were collectively named as ‘Kirthar’ by Blanford (1879) (Figure 3). 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, 1952b). The Drazinda Formation, more than 380 meters in thickness 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 upper part. The previous studies suggested a middle and/or late Middle Eocene age for the Drazinda Formation based on calcareous nanofossils (Köthe, Khan, & Ashraf, 1988), planktonic foraminifers (Afzal, Asrar, & Naseer, 1997; Samanta, 1973; Warraich & Nishi, 2003) and orthophragminids (Ali et al., 2018). According to Köthe et al. (1988), the age of this unit in Rakhi Nala section is middle Eocene based on the presence of nonplankton zones NP 16 and 17. Afzal et al. (1997) identified P14 and dated the lower part of Drazinda Formation (below the ‘Pellatispira beds’) as late middle Eocene (Bartonian) in age. The ‘Pellatispira’-beds containing Heterostegina, reticulate Nummulites and Pellatispira is considered Priabonian (Özcan et al., 2016a). 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). The Drazinda Formation is unconformably overlain by coastal deltaic to fluviatile deposits of Oligocene Chitarwatta Formation (Shah, 2009).

3. Material and methods

3.1. Material

The samples of the Fulra Limestone were collected from three sections, near Kharai and Harudi villages, 100 km northwest of Bhuj, Kutch (23°30’55.97″N, 68°40’5.98″E; 23°28’45.32″N, 68°40’49.23″E) (Figures 1, 2). We have sampled 15 levels representing the unit. 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 3, 4). 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 northwest 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) (Ali et al., 2018).

3.2. Sample preparation

Specimens extracted from the shale, marl and limestone beds were studied for their external features, features in the equatorial layer and axial sections. The oriented sections of 507 megalospheric and 70 microspheric specimens (A and B-Forms respectively) have been prepared through their equatorial layer. The morphometric measurements and counts were carried out on equatorial sections of the megalospheric specimens. Axial sections of 83 megalospheric and microspheric forms have been prepared for the comparisons in axial sections and also in order to facilitate specific recognition in rock thin sections.

4. Test features of the Tethyan orthophragminids

Orthophragminids are bilamellar, perforate foraminifera characterized by a discoidal, lenticular test with an equatorial layer consisting of cyclically arranged equatorial chambers and lateral layers composed of lateral chambers and pillars on either side of the equatorial layer (Figure 5(A)). Externally, the test surface is either smooth, occasionally with an inflated or depressed central part, or it is characterized by radially developed ribs and bulges (Özcan et al., 2016b). Based on the relationship of protoconch and deuteroconch in equatorial sections, about ten configurations are used in the description of the embryo (Figure 5(B)). The equatorial chambers are divided into chamberlets of different shapes as observed in equatorial sections. Tethyan orthophragminids consist of five genera; Discocyclina Gümbel, 1870, Nemkovella Less, 1987 and poorly known Astero phragmin a Rao, 1942 placed in Discocyclinidae Galloway, 1928 and two genera, Orbitoclypeus Silvestri, 1907 and Asterocyclina Gümbel, 1870 placed in Orbitoclypeidae Brönnimann, 1946 (Ferrández-Canadell, 1998; Less, 1987) (Figure 6). The obsolete genus Actinocy clina Gümbel 1870, characterized by the presence of numerous ribs, is assigned to
Figure 3. Location of Sulaiman Range in Pakistan (A), simplified geological map of the Sulaiman Range (B), and stratigraphic sections and sampling points from the Pirkoh and Drazinda formations (C).

Notes: Geological map is simplified from Kazmi and Rana (1982). PSB: Pellatispira beds (from Ali et al., 2018).
genus *Discocyclina* after their discyclinid-type microspheric juvenarium (Ferrández-Cañadell, 1997; Less, 1987) (Figure 6.1). The microspheric forms of some of the Tethyan genera are illustrated in Figure 6.

