First record of *Gyroconulina columellifera* Schroeder & Darmoian, 1977 (larger benthic foraminifera) from the Maastrichtian Tarbur Formation of SW Iran (Zagros Fold-Thrust-Belt)

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Abstract

The larger benthic foraminifera *Gyroconulina columellifera* Schroeder & Darmoian, 1977 (type-locality: Maastrichtian Aqra Formation of Iraq) is described for the first time from two sections of the Maastrichtian Tarbur Formation of the Zagros Fold-Thrust-Belt, SW Iran. New details on its wall microstructure are provided. The microfacies is represented by bioclastic wacke-/pack-/grainstones with benthic foraminifera (e.g., *Loftusia* ssp., *Neobalkhania bignoti*, *Omphalocyclus macroporus*) and dasycladalean algae. The Iranian discoveries give further evidence for the biostratigraphic importance of the taxon. The biostratigraphy of the Tarbur Formation based on larger benthic foraminifera is reviewed and critically discussed. Both *Gyroconulina columellifera* Schroeder & Darmoian, and the dasycladale *Pseudocymopolia anadyomenea* (Elliott), which have been first described from the Maastrichtian of Iraq, are now also reported from the Tarbur Formation of Iran. Their restricted occurrences along the southeastern northern margin of the Arabian plate and the Taurides of Turkey (Anatolian plate) are indicative for a Late Cretaceous provincialism, partly coinciding with the larger *Loftusia* bioprovince.

Keywords: *Benthic Foraminifera, Dasycladales, Zagros Zone, Biostratigraphy, Palaeobiogeography*

Introduction

The Late Cretaceous Tarbur Formation, named after the village of Tarbur (Fars Province), and cropping out in the SW Zagros basin, represents a predominantly carbonate lithostratigraphic unit that contains rich microfauna and microflora associated with rudists (James & Wynd, 1965). It extends from the northwest to the southeast of the Zagros basin along the western edge of the imbricated Zagros zone, between the main Zagros fault and the Shabazan fault to the east (Alavi, 2004). Towards the southwest the Tarbur Formation interfingers with the Gurpi Formation that usually underlies the former. The type section of the Tarbur Formation with a thickness of ~527 m is located at Kuh-e Gadvan about 1.2 km north of Tarbur village (James and Wynd, 1965). Noteworthy, a new type-locality southeast of Shiraz city has been proposed by Bakhtiyar *et al.* (2008a), but according to our knowledge a publication with details on lithology, and biostratigraphy is still lacking. In the stratigraphic chart of Iran provided in 1995 by the Geological Society of Iran, the Tarbur Formation is assigned to the Campanian-Maastrichtian interval, following the pioneer work of James and Wynd (1965).

The rudist fauna of the Tarbur Formation has already been described by several authors (e.g.,

Douvillé, 1904; Kühn, 1932; Khazaei *et al.*, 2010). In contrast, the micropalaeontological composition of the Tarbur Formation is still poorly constrained. Some taxa of calcareous algae and benthic foraminifera are indicated and illustrated in various recently papers (Vaziri-Moghadam *et al.*, 2005; Afghah, 2009; Maghfouri-Moghaddam *et al.*, 2009; Rajabi *et al.*, 2011; Abyat *et al.*, 2012, 2015; Afghah and Farhoudi, 2012; Pirbaluti and Abyat, 2013; Pirbaluti *et al.*, 2013; Afghah and Yaghmour, 2014). Several determinations however are incorrect and therefore need revision (e.g., Schlagintweit *et al.*, 2016). In the present paper, *Gyroconulina columellifera* Schroeder & Darmoian, Darmoian, 1977, a taxon previously unrecorded from Iran is described from two sections of the Tarbur Formation (Fig. 1). The well preserved material of this taxon merits a separate publication; the detailed analyses and micropalaeontological description of the microfauna and microflora (including some new taxa) will be described separately later.

Studied sections

Mandegan section: The study area, located in the High Zagros Belt, is situated north of Mount Dena, about 65 km south of the town of Semirom. The section of the Tarbur Formation is exposed about

10 km south of the village of Mandegan. Here the Tarbur Formation with a thickness of ~272 m overlies conformably the Gurpi Formation (Fig. 2). The top of the section is unconformably overlain by conglomerates of the Pliocene Bakhtiari Formation (see Bahrami, 2009, for details). Based on the lithostratigraphy, the section has been divided into three units (from base to top): unit 1 is dominated by thick-bedded limestones, unit 2 mostly contains medium-bedded limestones with intercalated marly limestone layers, and unit 3 consists of marly limestones. *Gyroconulina columellifera* appears in the upper part of unit 1, persisting through units 2 and 3, not reaching the topmost parts of the Tarbur Formation as several other taxa. The Greenwich coordinates of the section base are N 31º, 25', 8.13" and E 51º, 24', 34.58".

Fasa Section: It is located in the interior Fars (Folded Zagros Belt), about 20 km southwest of the town of Fasa, close to the village Khane Nahar. The exposed thickness of the Tarbur Formation is about 257 m. At the base, it is covered by alluvium and the Gurpi Formation is not exposed.
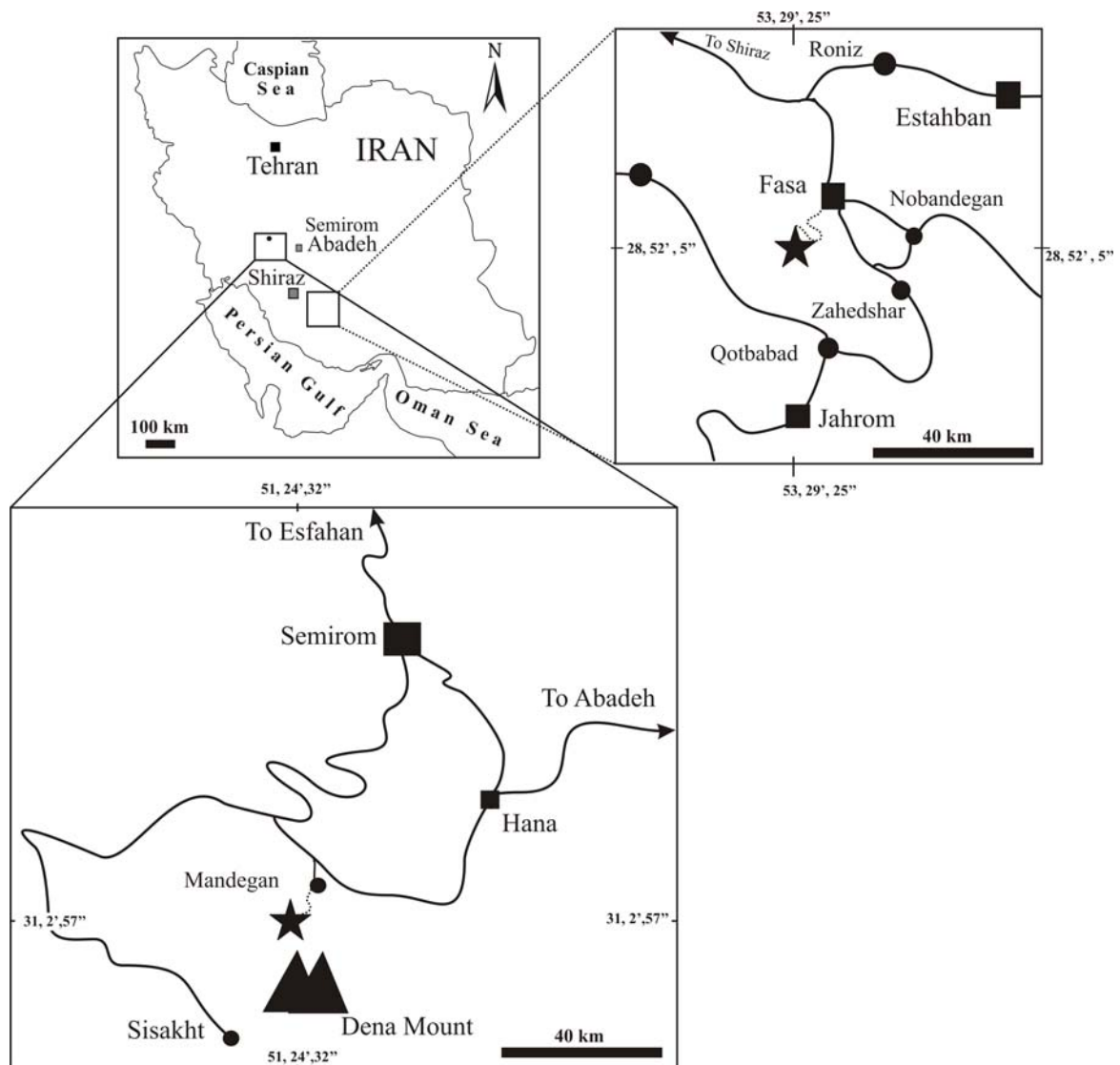

