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ORIGINAL ARTICLE

The "*Orbitolina Limestone*" of central Iran: new data about microfacies, orbitolinid biostratigraphy, and palaeogeography

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Abstract

A section of the Lower Cretaceous Taft Formation of Central Iran, belonging to the Yazd Block yields new data about the microfacies, orbitolinid biostratigraphy, and palaeogeographic setting of this poorly known lithostratigraphic unit. The studied section is characterized throughout by the common occurrence of corals, stromatoporoids and small benthic foraminifera (lenticulinids, *Neotrocholina*) that indicate deposition in an open marine external carbonate platform environment. The orbitolinid assemblage is characterized by *Montseciella*? *arabica* (Henson) in the basal part of the section followed by *Rectodictyoconus giganteus* Schroeder (up to the top), in association with *Paleodictyoconus actinostoma* Arnaud-Vanneau & Schroeder, *Dictyoconus*? *pachymarginalis* Schroeder, and *Palorbitolina ultima* Cherchi & Schroeder. The observed ranges of some taxa reveal slight modifications of widely used and, therefore, "standard" orbitolinid biozonations. Like any other group of larger benthic foraminifera, orbitolinids display a facies sensitivity (e.g., inner vs. outer platform) that may lead to different local or regional biozonations evidencing the need for plausibility check of the data when transferred to other regions. Moreover, the orbitolinid assemblages observed from different sections of the Taft Formation give evidence for its diachronous base (late Barremian or early Aptian) becoming younger towards presumably exposed land areas.

Keywords Benthic foraminifera · Orbitolinidae · Biostratigraphy · Microfacies · Lower Cretaceous · Yazd Block

Introduction

Lower and mid-Cretaceous orbitolinid larger benthic foraminifera are well-known for their use as biostratigraphic marker species world-wide in (sub-) tropical shallow-water carbonates such as Neotethys (e.g., Moullade et al. 1985). This statement must be clarified however as there are species that exhibit rather long stratigraphic ranges encompassing several stages and others that have a relatively small range within a stage or even substage. Especially in the early Aptian, several taxa with a short stratigraphic range are known including for example *Rectodictyoconus giganteus* Schroeder, 1964a, *Praeorbitolina cormyi* Schroeder, 1964b, or *Palorbitolina ultima* Cherchi & Schroeder, 2010. With respect to general stratigraphic distribution, the range charts provided by Schroeder et al. (2010, figs. 3, 10: Arabian Plate), slightly modified by Cherchi and Schroeder (2013, fig. 1: Arabian Plate, Apulian and Adriatic Carbonate Platforms), can be considered as having a "classical" or "standard" character, widely used, elaborated and tested throughout almost 50 years of intense research in different areas of the Neotethys realm, not only the Arabian Plate. It is worth mentioning that almost all of the taxa included in this chart are cosmopolitan forms with complex embryo and the ranges indicated correspond to the taxa total ranges so that it cannot be considered just as a local zonation.

The so-called "*Orbitolina* Limestone" represents a widespread lithostratigraphic unit of Central Iran (= Taft and Shah Kuh formations) belonging to the Northern margin of Tethys (Wilmsen et al. 2013). Concerning the taxonomic inventory of Orbitolinidae of this unit and their biostratigraphic framework, there is still need for

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further data allowing also a more refined palaeogeographic reconstruction of its numerous tectonic (sub-)units. The objective of the present study is primarily the general documentation as well as micropalaeontological and biostratigraphic analyses of a section of the "*Orbitolina* Limestone" located in the Yazd area of Central Iran named the Ab Anbar section. The new data are the basis for a confrontation with the widely used stratigraphic distributional charts of the Orbitolinidae (e.g., Cherchi and Schroeder 2013) and their inter-regional importance. Furthermore, the assemblages of orbitolinids, and other fossil groups of the Ab Anbar section are contrasted with those of two other sections in the study area, the Anarak (Schlagintweit and Rashidi 2022) and Chah Palang sections (Figs. 1, 2a–b).

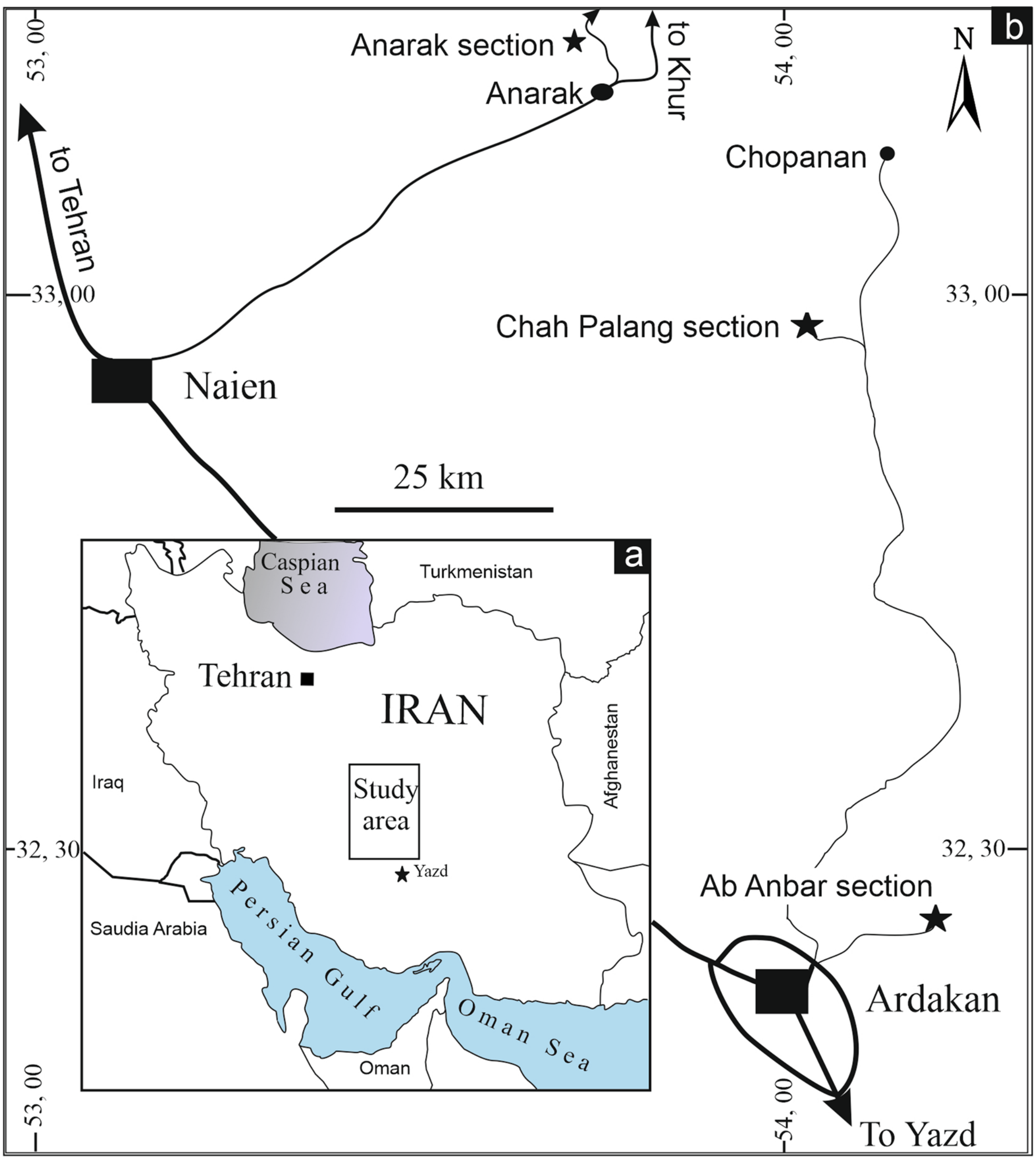


Fig. 1 Geographic setting of the study area: **a** Regional geographic sketch map with detail (rectangle) of the study area in Central Iran; **b** detail from **a** showing the location of the Ab Anbar section studied herein and other sections mentioned in the text (Anarak and Chah Palang sections)