5. The orthophragminids from the Fulra Limestone and Pirkoh and Drazinda formations

The LBF in Fulra Limestone are characterized by common occurrence of orthophragminids, nummulitids and alveolinids accompanied by rare rotaliids, and some stratigraphically important taxa as *Dictyoconoides, Linderina, Calcarina*, and smaller benthic foraminifera (Khanolkar et al., 2017; Samanta, 1993; Samanta & Lahiri, 1985; Samanta et al., 1990; Saraswati et al., 2000; Sen Gupta, 1963a, 1963b). Orthophragminids belong mainly to *Discocyclina* Gümbel, 1870, a single species of *Orbitocyclus* Silvestri, 1907 and three species of *Asterocyclina* Gümbel, 1870 were also recognized. The following species are identified; *Discocyclina dispansa* (Sowerby, 1840), *Discocyclina pseudodispansa* Özcan, Ali & Yücel, 2018, *Discocyclina kutchensis* Özcan & Saraswati, 2016, *Discocyclina praemphalus* Samanta & Lahiri, 1985; *Discocyclina augustae* van der Weijden, 1940; *Discocyclina discus* (Rütimeyer, 1850), *Discocyclina pratti* (Michelin, 1846), *Orbitocyclus haynesi* (Samanta & Lahiri, 1985), *Asterocyclina sireli* Özcan & Less, 2006, *Asterocyclina alticostata* (Nuttall, 1926), *Asterocyclina stellata* (d’Archiac, 1846) (Figure 7(A)). The nummulitids, such as *Nummulites beamontii* (Figure 8.1–2), *Nummulites* sp. 1 (Figure 8.3–4), *Nummulites maculatus* (Figure 8.5–6), *Nummulites gr. bulatus* (Figure 8.7–8), *Operculina gr. gomezi* (Figure 8.9–10), *Linderina* sp. (Figure 8.11–12), *Calcarina* sp. (Figure 8.13–14), and *Dictyoconoides* sp. (Figure 8.15). *Operculina gr. gomezi*, a diagnostic Bartonian-Priabonian species in Western Tethys (Less & Özcan, 2012), is identified for the first time from the Fulra Limestone.

Orthophragminids in the Pirkoh and Drazinda formations are represented by *Discocyclina* and scanty *Asterocyclina* while *Orbitocyclus* and *Nemkovella* are absent (Figure 7(B)). The Pirkoh Formation yielded only discocyclinids, represented by *D. dispansa* (Sowerby, 1840), *D. discus* (Rütimeyer, 1850), *D. praemphalus* Samanta & Lahiri, 1985 accompanied by *Dictyoconoides, Nummulites, Assilina, Operculina, Linderina and*
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 (Ali et al., 2018).

6. Systematic paleontology

Detailed description of some of the orthophragminids from the Fulra Limestone was given by Sen Gupta (1963a) and Samanta and Lahiri (1985). We here focus on 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* van der Weijden, 1940; *D. sulaimanensis* Özcan, Ali & Hanif, 2016, *D. kutchensis* Özcan & Saraswati, 2016, *D. nandori* Less, 1987; *D. pseudodispansa* Özcan, Ali & Yücel, 2018, *D. rakhinalaensis* Özcan, Ali & Yücel, 2018, *D. zindapirensis* Özcan, Ali & Yücel, 2018, *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.

Figure 5. General test features in Tethyan orthophragminid genera (A) (after Less, 1987; Ferrández-Cañadell, 1997; Özcan et al., 2016b), 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* from Sulaiman Range (C). pac: principal auxiliary chamberlets.
Diagnosis. *Discocyclina dispansa* is a small to large sized, 'flat to saddle' shaped, unribbed form. The small to medium-sized megalospheric embryon 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 order Foraminiferida Eichwald, 1830
Family Discocyclinidae Galloway, 1928
Genus *Discocyclina* Gümbel, 1870
Type-species: *Orbitolites pratti* Michelin, 1846

*Discocyclina dispansa* (Sowerby, 1840) (Figures 9(B), 10)
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.
2018 *Discocyclina dispansa* (Sowerby, 1840), Ali et al., Figs. 9, 12, 15, 17.

*Diagnosis. Discocyclina dispansa* is a small to large sized, 'flat to saddle' shaped, unribbed form. The small to medium-sized megalospheric embryon 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
Figure 7. Distribution of orthophragminids and associated LBF from the Fulra Limestone (A) and Pirkoh and Drazinda formations (B).

Notes: The synthetic stratigraphic columnar section representing Pirkoh and Drazinda formations in Sulaiman Range includes data from Rakhi Nala A and B, Zinda Pir, and Domanda Bridge sections.
Less, 1987 (Dmean < 160 μm); *D. d. taurica* Less, 1987 (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) 

...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 (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)
Discocyclina 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). We think that a revision of this group is necessary focusing on the distinction between the flat and saddle forms. Based on biometry (Table 1), the species is represented by D. d. dispansa (Sowerby, 1840) in the Fulra Limestone. This species may externally be confused with D. pseudodispansa.

Discocyclina pseudodispansa Özcan, Ali & Yücel, 2018
(Figures 9(C), 11)
2018 Discocyclina pseudodispansa n. sp. Özcan, Ali, & Yücel, Ali et al., Figs. 9, 12, 15, 16.

Figure 9. External test features of orthophragminids from the Fulra Limestone (B, F, I-N) and Drazinda Formation (A, C-E, G-H). A: Discocyclina discus, B: D. dispansa, C: D. pseudodispansa, D: D. sulaimanensis, E: D. zindapirensis, F: D. augustae, G–H: D. nandori, I: D. praeomphalus, J–K: D. kutchenis, L: Asterocyclina alticostata, M: A. sireli, N: Orbitoclypeus haynesi.

