Dictyoconus aydimi (Gallardo-Garcia and Serra-Kiel, 2016) comb. nov., larger benthic foraminifera from the Middle-Upper Eocene of the Middle East (SE Turkey, Iraq, SW Iran, Oman): New evidence for Arabian Plate faunal provincialism

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Abstract: Rogerella aydimi Gallardo-Garcia and Serra-Kiel was described from the Priabonian Haluf Member of the Aydim Formation, Oman. Based on new finds from the Bartonian Hoya Formation of SE Turkey and the Jahrum Formation of Iran, its taxonomic status is discussed herein. It is concluded that it represents a species of Dictyoconus with a simple subepidermal network (1 rafter, 1 intercalary beam) below a thin epiderm. The stratigraphic range of D. aydimi known thus far is Bartonian-Priabonian or Shallow Benthic Zone 17–20. The distribution of D. aydimi gives further evidence for a Middle-Late Eocene faunal provincialism of the Arabian Plate (Somalia, Oman, Iran, Iraq, SE Turkey).

Key words: Benthic foraminifera, taxonomy and systematics, biostratigraphy, paleobiogeography, Eocene, SE Turkey

1. Introduction
Larger agglutinated conical benthic foraminifera are a typical constituent of Paleogene inner platform carbonates (e.g., Hottinger and Drobne, 1980; Vecchio and Hottinger, 2007; Powell, 2010). As in the Lower and Upper Cretaceous (e.g., Cherchi et al., 1981), the representatives of the Dictyoconinidae displayed a biogeographic distribution pattern during the Paleogene with different assemblages on both sides of the Atlantic Ocean (e.g., Carribean Bioprovince, Hottinger and Drobne, 1980; Goldbeck and Langer, 2009, Figure 27) for this group of agglutinated conical foraminifera. Paleocene taxa (e.g., Coskinon, Dictyoconus, Fallotella, and Karsella) have been reported from the Taurides of Turkey (provinces of Elazığ and Kars) (e.g., Sirel, 2015). Assemblages of Middle Eocene (Bartonian) larger benthic foraminifera (LBF), including Orbitolinidae, have been studied from the Hoya Formation in SE Turkey (north eastern Diyarbakir), belonging to the northernmost part of the Arabian Plate (Özgen-Erdem and Sinanoğlu, 2016; Sallam et al., 2018). Large-sized dictyoconids, previously referred to as Dictyoconus aegyptiensis (Chapman), usually occur above limestones with Somalina stefaninii Silvestri. They have been recognized as Rogerella aydimi Gallardo-Garcia and Serra-Kiel, as described recently in Serra-Kiel et al. (2016), from the Middle-Upper Eocene of Oman. The present findings from Turkey represent the first discovery of its type-locality. The aim of the present study was to 1) comment and revise its taxonomic status and 2) constrain its paleobiogeographic distribution, also including further specimens from the Jahrum Formation in Iran.

2. Geological setting
2.1. Geological overview
The south eastern Anatolian region forms the northern part of the Arabian Platform (Figure 1A) and consists of the Bitlis-Püttürge Crystalline Melange, Precambrian Basement, and Early Paleozoic-Cenozoic sedimentary deposits (Rigo de Righi and Cortesini, 1964; Sungurlu, 1974; Şengör and Yilmaz, 1981). The geological framework of this region was shaped by the Late Mesozoic and Cenozoic closure of the multibranched Neotethyan Ocean (Şengör and Yilmaz, 1981). Important folding structures developed during the Neotectonic period as a result of the N-trending compressional tectonic regime. The Cambrian, APTian-Cenomanian, Campanian-Maastrichtian, and Middle Eocene periods are represented by marine sequences, which indicate widespread transgression
processes throughout the region. In the middle Eocene-Oligocene, shallowing took place in the south eastern Anatolian region, followed by a continuous deposition of carbonates.

In the semi-closed basins that developed as a result of the rapid closure of the Neotethys, shallow-marine conditions prevailed, and carbonates alternating with evaporites were deposited (Ziegler, 2001). By the end of the Oligocene, the

Figure 1. Geological and geographic setting of the Hazro section in SE Turkey. A: Geotectonic situation and location on the north-western boundary of the Arabian Platform (after Okay and Leven, 1996). B: Geological map of the study area and surroundings (modified from MTA, 2008).
Arabian Platform was subjected to highly tectonic pulses that resulted in significant palaeogeographical changes in this region (Perinçek, 1980). The Eocene–Oligocene deposits are generally represented by carbonate platform sediments that display lateral and vertical facies changes. The Lower Eocene units consist of conglomerates, sandstones, siltstones, and clayey limestones. The Middle Eocene–Lower Oligocene sequences are composed of thin- to thick-bedded, massive limestones and dolomites. The Upper Oligocene consists of limestones, marls, cherty limestones, and evaporites (Duran et al., 1988; Çoruh et al., 1997).