Geological setting

Geological overview

Tectonically, the study area belongs to the Yazd Block that along with the Tabas and Lut blocks make up the former Central-East Iranian Microcontinent or CEIM (Takin 1972; Berberian and King 1981; Aghanabati 2004, for overviews). The Yazd Block, the westernmost subunit is bounded northward by the Doruneh fault and towards the west by the Naien Baft ophiolite belt. From a palaeogeographic viewpoint, the CEIM was part of the northern margin of the Neo-Tethys during the Lower Cretaceous (e.g., Barrier and Vrielynck 2008). In this period, narrow oceanic realms (Nain-Baft, Sabzewar and Sistan oceans) surrounded the CEIM and subsequently closed during the late Cretaceous–Paleocene time interval (e.g., Tirrul et al. 1983; Moghadam et al. 2009; Kazemi et al. 2019). During the Early Cretaceous, transgressive fossiliferous shallow-water carbonates were part of a large-scale carbonate platform system that characterized wide parts of the Yazd Block at that time (e.g., Wilmsen et al. 2013, 2015, 2020; Safaei et al. 2020). In many areas these were mapped as "*Orbitolina* Limestones". In the northern part of Yazd Block (Khur area), this lithostratigraphic unit is named Shah Kuh Formation and in its western part Taft Formation (see overview in Wilmsen et al. 2015). The lithostratigraphic formalization of these orbitolinid-bearing strata in Iran, including the establishment of a biostratigraphic framework, is still in progress.

Ab Anbar section

The studied profile of the Taft Formation is named the Ab Anbar section after the Persian word for antique traditional roofed cisterns in Iran, one of which is located near-by (Fig. 2b). It is located about 1.5 km northeast of Ardakan city, and ~ 6 km north of Yazd city, the eponymous province in Central Iran (Fig. 1). Along with two other sections (e.g., the Chah Palang section; see Fig. 1), the Ab Anbar section has already been investigated by Hanifzadah et al. (2015) concluding a Barremian-Aptian age. At the Ab Anbar section, the Taft Formation with a total thickness of almost 470 m forms a rounded hill rising from the flat desert-like plain (Fig. 2a). The base of the section is covered by alluvial sediments and the top corresponds to the hill summit. The exposed carbonates of the Taft Formation are light grey and predominantly thick-bedded to massive displaying numerous cleavage-structures ("feather joints") (Fig. 2c). Thin-sections indicate the presence of dolomite more or less throughout the entire section (Fig. 3e). It may represent the entire matrix, or is concentrated along the veins. Orbitolinid tests may show irregular-shaped dolomitic patches within the central zone of the test. The dominance of rather massive limestones, and the abundance of both veins and dolomite are likely causally linked. Many beds are characterized by the abundance of orbitolinid tests including both low- and high-conical forms (Fig. 2d), while banks with accumulation of rudist shells are rare (Fig. 2e). The vertical distribution of the main fossil groups and selected orbitolinid taxa in the Ab Anbar section is shown in Fig. 4. The coordinates of the base of the Ab Anbar section are 32° 20′ 27.00″ N and 54° 13′ 58.99″ E.

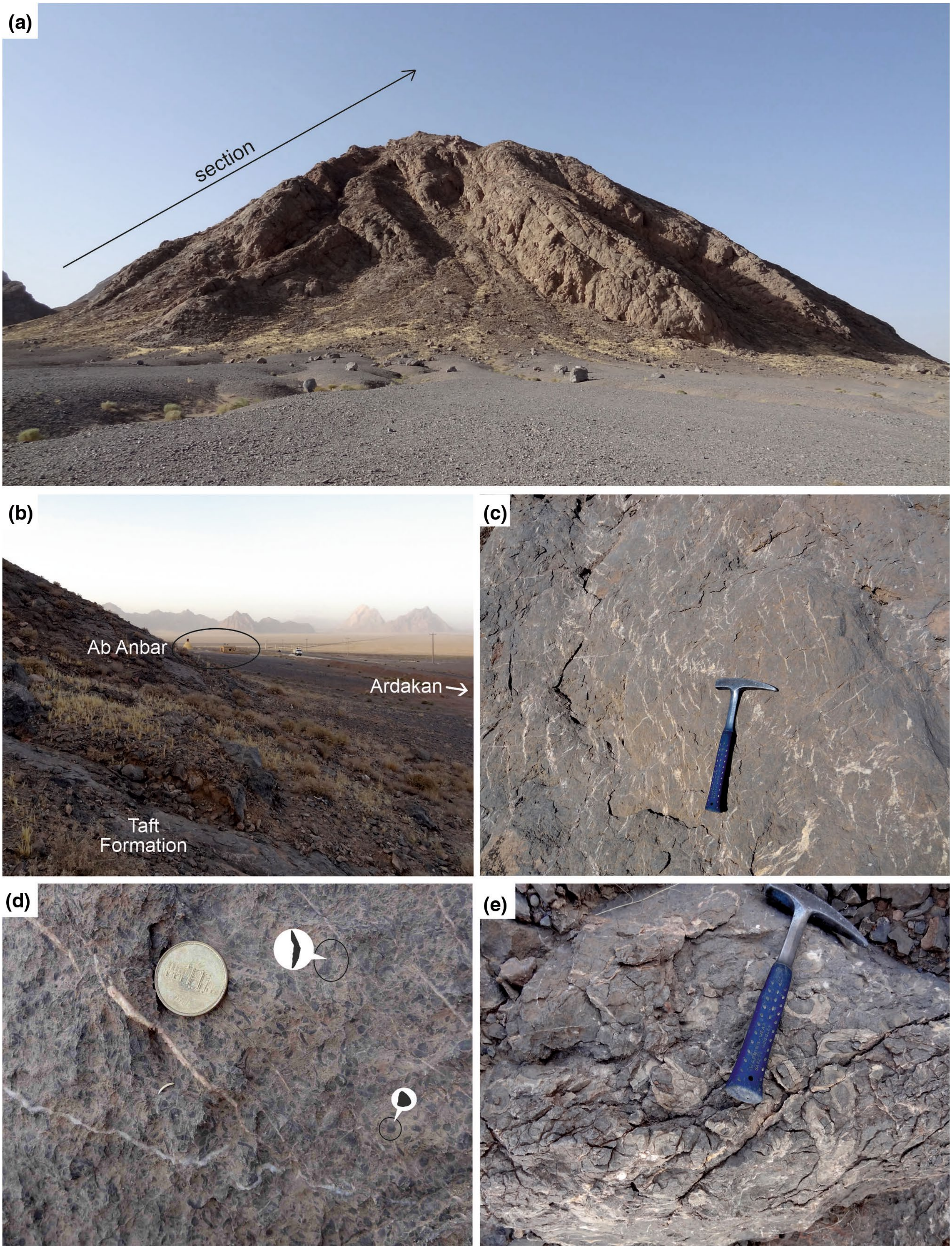
Material and methods

The analyses of the Lower Cretaceous limestones of the Taft Formation are based exclusively on thin-sections. The thin-sections containing the specimens illustrated herein are deposited in the Yazd University, Rashidi collection.