Figure 1. Location maps of the studied areas of the Tarbur Formation, and location of the Fasa and Mandegan sections.
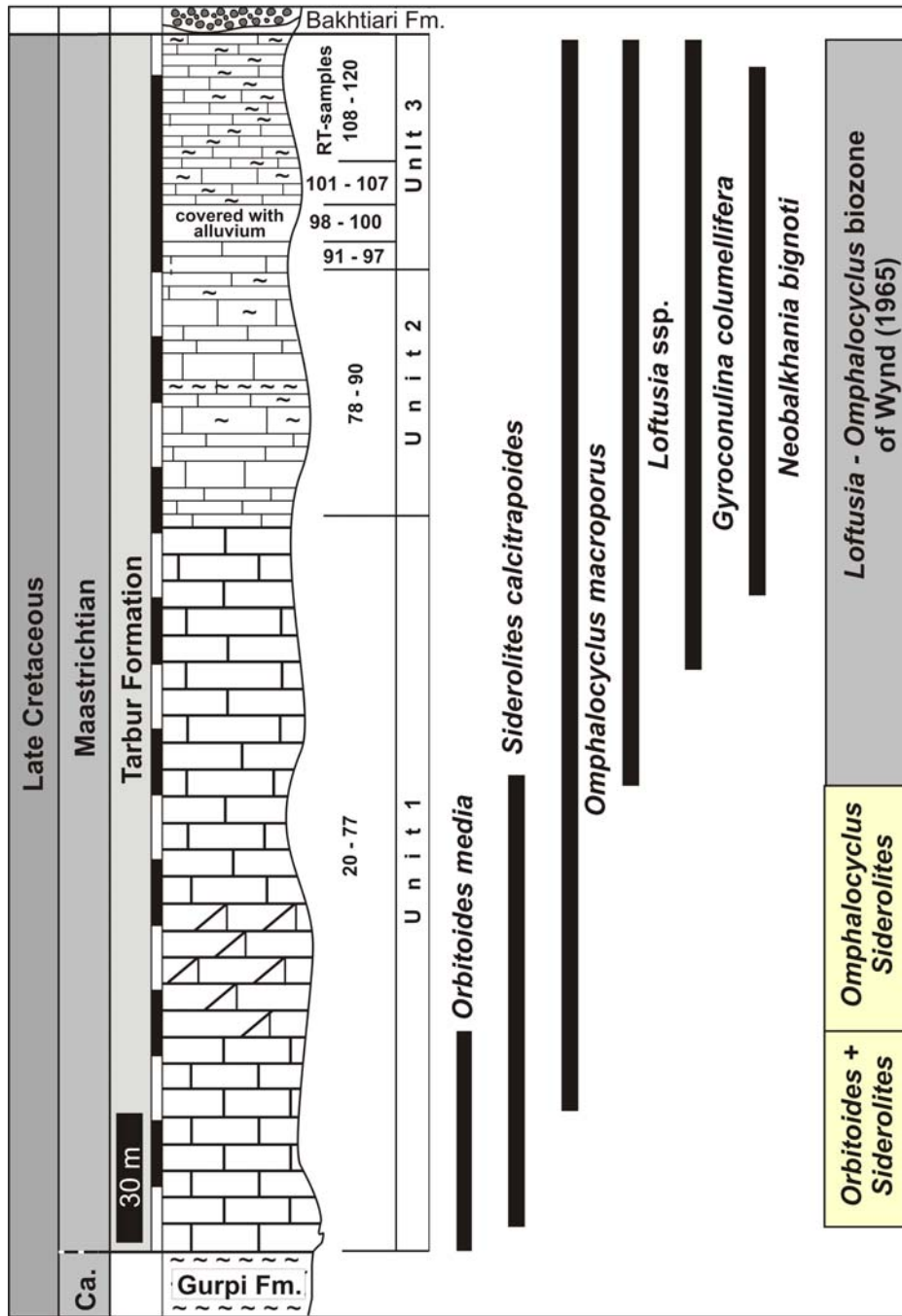
Figure 2. Distribution (total vertical range) of selected larger benthic foraminifera in the Tarbur Formation of the Mandegan section.

The Tarbur Formation can be subdivided into 3 lithostratigraphic units: medium- to thick-bedded limestones (73.1 m) (unit 1) followed by 124.4 m medium-bedded limestones with *Loftusia* (unit 2) and some intercalated dolomitic layers in the lower part, and finally unit 3 (74.5 m) consisting of medium- to thick-bedded limestones, yellow marls, and thick-bedded dolomites (uppermost part). The

top of the section is represented by the Paleocene Sachun Gypsum. The coordinates of the section base are N 28º, 51', 2.49", and E 53º, 30', 55.82".

Systematic palaeontology
The high-rank classification follows Pawlowski *et al.* (2013). For the low-rank classification see Kaminski (2014). For glossary, report to Hottinger

(2006).

Phylum Foraminifera d´Orbigny, 1826
Class Globothalamea Pawlowski et al., 2013
Order Loftusiida Kaminski & Mikhalevich, 2004
Suborder Orbitolinina Kaminski, 2004
Superfamily Pfenderinoidea Smout & Sudgen, 1962
Family Pfenderinidae Smout & Sudgen, 1962
Subfamily Anatoliellidae Sirel, 2013

Remarks. The genus *Gyroconulina* was previously placed in various families: Ataxophragmiidae Schwager (Schroeder and Darmoian, 1977), Pfenderinidae Smout and Sudgen, 1962 (subfamily Kurnubiinae) (Loeblich and Tappan, 1987; Kaminski, 2014), and Anatoliellidae Sirel (Sirel, 2013). In 2013, Sirel introduced the Anatolliellidae for the two genera *Gyroconulina* Schroeder & Darmoian, 1977, and *Anatoliella* Sirel, 1988, both having high-conical serial tests with complex exoskeleton and endoskeletal pillars.

Genus *Gyroconulina* Schroeder & Darmoian, 1977
(type-species: *Gyroconulina columellifera*
Schroeder & Darmoian, 1977)
Gyroconulina columellifera Schroeder &
Darmoian, 1977
(Figs. 3-5, 6B pars)

1977 *Gyroconulina columellifera* n. gen., n. sp. Schroeder & Darmoian, p. 120, pl. 1, figs. 1-4, pl. 2, figs. 1-7, text-fig. 2.
1985 *Gyroconulina columellifera* Al-Rawi and Al-Hamadani, pl. 4, fig. 3 (?), 4.
1986 *Gyroconulina columellifera* Farinacci and Yeniay, p. 260, not figured.
1986 Gyroconulina aqraensis n. sp. Lawa *et al.,* p. 77, pl. 1, figs. 3-6, pl. 2, figs. 7-10, pl. 4, figs. 16-17.
?2014 *Coskinolina* sp. Afghah and Yaghmour, pl. 2, fig. 2.

Description. Test medium conical to cylindro-conical (adults: Figs. 3J-K), low trochospirally coiled throughout ("chrysalidinid" sensu Hottinger and Drobne, 1980) with numerous marginally overlapping chambers arranged in up to 15/16 whorls. The tests of these forms are about twice as long as broad. The cone base (= apertural face) is subflat to slightly convex. Transverse sections are circular. Chambers rapidly increasing: measured along the cone axis, there are 4 to 5 whorls in the last 0.5 mm. The number of chambers in a whorl cannot clearly be deduced from the transverse sections available for juvenile specimens, but specimen shown in Fig. 4A shows an initial trochospiral arrangement with the number of chambers exceeding 3. In axial sections of adult

forms, two to three chambers are discernible (e.g., Fig. 3B, D-F, N). Following a spherical proloculus, the first post-embryonic chambers lack any subdivisions (Fig. 4B, 4J). The arched outermost part of the following chambers (marginal zone of Schroeder & Darmoian, 1977) all bear an exoskeleton that consists of two generations of beams (beams and intercalary beams) and up to 3 (4?) rafters in the adult test part. In shallow tangential sections, the beams (primary and secondary) and rafters display a polygonal network (Fig. 3J-K). Deeper tangential sections only cut the secondary beams revealing a pattern of rectangular chamberlets distinctly higher than wide (Fig. 3I, 4F). The endoskeleton is characterized by numerous comparably thick pillars (compared to thickness of rafters and septa) that follow the foraminal axes, thereby being almost in line (subcontinuous) from one chamber to the next. In the central part of the test, the pillars are densely set (Fig. 4L). The wall is thin and exhibits a finely friable hyaline structure limited to the spiral side of the test (e.g., Fig. 3A, K). The innermost part appears somehow darker. Externally, it is sealed by a very thin microgranular micritic layer (or coating) (Fig. 4H, 5; = epiderm sensu Hottinger, 2006). In contrast hereto, the microstructure of the exo- and endoskeleton is micritic (Fig. 5). Wall and septa are equal in thickness. It is worth mentioning that any kind of test dimorphism was not mentioned in the original description and is also not evident in the Iranian material.