Remarks. Discocyclina dispansa, one of the most common orthophragminid species in the Fulra Limestone, first described from this unit by Sowerby (1840). In Fulra Limestone and Drazinda Formation, the species is represented by a flat test with a thick umbo, surrounded by a thin flange. In equatorial layer, a characteristic feature is the presence of the high early chambers followed by low chambers (Figure 10.1–2). 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 been lumped under this species as evidenced by 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). We think that a revision of this group is necessary focusing on the distinction between the flat and saddle forms. Based on biometry (Table 1), the species is represented by D. d. dispansa (Sowerby, 1840) in the Fulra Limestone. This species may externally be confused with D. pseudodispansa.

Discocyclina pseudodispansa Özcan, Ali & Yücel, 2018
(Figures 9(C), 11)
2018 Discocyclina pseudodispansa n. sp. Özcan, Ali, & Yücel, Ali et al., Figs. 9, 12, 15, 16.
Discocyclina augustae van der Weijden, 1940
(Figures 9(F), 12)
1940 Discocyclina augustae n. sp. van der Weijden, p. 23–26, pl. 1, Figs. 4, 5, 7, 8; pl. 2, Figs. 1, 2, 11.
2018 Discocyclina augustae van der Weijden, 1940, Ali et al., Figs. 10–11, 12, 21.

Diagnosis. Discocyclina augustae is an unribbed form having a very small to small, semi-iso- to nephrolepidine embryon, 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. olianae Almela & Rios, 1942 (Dmean = 180–225 μm); D. a. augustae van der Weijden, 1940 (Dmean > 225 μm).

Remarks. Discocyclina augustae is easily differentiated externally by its flat test with small central umbo and uniformly distributed piles (Figure 9(F)). It can be, however, easily confused with D. pseudodispana in equatorial sections, whereas their axial sections are completely different. This species has a much larger embryon than that of D. rakhinalaensis (Ali et al., 2018). In the studied material, D. augustae is represented by transitional stages between D. a. atlantica and D. a. olianae, according to the evolutionary scheme of the genus in the Western Tethys (Table 1).

Discocyclina praeomphalus Samanta & Lahiri, 1985
(Figures 9(I), 13)
1985 Discocyclina praeomphalus n. sp. Samanta & Lahiri, p. 272–275, pl. 5, Figs. 1–6, text Figures 5–7, 12.
2018 Discocyclina praeomphalus, Ali et al., Figs. 10, 14, 23–24.