Results

Microfossils and palaeoenvironment

With respect to macrofossils, the Ab Anbar section is characterized by rare rudists, common stromatoporoids (actinostromariid-type), rare chaetetid sclerosponges (genus *Neuropora* Bronn), pharetronids, corals and bryozoans (Fig. 4a–d). Micropalaeontologically, the Ab Anbar section is characterized by the rarity of dasycladalean green algae in contrast with other sections of the Taft Formation (e.g., Bucur et al. 2012, 2016; Schlagintweit et al. 2021). For example, we observed a single section of *Pseudoactinoporella iranica* Bucur et al. (Fig. 3f), one unknown taxon with two? orders of laterals (Fig. 3g) and some specimens of *Bakalovaella*? *elitzae* (Bakalova) Bucur (Fig. 3h). *Morelletpora turgida* (Radoičić) Barattolo, frequently recorded from the Anarak section (Bucur et al. 2016; Fig. 5a), or *Kopetdegaria sphaerica* Maslov, rare to common in the Chah Palang section, are absent in the Ab Anbar section. Also the comparably low diversity of benthic foraminifera is noteworthy as is the absence of taxa such as *Vercorsella* Arnaud-Vanneau, *Akcaya* Özdikmen, *Mayncina* Neumann or of siliciclastic facies with *Torremiroella* Brun & Canérot, *Balkhania* Mamontova, or *Pseudochoffatella* Deloffre. Summarizing, the occurrence of lenticulinids and neotrocholinids in some samples together with the metazoans, sponges respectively indicate an external platform depositional environment of the Ab Anbar section


(a)
section
(b)
Ab Anbar
Ardakan
Taft
Formation
(c)
(d)
(e)

◀**Fig. 2** Studied section. **a** Field view of the Ab Anbar section, central Iran; **b** Ab Anbar section and surrounding landscape; **c** massive limestone showing calcite-filled cleavage structures, sample a26; **d** limestone rock surface (between samples a41 and a47) showing abundant orbitolinids mostly flat, almost discoidal (*Palaeodictyoconus actinostoma* Arnaud-Vanneau & Schroeder), and conical forms (e.g., *Rectodictyoconus giganteus* Schroeder); coin diameter = 2.3 cm; **e** limestone with rudists, middle part of the section

accounting also for a characteristic orbitolinid assemblage (see *Systematic Micropalaeontology*) differing from that atother localities of the Taft Formation. For example, the chaetetid sclerosponge *Neuropora* was living in open-marine outer platform depositional settings and reefs during Mesozoic times (Flügel 2004, p. 507). The environmental interpretation put forward herein is in line with standard Lower Cretaceous Urgonian-type carbonate platform systems, the general distribution of individual fossil groups including both macro- and microfossils such as larger and small benthic foraminifera (e.g., Arnaud-Vanneau 1980, 1987).

The dominance of *Montseciella*? *arabica* Henson, *Rectodictyoconus giganteus* Schroeder, and *Paleodictyoconus actinostoma* Arnaud-Vanneau & Schroeder on the one hand and the lack of some taxa (e.g., *Praeorbitolina*, *Palorbitolinoides*) or scarcity of others (e.g., *Iraqia simplex* Henson, Fig. 4g–i) on the other hand are worth mentioning. Stratigraphically comprising the entire early Aptian, these taxa could principally be expected. The differences are likely due to different facies preferences, inner (e.g., *Praeorbitolina* div. sp., Figs. 5, 6) versus external platform (e.g., *Rectodictyoconus*), reflected also by the small benthic taxa. In the literature, there are several contributions discussing the palaeoenvironmental influence of parameters such as water depth, light penetration, or clay content in the water column on the test morphology (flattened, discoidal *versus* conical = ratio diameter-height) of Orbitolinidae also in the context of sequence stratigraphic analyses (Vilas et al. 1995; Simmons et al. 2000; Rahiminejad and Hassani 2016). Any conclusions based on this approach however must carefully consider the group respectively the subfamily status of the taxa compared both in general and from different stratigraphic levels. Such test adaptations refer essentially to the Orbitolininae (forms with complex embryo) such as *Palorbitolina* or *Mesorbitolina* while Dictyoconinae (forms with simple embryo) such as the conical representatives of *Montseciella* do not. Any comparison including a mixture of the two groups represents incongruent data and is therefore a little bit like comparing apples and pears that in turn might lead to misleading conclusions. This concept is not applicable in our case study and has not been pursued herein a little further.

The most widespread orbitolinid recorded as common to frequent from all three sections is *Palaeodictyoconus actinostoma* Arnaud-Vanneau & Schroeder (Fig. 4k). Taxa preferentially associated to high-energy shoal facies partly with ooids—as observed in the Chah Palang section—are *Torremiroella hispanica* Brun & Canérot, *Balkhania balkhanica* Mamontova, *Neorbitolinopsis conica* (Matsumaru), or the dasycladale *Kopetdagaria sphaerica* Maslov (Fig. 5b).

The Anarak section (see Fig. 1), in contrast, is located close (or proximal) to the Paleozoic Anarak Metamorphic Complex that might have been an elevated area during the time of the Lower Cretaceous transgression. Sections of the Taft Formation close to former land areas (e.g., Anarak section, Schlagintweit and Rashidi 2022; Wilmsen et al. 2020, Rudkhaneh-ye-Arusan) determined a younger, (late) early Aptian age of the base documented by different species of *Praeorbitolina* (Figs. 5, 6), whereas late Barremian parts at the base (e.g., Ab Anbar section with *Montseciella*? *arabica*, this work) appear to be restricted to distal platform sections. The orbitolinid association of the Ab Anbar sections shows great similarities to a section of the "*Orbitolina* Limestone" (not referred to any formation) studied by Rahiminejad and Hassani (2016) in eastern Rafsanjan (Central Iran) including *R. giganteus*, *P. actinostoma*, and most likely also *P. ultima* (see the synonymy list provided herein). The lithology however with several sandstone intercalations is different. The biostratigraphy was roughly indicated as Aptian–Albian by Rahiminejad and Hassani (2016), but none of the illustrated taxa confirms Albian parts of the studied section. Unfortunately, also the three sections studied in the Taft area south of Yazd by Safaei et al. (2020) including the "Taft section" with the exposed base of the formation, lack any biostratigraphic data that would allow us to draw a wider palaeogeographic picture. The results obtained from different sections that we studied reveal a clear diachronous base of the Taft Formation whereas the top seems to be uniformly recorded within the late Aptian (see also Schlagintweit and Wilmsen 2014; Wilmsen et al. 2020).

Systematic micropaleontology

The orbitolinid taxa observed in the Ab Anbar section belong to the two subfamilies Dictyoconinae Schubert, 1912 (with simple embryo) and Orbitolininae Martin, 1890 (with complex embryo) (see Loeblich and Tappan 1987). For each species, short comments are included; for detailed description reference is made to the relevant literature. With respect to *Neorbitolinopsis conica* (Matsumaru in Matsumaru and Furusawa 2007), reference is made to the recent taxonomic revision by Schlagintweit and Rashidi 2022).

Family Orbitolinidae Martin 1890
Subfamily Dictyoconinae Schubert 1912
Genus *Montseciella* Cherchi and Schroeder 1999