Dimensions (data of Schroeder and Darmoian, 1977, in brackets).
Test height: up to 1.7 mm (up to 2 mm)
Test diameter: up to 1.3 mm (up to 1.4 mm)
Apical angle ~25-65 degrees (often around 45 degrees)
Wall thickness: ~0.02 to ~0.03 mm

Remarks. In the original description, the occurrence of an exterior hyaline wall layer ("vitreous layer" of Henson, 1948) was not mentioned (and is not clearly detectable in the provided illustrations). Often reported in larger porcelaneous taxa (e.g., Soritidae, Henson, 1948), this outer layer is also recorded in agglutinating conical taxa such as *Accordiella* Farinacci (e.g., Loeblich and Tappan, 1987, p. 151) or some orbitolinids (e.g., Douglass, 1960). In our material, this layer is clearly present, whatever the microfacies type (wackestone to grainstone).
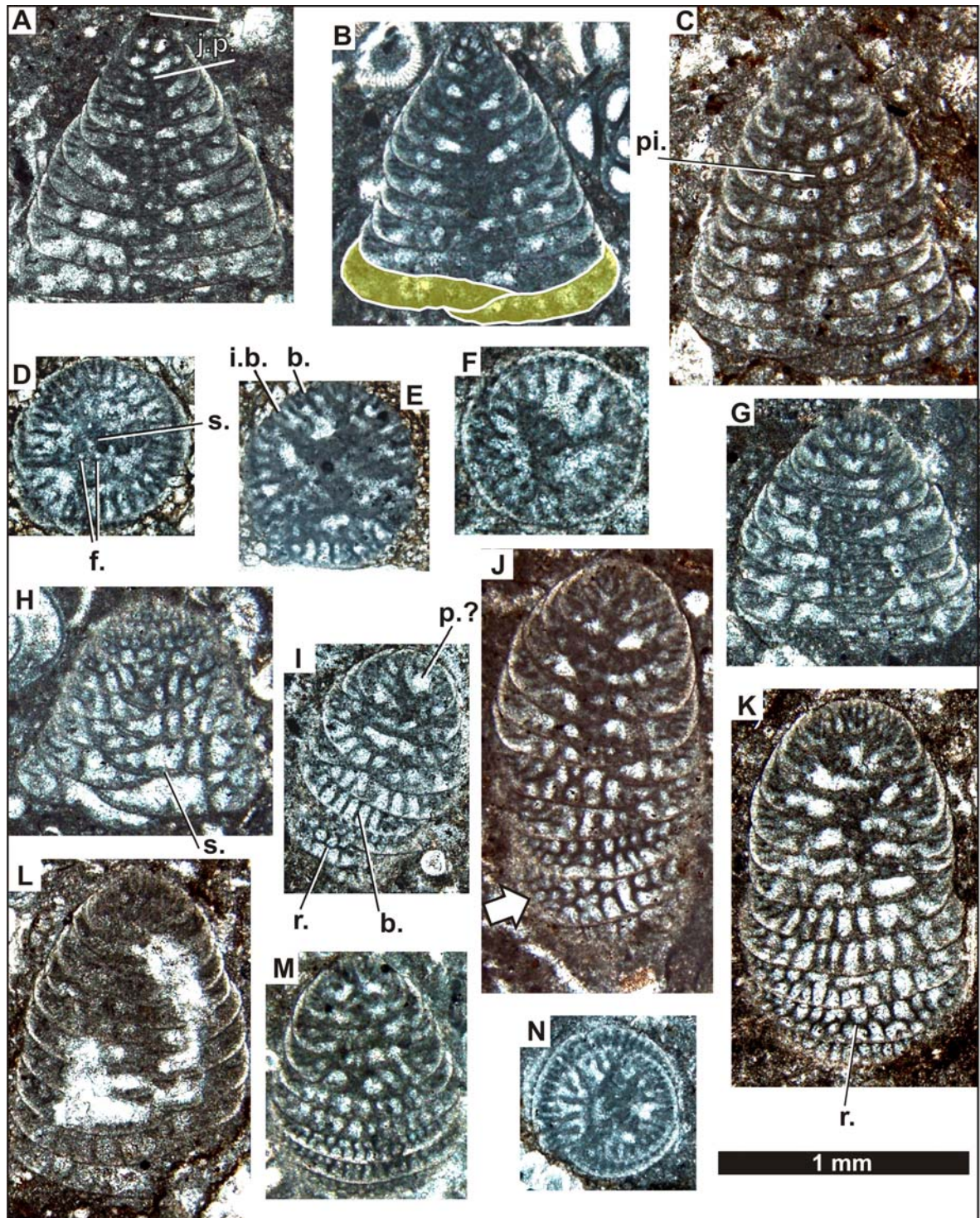
Figure 3. *Gyroconulina columellifera* Schroeder & Darmoian, Maastrichtian Tarbur Formation of Fasa section. A: Subaxial section, thin-section T 25. B: Axial, subcentered section, two chambers of the last whorl highlighted, thin-section T 25. C: Subaxial section, thin-section M 5. D, F: Transverse sections, thin-sections A 6, and A 6n. E: Slightly oblique transverse sections, thin-section A 6. G: Oblique section, thin-section T 25. H: Tangential-oblique section, thin-section A 6. I: Oblique? centered section, showing polygonal subepidermal network, thin-section A 6n. J-K: Oblique-tangential sections showing subepidermal network, thin-section Fa 3. L: Subaxial section of a specimen displaying dissolution cavities, thin-section M 5. M: Oblique section, thin-section T 55. N: Transverse, slightly oblique section through a biserial part of the test, thin-section M 5. Abbreviations: b. = beam, f. = foramina, i.b. = intercalary beam, j.p. = juvenile part (with incipient partitions?), p. = proloculus, pi. = pillar, r. = rafter, s. = septum.
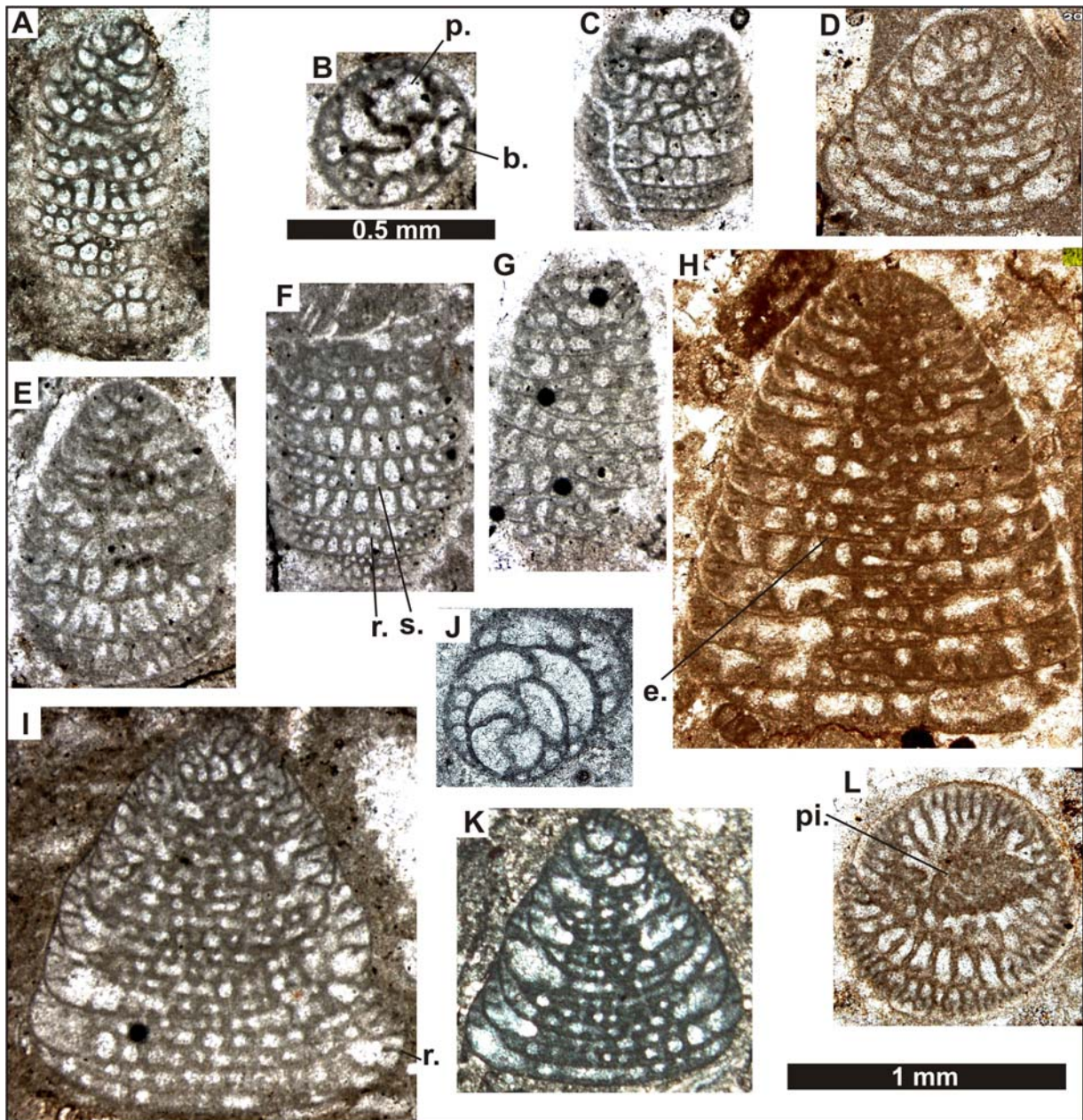
Figure 4. *Gyroconulina columellifera* Schroeder & Darmoian, Late Maastrichtian Tarbur Formation of Mandegan section. H-I: Subaxial section. B, J: Oblique section through the juvenile test part showing undivided early ontogenetic chambers. A, C, F-G: Tangential sections. D-E, H: Oblique sections. K: Axial (centered?) section. Note the aligned foramina in the central region L: Oblique transverse section. Thin-sections: Rt 79-3: A, Rt 100: B-C, G; Rt 108: D; Rt 102: E-F; Rt 102-2: H; Rt 113: I; Rt 68: J; Rt 108-2B: L; Rt 111-2: K. Abbreviations: b. = beam, e. = epiderm, f. = foramina, p. = proloculus, pi. = pillar, s. = septum.