Figure 10. Equatorial and axial sections of D. dispansa dispansa from the Fulra Limestone. 1: sample FUL12–72, 2: FUL8–23, 3: FUL7–5, 4: FUL13–208.
| Sample | N  | Range       | Mean ± S.E | Range | Mean | Range | Range | Annuli/0.5 mm | Height | Width | Species/subspecies |
|--------|----|-------------|------------|-------|------|-------|-------|---------------|--------|-------|-------------------|
| FUL1   | 16 | 270–385     | 329.38 ± 10.1 | 120–170 | 143.57 | 23–31 | 30–70 | 30–65          | 9–12   | 50–90 | Discocyclina pseudodispansa |
| FUL2   | 15 | 180–300     | 223.67 ± 7.6 | 85–135 | 103.67 | 23–25 | 25–55 | 20–70          | 11–14  | 40–65 | Discocyclina praemphilus |
| FUL3   | 12 | 185–255     | 223.3 ± 7.2  | 80–105 | 91.11  | 25–28 | 30–50 | 20–35          | 12–16  | 50–85 | Discocyclina discus sowerbyi |
| FUL4   | 2  | 1170–1755   | 1462.5      | -      | 61.5   | -     | 65–155 | 65–90          | 3–5    | 85–115| Discocyclina pseudodispansa |
| FUL5   | 2  | 1140–1220   | 1180.0      | -      | 440.0  | -     | 150–205 | 55–85          | 3      | 140–150| Discocyclina pseudodispansa |
| FUL6   | 10 | 1030–1910   | 1396.5 ± 73.3 | 460–1405 | 761.6  | 25–100 | 25–100 | 25–100         | 7–9    | 75–120| Discocyclina pseudodispansa |
| FUL7   | 3  | 1180–1875   | 1481.6 ± 160.0 | -      | 765.0  | -     | 80–210 | 55–90          | 3–4    | 70–80 | Discocyclina pseudodispansa |
| FUL8   | 9  | 800–1670    | 1259.0 ± 125.3 | 390–515 | 447.0  | -     | 55–200 | 40–100         | 4–5    | 75–120| Discocyclina pseudodispansa |
| FUL9   | 3  | 1430–1560   | 1480 ± 33.0 | 550–710 | 630.0  | 88     | 85–170 | 55–105         | 4–5    | 125–165| Discocyclina pseudodispansa |
| FUL10  | 3  | 1170–1755   | 1462.5      | -      | 61.5   | -     | 65–155 | 65–90          | 3–5    | 85–115| Discocyclina pseudodispansa |
| FUL11  | 5  | 1030–1910   | 1396.5 ± 73.3 | 460–1405 | 761.6  | 25–100 | 25–100 | 25–100         | 7–9    | 75–120| Discocyclina pseudodispansa |
| FUL12  | 7  | 1180–1875   | 1481.6 ± 160.0 | -      | 765.0  | -     | 80–210 | 55–90          | 3–4    | 70–80 | Discocyclina pseudodispansa |
| FUL13  | 24 | 150–215     | 1741.7 ± 24.7 | 65–110  | 75.0   | 20–25 | 20–40  | 20–40          | 15–16  | 30–80 | Discocyclina pseudodispansa |
| FUL14  | 4  | 165–175     | 1712.2 ± 70.7 | 70–75   | 71.7   | 22     | 30–45  | 20–45          | 12–17  | 50–65 | Discocyclina pseudodispansa |
| FUL15  | 1  | 150         | 70          | 19      | 25–30  | 25–45  | 18      | 50–65          | 30–45  | Asterocyclina sireli |
| FUL16  | 5  | 150–200     | 1800.0 ± 8.12 | 70–85  | 80.0   | 21     | 20–30  | 20–35          | 16–18  | 50–55 | Discocyclina pseudodispansa |
| FUL17  | 24 | 150–215     | 1844.3 ± 36.1 | 60–110  | 86.1   | 22–26  | 25–45  | 20–40          | 15–17  | 25–60 | Discocyclina pseudodispansa |
| FUL18  | 34 | 275–610     | 411.1 ± 14.6 | 105–250 | 169.4  | 27–47  | 70–110 | 25–50          | 5–6    | 75–100| Discocyclina pseudodispansa |
| FUL19  | 3  | 310–460     | 423.3 ± 21.0 | 150–200 | 177.5  | 28–36  | 80–120 | 25–45          | 5–6    | 80–120| Discocyclina pseudodispansa |
| FUL20  | 6  | 605–865     | 730.8 ± 35.8 | 250–395 | 335.0 | 70–74  | 120–120 | 25–65         | 4–7    | 75–110| Discocyclina pseudodispansa |
| FUL21  | 1  | 150         | 75          | -      | -      | -     | -      | -              | 14     | 30–50 | Discocyclina pseudodispansa |
| FUL22  | 2  | 225–260     | 242.5 ± 12.3 | 110–140 | 125.0 | 25     | 25–50  | 20–60          | 12–13  | 65      | Discocyclina pseudodispansa |
| FUL23  | 16 | 215–310     | 251.8 ± 6.9  | 90–175 | 130.0  | 23–32  | 30–50  | 25–45          | 14–15  | 45–70 | Discocyclina pseudodispansa |
| FUL24  | 1  | 230         | 150         | -      | 30–45  | 20–45  | 15      | 35–55          | 25–35  | Asterocyclina sireli |
| FUL25  | 8  | 205–250     | 225.0 ± 5.5  | 80–115 | 105.0  | 25–30  | 25–55  | 25–40          | 12–14  | 40–90 | Discocyclina pseudodispansa |
| FUL26  | 51 | 165–300     | 231.8 ± 3.8  | 85–160 | 115.7  | 26–28  | 35–60  | 20–50          | 13–17  | 40–70 | Discocyclina pseudodispansa |
| FUL27  | 24 | 190–300     | 243.3 ± 5.6  | 100–165 | 122.5 | 27–30  | 35–65  | 25–45          | 12–15  | 35–95 | Discocyclina pseudodispansa |
| FUL28  | 4  | 200–245     | 218.75 ± 8.3 | 90–135 | 108.7  | 26–29  | 35–50  | 20–100         | 13–15  | 50–100| Discocyclina pseudodispansa |
| FUL29  | 6  | 110–140     | 124.7 ± 2.1  | 60–90  | 74.74  | 115    | 30–45  | 20–45          | 15     | 35–55 | Discocyclina pseudodispansa |

(Continued)
Diagnosis. *Discocyclina praecomphalus* is a medium sized (2.4–4 mm), saddle shaped, unribbed form with a slight depression at the center of the test. The megaspheric embryon (average 222.0–223.7 μm in diameter) exhibits semi-nephrolepidine to trybliolepidine type configuration. The adauxiliary chamberlets 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 Fulra Limestone (Samanta & Lahiri, 1985), occurs abundantly in the Drazinda Formation in the Sulaiman Range (Ali et al., 2018). It differs externally from other orthophragminids from the Drazinda Formation by its characteristic saddle shape and the central depression of the test. *Discocyclina sulaimanensis*, another omphaloid species from the Drazinda Formation, has a flat and smaller test than that of *D. praecomphalus*. The axial sections of *D. praecomphalus* are easily differentiated from that of the saddle-shaped *D. discus* in having very low (slit-like) chamberlets. This is a common discocyclinid in the middle Eocene of the Indian Subcontinent.