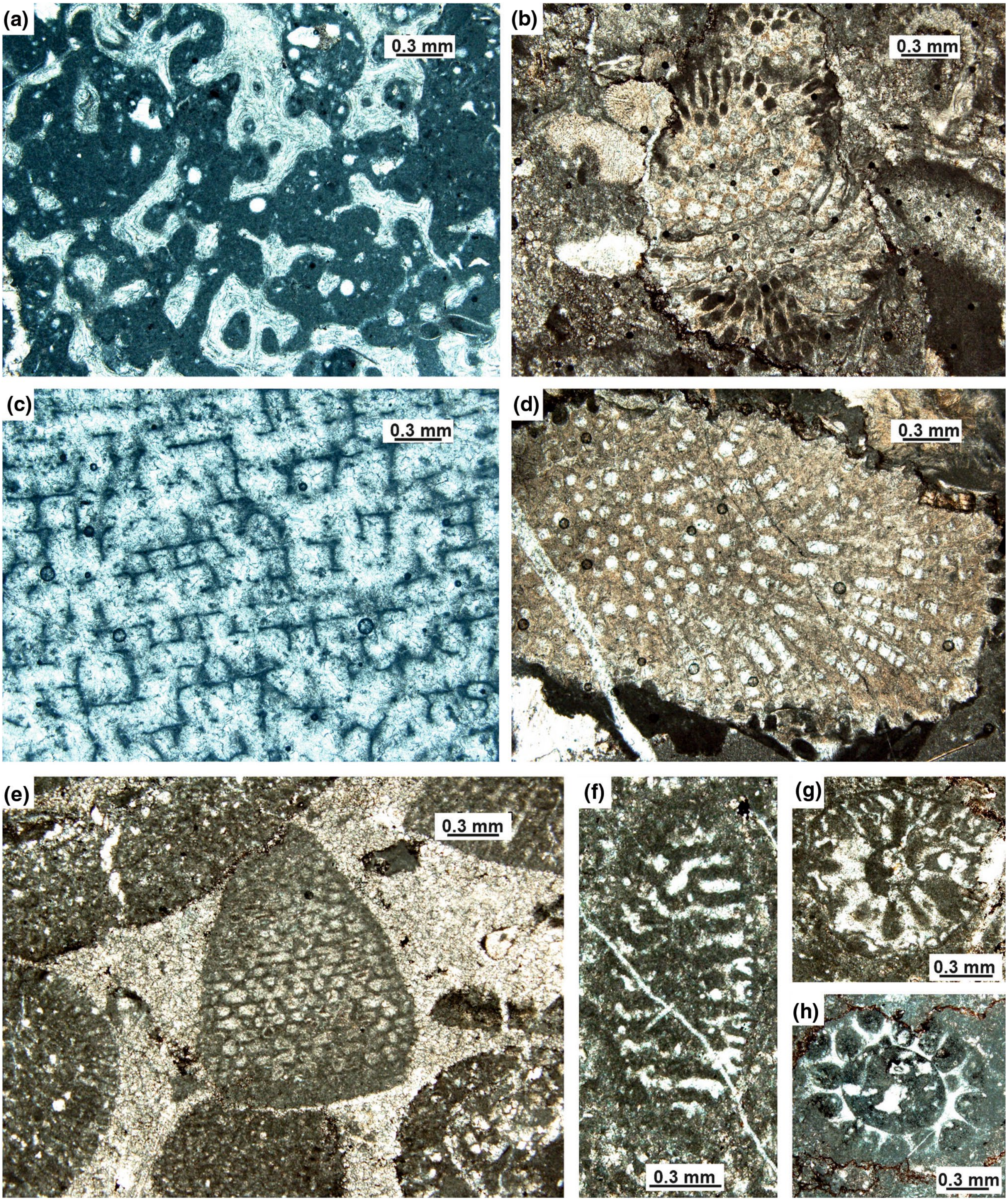


Fig. 3 Metazoans from the Taft Formation of the Ab Anbar section, Central Iran: **a** Pharetronid sponge, thin-section a8; **b** bryozoans, thin-section a10; **c** *Actinostromaria*-type stromatoporoid, thin-section a70; **d** chaetetid sclerosponge *Neuropora* Bronn, thin-section a11; **e** subaxial section of *Montseciella*? *arabica* (Henson) within dolomitized orbitolinid limestone, thin-section a53; **f** oblique section of the dasycladale *Pseudoactinoporella iranica* Bucur et al., thin-section a119; **g** unknown dasycladale with small main axis and two orders of laterals, thin-section a112. **h** dasycladale *Bakalovaella elitzae* (Bakalova) Bucur, thin-section a121, upper part of the section

Type-species *Paleodicytoconus glanensis* Foury 1968

Montseciella? *arabica* (Henson, 1948) (Figs. 3e, 4a–b, 7j).

1948 *Dictyoconus arabicus* n. sp.—Henson: p. 35, pl. 1, figs. 5–8, pl. 14, figs. 1–12.

2014 *Montseciella arabica* (Henson)––Bucur et al.: fig. 4a–l.

2016 *Montseciella arabica* (Henson)––Hosseini et al. (2016): fig. 9e–k.

2018 *Montseciella arabica* (Henson)—Mehrabi et al.: fig. 8L.

Remarks The species lacks features typical for *Dictyoconus* Blanckenhorn (e.g., Cherchi and Schroeder 1999; Schlagintweit 2021), and has been transferred to the genus *Paleodictyoconus* Moullade (e.g., Schroeder in Schroeder et al. 1966), then cautiously to *Montseciella* (Cherchi and Schroeder 1999, p. 12) and finally confidently to the latter (e.g., Schroeder et al. 2002). Apart from other features, the lack of a "strongly developed trochospiral", a morphological diagnostic genus criterion of *Montseciella* (Cherchi and Schroeder, 1999, p. 9) renders doubts not only on the assignment to this genus but also to *Dictyoconus* and *Paleodictyoconus*. It is worth mentioning that the title of the paper by Cherchi and Schroeder (1999), "*Montseciella*, a new orbitolinid genus (Foraminiferida) from the Uppermost Hauterivian–Early Barremian of SW Europe" excludes the inclusion of the late Barremian-lowermost Aptian species of Henson (1948). A final conclusion of the generic status (new genus or emendation of the genus) is beyond the scope of the present paper. One possibility would be the genus emendation including at least the elimination of an obligatory "strongly developed trochospiral" (Cherchi and Schroeder 1999, p. 9) and the possibility (only in the species *arabica*) that the rudimentary partitions might be "radially arranged within the outer part of the central zone of the chambers… (becoming)… labyrinthic in the center of…(the central)… zone" (Schroeder and Cherchi 1979, p. 575).

The record of *Montseciella*? *arabica* from Central Iran gives evidence that this species is not endemic to the former southern margin of Neo-Tethys as previously assumed (Cherchi et al. 1981; Schroeder and Cherchi 1979; Moullade et al. 1985). *M*.? *arabica*, is for example, reported from the Daryan Formation of SW Iran (Schroeder et al. 2010; Mehrabi et al. 2018, "lower-middle Aptian"?), but also from the Taft-Shah Kuh formations of Central Iran. The distinction between *Montseciella*? *arabica* and its phylogenetic successor *Rectodictyoconus giganteus* Schroeder is difficult because the only undoubted difference refers to the megalospheric embryo: simple (= no vertical partitions) biloculine, slightly eccentric in *M*.? *arabica* and in a central position with rather short vertical partitions at the top of the deuteroconch in *R. giganteus* (Schroeder 1964a) (Fig. 7i, j). Transitional types show an eccentric embryo with few rudimentary partitions (*M. arabica* in Schroeder et al. 2010, fig. 4.3). Baud et al. (1994, p. 387) also stressed the larger test dimensions of *R. giganteus*, its greater chamber height, and also its more complex marginal zone with up to five horizontal partitions (mostly one in *M*.? *arabica*). The practicability of these differences however cannot be applied to our lower Aptian material from Iran. For example, even in the uppermost samples (above *P. ultima*) specimens of *R. giganteus* with only one rafter are reported (compare Fig. 4d, 7a). Both taxa, *M*.? *arabica* and *R. giganteus*, also display pillars that fuse to form rudimentary undulating partitions (Schroeder and Cherchi 1979, pl. 1, figs. 3–5 for *M*.? *arabica* and Fig. 7g herein for *R. giganteus*). Microspheric specimens of *M*.? *arabica* show a low-conical and broad test with a diameter of up to 7 mm (Fig. 7l; compare also Schroeder et al. 2010, fig. 4 b.7). For the different stratigraphic ranges of the two see the comments in the chapter *Biostratigraphic issues*.

Genus *Dictyoconus* Blanckenhorn 1900

Type-species: *Patellina egyptiensis* Chapman 1900

Dictyoconus? *pachymarginalis* Schroeder 1965 (Fig. 4c, j).

1965 *Dictyoconus pachymarginalis* n. sp.—Schroeder: p. 976–978, pls. 1–2.