In the case of the soritids, this fine outer layer may exhibit calcite crystals with chaotic orientation and were therefore interpreted by Consorti *et al.* (2015) as a diagenetic modification of the original wall structure. In the case of *Gyroconulina* it seems to be just the other way round as the original material of Schroeder and Darmoian (1977) is less preserved than the Iranian material. The homogeneous (micritic) appearance of the Iraqian type specimens It is more affected by diagenetic alterations (e.g., micritization) displaying a homogeneous micritic appearance. The thin outermost micritic coating in the Iranian specimens of *Gyroconulina* can be ascribed to an epiderm that might be homologous with the tectum of Paleozoic fusulinids (Hottinger, 2006, p. 14; see also Vachard

et al., 2004). There is a transition from the hyaline (agglutinating?) structure of the wall to the micritic structure of the exoskeleton, not a sharp boundary (Fig. 5).
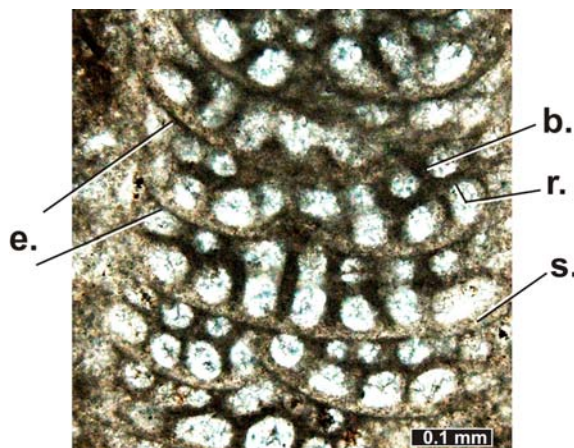

Figure 5. *Gyroconulina columellifera* Schroeder & Darmoian, Late Maastrichtian Tarbur Formation of Mandegan section. Detail from Figure 3A showing differing microstructure of septa and exoskeleton (beams and rafters). Abbreviations: e. = epiderm, b. = beam, r. = rafter, s. = septum.

For discussion on agglutinating versus secreted (microgranular) test walls see Rigaud *et al.* (2015).

Based on both isolated and thin-section specimens, Lawa *et al*. (1986) described another species as *Gyroconulina aqraensis*. Diagnostic criteria include the "cylindrical stage, biserial stage during the late ontogeny, slightly inclined axis of test in early stage of growth, greater diameter of chambers and large size" (Lawa *et al*., 1987, p. 78). It is worth mentioning that no structural differences between *G. aqraensis* and *G. columellifera* were described (and none are visible in the provided illustrations). Like in *G. columellifera*, the specimens of *G. aqraensis* are conical in the early stage, becoming cylindrical (to cylindroconical) in the adult stage (see Schroeder and Darmoian, 1977). For *G. columellifera*, Schroeder and Darmoian (1977, p. 120) also noted that "sometimes the conical part seems to be inclined". Concerning the dimensions, Schroeder and Darmoian (1977) reported a test height of up to 2 mm (Lawa *et al*., 1987: up to 3 mm), and a diameter of up to 1.4 mm (Lawa *et al*., 1987: up to 1.5 mm). It results that there are no specific differences between *G. columellifera* and its junior synonym *G. aqraensis*. Both are described from the same lithostratigraphic unit, the Maastrichtian of the Aqra Formation of Iraq.

Occurrences, and associations. So far, *Gyroconulina columellifer*a, was reported from three regions.

Iraq: In the Aqra Formation, *Gyroconulina columellifer*a was reported from Late Masstrichtian strata by Schroeder and Darmoian (1977) in strata containing *Loftusia* ssp., *Omphalocyclus macroporus* (Lamarck), *Dictyoconella complanata* Henson, *Rhapydionina* sp., and cuneolinids. In the microfacies and micropalaeontological study of Al-Rawi and Al-Hamadani (1985, Tab. 2), *Gyroconulina* is widely distributed within a section of about 500 m in the Maastrichtian Aqra Formation, but displays an anticyclical pattern with *Loftusia*, meaning that both are not co-occurring.

Turkey: From the Western Taurides, it was reported by Farinacci and Yeniay (1986) also from the Late Maastrichtian when a "restricted shallow marine environment" developed. Here, *G. columellifera* is associated with *Rhapydionina liburnica* Stache, *Antalyna korayi* Farinacci & Koylüoglu, cuneolinids, dicyclinids, and other benthic foraminifera.

Iran: In the Tarbur Formation, *G. columellifera* was observed in for-algal wackestones/packstones, occasionally also in grainstones. The microfacies for two different samples is exemplarily provided in Figure 6. In the thin-sections of samples containing *Gyroconulina columellifera* we observed the following taxa (in alphabetical order) (see Figs. 7-8):

Antalyna korayi Farinacci & Köylüoglu
Broeckina cf. *dufrenoyi* (d'Archiac)
Cuneolina sp.
Cuvillerinella cf. *salentina* Papetti & Tedeschi
Dicyclina cf. *schlumbergeri* Munier-Chalmas
Dictyoconella complanata Henson
Elazigella? sp.
Fallotia aff. *jacquoti* Douvillé
Fleuryana adriatica De Castro, Drobne & Gušić
Laffiteina monodi Marie (Astre)
Loftusia harrisoni Cox
Loftusia coxi Henson
Loftusia morgani Douvillé
Mississippina? *binkhorsti* (Reuss)
Minouxia sp.
Nezzazatinella? cf. *picardi* (Henson)
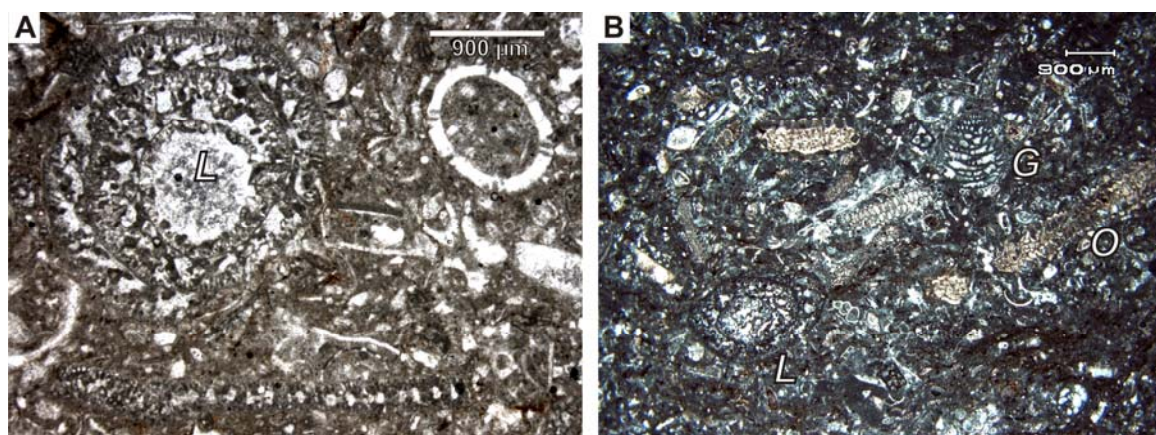*Neobalkhania bignoti* Cherchi, Radoičić & Schroeder

Figure 6. Example of microfacies of Mandegan (A) and Fasa sections (B). A-B: Bioclastic packstones with *Gyroconulina columellifera* Schroeder & Darmoian (*G*), *Omphalocyclus macroporus* (Lamarck) (*O*) and *Loftusia* sp. (*L*). Thin-sections Rt 79 and A 7.