**Discocyclina kutchensis Özcan & Saraswati, 2016**

(Figures 9(J), (K), 14)

2016b *Discocyclina kutchensis* sp. nov. Özcan & Saraswati, p. 267–274, Figs. 5L, 6A–I, 7A, 8A–D, 9, 10A–D.

2018 *Discocyclina kutchensis* Özcan, Ali, & Yücel, Ali et al., Figs. 9, 11, 14, 22–23.

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 embryon is large, with an average diameter of the deuteroconch ranging between 410 and 478 μm, trybliolepidine to umbilicolepidine in configuration. The adauxiliary chamberlets (37–53 in number) are high and archiaci-type. The equatorial chamberlets are typically high, narrow and rectangular in shape.

Remarks. This species, originally described from the Fulra Limestone and Drazinda Formation, differs from most 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., 2016b). 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 equatorial layer adjacent to the
Diagnosis. Discocyclina pratti is an unribbed species having a medium-sized to large, tryblio- to excentrilepidine-type embryon, numerous moderately wide and high, ‘pratti’ type adauxiliary chamberlets and narrow but high equatorial chamberlets with ‘pulcra’ type growth pattern. This species includes three subspecies: D. p. montfortensis Less, 1987 (Dmean < 510 μm), D. p. pratti (Michelin, 1846) (Dmean = 510–700 μm), D. p. minor Meffert, 1931 (Dmean > 700 μm) after the analysis of rather rich assemblages from Turkish sections (Özcan, Less, & Kertész, 2007).

Remarks. Some specimens with thin, fragile and undulated test revealed embryos ranging from 600 to 865 μm. The embryos display various embryonic configurations ranging from umbilicolepidine to centrilepidine where the wall of deutroconch may merge to the protoconch wall at some points. The equatorial chambers are relatively high compared to those of D. discus. The embryon appears to be smaller than of D. discus. This species is rare in the studied material.
Discocyclina discus (Rütimeyer, 1850)

(Figure 9(A), 16)

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.

1985 Discocyclina adamsi n. sp., Samanta & Lahiri, p. 229–242, pl. 1, Figs. 6–10, pl. 5, Fig. 9, text –Figs. 5, 8.

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

2018 Discocyclina discus (Rutimeyer), Ali et al., Figs. 11, 14, 24–25.

Diagnosis. Discocyclina discus is a large, saddle-shaped and unribbed form with a giant, mostly umbilicolepidine (rarely also tryblo- or excentrilepidine) embryon, 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 Tethys: D. d. discus (Rütimeyer, 1850) (Dmean < 1350 μm) and D. d. sowerbyi Nuttall, 1926 (Dmean > 1350 μm) after our present data from Fulra Limestone.

Remarks. Discocyclina discus, widely reported from the Fulra Limestone and the Drazinda Formation as D. sowerbyi, is distinguished from other orthophragminids by its thick, saddle-shaped test and its large embryon with irregular wall. D. praeomphalus, another saddle-shaped species, is much smaller and thinner than D. discus (compare the axial sections in Figures 12 and 16). In addition, the equatorial chambers of D. discus are much higher than those of D. praeomphalus. Our data show that the thick, saddle-like forms described as Discocyclina sowerbyi (Nuttall, 1926) by Nuttall (1926) and Sen Gupta (1963a) 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 preoccupied 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. Discocyclina adamsi, established
by Samanta and Lahiri (1985) from the Fulra Limestone, is however, a junior synonym of *D. sowerbyi*, which was established from the same unit by Nuttall (1926). We emend here the subdivision of *D. discus* lineage by differentiating two subspecies, *D. discus discus* and *D. discus sowerbyi*. This requires the replacement of ‘adamsi’ by ‘sowerbyi’. In Fulra Limestone the species belongs to *D. discus sowerbyi*. Matsumaru and Sarma (2010) illustrated an axial section of a saddle-shaped specimen with a large and thick embryon 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, Fig. 11). This was interpreted to be the first record of the genus in Meghalaya and significant 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 embryon, high and wide lateral chamberlets and saddle-shaped test.

**Family Orbitoclypeidae Brönnimann 1946**

**Genus Orbitoclypeus Silvestri, 1907**

*Orbitoclypeus haynesi* (Samanta & Lahiri, 1985) (Figure 9(N), 17)

1985 *Discocyclina haynesi* n. sp. Samanta & Lahiri, p. 262–272, pl. 4, Figs. 1–6; pl. 12, Figs. 9–14; text-Figures 5–7.

2010 *Orbitoclypeus haynesi* (Samanta & Lahiri), Özcan et al., 2010, p. 59–61, Fig. 29i–n.

2013 *Orbitoclypeus haynesi* (Samanta & Lahiri), Ben Ismail-Lattrache et al., 2013, p. 12, pl. 2, Fig. 9–15, fig. 8.

2017 *Discocyclina dispensa* Sowerby, BouDagher-Fadel and Price (2017), Fig. 5–9.