2006 *Dictyoconus pachymarginalis* Schroeder––Mancinelli and Chiocchini, p. 96, pl. 2, figs. 1–10.

2015 *Dictyoconus pachymarginalis* Schroeder—Hanifzadah et al., pl. 1, figs. 2, 4 (cf.), pl. 2, Fig. 5.

Remarks The first specimen of *D*.? *pachymarginalis* has been observed within the upper range of *M*.? *arabica* in sample a39 referred either to the latest Barremian or earliest Aptian. In any case, this age is older than the occurrence in the late Aptian (Gargasian) type-area (six localities) of the Alborz mountain range, northern Iran (Schroeder 1965). At the Ab Anbar section, *D*.? *pachymarginalis* ranges almost toward its top. The species has frequently been reported from the "*Orbitolina* Limestone" of Central Iran (e.g., Schlagintweit and Wilmsen 2014; Wilmsen et al. 2020), and the Tirgan Formation of northeastern Iran (Bucur et al. 2019).

It is worth mentioning that *D*.? *pachymarginalis* has not been included in the range chart of Cherchi and Schroeder (2013) although the species was recorded by Mancinelli and Chiocchini (2006) from southern Italy.

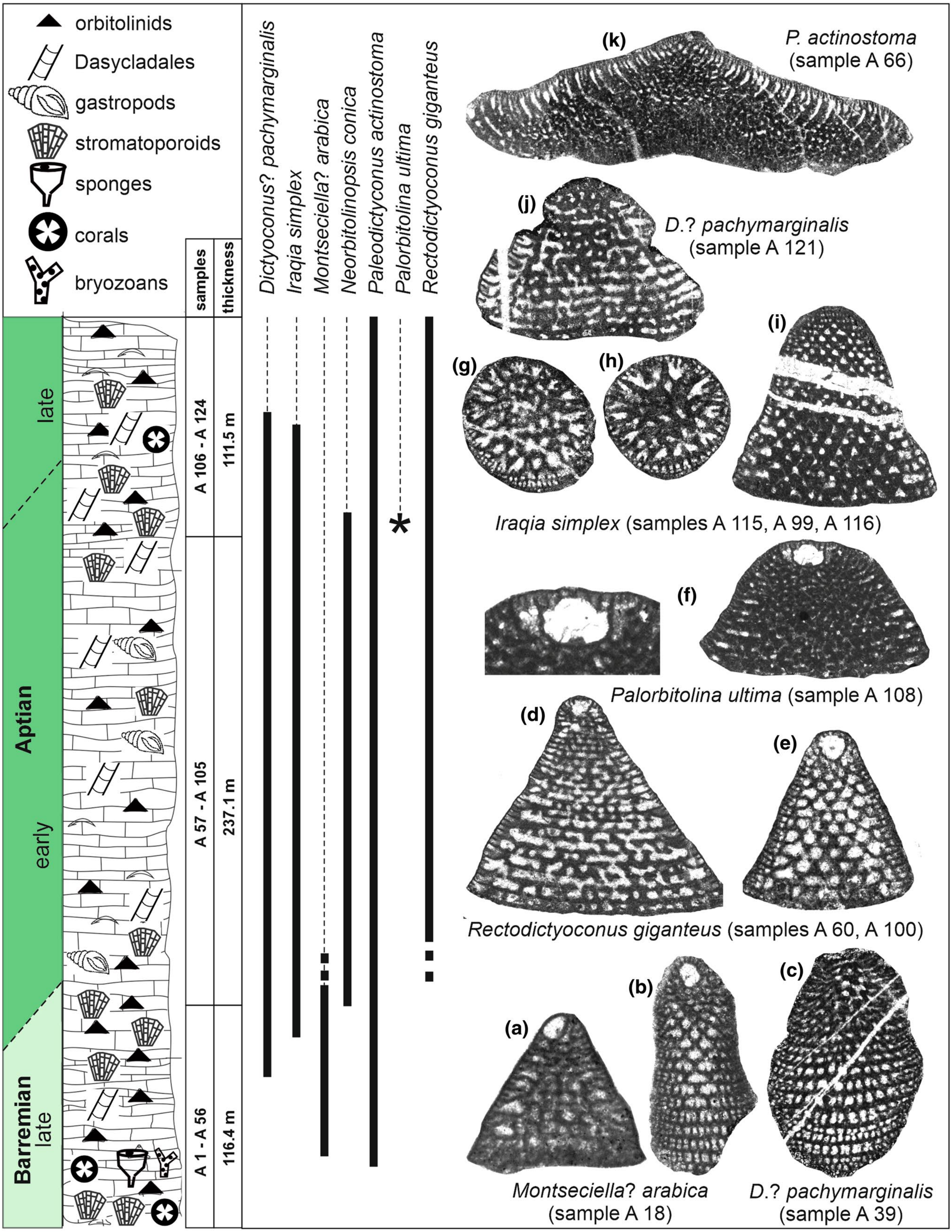
Genus *Iraqia* Henson 1948

Type species: *Iraqia simplex* Henson 1948

Iraqia simplex Henson 1948

Type-species: *Iraqia simplex* Henson 1948 (Fig. 4g–i).

1965 *Iraqia simplex* n. gen., n. sp.—Henson, p. 70, pls. 1, figs. 1–3.



orbitolinids
Dasycladales
gastropods
stromatoporoids
sponges
corals
bryozoans
samples
thickness
Dictyoconus? pachymarginalis
Iraqia simplex
Montseciella? arabica
Neorbitolinopsis conica
Paleodictyconus actinostoma
Palorbitolina ultima
Rectodictyoconus giganteus
late
Aptian
early
Barremian
late
A 106 - A 124
111.5 m
A 57 - A 105
237.1 m
A 1 - A 56
116.4 m
(k)
P. actinostoma
(sample A 66)
(j)
D.? pachymarginalis
(sample A 121)
(g)
(h)
(i)
Iraqia simplex (samples A 115, A 99, A 116)
(f)
Palorbitolina ultima (sample A 108)
(d)
(e)
Rectodictyoconus giganteus (samples A 60, A 100)
(a)
(b)
(c)
Montseciella? arabica
(sample A 18)
D.? pachymarginalis
(sample A 39)

◂**Fig. 4** Distribution of Orbitolinidae (total vertical ranges; images without scale) in the Taft Formation of the Ab Anbar section, Central Iran: **a–b** *Montseciella? arabica* (Henson); **c, j** *Dictyoconus*? *pachymarginalis* Schroeder; **d, e** *Rectodictyoconus giganteus* Schroeder; **f** *Palorbitolina ultima* Cherchi & Schroeder; **g–i** *Iraqia simplex* Henson; **k** *Paleodictyoconus actinostoma* Arnaud-Vanneau & Schroeder. Age calibration: "Standard" orbitolinid range chart of Schroeder et al. (2010) and Cherchi and Schroeder (2013)

1998 *Iraqia simplex* Henson—Whittaker et al., pl. 12, fig. 3, pl. 13, fig. 2, pl. 61, figs. 4–6, pl. 62, fig. 1.