Elphidiella? *cretacea* (Pérébaskine) [= *Rotalia* cf. *skorensis* in Pirbalouti and Abyat, 2013, Pl. 1, Fig. 9; *Nonion senonicus* (Pérébaskine) in Gendrot, 1968, Pl. 10, Fig. 15, text-fig. 6a, b; *Elphidiella senonica* (Pérébaskine) in Radoičić, 1979, Pl. 8, Figs. 6-7, Maastrichtian of Iraq]
Omphalocyclus macroporus (Lamarck)
Orbitoides gr. *media* d´Archiac
Pararotalia? sp.
Pyrgo? sp.
Siderolites calcitrapoides Lamarck
Sirtina ornata (Rahaghi)
Valvulina? sp. 1 Sirel

Apart from these, there are several new taxa that are currently under systematic investigation and description. It must be stressed, that not all the above listed taxa necessarily are co-occurring. Among these taxa, we draw attention to the occurrence of *Neobalkhania bignoti* (Fig. 7B, D), originally described by Cherchi *et al.* (1991) from the Late Maastrichtian of Croatia. Besides, they also noted its occurrence in time-equivalent strata from Greece, leading Cherchi *et al*. (1991, p. 288) to conclude that *N. bignoti* represents "an excellent marker of this time interval" (see also Fleury, 2014, Fig. 3).

Drobne *et al*. (1994) reported *Gyroconulina* sp. from the Late Maastrichtian of Slovenia. This form however represents a new genus, different from *Gyroconulina*, that is currently under description and publication (K. Drobne, pers. comm.).

Biostratigraphy of the Tarbur Formation
Critical review of the literature
As already remarked, a Campanian–Maastrichtian age is usually referred to the Tarbur Formation.

Whereas the Maastrichtian is well constrained by larger benthic forams (e.g., Wynd, 1965; this work), dasycladalean algae (Rashidi *et al*., 2013), rudists (e.g., Khazaei *et al.*, 2010), and ostracods (Colin, 2012), the lower (base) and upper boundaries (top) need some discussion and critical remarks based essentially on larger benthic foraminifera.

