***Carnets Geol.* 25 (4)**

E-ISSN 1634-0744
DOI: 10.2110/carnets.2025.2504

Calcareous green algae (Dasycladales, Halimedaceae) from the Upper Cretaceous of the western Tarim Basin, NW China: Systematic palaeontology, microfacies, and palaeobiogeographic significance

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Abstract: Few stratigraphical and micropalaeontological data are available from Upper Cretaceous shallow-water marine carbonates of the southwestern Tarim Basin, western China. The present study provides new data about the microfauna and calcareous algae of the Cenomanian-Turonian Kukebai Formation and the Campanian Yigeziya Formation. The investigated bioclastic carbonates yield a rather poorly diversified microfauna (benthic foraminifers) contrasting with a relatively well diversified assemblage of dasycladalean green algae comprising 16 taxa. For several taxa, the available material does only allow for an open taxonomic treatment. A new species is described herein as *Morelletpora sinica*. These calcareous algae are supplemented by debris of halimedacean algae (*Arabicodium*? sp.). Occurrences of calcareous algae and larger benthic foraminifers in Cenomanian and Campanian carbonates coincide with two major transgressions reported from the Tarim Basin. The observed faunal and phycological elements indicate a direct connection between the Neotethys and the Tarim epicontinental sea. The lack of several typical Cenomanian (*e.g.*, alveolinoids, orbitolinids) and Campanian larger benthic foraminifers in the studied material is striking.

Keywords:

- green algae;
- Late Cretaceous;
- taxonomy;
- biostratigraphy;
- palaeobiogeography

Citation: SCHLAGINTWEIT F., XU Y. & ZHANG S. (2025).- Calcareous green algae (Dasycladales, Halimedaceae) from the Upper Cretaceous of the western Tarim Basin, NW China: Systematic palaeontology, microfacies, and palaeobiogeographic significance.- *Carnets Geol.*, Madrid, vol. 25, no. 4, p. 89-108. DOI: 10.2110/carnets.2025.2504

Résumé : *Algues vertes calcaires (Dasycladales, Halimedaceae) du Crétacé supérieur de l'ouest du bassin du Tarim, nord-ouest de la Chine : Paléontologie systématique, microfaciès et signification paléobiogéographique.-* Peu de données stratigraphiques et micropaléontologiques sont disponibles concernant les carbonates marins peu profonds du Crétacé supérieur du sud-ouest du bassin du Tarim, dans l'ouest de la Chine. Cette étude présente de nouvelles données sur la microfaune et les algues calcaires des formations de Kukebai (Cénomanien-Turonien) et de Yigeziya (Campanien). Les carbonates bioclastiques étudiés montrent une microfaune peu diversifiée (foraminifères benthiques), contrastant avec une association relativement diversifiée d'algues vertes dasycladales comprenant 16 taxons, parmi lesquels une nouvelle espèce, *Morelletpora sinica*, est décrite. Cependant, en raison du matériel disponible, certains taxons sont laissés en nomenclature ouverte. Cette association d'algues calcaires est complétée par des débris d'algues halimédacées (*Arabicodium*? sp.).

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Published online in final form (pdf) on February 3, 2025
[Editor: George E. PLEŞ; technical editor: Bruno R.C. GRANIER]

Il est à noter que la présence d'algues calcaires et de grands foraminifères benthiques dans les carbonates cénomaniens et campaniens coïncide avec deux grandes transgressions signalées dans le bassin du Tarim. Les éléments microfauniques et phycologiques observés indiquent une connexion directe entre la Néotéthys et la mer épicontinentale du Tarim. L'absence de plusieurs grands foraminifères benthiques typiques du Cénomanien (par exemple, les alvéolinidés et les orbitolinidés) et du Campanien dans le matériel étudié est remarquable.