Remarks The type-locality of *I. simplex* is Alana Gorge, northern Iraq (High Folded Zone) "in Lower Cretaceous limestone, probably Aptian" (Henson 1948, p. 70). The coordinates have been indicated as "Latitude Nord 36° 37′ and Longitude East 44° 26′ by Henson (1948, p. 111); further information such as rock lithology, associated taxa etc. is not available. There is a discontinuous latitudinal distributional pattern with occurrences in Spain (e.g., Bassoullet et al. 1985: "sous-province à *Iraqia simplex*"; Ramírez del Pozo 1971; Ullastre et al. 2002) and the Middle East area (e.g., Henson 1948). From a stratigraphic viewpoint, *I. simplex* could be well present in the Lower Cretaceous shallow-water carbonates of southern France (see Clavel et al. 2014) or the periadriatic carbonate platforms (e.g., Velić 2007: Croatia; Chiocchini 2012: Italy), but is absent in these areas. Referring to biostratigraphy, the range of *I. simplex* including the "European and Arabo-African Tethyan margins", has been indicated as uppermost Bedoulian (Furcata Zone and possibly the upper part of the Deshayesi Zone) by Masse (2003). This data might be in line with the "probably Aptian" age of the Iraqi type-locality, but Henson (1948, p. 70) also indicated other localities of *I. simplex* from Iran near the top of the "Middle Cretaceous limestone" (~ late Albian Mauddud Limestone; e.g., Whittaker et al., 1998). It is worth mentioning that Bassoullet et al. (1985, p. 707) envisaged a possible different taxonomic status (= species level) for the European and Middle East forms. This short summary gives evidence, that further clarification about the type-locality, distributional pattern, taxonomic inventory and stratigraphic range(s) is still required. In the Ab Anbar section, *Iraqia simplex* is comparably rare.

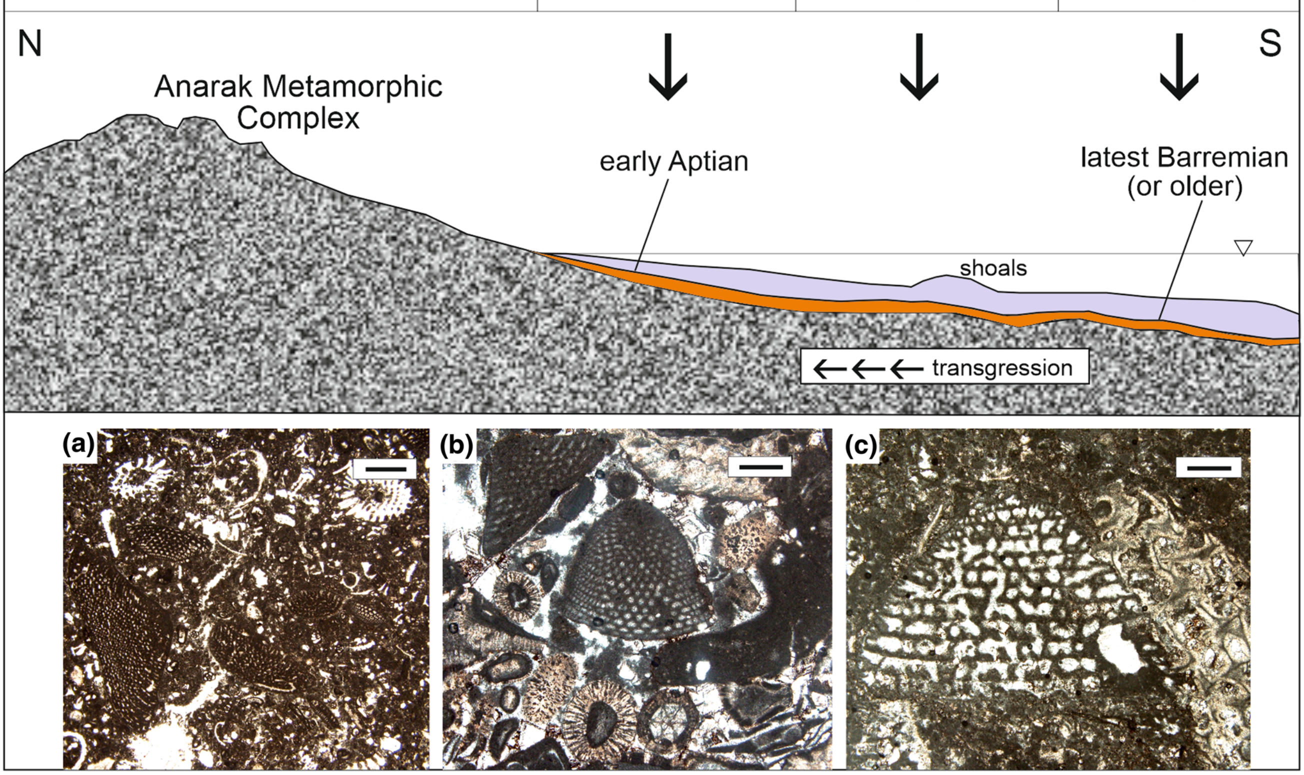
Genus *Paleodictyoconus* Moullade 1965
Type-species: *Dictyoconus cuvillieri* Foury 1963
Palaeodictyoconus actinostoma Arnaud-Vanneau & Schroeder 1976 (Fig. 4k).
1976 *Palaeodictyoconus actinostoma* n. sp.— Arnaud-Vanneau and Schroeder, pl. 1, figs. 1–6, pl. 2, figs. 1–6.
2015 cf. *Paleodictyoconus* sp., *Paleodictyoconus actinostoma*—Hanifzadah et al., pl. 1, figs. 3, 10, 12, pl. 2, fig. 9 (as *Palorbitolina lenticularis*), 10, 11 (as *Palorbitolina* sp.).
2016 *Orbitolina* cf. *wadiai*, *Iraqia* sp., *Palorbitolina* cf. *lenticularis*, *Orbitolina discoidea*, *Orbitolina* spp.—Rahiminejad and Hassani, fig. 4(a–b), (d–e), (g–h), (k).

Remarks The rather large-sized (diameter of several millimetres), low- to medium-conical tests of *Paleodictyoconus actinostoma* are common to frequent throughout the Ab Anbar se ction from the base toward the top. In the middle part of the section, the tests (respectively the central part) are often dolomitized.

Subfamily Orbitolininae Martin 1890
Genus *Palorbitolina* Schroeder 1963
Type-species: *Madreporites lenticularis* Blumenbach 1805
Palorbitolina ultima Cherchi & Schroeder in Schroeder et al. 2010 (Fig. 4f).
1982 *Orbitolina* (*Palorbitolina*) *lenticularis* (Blumenbach)—Zhang: pl. 7, fig. 12.
1991 *Palorbitolina lenticularis* (Blumenbach)—Zhang: pl. 1, figs. 5, 9.
2010 *Palorbitolina ultima* Cherchi & Schroeder n. sp.—Schroeder et al.: p. 56, and 59, figs. 5(b)6 (holotype), and fig. 8.14.
2013 *Palorbitolina ultima* Cherchi & Schroeder—Cherchi and Schroeder, fig. 3 (image right above).
2015 *Palorbitolina ultima*—Hanifzadah et al., pl. 1, fig. 11.
?2016 *Mesorbitolina parva*—Rahiminejad and Hassani, figs. 3(s)–3(t).

Remarks This species of *Palorbitolina* is characterized by a peri-embryonic ring (or zone) stretching laterally down to the base of the protoconch "but without covering completely its basal surface" (Schroeder et al. 2010, p. 59). The diameter of the embryo of the Iranian specimen observed in the upper part of the section (sample a108) is 0.45 mm, the one of the protoconch 0.22 mm; the respective values for the holotype specimen (pl. 3, Fig. 3 in Cherchi et al. 1978 as indicated in Schroeder et al. 2010, p. 59) are 0.63 mm and 0.26 mm (measured from the literature). According to our knowledge, the "detailed description of this new species"… "based upon a rich and well-preserved material from the Bari region (Apulia Carbonate Platform, southern Italy)" as announced in Schroeder et al. (2010, p. 59) has not been provided. In a later paper (Cherchi and Schroeder 2013), the holotype of *P. ultima* was re-illustrated, again without description. Anyway, the diagnostic feature of the species

section		Anarak	Cha Palang	Ab Anbar
	corals	rare	rare	rare
	stromatoporoids	–	very rare	rare to common
	pharetronid sponges	–	very rare	rare
	bryozoans	–	common	rare
Green algae	Dasycladales	common	common	rare
	Kopetdagaria sphaerica	–	rare	–
	Udoteaceae	very rare	rare	–
Red algae	*Marinella lugeoni*	–	common	rare
Foraminifera Orbitolinidae		abundant	common-abundant	abundant
	M. arabica-R. giganteus	–	rare	abundant
	Neorbitolinopsis conica	common	rare	rare
	Paleodictyoconus actinostoma	abundant	common-abundant	abundant
	Praeorbitolina	rare-common	–	–
	Dictyoconus? pachymarginalis	common	common	common
Diverse	*Mayncina-Charentia-Akcaya*	common	very rare	–
	Balkhania balkanica	–	very rare	–
	Torremiroella hispanica	–	very rare	–
	lenticulinids	–	rare	rare