Basal part of the Tarbur Formation. Here above all the difficulties in distinguishing the Campanian-Maastrichtian boundary in shallow-water facies using larger benthic forams are in the focus. Restricted to the lower part of the Tarbur Formation (~60 m to ~91 m), the first biozonation was provided by Wynd (1965) who defined a *Monolepidorbis-Orbitoides* assemblage zone, defined by the co-occurrence of *Monolepidorbis* cf. *douvillei* (= *Orbitoides douvillei*, e.g., Albrich *et al*., 2014) and *Orbitoides*, e.g. *Orbitoides media*. He attributed this zone to the Campanian. This zone in turn is followed by the *Omphalocyclus-Loftusia* assemblage Zone, defined by the co-occurrence of *Omphalocyclus macroporus* and *Loftusia* ssp. and attributed to the Maastrichtian. *Omphalocyclus macroporus* is traditionally reported as a Late Maastrichtian taxon (e.g., Neumann, 1987), so that a time gap would occur between the Campanian "*Monolepidorbis-Orbitoides* assemblage Zone" and the following Maastrichtian "*Omphalocyclus-Loftusia* assemblage Zone". *Omphalocyclus* has long time been considered a monospecific genus but in recent years several new species have been described (Gunter *et al.*, 2002; Özcan, 2007). In his stratigraphic review, Özcan (2007) reported *Omphalocyclus* from strata as old as the Late Campanian.
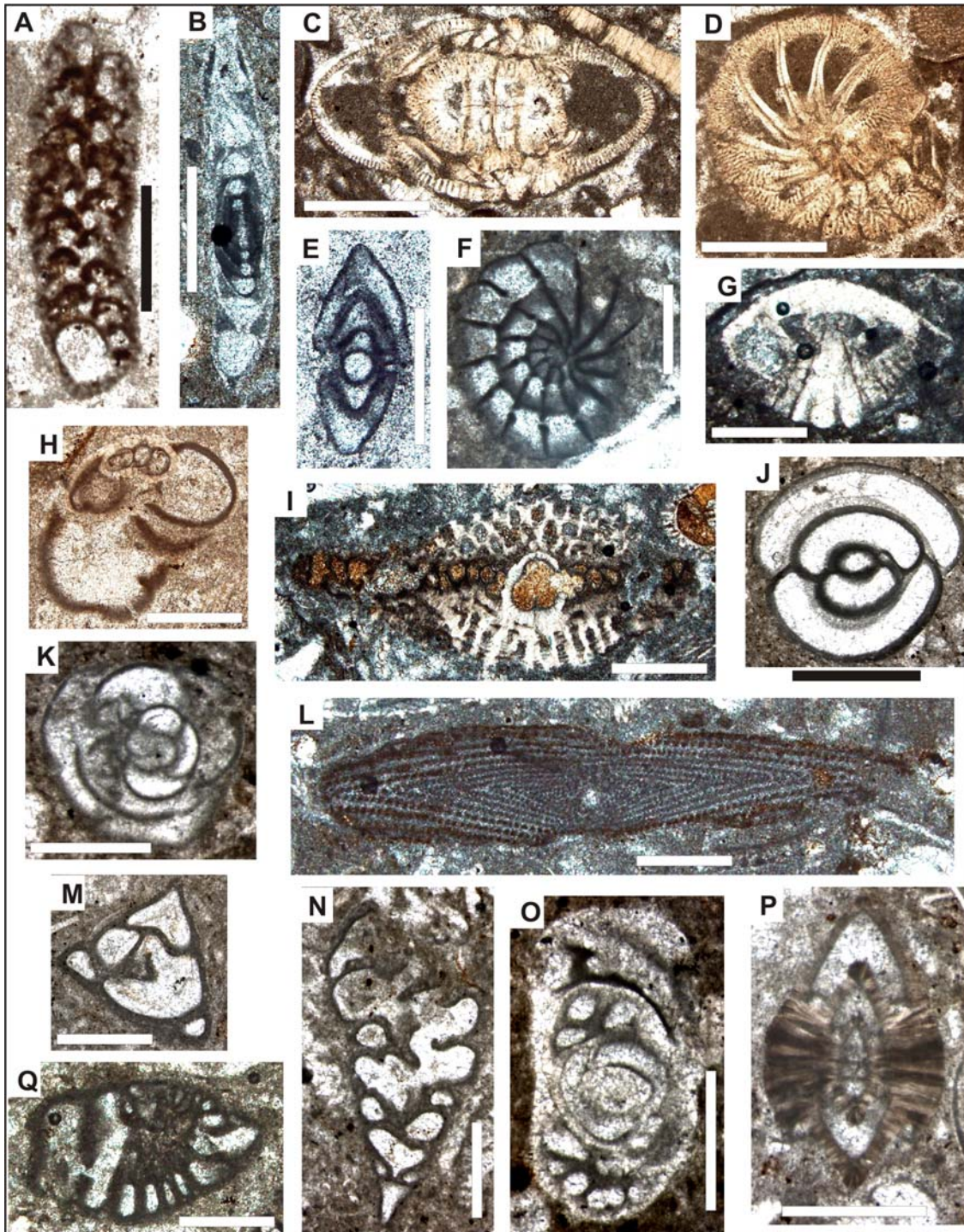
Figure 7. Benthic foraminifera that may co-occur with *Gyroconulina columellifera* Schroeder & Darmoian in the Late Maastrichtian of the Tarbur Formation, Fasa (L) and Mandegan sections (all others). A: *Cuneolina* sp., thin-section Rt 108-2b. B: *Elazigella?* sp., thin-section Rt 113-3. C-D: *Laffiteina monodi* Marie (Astre), thin-section Rt 102. E-F: *Fleuryana adriatica* De Castro, Drobne & Gušić, thin-sections Rt 68, Rt 87. G: *Pararotalia?* sp., thin-section A 6. H: *Mississippina? binkhorsti* (Reuss), thin-section Rt 100-2. I: *Orbitoides media* d´Archiac, thin-section A 9. J: *Pyrgo?* sp., thin-section Rt 113-1. K: *Minouxia* sp., thin-section Rt 72. L: *Fallotia* aff. *jacquoti* Douvillé, thin-section A 7. M-N: *Valvulina?* sp. 1 Sirel, thin-sections Rt 113-1, Rt 79. O: *Cuvillerinella* sp. thin-section Rt 113. P: *Elphidiella? cretacea* (Pérébaskine) [= *Rotalia* cf. *skorensis* in Pirbalouti and Abyat, 2013, Pl. 1, Fig. 9; *Elphidiella senonica* (Pérébaskine) in Radoičić, 1979, Pl. 8, Figs. 6-7, Maastrichtian of Iraq]. Q: *Nezzazatinella?* cf. *picardi* (Henson), thin-section Rt 72. Scale bars: 0.3 mm, except H 0.5 mm.
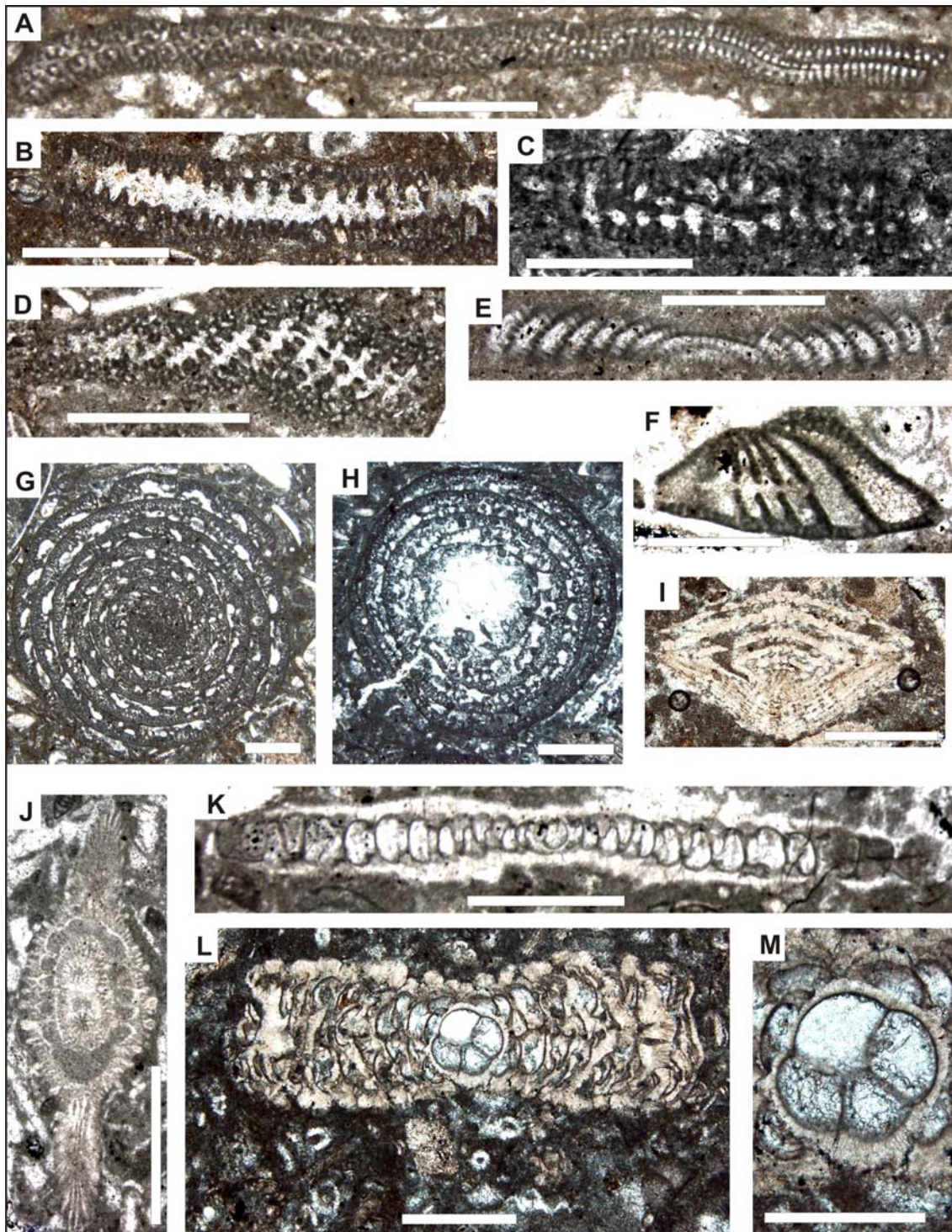
Figure 8. Benthic foraminifera that may co-occur with *Gyroconulina columellifera* Schroeder & Darmoian in the Late Maastrichtian of the Tarbur Formation, Fasa (G-H, L-M) and Mandegan sections (all others). A: *Dicyclina* cf. *schlumbergeri* Munier-Chalmas, thin-section Rt 72. B, D: *Neobalkhania bignoti* Cherchi, Radoičić & Schroeder, thin-section Rt 79. C: *Dictyoconella complanata* Henson, thin-section Rt 79. E: *Broeckina* cf. *dufrenoyi* (d'Archiac), thin-section Rt 113. F: *Antalyna korayi* Farinacci & Köylüoglu, thin-section RT 102. G: *Loftusia morgani* Douvillé, thin-section T 25a. H: *Loftusia harrisoni* Cox, thin-section M 25. I: *Sirtina ornata* (Rahaghi), thin-section Rt 108. J: *Siderolites* cf. *calcitrapoides* Lamarck, thin-section RT 102. K: *Orbitoides? concavatus* Rahagi, thin-section Rt 102. L-M: *Omphalocyclus macroporus* (Lamarck), thin-section T 25. M showing detail of quadrilocular embryonic apparatus. Scale bars: 1.0 mm for A-B, D, G-H; 0.5 mm for C, E, I-J, K-L; 0.3 mm for F, M.

The dilemma of resolution of the Campanian-Maastrichtian boundary has to be taken into consideration when assigning parts of the Tarbur Formation to the Late Campanian or to the Early Maastrichtian without any additional orthostratigraphic calibration. Many workers still uncritically follow the classical two-fold biozonation of the Tarbur Formation used by Wynd (1965) (e.g., Rajabi et al., 2011; Abyat *et al*., 2012). The taxonomy of primitive orbitoids, such as *Monolepidorbis* (= *Orbitoides*) *douvillei* is problematic and even determinations by specialists are ambiguous. For example, illustrations of *Orbitoides tissoti* provided by Neumann (1987) were included in the synonymy list for *O. douvillei* (see Albrich et al., 2014). In other papers, a Campanian age is assigned for the lower part of the Tarbur Formation due to the occurrence of *Orbitoides? concavatus* Rahaghi (e.g., Afghah, 2009). This species described by Rahaghi (1976) from the Campanian of Iran was interpreted as a primitive type of *Omphalocyclus* by Meriç and Coruh (1991) for which they established the genus *Praeomphalocyclus* (type-species *P. concavatus*). In other sections of the Tarbur Formation, the Campanian age for the lower part is based on the occurrence of (unfigured!) *Murciella cuvillieri* Fourcade (Afghah and Farhoudi, 2012). This assignment is in total or partial contradiction with other works where *M. cuvillieri* is treated as a classical Maastrichtian marker taxon (e.g., Velic, 2007, Fig. 11) or as having a Late Campanian to Late Maastrichtian range (Vicedo, 2008).

Another taxon of larger benthic foraminifera frequently reported from the Tarbur Formation is *Loftusia* Brady. Classically being reported as confined to the Maastrichtian (Meriç *et al.*, 2001; Meriç & Görmüş, 2001), Goldbeck and Langer (2009, Tab. 2) indicate a Campanian-Maastrichtian range in their data compilation. Besides several occurrences in the Maastrichtian, one report from the Campanian of Oman is provided referring to the paper of Abdelghany (2003). Obviously based on this assumed oldest occurrence, Goldbeck and Langer (2009, p. 192) assumed that *Loftusia* "originated in the Oman area, from which it dispersed over the eastern parts of the Tethys". In the paper of Abdelghany (2003), *Loftusia* is reported from the Campanian-Maastrichtian Simsima Formation of the Northern Oman Mountains. In the studied sections (op. cit., Fig. 2), *Loftusia morgani* occurs together with *Orbitoides media*, *Lepidorbitoides minor*, and *Omphalocyclus macropora* in a ~25 m thick package of limestones. This association indicates a Maastrichtian and not a Campanian age (e.g., Meriç *et al*., 2001, Fig. 6: *L. morgani* = Late Maastrichtian marker taxon). Only ~5 m upwards above this association, *Siderolites calcitrapoides* Lamarck appears, a taxon that according to Robles Salcedo (2014) has its first appearance in the latest early Maastrichtian. In conclusion, without any further reliable data, *Loftusia* should still be considered an exclusively a Maastrichtian taxon.