2.2. Studied section and biostratigraphic framework

The Hazro Section is located about 2 km southwest of the town of Hazro in the Diyarbakır district of Turkey (Figure 1B). Coordinates of the section are 65°54′′ E and 42°33′′41.9′′ N. In the study area, the oldest exposed rocks belong to the Paleocene Antak Formation, which unconformably underlies the Hoya Formation. The Lower Miocene carbonates of the Kapıkaya and Furat formations overlie unconformably the Hoya Formation. The Hoya Formation (~45-m-thick) consists mainly of cream-colored micritic limestones, alternating with partly dolomitic limestone beds at the lower and upper parts. Assemblages of LBF from this locality were reported by Özgen-Erdem and Sinanoğlu (2016) and Sallam et al. (2018).

The rich assemblages of LBF observed in the Hoya Formation are represented by alveolinids, soritids, and orbitolinids (Figure 2). In the basal part of the Hazro section, small- to medium-sized milolids and textulariids occur. The LBF show an increase in terms of diversity and quantity, starting from the midsection towards the upper part of the section, especially, the alveolinids and soritids, together with the orbitolinids (Figures 2a–2c). The porcelaneous taxa are represented by Rhabdorites malatyaensis (Sirel), Haymanella paleocenica Sirel, Somalina stefaninii Silvestri, Alveolina fragilis Hottinger, Alveolina fusiformis Stache, Alveolina stercusmuris Mayer-Eymar, Alveolina nuttali Davies, Idalina sp., and Spirolina sp. Agglutinated taxa include Dictyoconus aydimi (Gallardo-Garcia and Serra Kiel) comb. nov. were collected from the Hazro Section (SE Turkey). Altogether, 15 rock samples were collected, from which about 130 thin sections were prepared. Due to the hard lithology of the limestones, the identification of benthic foraminifera in this study was mainly based on unoriented thin sections. The thin sections of the Hazro Section were deposited in the Özgen-Erdem collection at the Department of Geological Engineering, Sivas Cumhuriyet University (Sivas, Turkey). The specimens, kindly provided by Iranian colleagues, are from the Middle–Upper Eocene of the Jahrum Formation, which crops out in the Zagros Zone of SW Iran (e.g., Nafarieh et al., 2019). They are housed within the micropaleontological collections of the National Iranian Oil Company (NIOC).

5. Results and discussion

5.1. Taxonomic remarks

In his PhD on Middle Eocene–Early Miocene LBF from Dhofar (Oman) and Socotra Island (Yemen), Gallardo-Garcia (2015) established some new taxa, and among others, Dhofarella aydimi gen. et sp. nov. However, to be considered published according to the International Code of Zoological Nomenclature (ICZN), under article 8.5.3., new taxa must “be registered in the Official register of zoological nomenclature (ZooBank) (see article 78.2.4) and contain evidence in the work itself that such registration has occurred”. Such a procedure, however, has, according to our knowledge, never been undertaken. In any case, the name was already occupied by Dhofarella Sigé et al., 1994, a genus of bats established from teeth in Oligocene marls of the Ashaq Formation of Oman. Based on the same material with the same illustrations and holotype, Serra-Kiel et al. (2016) introduced Rogerella aydimi gen. et sp. nov., without mentioning Dhofarella Gallardo-Garcia, 2015 (or its homonym). Again, the new genus name was already occupied by Rogerella Saint-Seine (1951), an ichnofossil, that is included in the ICZN (see article 1.2.1). The authors were informed about this homonymy (pers. comm. Francois Le Coze, 06/22/20), and given the opportunity to provide a replacement name (see Code of ethics, Appendix A of the ICZN).
As summarized in Table 1 of the research of Serra-Kiel et al. (2016), *Rogerella* should differ from *Dictyoconus* Blanckenhorn by 1) a pseudo-keriothecal wall, 2) the absence of a subepidermal network, 3) a planispiral initial coil, and 4) an embryo (protoconch + deuteroconch) that lacks skeletal elements.