**Diagnosis.** *Orbitoclypeus haynesi* is an unribbed species with ‘marthae’-type rosette, small eulepidine (rarely excentrilepidine) embryon, adauxiliary chamberlets of ‘varians’-type of average size and shape, moderately wide and high equatorial chamberlets arranged into strongly undulated annuli with ‘varians’-type growth pattern.

**Remarks.** *Orbitoclypeus haynesi* is the only orbitoclypeid in the Bartonian of Indian subcontinent. This species, referred to *Discocyclina* by Samanta and Lahiri (1985), was later assigned to *Orbitoclypeus* based on the embryonic configuration, presence of undulated annuli and shape of the equatorial chamberlets (Özcan et al., 2010). We here show a microspheric form showing orbitoclypeid type juvenarium justifying the generic assignment (Figure 17.5–6). Although similar to *O. varians* in external and internal test features, *O. haynesi* possesses a much smaller embryon, tighter annuli (parameter n0.5) and also commonly eulepidine-type embryonic configuration. Some specimens may exhibit
Figure 14. Equatorial and axial sections of *D. kutchensis* from the Fulra Limestone. 5, microspheric; others, megalospheric. 1: FUL6–51, 2: FUL6–131, 3: FUL6–132, 4: FUL13–145, 5: FUL6–59, 6: FUL6–123, 7: FUL6–127, 8: FUL6–102.

Figure 15. Equatorial sections of *Discocyclina pratti* from the Fulra Limestone. 1: FUL9–4, 2: FUL13–174, 3: FUL13–188, 4: FUL13–172, 5: FUL13–192.
Genus *Asterocyclina* Gümbel, 1870
Type species *Asterocyclina stellata* (d’Archiac, 1846)

*Actinocyclina alticostata* (Nuttall, 1926) (Figures 9(L), 18)

1926 *Actinocyclina alticostata* sp. nov., Nuttall, p. 151, pl. 8, Figs. 6–8.

O. *haynesi*, also recorded from Turkey (Özcan et al., 2010) and northern margin of Africa (Ben Ismail-Lattrache et al., 2014) but not known from Europe, might be immigrant from the Indian subcontinent because of the expansion of the Eastern Tethyan fauna during Middle Eocene Climatic Optimum (MECO).

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**Figure 16.** Equatorial and axial sections of *D. discus sowerbyi* from the Fulra Limestone. 1: FUL3–26, 2: FUL3–32, 3: FUL6–12, 4: FUL6–14, 5: FUL8–57, 6: FUL6–44, 7: FUL13–44, 8: FUL13–42, 9: FUL3–31.
isolepidine-type embryo, very few, very wide and moderately low, ‘alticostata’ type adauxiliary chamberlets and also wide and moderately high equatorial chamberlets.

**Diagnosis.** *Asterocyclina alticostata* is a star-shaped species usually with five to ten rays and ‘chudeau’ type rosette. It has a medium-sized to relatively large

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**Figure 17.** Equatorial and axial sections of *Orbitoclypeus haynesi* from the Fulra Limestone. 5–6, microspheric; others, megalospheric. 1: FUL8–55, 2: FUL13–30, 3: FUL12–44, 4: FUL8–17, 5–6: FUL13–57, 7: FUL9–30.

**Figure 18.** Equatorial and axial sections of *A. alticostata* ex. interc. *alticostata-cuvillieri* (2–5) and *A. alticostata* ex. interc. *cuvillieri-alticostata* (1) from the Fulra Limestone. 1: FUL13–9, 2: FUL12–11, 3: FUL12–5, 4: FUL6–24, 5: FUL6–30.
arranged into asteroidal annuli with ‘strophiolata’ or ‘varians’ type growth pattern. This species includes four subspecies as: *A. a. gallica* Less, 1987 (Dmean < 275 μm); *A. a. cuvillieri* (Neumann, 1958) (Dmean = 275–350 μm); *A. a. alticostata* (Nuttall, 1926) (Dmean = 350–450 μm); *A. a. danubica* Less, 1987 (Dmean > 450 μm).

Remarks. Nuttall (1926) erected this species from Kutch and noted the presence of about eight to twelve fairly wide prominent ribs in twelve specimens. He assigned these ribbed specimens to *Actinocyclus* (Gümbel) based on numerous ribs. We have collected a large number of specimens from the Fulra Limestone while this species is extremely rare in the Drazinda Formation. The number of ribs counted in fifty-four specimens from the Fulra Limestone is given in Table 2. This suggests that *A. alticostata* commonly develops more than five ribs, the maximum number being ten ribs in our material. Some of these ribs develop only in the adult stage of the test and they look like as if they are ‘secondary ribs’ on the test surface. The consistent occurrence of more than five ribs in this species in Indian Subcontinent as well as lower Bartonian Reineche Limestone in North Africa and coeval deposits in Turkey and Europe (Neumann, 1958; Köhler, 1967; Less, 1987; Less et al., 2011; Zakrevskaya et al., 2011; Ben Ismail-Lattrache et al., 2014) also points that this is not an ecological feature, but a specific character. The same feature is also observed in *A. schweighauseri*, a rare species recorded in the Cuisian and lower-middle Lutetian in Europe and Israel (Less, 1987, 1998). According to Less (1987), always five rays start from the embryo of *A. alticostata* with further development of other rays in the adult stage (up to 10 rays), and many ribs start directly from the embryo in *A. schweighauseri*. We think that this is not a valid criterion for the distinction of these species since in some specimens of *A. alticostata* more than five rays may start to develop from the embryo (Figure 18.1). In Fulra Limestone, this species is represented by the transitional developmental stages of *A. alticostata cuvillieri* and *A. alticostata alticostata* (Table 1).