Mots-clefs :

- algues vertes ;
- Crétacé supérieur ;
- taxinomie ;
- biostratigraphie ;
- paléobiogeographie

1. Introduction

The Tarim Basin in western China represents the eastern end (or gulf) of an epicontinental sea extending from the Mediterranean Neotethys across the eastern Eurasian continent during Late Cretaceous and Palaeogene times (*e.g.*, Hao & Zeng, 1984) (Fig. 1.1). It is also referred to as Proto-Paratethys in Paleogene times (see Kaya, 2020, for details). Being the largest sedimentary basin in China (about 530.000 km^2), it represents an important area for the study of Upper Cretaceous marine strata in China (*e.g.*, Yang *et al.*, 1983; Xi *et al.*, 2016, 2019: Fig. 2; Zhang *et al.*, 2018). Most biostratigraphic data such as dinoflagellate cysts have been obtained from the marly lithologies (*e.g.*, Zhang *et al.*, 2022). Data about micropalaeontogical assemblages from thin-sections of the Upper Cretaceous marine carbonates of the southwestern Tarim Basin are rare. In his paper about 'Late Cretaceous palaeobiogeography of calcareous algae', Mu (1993: Table 1) reported several genera of calcareous algae (including Dasycladales) from the Tarim Basin referring to unpublished data that, according to our knowledge, still remain unpublished. Recently, larger benthic foraminifers were described by Sun and Schlagintweit (2024) from the Campanian Yigeziya Formation. Our paper provides the first description and illustration of calcareous green algae (mainly Dasycladales) from the Kukebai and Yigeziya formations. New data about the micropalaeontological inventory including also some benthic foraminifers, the palaeoenvironment, and the biostratigraphy as well as the palaeobiogeographical relevance of the foram-algal assemblages are presented.

2. Geological setting

The study area is located in the western Tarim Basin (Xinjiang Uygur Autonomous Region, China), bounded by the Tianshan range to the north, the Pamir to the west-southwest, and the West Kunlun range to the south (Fig. 1). Due to the heterogeneity of inherited paleogeomorphology, the Upper Cretaceous strata in the western Kunlun-Pamir piedmont and the Tianshan piedmont are different. The Upper Cretaceous strata in the western Kunlun-Pamir piedmont are better developed, also yielding abundant and diversified marine fossils. The marine-transitional Upper Cretaceous sequences, defined as the Yingjisha Group, are composed of the Kukebai, Wuyitake, Yigeziya, and Tuyiluoke formations from bottom to top (Yang *et al.*, 1983; Tang *et al.*, 1989, 1992; Hao *et al.*, 2001; Xi *et al.*, 2019). Lithostratigraphically, the Kukebai Formation (Cenomanian-Turonian) is dominated by gray-green argillites, muddy siltstone and bioclastic limestones, interbedded with gypsum and dolostones (~240 m). The Wuyitake Formation (Coniacian-Santonian) consists of orange-red argillites, gypsiferous argillites, and siltstones (~50 m). The Yigeziya Formation (Campanian-?early Maastrichtian) is dominated by white and purple-red bioclastic limestones (~110 m). The Tuyiluoke Formation ((late) Maastrichtian-Danian) in turn consists of orange-red argillites and gypsiferous argillites (~20 m). These formations are attributed to at least two transgressive (Kukebai and Yigeziya formations) - regressive (Wuyitak and Tuyiluok formations) cycles (Guo *et al.*, 2015; Zhang *et al.,* 2018). The algal assemblages described here from three sections are from carbonate rocks belonging to the two transgressive cycles of the Kukebai and Yigeziya formations.

The Kukebai Fm. was established by the No. 107 Geological Team under the Xinjiang Petroleum Administration in 1976. The type section is located about 20 km west of Ulugqat in the Wuqia County of Xinjiang. It is subdivided either into lower and upper members with the first one attaining greater thickness (Yang *et al.*, 1983) or a tripartite: lower, middle, upper units (*e.g.*, Guo *et al.*, 2015; Xi *et al.*, 2016). Lithologically, the Kukebai Formation represents a series of mixed siliciclastic-carbonatic sediments. Macrofossils from the lower Kukebai Formation include mainly gastropods (Pan, 1990) and rudists (Scott *et al.*, 2010), while the microfossils consist of benthic foraminifers (Hao *et al.*, 2001) and nannoplankton, as well as dinoflagellates from marly lithologies indicating a Cenomanian-Turonian age (Yang *et al.,* 1983; He, 1991; Zhong, 1992; Zhang *et al.*, 2022). Recent isotope analyses also confirmed the presence of the Cenomanian-Turonian boundary in the Kukebai Formation (Zhang *et al.*, 2025).