**Wall structure:** The pseudo-keriothecal wall structure is not discernible in any of the specimens of *Rogerella aydimi* illustrated by Serra-Kiel et al. (2016), an observation also remarked by Cruz-Abad (2018) in her critical revision of the Orbitolinidae. It is worth mentioning, however, that *Rogerella* was regarded as a valid taxon by Cruz-Abad (2018). In conical agglutinated taxa, a thin wall "with a pseudo-keriothecal structure" (Serra-Kiel et al., 2016) exclude each other. Usually, a pseudo-keriothecal wall is thick and either found in taxa with alcoves (Hottinger, 2006, for definition), such as the late Cretaceous *Lepinoconus* (see Cruz-Abad et al., 2018)
Figure 3. *Dictyoconus aydimi* (Gallardo-Garcia and Serra-Kiel, 2016) comb. nov. from the Bartonian Hoya Formation of SE Turkey. A–C, I) Axial sections, samples HzBA1, Hz8b, Hz8-9B2, and HZ8e2. D) Oblique section passing the megalospheric embryo, sample Hz8-20. D') Detail from D showing the moderate simple subepidermal network with 4 alveolar subunits per main compartment. E) Oblique section through the uniserial part, sample c1b. F) Oblique transverse section showing 1 intercalary beam per main compartment, Hz8b1. G) Subaxial section, sample Hz8h1. H) Fragmentary axial section of a megalospheric specimen, sample Hz8b2. J) Subaxial section of a possibly microspheric specimen, sample Hz8f.
ozgen-erdem et al. / Turkish J Earth Sci 2017) or the Eocene Coleiconus (Hottinger and Drobné, 1980), or in those lacking any exoskeleton, such as the Paleogene Coskinolina Stache (e.g., Hottinger and Drobné, 1980) (Figure 4A). The epiderm covering a subepidermal network is thin (Douglass, 1960; Septfontaine, 1980). Instead, it is the opinion herein that the wall structure of Rogerella is homogeneous, finely agglutinated (without any internal structure), as in Dictyoconus Blanckenhorn.

**Exoskeleton**: The presence or absence of a subepidermal network in Orbitolinidae may have generic value (e.g., Hottinger and Drobné, 1980), but its grade of complexity is classically considered a specific characteristic (e.g., Arnaud-Vanneau, 1980; Schlagintweit, 2020). In the differences between Rogerella and Dictyoconus, Serra-Kiel et al. (2016) stated “the absence of a subepidermal network” and that... “there is only 1 beam intercalated between 2 successive beams and 1 generation of rafters” in the former. An exoskeleton with 1 rafter and 1 intercalary beam occurs, for example, in the Paleogene Fallotella kochanskae and F. persica (Hottinger and Drobné, 1980). The resulting "subepidermal network with 4 alveolars per unit" (or chamber compartment) can be considered a moderate simple/complex subepidermal network (Figure 4B), but it cannot be appropriate to define Rogerella as lacking such a feature. The rafters and intercalary beams of Rogerella are both rather short, so that only very shallow tangential sections display the network of 4 compartments (see Figure 3D). The moderate simple/complex subepidermal

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**Figure 4.** Schematic drawing of an exoskeleton in the tangential section of the selected agglutinated conical foraminifera (with examples from the Lower/Upper Cretaceous and Paleogene). For terminology see Hottinger (2006). Note that Dictyoconus aydimi belongs to type B, and D. aegyptiensis and D. indicus belong to type C.
network of Rogerella is considered as nothing but a specific feature. Other species of Dictyoconus, such as D. aegyptiensis (Chapman) or D. indicus Davies, display a rather complex network, consisting of several series of both rafers and intercalary beams (Davies, 1939; Henson, 1948; Hottinger and Drobné, 1980; Hottinger, 2007; Serra-Kiel et al., 2016) (Figure 4C).

**Coiling of initial stage:** Compared to the type-species, D. aegyptiensis or also D. indicus, Rogerella aydimi exhibits a more voluminous initial spire. According to Serra-Kiel et al. (2016), the spire should be trochospiral in Dictyoconus when compared to the allegedly planispiral coiling in Rogerella. It is the opinion herein that a planispiral coiling was not convincingly clear in the single axial section of the holotype specimen that seemingly passed the spire obliquely. It is also worth mentioning that in the type-species, D. aegyptiensis (Chapman), the embryo is “followed by 6–8 almost planispiral chambers” (Hottinger and Drobné, 1980). Moreover, for subsequent works, it would be impossible to make a clear decision without having oriented the sections at hand. Concerning the more prominent coil, this should rather be considered a specific than generic feature.