Upper part/top of the Tarbur Formation. For the top of the Tarbur Formation three different views can be found in the literature: (1) a subaerial unconformity referred to the middle Maastrichtian (e.g., Alavi, 2004), (2) an unconformity-bound top at the KT boundary (e.g., Stratigraphic chart of Iran), and (3) a continuous continuation into the early Paleogene (without gap or unconformity) (e.g., Afghah and Farhoudi, 2012).

(1) According to Alavi (2004), the Tarbur Formation ends with an unconformity in the Middle Maastrichtian, thereby terminating a "Late Cretaceous Megasequence" (latest Turonian-middle Maastrichtian). It is followed by the Late Maastrichtian to Paleocene Sachun Formation (that in other concepts should start with the Paleocene). This scenario correlates the top of the Tarbur Formation with a supposed initiation of the collision of the Zagros orogeny at ~68 Ma., a middle Maastrichtian event. According to the two-fold subdivision of the Maastrichtian, this event dates the early late Maastrichtian (e.g., Keller, 2011, Fig. 5, *Abathomphalus mayaroensis* planktonic foraminifera zone). It is worth mentioning that the youngest Maastrichtian eustatic event that can be tracked also in the Arabian platform is recorded at 68.8 Ma. (Haq, 2014, = KMa5). After a gap of roughly 2 Ma, the Sanchun Formation should start in the Late Maastrichtian ranging into the early Paleogene (see also Kalantari, 1976). It is however noteworthy that James and Wynd (1965, Fig. 26) note a conformable boundary between the Tarbur and Sanchun Formations at the type-locality of the latter, also indicating a late Maastrichtian to upper Eocene age.

(2) This lithostratigraphic concept is ambiguous. In the Stratigraphic chart of Iran published by the Geological Society of Iran, the top of the Tarbur Formation corresponds to an unconformity at the KT boundary. This boundary is regarded as the top

of the Tarbur Formation also in several other compilations, for example Heydari (2008) who referred it to the so-called Campanian-Maastrichtian Ardavan supersequence. This supersequence represents a shallowing sequence that ended with an exposure of the former platform and the formation of palaeosoils. For example, a palaeosol horizon was observed between the Tarbur and Sachun formations and correlated with the Cretaceous-Tertiary (KT) boundary by Bakhtiyar *et al.* (2008b).

(3) According to Afghah (2010, 2016) and Afghah and Farhoudi (2012), the Tarbur Formation ranges continuously (without unconformity and gap) in some sections into the Early Paleocene. This attribution is based on the occurrence of *Laffiteina* sp. (or *Laffiteina* sp. biozone) and *Vania anatolica* Sirel & Gündüz (or *Vania anatolica* biozone). The rotaliid foraminifer illustrated as *Laffiteina* sp. (e.g., Aghfah & Farhoudi, 2012, Pl. 2, Fig. 5) is badly preserved and not diagnostic. Actually, *Laffiteina* is well recorded from the Maastrichtian with the three species *L. marsicana* Farinacci, *L. mengaudi* (Astre), and *L. monodi* Marie (see Hottinger, 2014, Fig. 1.3-b). Concerning *Vania anatolica*, the illustrated specimen is also not diagnostic and corresponds in our opinion to the same taxon depicted as *Broeckinella* sp. (? *Broeckinella arabica* Henson, Maastrichtian of Qatar) (e.g., Aghfah and Farhoudi, 2012, Pl. 3, Fig. 3 versus Fig. 7). Also no further indications on stages are provided about the assumed Early Paleocene age (Danian? Selandian?). Moreover, the *Vania anatolica* biozone should directly follow the Maastrichtian, although this taxon is restricted to the Thanetian (Sirel and Gündüz, 1985; Sirel, 2015). Another inconsistency is the ranging of *Loftusia* and *Omphalocyclus* into the lower part of the "*Vania anatolica* biozone" surpassing the supposed Cretaceous-Paleogene boundary (Afghah, 2016, Fig. 3). Also Pirbaluti *et al.* (2013) indicate a possible Paleocene age for the uppermost part of the Tarbur Formation. With ranges of both *Omphalocyclus* and *Loftusia* until the top of the Tarbur Formation (Pirbaluti et al., 2013, Fig. 4) this view is incorrect. In conclusion, there is so far no evidence for a ranging of the Tarbur Formation into the Paleocene.

Summarizing, a Campanian age for the basal parts of the Tarbur Formation is in our opinion biostratigraphically unprooven, whereas the Maastrichtian stage is well documented (e.g., the *Omphalocyclus–Loftusia* assemblage zone of Wynd, 1965). For the upper boundary of the Tarbur Formation, differing views exist that necessitate further biostratigraphic investigations for final conclusions (hypotheses 1 to 3).

Biostratigraphy of the Mandegan section

The vertical distribution of selected taxa of larger benthic foraminifera is shown in Figure 2. With the first occurrence of *Siderolites calcitrapoides* Lamarck in the lower samples, a Campanian age can be excluded on the one side. On the other side, as *S. calcitrapoides* has its first appearance in the latest early Maastrichtian (according to Robles Salcedo, 2014), it is most likely that the Gurpi Formation ranges into the Maastrichtian at the Mandegan section. The vertical distribution of the *Omphalocyclus* and *Loftusia* clearly displays the poor resolution when applying the two-fold biozonation of the Tarbur Formation provided by Wynd (1965). The *Omphalocyclus-Loftusia* biozone (or assemblage zone) should be indicative for the Maastrichtian, but in the Mandegan section *Omphalocyclus* has its first appearance distinctly earlier than *Loftusia*. Only in a certain interval (the upper part of the Tarbur Formation), both taxa co-occur. In the Mandegan section, both have the first appearance in the upper part of unit 1. The lower part of unit 1, following the Gurpi Formation, we first observed an assemblage of *Orbitoides media* and *Siderolites*, followed by an interval where *Siderolites* co-occurs with *Omphalocyclus*. It is worth mentioning that *Gyroconulina columellifera* has an almost identical vertical distribution as *Loftusia*. With *Gyroconulina*, *Neobalkhania*, *Omphalocyclus*, and *Loftusia* reaching the top of the Mandegan section, a ranging into the Paleocene can be excluded in this case. In conclusion, at the Mandegan section the Tarbur Formation is exclusively of Maastrichtian age.

Remarks on palaeobiogeography

The analyses of distributional patterns of Late Cretaceous larger benthic foraminifera have revealed different patterns, i.e. faunal provinces (Fleury *et al.*, 1985, 1990; Hottinger *et al.*, 1989; Goldbeck & Langer, 2009). The restricted occurrence of the Maastrichtian *Loftusia* was already stressed in several contributions (Fleury *et al.*, 1990; Meriç *et al.*, 2001). Goldbeck and Langer (2009) placed *Loftusia* among the taxa displaying a superregional distributional pattern. Together with

several other taxa, *Loftusia* was assigned a key taxon of the so-called African Faunal Province. With respect to *Loftusia*, this name is somehow misleading as there is just one African report from the Maastrichtian of Somalia (see Goldbeck and Langer, 2009, Fig. 3). *Gyroconulina columellifera* as well displays a restricted distributional pattern with the three known occurrences in Iraq (Aqra Formation, type-locality), Iran (Tarbur Formation), and the Western Taurides of Turkey. From all these localities, *Gyroconulina* is reported together with *Loftusia*, *Siderolites* and *Omphalocyclus*. Another potential benthic foraminifer of this assemblage is *Dictyoconella complanata* described by Henson (1948) from the Maastrichtian of the Qatar Peninsule. This species is also known from the Maastrichtian of the Taurides S-Turkey (Farinacci and Köylüoglu, 1985), the Aqra Formation of Iraq (Al-Rawi and Al-Hamadani, 1985), and the Tarbur Formation (Afghah and Farhoudi, 2012). The paleobiogeographic distribution of *Neobalkhania bignoti* was stressed by Cherchi *et al*. (1991, p. 288) as corresponding largely to the "province à *Rhapydionina liburnica*" of the Adriatic-Egean

platform (e.g., Fleury *et al*., 1985). The new finding in the Iranian Tarbur Formation still witnesses its restriction to the southern Neotethyan margin, but distinctly enlarges its distribution eastwards towards the Central Tethyan domain. Noteworthy, *Rhapydionina liburnica* has so far not been recorded from Iran.