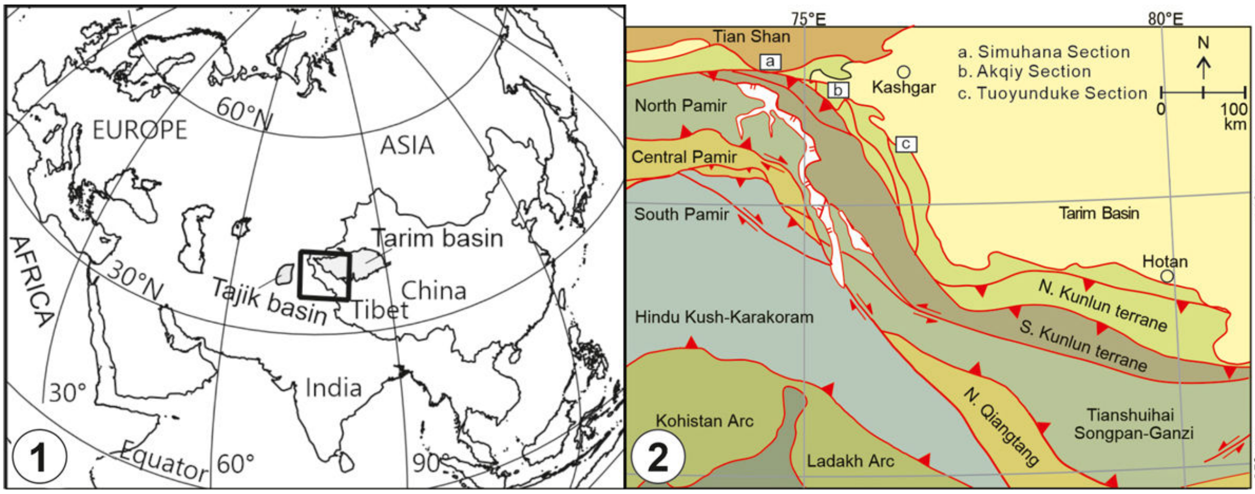

Figure 1: (1) Location of the Tarim Basin and (2) simplified tectonic map of the Pamir collision zone showing locations of the three studied sections (modified from Cowgill, 2010, and Zhang *et al.*, 2018: Fig. 1).

The Yigeziya Formation was established and defined by the No. 107 team of the department of geological survey under the Xinjiang Petroleum Administration in the year 1976. The type section is located near Yi Geziya about 20 km south of Yingisar county, Xinjiang. It consists mainly of massive neritic carbonates (*e.g.*, Zhang *et al.*, 2022). Macrofossils of the Yigeziya Formation are represented by rudists (X. Rao, 2019; Lan & Wei, 1995; X. Rao *et al.*, 2023), brachiopods, echinoids, and gastropods (Pan, 1990). Among microfossils, dinoflagellates and acritarchs have repeatedly been described (Shaozhi & Norris, 1988; He, 1991; Zhong, 1992; Zhang *et al.*, 2022). Calcareous algae were reported in open nomenclature and without illustration by Mu (1993), but also small benthic foraminifers obtained from washed samples (Hao *et al.*, 2001). The age of the Yigeziya Formation is generally assigned to the Campanian-early Maastrichtian (*e.g.*, Xi *et al.*, 2019: Fig. 7). Recently, the early Maastrichtian age was reinstated referring to the occurrence of the said 'lower Maastrichtian index taxon' *Biradiolites boldjuanensis* in the upper part of the formation (X. Rao *et al.*, 2023; Gao *et al.*, 2024). In our opinion, the early Maastrichtian age of the upper part of the Yigeziya Formation - though deducible by this rudist species - needs to be reconfirmed by other biogenic groups such as larger benthic foraminifers.

The foraminiferal-algal assemblages described here are from three outcrops: Simuhana, Akqiy and Tuoyundoke sections (Fig. 1.2). The systematic part refers essentially to the algae. In the following, some basic information on each locality is given, comprising the logs (Figs. 2-3), the microfacies of the algal-bearing samples (Fig. 4), and some of associated benthic foraminifers (Fig. 5).