◂**Fig. 5** Above: comparable distribution (semi-quantitative) of main biogenic groups, selected benthic foraminifera and calcareous algae of the Anarak (see Schlagintweit and Rashidi 2022), Chah Palang (unpublished) and Ab Anbar sections (this work). Middle: Schematic drawing of the relative position of the three sections in terms of (micro)facies, macro- and microfossil assemblages. Below: Examples of microfacies: **a** Packstone with orbitolinids and the dasycladale *Morelletpora turgida* (Radoičić) Barattolo (right above), Anarak section, thin-section AQ18, scale bar = 900 µm; **b** bioclastic grainstone with orbitolinids and ooids, Chah Palang section, thin-section c11, scale bar = 300 µm; **c** packstone with *Rectodictyoconus giganteus* Schroeder and *Actinostromaria*-type stromatoporoid, Ab Anbar section, thin-section a108, scale bar = 300 µm

as depicted in the structure of the embryo has been clearly stressed in Schroeder et al. (2010) allowing species identification in axial sections thereby fulfilling the requirement of article 13.1.1. of the International Code for Zoological Nomenclature (ICZN, 1999: "description or definition that states in words characters that are purported to differentiate the taxon"). The overall test construction refers to the one of *Palorbitolina lenticularis* (see Schroeder 1963).

Genus *Rectodictyoconus* Schroeder, 1964a
Type-species: *Rectodictyoconus giganteus* Schroeder, 1964a
Rectodictyoconus giganteus Schroeder, 1964a (Figs. 3d, e, 7a–i, k–l).
1964a *Rectodictyoconus giganteus* n. gen., n. sp.—Schroeder: p. 466, fig. 2.
2012 *Rectodictyoconus giganteus* Schroeder—Schlagintweit et al.: fig. 5c–e pars, Fig. 7a–c.
2015 *Montseciella arabica*—Hanifzadah et al., pl. 1, figs. 5–7.
2016 *Simplorbitolina* ssp., *Simplorbitolina milani*?—Rahiminejad and Hassani, figs. 3(s)–3(t).

Remarks Beside *P. actionostoma*, *R. giganteus* is the most abundant orbitolinid observed in the Ab Anbar section. Its distribution ranges from sample A60 (Fig. 4d) up to the ultimate sample from the section top (A124), referring to a thickness of ~ 327 m. This data necessitates some modification of the range included in "standard" orbitolinid range charts (further details see "Biostratigraphic issues").

Biostratigraphic issues

The ranges of some Barremian–early Albian orbitolinids included in the chart provided by Schroeder et al. (2010) mainly comprises forms with complex embryo (subfamily Orbitolininae), including only *Montseciella*? *arabica* from the Dictyoconinae. Although many of the Orbitolininae reported from Central Iran are cosmopolitan forms, several dictyoconids are not included because the range chart is primarily referring to the taxa occurring in the Lower Cretaceous of the Arabian Plate. Referring to the total ranges of the involved taxa, from the first (FAD) to last appearance datum (LAD) (= interval biozone, e.g., Armstrong and Brasier 2005), this chart can be considered as a standard used by many researchers since then. Due to their assumed planktonic larval stage of the megalospheric embryo

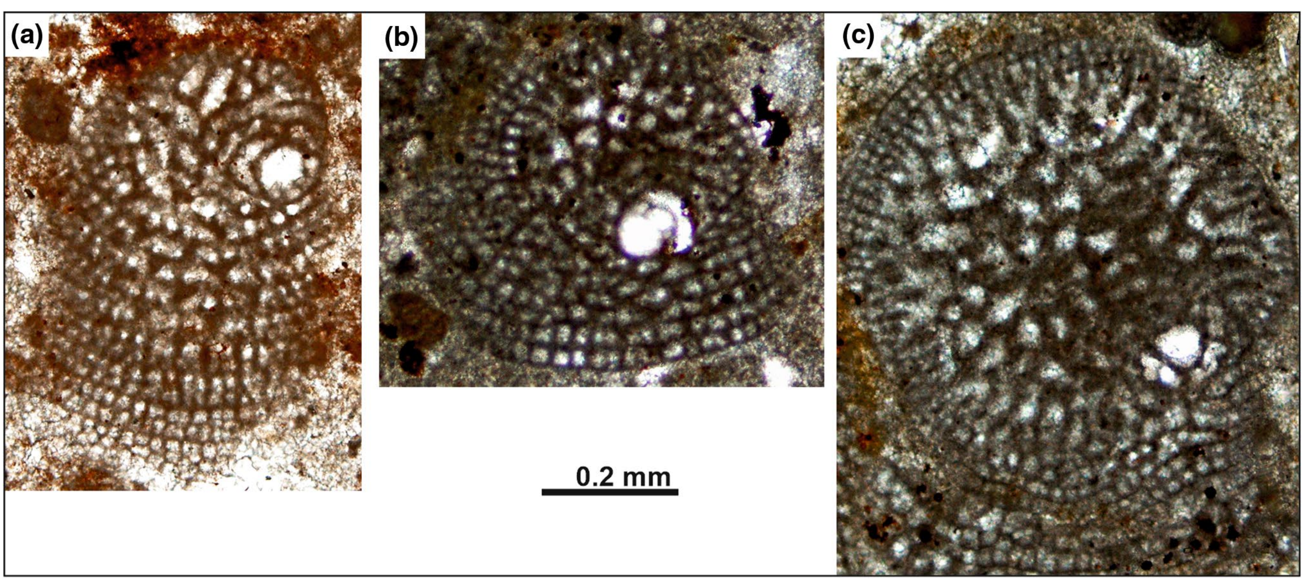
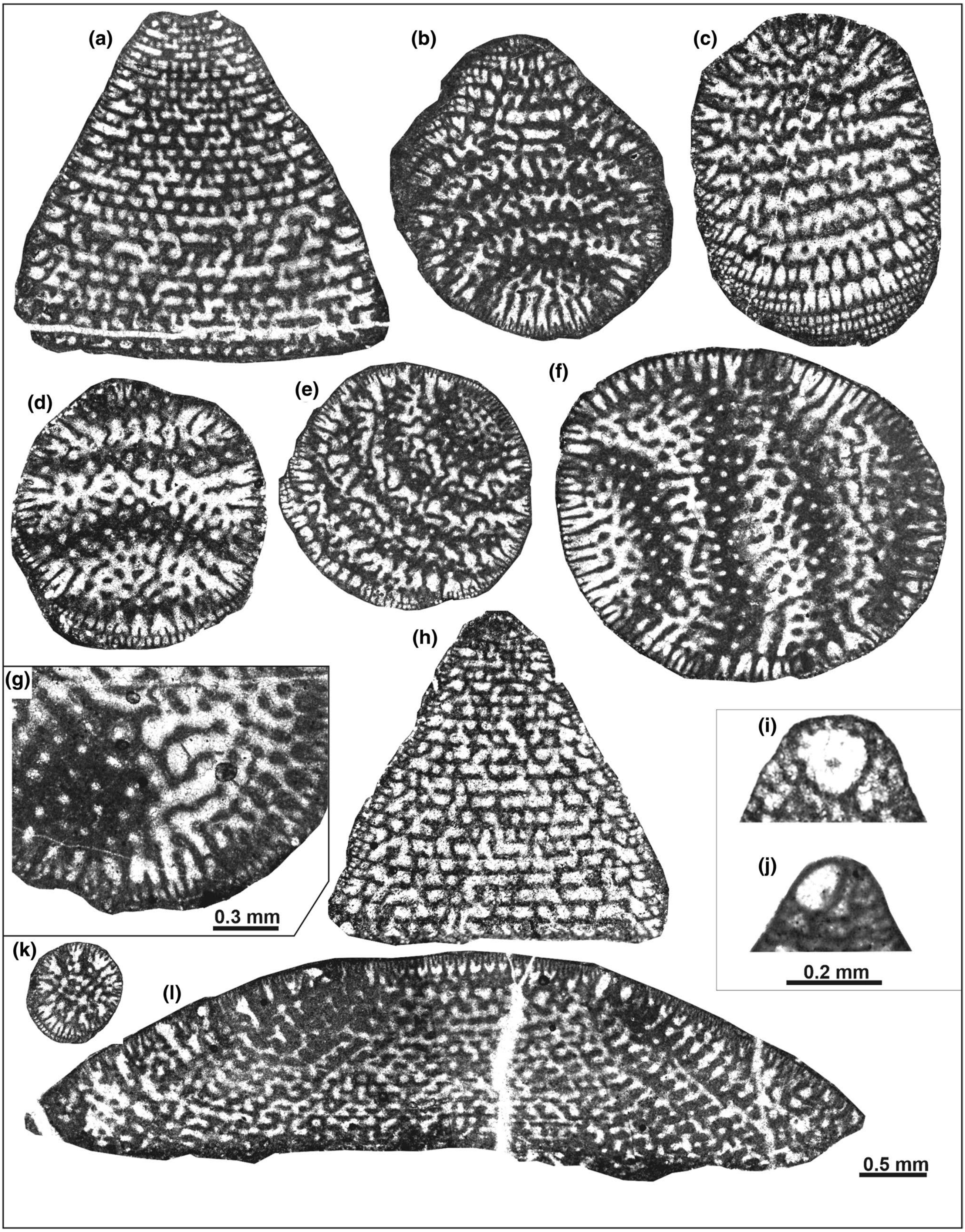