Among the dasycladalean green algae, the occurrence of *Pseudocymopolia anadyomenea* (Elliott, 1959) (Fig. 9A-B) and *Ovulites delicatula* Elliott, 1959 (Fig. 9C-D), both originally described from the Maastrichtian Tanjero Formation of Iraq, in the Tarbur Formation is worth mentioning. *P. anadyomenea* was also reported by Elliott (1968, Pl. 8, Fig. 5) from the Maastrichtian of the Aqra Formation, Iraq. Plotted on a palaeomap, these occurrences refer to the northern margin of the Arabian plate and the Taurides of Turkey (Anatolian plate) as part of the larger *Loftusia* bioprovince (Fig. 10). An equivalent Afro-Arabian endemic character has already been evidenced for the associated rudist fauna (Khazaei, *et al*., 2010; Özer *et al*., 2013).
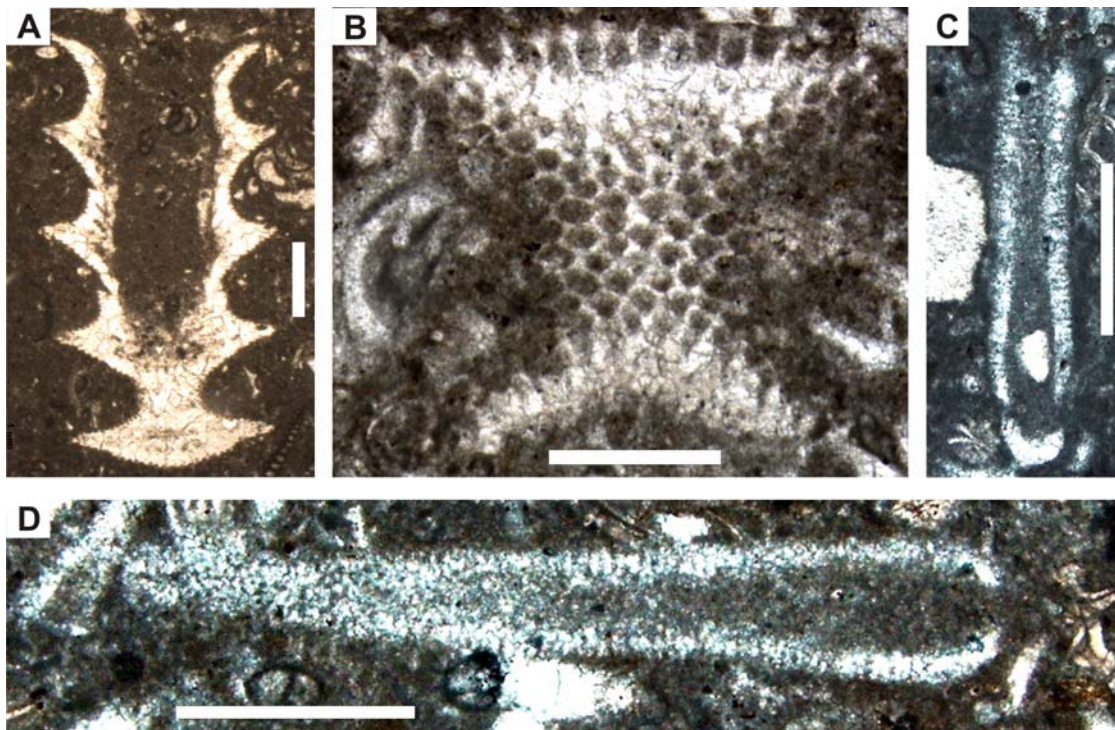

Figure 9. Dasycladales from the Maastrichtian of the Tarbur Formation. A: *Pseudocymopolia anadyomenea* (Elliott), longitudinal section of cutting 5 segments, Fasa section, thin-section BT 8. B: *Pseudocymopolia anadyomenea* (Elliott), tangential section of cutting two segments showing primary laterals, Mandegan section, thin-section Rt 79. C: *Ovulites delicatula* Elliott, longitudinal section, thin-section T 18, Fasa section. D: *Ovulites delicatula* Elliott, tangential (left side) to longitudinal oblique section (right side), thin-section T 25a. Scale bars: A = 1.0 mm, B-D: 0.5 mm.
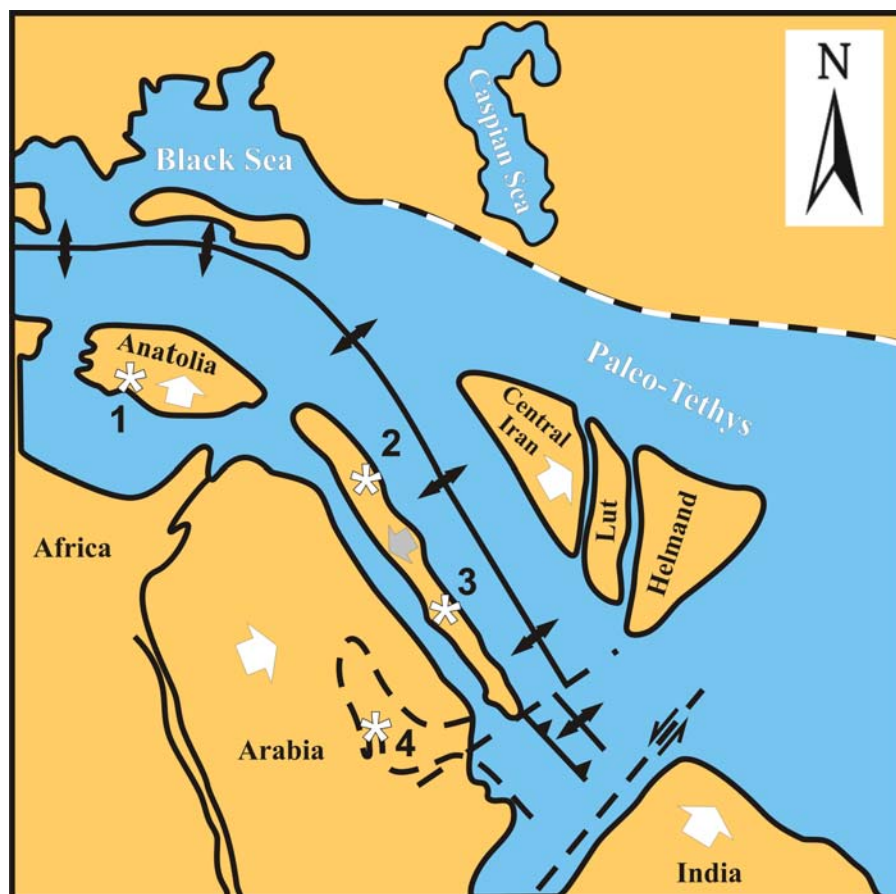
Figure 10. Paleogeographic situation of the eastern section of the Arabian plate during the Late Cretaceous (here: Campanian) (redrawn after Glennie, 1982). 1* Western Pontides, Turkey, 2*: Tanjero and Aqra formations of Iraq: type localities of dasycladale *Pseudocymopolia anadyomenea* (Elliott, 1959), and the benthic foraminifera *Gyroconulina columellifera* Schroeder & Darmoian, 1976. 3*: Tarbur Formation of Iran. 4*: Dukhan Wells, Qatar Peninsula (Henson, 1948). Benthic Foraminifera: *Gyroconulina columellifera* 1, 2, 3; *Dictyoconella complanata* 1, 2, 3, 4. Dasycladales: *Pseudocymopolia anadyomenea* and *Ovulites delicatula* 2, 3. References are given in the text.

Conclusions

The benthic foraminifera *Gyroconulina columellifera* Schroeder & Darmoian, and *Neobalkhania bignoti* Cherchi, Radoičić & Schroeder, are reported for the first time from the Late Maastrichtian of the Tarbur Formation. They have been observed in shallow-water carbonates (wackestones, packstones) (pro parte *Loftusia-Omphalocyclus* biozone of Wynd, 1965). The two-fold biozonation of the Tarbur Formation of Wynd (1965) with an upper *Loftusia-Omphalocyclus* biozone of Maastrichtian age does not take into account the distinctly varying first occurrences of both taxa in some sections.

A critical review of the literature reveals that the stratigraphy of both the basal and top parts of the Tarbur Formation are not well constrained by larger benthic foraminifera. A Campanian age for basal parts of some sections cannot be excluded but is not directly proven. The same holds true for the top of the Tarbur Formation, for which differing stratigraphic views exist. Further investigations hereto are needed. A more differentiated biozonation of the Maastrichtian of the Tarbur Formation should be possible in the future integrating both the occurrence of larger benthic foraminifera and dasycladalean algae.

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