2.1 Kukebai Formation of the Simuhana section

The studied locality is close to the Simuhana 1 section studied by Xi *et al.* (2016) named after the nearby Simuhana village. The GPS coordinates of the section are 39°43'29.335"N, 73°59' 34.799"E. The herein investigated carbonates correspond to "bed six" and "bed eight" in the subdivision of the section by Xi *et al.* (2016: Fig. 6) separated by an intercalation of calcareous shales with abundant ostracods ("bed seven"). These bioclastic limestones with ooids were illustrated by Xi *et al.* (2016: Fig. 5B) but no microfossils were indicated (Fig. 4.1-4.3). Besides dasycladalean algae, these carbonates also yielded a poorly diversified assemblage of benthic foraminifers with *Charentia cuvillieri* Neumann, *Cuneolina compressa* Schlagintweit, *Comaliamma* sp., miliolids, and some not further specified planispirally coiled taxa (Figs. 2, 5.1-5.14).

2.2 Kukebai Formation of the Akqiy section

The Akqiy section is located about 100 km west of Kashgar City (39°20'20.98"N, 74°56' 31.42"E) and has been studied by Zhang *et al.* (2018: Fig. 8 left column) (Fig. 3.1). The name refers to the Akqiy Village, Piaoertuokuoyi Town, Wuqia County, in the Xinjiang Uygur Autonomous Region. It is located in the hanging wall of the Main Pamir Thrust. The algal-bearing sample (AK28) represents a bioclastic oolitic packstone with common to abundant ooids, bryozoans, gastropods and dasycladales (*Acicularia macropora* Kuss, one specimen of *Morelletpora sinica* sp. nov.) (Figs. 2, 4.4). This microfacies compares to the type strata of *M. sinica* sp. nov. from the Yigeziya Formation (Fig. 4.5). The sample is from the upper part of the Kukebai Formation and might be of Turonian age although direct evidence is missing (see Zhang *et al.*, 2018: Fig. 8 left column).