**Asterocyclina sirelii** Özcan & Less, 2006

(Figures 9(M), 19)

2006 *Asterocyclina sirelii* n. sp., Özcan et al., p. 506–507, 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 deuteroconchal 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 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, Less, Báltá-Beké, Kollányi, & Kertesz, 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 (Table 2). 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. sirelii* is essentially a four-ribbed species. In contrast to its common occurrence in the Fulra Limestone, *A. sirelii* is very rare in the Drazinda Formation.

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

(Figure 19)

**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. stellaria* (Brünner, 1848 in Rütimeyer, 1850) (Dmean = 190–240 μm); *A. s. buickensis* Less, 1987 (Dmean > 240 μm).

Remarks. *A. stellata*, recorded only from the Priabonian of Assam as *A. matanzenose* Cole by Samanta (1965) from the Indian subcontinent, occurred sporadically in the Fulra Limestone. A subspecies designation is not possible because of the rare specimens in the studied material.

### Table 2. The variation in the number of ribs in *A. alticostata* (Nuttall) and *A. sirelii* Özcan & Less.

| Species   | Sample | Number of ribs and corresponding number of specimens |
|-----------|--------|-----------------------------------------------------|
| *A. alticostata* | FULL.13 34 | 4 5 6 7 8 9 10 |
|           | FUL.6 20 | – 3 6 7 3 – 1 |
| *A. sirelii* | FUL.13 31 | 50 1 |
|           | FUL.6 29 | 29 – |
|           | RNL.8.8 18 | 18 – |
|           | ALM.6 25 | 22 3 |

Note: The data from the type level of *A. sireli* (sample ALM.6) from Turkey are also incorporated.

7. A synthesis of orthophragminids characterizing SBZ 17 in Tethys

The orthophragminids occurring in SBZ 17 in the first scheme of shallow benthic zonation (SBZ) in Tethys included thirteen species and *Discocyclina pulca baconica* was marked as the key orthophragminid species for this zone (Serra-Kiel et al., 1998). This scheme was subsequently improved in Western Tethys as to include twenty-three species in SBZ 17 (Özcan et al., 2006, 2010; Less et al., 2011). Because of the recalibration of orthophragminid zones across the Lutetian-Bartonian boundary with respect to the boundaries of SBZ 17,
nine species (species shown by green colour in Figure 20) are common in Western Tethys and Indo-Pakistan region.

As opposed to Western Tethyan orthophragminids, the orthophragminid fauna in Eastern Tethys is dominantly characterized by genus *Discocyclina* (Figure 21). The genus *Orbitoclypeus*, represented by a single species, *O. haynesi*, was only recorded from the Fulra Limestone and it is not present in the Sulaiman Range. The true *Nemkovella* does not occur in both regions. *Nemkovella daguini*, which displays a different peri-embryonic chamber arrangement than the true nemkovellids, occurs only in the Bartonian deposits of Meghalaya, India (unpublished data of E. Özcan). At present it is the only nemkovellid species in Eastern Tethys, where generic affiliation is also not certain. *Asterocyclina sireli* presents a wide geographic distribution in Tethys, from Turkey and Tunisia to the Indian subcontinent and probably distribution of these taxa has also changed with respect to SBZ zonation (Özcan et al., 2006). In updated scheme, stratigraphic range of no any subspecies corresponds to the full range of this zone. With the integration of six species confined to Indian subcontinent (species shown by yellow colour in Figure 20) and two species common to Indian subcontinent, Turkey and North Africa (*A. sireli* and *O. haynesi*), a total of twenty-nine species are now recorded in SBZ 17 in Tethys. In Indian subcontinent, this zone is characterized by the occurrence of fifteen species; *Discocyclina dispansa*, *Discocyclina pseudodispansa*, *Discocyclina kutchensis*, *Discocyclina pratti*, *Discocyclina praeomphalus*, *Discocyclina augustae*, *Discocyclina discus*, *Discocyclina sulaimanensis*, *Discocyclina rakhinalaensis*, *Discocyclina zindapirensis*, *Discocyclina nandori*, *Orbitoclypeus haynesi*, *Asterocyclina sireli*, *Asterocyclina stellata*, and *Asterocyclina alticostata*. Among these only

Figure 19. Equatorial and axial sections of *A. sireli* (1–11) and *A. stellata* (12–14) from the Fulra Limestone. 1: FUL13–71, 2: FUL13–152, 3: FUL13–92, 4: FUL6–66, 5: FUL6–107, 6: FUL6–135, 7: FUL8–2, 8: FUL6–138, 9: FUL6–136, 10: FUL8–1, 11: FUL8–3, 12: FUL8–20, 13–14: FUL13–153.
similar migration scenario is also proposed here for *O. haynesi*, which occurs abundantly in Fulra Limestone, in North Africa and Turkey but not recorded in European platforms.