**Embryo:** Concerning the structure of the embryo, there are some contradictory statements. On the one side, the embryo of Rogerella is said to consist of a protoconch + deuteroconch instead of a protoconch + deuteroconch that may have skeletal elements in Dictyoconus, respectively D. indicus (Table 1 in Serra-Kiel et al., 2016). Referring to the holotype specimen (Figure 38.1 in Serra-Kiel et al., 2016), being the only megalospheric specimen illustrated in the axial section with an embryo, the researchers described the deuteroconch “with beams” (if any, these should be termed rafters?). It is the opinion herein that the deuteroconch is not well discernible in the holotype specimen and the occurrence of several “beams” followed by the neanic chambers, with just 1 rafter and 1 intercalary beam, would be a curious feature. In any case, the presence of skeletal elements in the deuteroconch of Dictyoconus, although debatable with respect to suprageneric classification (Orbitolininae vs. Dictyoconinae), is accepted as species criterion (D. indicus with and D. aegyptiensis without skeletal elements; Davies, 1939; Hottinger and Drobné, 1980; Hottinger, 2007; Serra-Kiel et al., 2016). Again, such a feature is not an adequate criterion for the separation of Rogerella from Dictyoconus.

In summary, with an appreciation of all aspects, no feature, or a combination of various features, were observed that would permit the establishment of an individual genus clearly distinguished from Dictyoconus. Some differences in the type-species, D. aegyptiensis, as discussed above, are considered specific features. To conclude, Rogerella (Gallardo-Garcia and Serra-Kiel, 2016) is considered a subjective junior synonym of Dictyoconus Blanckenhorn (1900). With respect to the moderate complex subepidermal network and the embryo seemingly lacking any subdivisions, D. aydimi can be considered as a simple structured species of the genus.

**5.2. Systematic description**

**Remarks:** The classification of agglutinated foraminifera by Kaminski (2014) was followed herein.

- Phylum Foraminifera Eichwald, 1830
- Class Globothalamea Pawlowski et al., 2013
- Order Loftusida Kaminski and Mikhailievich in Kaminski, 2004
- Suborder Orbitolinina Kaminski, 2004
- Superfamily Orbitolinoidae Martin, 1890
- Family Orbitolinidae Martin, 1890
- Subfamily Dictyoconinae Moullade, 1965
- Genus Dictyoconus Blanckenhorn, 1900
- Type-species: Patellina aegyptiensis Chapmann, 1900

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( Figures 3A–3J, and 5A–5C).

2012 *Dictyoconus* - Nafarieh et al., Figure 6d (right specimen).

- 2013 *Coskinolina* - Zohdi et al., Figure 5i.
- 2016 *Dictyoconus aegyptiensis* (Chapman) - Özgen-Erdem and Sinanoğlu, pl. 2, Figures 1–3.
- 2018 *Dictyoconus aegyptiensis* (Chapman) - Sallam et al., Figures 5a and 5b.
- 2018 *Dictyoconus indicus* Davies - BouDagher Fadel, pl. 6.2, Figure 9.
- 2019 *Daviesiconus balsilliei* (Davies) - Nafarieh et al., p. 281, Figures 9/4, 9/5, and 9/6.

**Descriptions:** Test finely agglutinated, of medium conical shape and convex chamber base throughout ontogeny. Cone surface smooth. The wall lacks any ultrastructure. The embryo [proloculus with diameter ~0.24 mm (2 values) and undivided deuteroconch] is positioned eccentrically with a rather voluminous spire (height up to 1.0 mm) (Figures 3A and 3D). The main part of the cone consists of uniserial chambers, up to 20 in number in large adult specimens. There are 5–6 chambers per 1 mm axial cone length. Specimens that are broader due to a larger apical angle might correspond to the microspheric generation (Figures 31–33). The central zone consists of rather dense-set endoskeletal pillars alternating in position between neighbouring chambers. There are 11–13 pillars cut in axial sections when the cone diameter reaches ~2.5 mm. As discernible in transverse sections,
Figure 5. *Dictyoconus aydimi* (Gallardo-Garcia and Serra-Kiel, 2016) comb. nov. from the Jahrum Formation of SW Iran. A) Oblique section. B) Subaxial section. C) Oblique section.