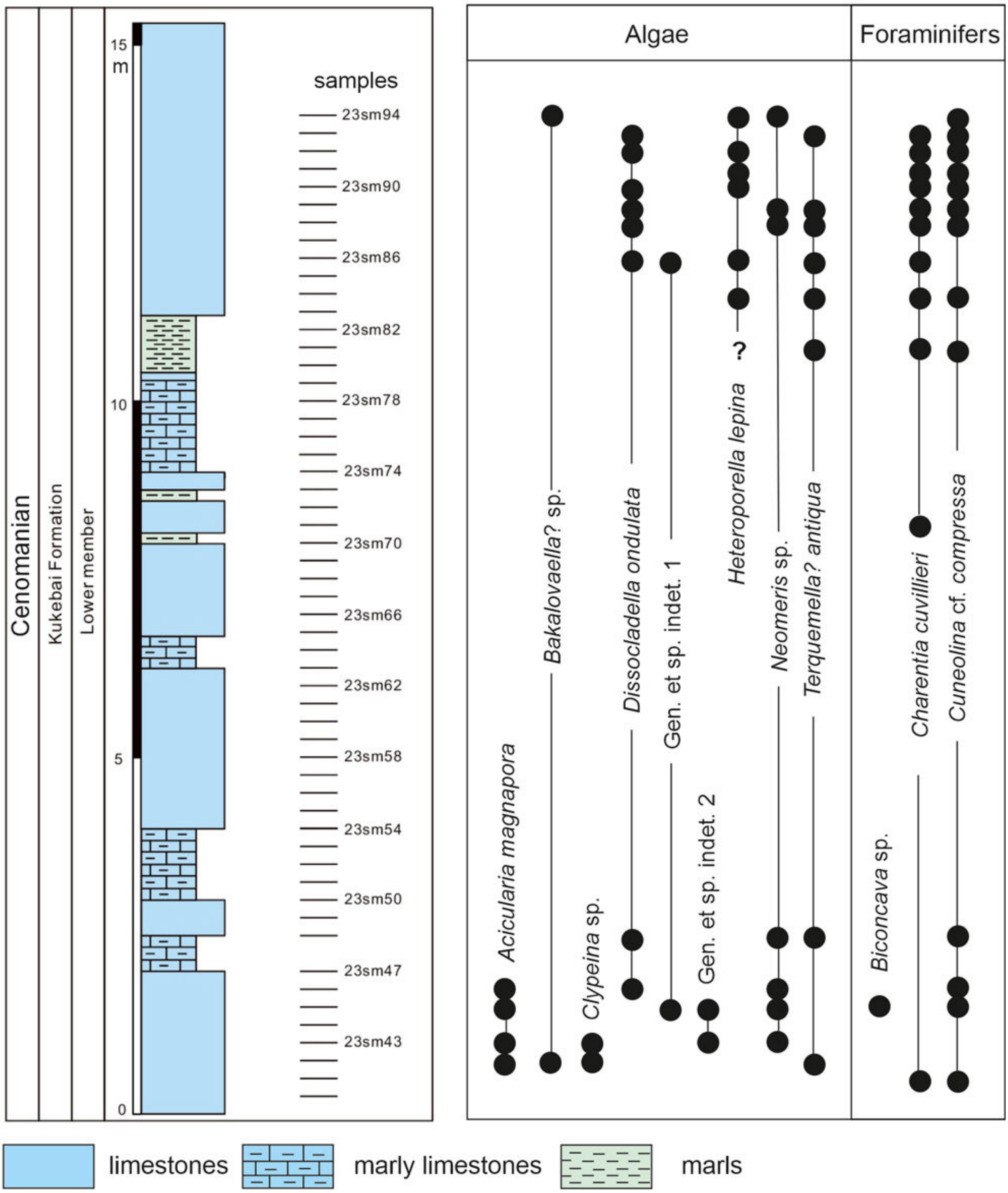

Figure 2: Log of the lower Kukebai Formation of the Simuhana section showing vertical distribution of calcareous algae and some benthic foraminifers.

2.3 Yigeziya Formation of the Tuoyunduke section

The Tuoyunduke section is located about 100 kilometers south of Kashgar City (coordinates: 38°32'00.78"N, 76°16'00.22"E), and has been examined by ZHANG *et al.* (2018: Fig. 9, left column) (Fig. 3.2). The section name refers to the nearby Toyunduk Village and refers to the Tuyiluoke Formation which overlies the Yigeziya Formation. The Yigeziya Formation in this section is ~87 meters thick and is characterized by purple-red and grayish bioclastic wackestones/packstones and bioclastic grainstones. The bioclasts include bivalves, rudists, benthic foraminifers, crinoids, bryozoans, debris of coralline algae and gastropods. Laminoid fenestrae and biolaminae are prevalent. The depositional environments primarily comprising tidal flats, shoal to mid-ramp deposits. The algal-bearing samples (TY31, TY32, TY37) comprise high-energy open-marine bioclastic packstones with scattered ooids, common to abundant