8. Conclusions

(1) The Bartonian orthophragminids characterizing the SBZ 17 from the Fulra Limestone belong to Tethyan genera *Discocyclina*, *Asterocyclina* and *Orbitoclypeus*. Among a total of eleven species, seven of them belong to *Discocyclina*, its range extends at least to the western Pacific region. According to Less (1987), the asterocyclinids in Western Pacific domain are characterized by the dominance of four-ribbed specimens. Less (1987) considers that these four-ribbed asterocyclinids are of Caribbean-Pacific affinity. Due to lack of detailed stratigraphic and taxonomic works from this area, a reliable correlation of *A. sireli* with Pacific *Asterocyclina* is presently not possible. It is highly probable that this species has migrated to Indian subcontinent and Western Tethys during the Middle Eocene Climatic Optimum that resulted in the expansion of Pacific fauna to higher latitudes in Bartonian. A similar migration scenario is also proposed here for *O. haynesi*, which occurs abundantly in Fulra Limestone, in North Africa and Turkey but not recorded in European platforms.
one to *Orbitoclypeus* and three to *Asterocyclina*. *Nemkovella* does not occur in Indian subcontinent. Taking into account the twelve species from the Drazinda Formation, some are common to the Fulra Limestone, a total of fifteen species [*Discocyclina dispensa* (Sowerby), *Discocyclina pseudodispansa* Özcan, Ali & Yücel, *Discocyclina kutchensis* Özcan & Saraswati, *Discocyclina pratti* (Michelin), *Discocyclina praeomphalus* Samanta & Lahiri, *Discocyclina augustae* van der Weijden, *Discocyclina discus* (Rütimeyer), *Discocyclina sulaimanensis* Özcan, Ali & Hanif, *Discocyclina rakhinalaensis* Özcan, Ali & Yücel, *Discocyclina zindapirensis* Özcan, Ali & Yücel, *Discocyclina nandori* Less, *Orbitoclypeus haynesi* (Samanta & Lahiri), *Asterocyclina sireli* Özcan & Less, *Asterocyclina stellata* (d’Archiac), and *Asterocyclina alticostata* (Nuttall)] are recognized from the Indian subcontinent. Six of them are confined only to Indo-Pakistan region (Figure 20). Two species, *A. sireli* and *O. haynesi*, common in the Fulra Limestone and also occurring in North Africa (Tunisia) and Turkey but not in Europe, appear to have migrated to Western Tethys during Middle Eocene Climatic Optimum (MECO).

(2) In addition to ribs, bulges, rounded surface structures corresponding to thickening of the lateral layers, are recognized in *D. kutchensis*, occurring abundantly in the Fulra Limestone as well as in the Drazinda Formation in Pakistan. This species is associated with *D. nandori* in the Drazinda Formation, while the latter species has not been recorded from the Fulra Limestone.

(3) We recorded two common asterocyclinid species, *A. sireli* and *A. alticostata*, and scanty *A. stellata* from the Fulra Limestone. *A. sireli* and *A. alticostata* display the consistent characteristic features by developing four and many ribs respectively in the Tethys. This is a feature not observed in most of the asterocyclinid species, predominantly developing five ribs. Except for the above taxa and *A. Schweighauseri*, a Cuisian to middle Lutetian species, other common asterocyclinid species, such as *A. stellata* and *A. stella* consistently develop mainly five ribs. Our specific examples from *A. sireli* and *A. alticostata* from geographically distant locations of Tethys suggest that common asterocyclinid taxa consistently develop a specific number of ribs. Thus, the traditional concept of *Asterocyclina* with ‘five-ribs’ is to be abandoned.

(4) We observed that the shape of the test (e.g. saddle-shaped vs flat tests) is a consistent character for each species. The saddle-shape test, for instance, is a specific feature of *D. discus* and *D. praeomphalus*. *D. dispensa* has always a flat test as *D. augustae*. This further requires re-evaluation of some *D. dispensa* populations in Western Tethys, which include both saddle and flat tests, interpreted to be ecological variations of the same species.

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ORCID

Pratul Kumar Saraswati [http://orcid.org/0000-0001-9115-8951](http://orcid.org/0000-0001-9115-8951)

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