Figure 6. Bartonian paleomap (modified from Scotese, 2016) showing the distribution of the LBF *Dictyoconus aydimi* (Gallardo-Garcia and Serra-Kiel) comb. nov. and *Somalina stefaninii* Silvestri. *Somalina*: Zakynthos Island, Greece (Di Carlo and Pignatti, 2009), Egypt (Shamah and Helal, 1994); Iran (Zohdi et al., 2013; Nafarieh et al., 2019); Iraq (Ghafor and Qadir, 2009; Avanah, Damnam Fm.); Oman (Serra-Kiel et al., 2016; Damnam Fm.), Somalia (Silvestri, 1939); Tanzania (Cotton, 2012).
the pillars are arranged in concentric rows (Figure 3F). Exoskeleton with alternating main partitions (beams), and 1 rather short intercalary beam (length 80–100 µm). There is 1 generation of rafters. The exoskeleton subdivides the marginal chamberlets into 4 alveolar compartments (Figures 3D and 4B). The foramina of the central zone display a cribrate distribution. Marginal foramina inclined ~45° to the cone axis (Figures 3E and 3G).

5.3. Remarks on the paleobiogeography

In the literature, records were found of *Dictyoconus* (see synonymy), from SE Turkey (ÖZGEN-Erdem and Sinanoğlu, 2016), Iraq (Zagros Zone; e.g., Nafarieh et al., 2019; see Figure 5), Iraq (BouDagher-Fadel, 2018), and Oman (Serra-Kiel et al., 2016). All of these occurrences were part of the Arabian Plate, with carbonate platform sedimentation during the Paleogene at the southern Neotethyan margin (Figure 6). In several of these localities, the sections containing *Dictyoconus* also delivered specimens of *Somalina stefaninii* Silvestri (Figure 6). In Turkey, Iran, and Oman, the *Somalina* levels occurred below the first appearances of *D. aydimi*. These *Somalina* wacke-/floatstones were clearly dominated by porcelaneous taxa and were interpreted as an internal infralittoral environment, like the Eocene “*Spirulina* facies” of the Adriatic Carbonate Platform (see Vecchio and Hottinger, 2007, Figure 5). *S. stefaninii* displays a wider distribution than *D. aydimi*, with additional reports from Tanzania (Cotton, 2012), Somalia (Silvestri, 1939), and far from there, the Zakynthos Island of Greece (Di Carlo and Pignatti, 2009). The spatial distributional pattern of *D. aydimi* reflects a faunal provincialism of the Dictyoconinae for the Arabian Plate reported previously from the Cenomanian (e.g., Henson, 1948; Bernaus and Masse, 2006; Schlagintweit and Rashidi, 2017, Table 1; Schlagintweit and Yazdi-Moghadam, 2020; Yazdi-Moghadam and Schlagintweit, 2020) and Maastrichtian (Schlagintweit et al., 2016). The Gulf of Aden was still closed in the Eocene, forming in the Oligocene-Miocene (e.g., d’Ecremont et al., 2005). During the Eocene, Somalia exhibited a continuous coastline with Oman; hence, the occurrence of *D. aydimi* can be expected there. Species of *Dictyoconus* have been reported by various researchers from the Eocene of Somalia (Nuttall and Brighton, 1931; Silvestri, 1939; Azzaroli, 1952). Silvestri (1939), for example, reported a species with a moderate complex exoskeleton, displaying 1 rafter and 1 intercalary beam, as *Dictyoconus aegyptiensis* (Chapman) var. *walnutensis* (Carsey). It is the opinion herein, however, that the available sections did not allow for a final conclusion.

In addition to *Dictyoconus aydimi* (Gallardo-Garcia and Serra-Kiel) comb. nov., there are further Eocene species endemic to the Arabian Plate, such as *Reticulotaberina jahrumiana* Nafarieh et al. (2019) (Iran), *Neorhipidionina spiralis* Hottinger (2007) (Iran), *Macetadiscus incolumnatus* Hottinger et al. in Serra-Kiel et al. (2016) (Oman), *Omanodiscus tenuissimus* Hottinger et al. in Serra-Kiel et al. (2016) (Oman), *Rotaliconus persicus* Hottinger (2007) (Iran), *Globoreticulina iranica* Rahaghi (1978) (Iran), *Neotaberina neaniconica* Hottinger (2007) (Iran), and *Penarchaias glynjonesi* (Henson, 1950) (Iraq). Further data are required to determine whether this endemism is related to the indicated species or also includes the higher taxonomic level (genus).

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Contribution of authors

Felix Schlagintweit and Nazire Özgen-Erdem wrote the results and discussion section.

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