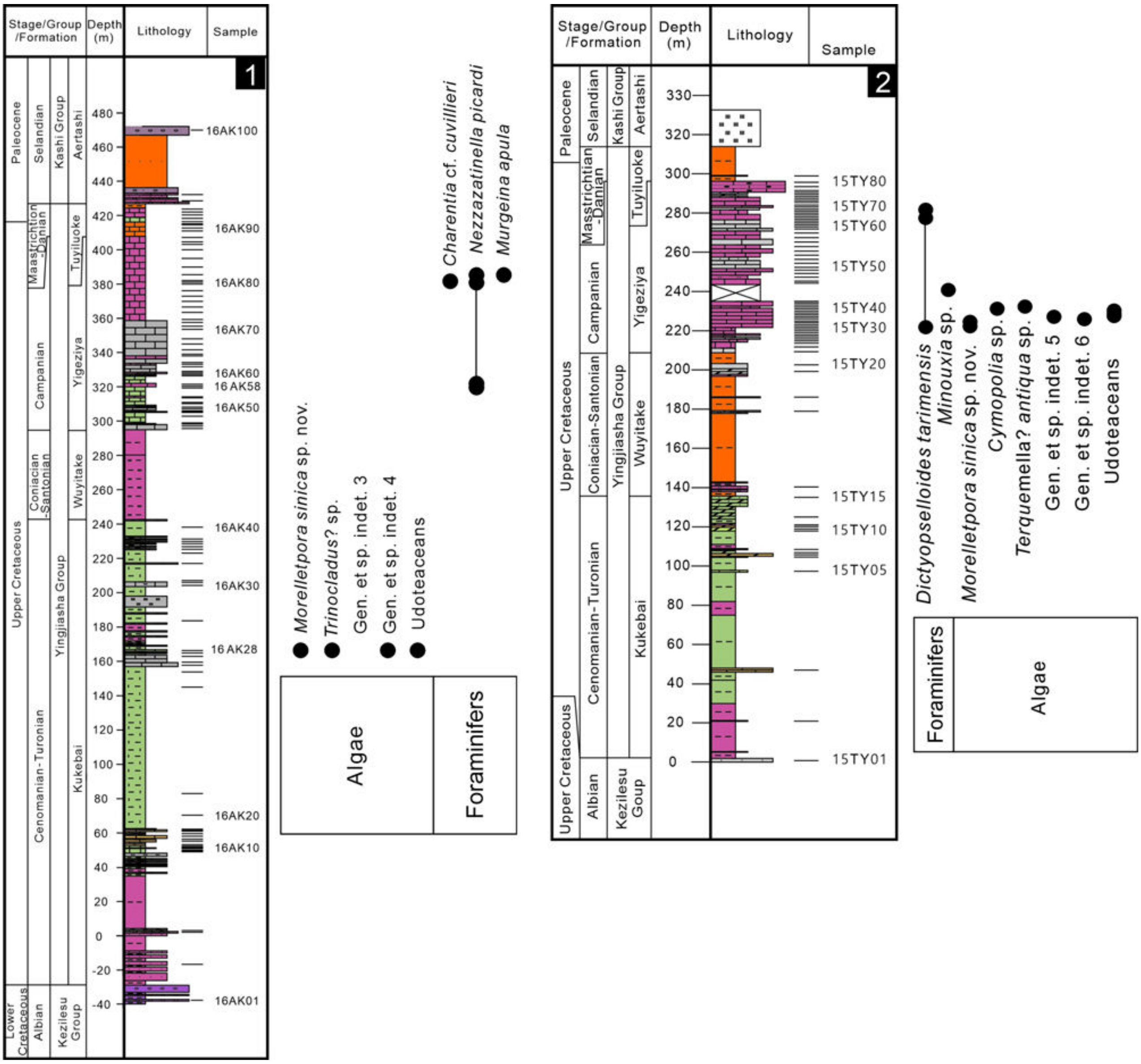

Figure 3: Logs of the Akqiy (1) and Tuoyundoke sections (2) showing vertical distribution of calcareous algae and some benthic foraminifers (modified from Zhang *et al.*, 2018: Figs. 8 left side, 9 left side).

bryozoans, pelecypod debris (rudists?), rare gastropods, some benthic foraminifers (*e.g.*, miliolids, *Minouxia* sp., *Dictyopselloides*? *tarimensis* Sun & Schlagintweit, Orbitolinidae indet. of Sun & Schlagintweit, 2024: Fig. 7a), and dasycladalean algae (*Morelletpora sinica* sp. nov.) (Figs. 4.5, 5.16, 5.19). Another variety of this microfacies type (sample TY36) almost completely lacks the dasycladales element, instead exhibiting common debris of halimedacean algae (*Boueina*? sp., *Arabicodium*? sp.) (Fig. 4.6). It is worth mentioning that the Yigeziya Formation of the Akqiy Formation (see §2.2) also yields inner ramp (tidal flat?) facies with abundant miliolids and *Nezzazatinella picardi* (Henson) but lacks calcareous green algae (Figs. 5.17-5.18). The occurrence of *Murgeina apula* (Luperto Sinni) (Fig. 5.18) is worth mentioning since it represents the first record from the Upper Cretaceous carbonates of the Tarim Basin and at the same time the most eastern occurrence within the Neotethys realm (Schlagintweit *et al.*, 2023; Simmons & Bidgood, 2023: Fig. 57). *M. apula* is indicative of a relatively wide age-range comprising the late early Cenomanian to early Maastrichtian and thus of no real biostratigraphic importance. Like several other taxa of (larger) benthic foraminifers, *M. apula* is also present in Campanian strata of the Tielongtan Group of the Western Kunlun Mountains (Sha *et al.*, 2020; Sun & Schlagintweit, 2024).