Fig. 6 Example of orbitolinids showing restricted distribution from the late Bedoulian (early Aptian) basal part of the Anarak section (see Fig. 1): **a** oblique section of *Praeorbitolina claveli* Schlagintweit et al., thin-section AQn21; **b** Oblique section of *Praeorbitolina cormyi* Schroeder, thin-section AQ5; Oblique section of *Praeorbitolina wienandsi* Schroeder, thin-section AQ5. Note that praeorbitolinas have not been observed from the Ab Anbar section


(a)
(b)
(c)
(d)
(e)
(f)
(g)
0.3 mm
(h)
(i)
(j)
0.2 mm
(k)
(l)
0.5 mm

◂**Fig. 7** *Rectodictyoconus giganteus* Schroeder (**a–i, k–l**) and *Montseciella*? *arabica* (Henson) (**j**), **l**) from the Taft Formation of the Ab Anbar section, Central Iran: **a, h** Subaxial sections of megalospheric specimens; **b–e, k** oblique sections; **k** refers either to a juvenile specimen or a section plane within the early part of an adult form; **f** oblique transverse section though a chamber; **g** detail from **f**, from right to left: marginal zone, columnar pillars arranged in concentric rows, pillars fusing and forming reticulate structures, and septum with foramina in concentric rows; **i–j** details of the megalospheric embryo: apical with short septules in *R. giganteus* (**i**) and subapical and simple in *M.*? *arabica* (**j**); **l** low-conical microspheric specimen. Thin-sections a109 (**a**), a100 (**b, e**), a91 (**c, h**), a92 (**d**), a39 (**f**), a108-1 (**g**), a100 (**i**), a18 (**j**), a60 (**k**), a58 (**l**)

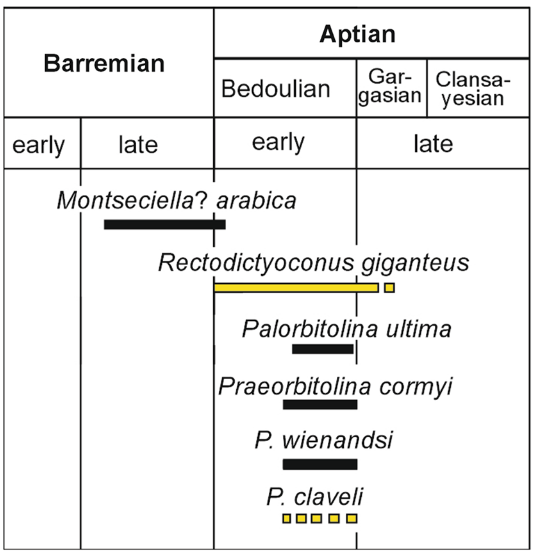


Fig. 8 Biostratigraphy of selected Orbitolinidae reported in the present study (excerpt from Schroeder et. al. 2010 and Cherchi and Schroeder 2013, black lines; modified by data from Schlagintweit et al. et al. 2012, 2013, this work) (yellow lines)

(Moullade et al. 1985, p. 153; Cherchi and Schroeder 2013), the Orbitolininae have a much wider (~cosmopolitan) distribution with many records from different areas. Their occurrence also in external platform facies facilitated their resedimentation in basinal sequences (incl. chronostratigraphic data, e.g., ammonites), and therefore their biostratigraphy is fairly well known dating back with sound data to the early sixties (e.g., Schroeder 1963, 1964a, b). Due to recent data, however, slight modifications of this range chart have to be made (Fig. 8). As noted by Schroeder et al. (2010, fig. 3), *R. giganteus* has not been observed on the Arabian Plate, e.g. the Aptian Dariyan Formation of southwestern Iran (Zagros Zone). The data for this species that has been included in the chart of Schroeder et al. (2010) and Cherchi and Schroeder (2013) are from the western part of the Neotethys, southeastern central Spain respectively (Schroeder, 1964a). The biozonation for this area comprises a zone with *Rectodictyoconus giganteus* observed within a ~42.5-m-thick complex of massive limestones (Schroeder 1964a, fig. 1). The observed "LAD" coincides with a facies change towards marly limestones (zone of *Orbitolinopsis kiliani*, Schroeder 1964a), a clear indication that the disppearance of the species at its type-locality is environmentally driven. In the Ab Anbar section instead, *R. giganteus* has been observed in a package of limestones of almost 340 m thickness indicating a wider stratigraphic range as reported from its Spanish type-locality. Already Schlagintweit et al. (2012) reported *R. giganteus* in association with mesorbitolinids from the Munella Carbonate Platform of Albania that were previously assigned to *M. texana* (Roemer), but that should be better placed into *M. parva* Schroeder herein. There, *R. giganteus* disappears within the range of *M. parva* indicating its occurrence the lower part of the Gargasian (late Aptian). An equivalent stratigraphic level level might be assumed for the Ab Anbar section of Central Iran where *R. giganteus* is reported until its top, almost 100 m above the level where *Palorbitolina ultima*, a late Bedoulian marker (Cherchi and Schroeder 2013) has been observed.

Conclusions

The "*Orbitolina Limestone*" of Central Iran (here: Yazd Block) shows a diachronous base varying between different sections that may include parts of the Barremian or the late early Aptian. Stratigraphic and facies differences (inner–outer platform) account for different assemblages of benthic foraminifera including orbitolinids and other biogenic groups in these carbonates. The available data are, however, still insufficient for wider palaeogeographic reconstructions including also results of time-equivalent strata of the Lut and Tabas Blocks as well as for a detailed range chart (or biozonation) including Orbitolinidae, selected other benthic foraminifera and dasycladalean algae as well.

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