3. Material and methods

The described calcareous algae are recorded in 13 thin-sections; 9 from the Kukebai Formation and 4 from the Yigeziya Formation (Table 1). The sample number prefixes are 16AK (Akgiy section), 23sm (Simuhana section) and 15TY (Tuoyunduke section). They are stored at the State Key Laboratory of Mineral Deposits Research, School of Earth Sciences and Engineering, Nanjing University, Nanjing 210023, China.

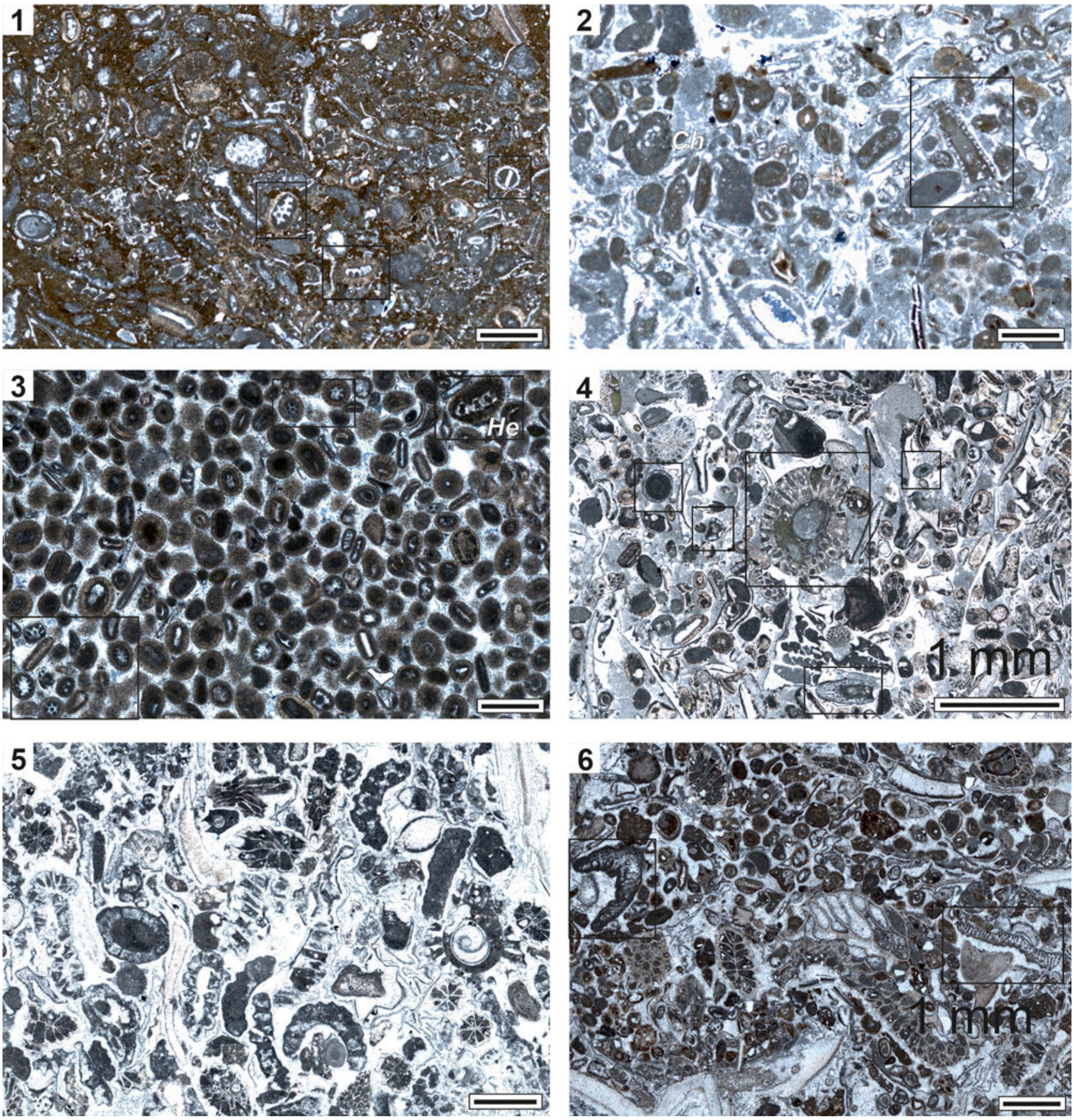

Figure 4: Microfacies of the algal-bearing samples (examples) from the Upper Cretaceous Kukebai (1-4) and Yigeziya formations (5-6) of the southwestern Tarim Basin, China. (1) Packstone with common debris of dasycladaleans showing oolitic envelopes (rectangles); Cenomanian of Simuhana section, sample sm43. (2) Packstone with rare debris of dasycladaleans (rectangle), ooids and a few benthic foraminifers such as *Charentia cuvillieri* NEUMANN (*Ch*); Cenomanian of Simuhana section, sample sm86. (3) Oolitic grain-packstone with dasycladales (*Terquemella antiqua* (PIA), *Heteroporella lepina* PRATURLON (*He*) as core of ooids (black rectangles); Cenomanian of Simuhana section, sample sm84. (4) Bioclastic packstone with ooids, bryozoans, pelecypod shells, and rare dasycladaleans (*e.g.*, *Morelletpora sinica* sp. nov. in the center) and halimedaceans (rectangles); Turonian? of Akqiy section, sample AK28. (5) Bioclastic grain-packstone with bryozoans, pelecypod shells and various sections of *Morelletpora sinica* sp. nov.; Campanian Yigeziya Formation of Tuoyunduke section, sample TY31. (6) Bioclastic packstone with ooids, bryozoans and debris of halimedaceans (rectangles); Campanian of Tuoyunduke section, sample TY37. Scale bars 1.0 mm.

Table 1: Studied samples and localities studied.

Localities	Simuhana section	Akqiy section	Tuoyunduke section
Reference	Xi *et al.*, 2016	Zhang *et al.*, 2018	Zhang *et al.*, 2018
Samples (thin-sections)	sm43	AK28	TY31
	sm45		TY32
	sm46		TY36
	sm84		TY37
	sm86		
	sm89		
	sm90		
	sm94		
Total number	8	1	4

4. Systematic palaeontology

The described taxa of calcareous algae include green algae of the orders Dasycladales Pascher, 1931, and Bryopsidales Schaffner, 1922 (Figs. 6-9). Some taxa are treated in open nomenclature (genus level) and also as gen. and sp. indet. in the cases where the available sections do not allow a final conclusion about the taxonomic status. The suprageneric classification of the Dasycladales is adopted from Granier & Bucur in Granier *et al.* (2013a). For the biometric data, the standard abbreviations of Bassoullet *et al.* (1975) have been used: The abbreviations used are as follows: D = outer thallus diameter, d = inner thallus diameter, h = vertical spacing of the verticils, l = length primary laterals, l' = length secondary laterals, l" = length tertiary laterals, p = diameter primary laterals, p' = diameter secondary laterals, p" = diameter tertiary laterals, w = number of laterals per verticil. The occurrences of the individual taxa described from the three localities are compiled in Table 2.

Table 2: Inventory of dasycladalean taxa in the Kukebai and Yigeziya formations of the southwestern Tarim Basin, China.

taxa	Kukebai Fm. Cenomanian	Kukebai Fm. ?Turonian	Yigeziya Fm. Campanian
Neomeris sp.	X		
Cymopolia sp.			X
Dissocladella ondulata	X		
Trinocladus? sp.			X
Morelletpora sinica sp. nov.		X	X
Heteroporella lepina	X		
Bakalovaella? sp.	X		
Acicularia magnapora	X		
Terquemella? *antiqua*	X		X
Clypeina sp.	X		
Gen. and sp. indet. 1	X		
Gen. and sp. indet. 2	X		
Gen. and sp. indet. 3			X
Gen. and sp. indet. 4			X
Gen. and sp. indet. 5			X
Gen. and sp. indet. 6			X
Number	9	1	8

Order Dasycladales Pascher, 1931
Family Dasycladaceae (Kützing, 1843)
Tribe Dasycladeae (Pia, 1920)
Genus *Bakalovaella* Bucur, 1993

Type species: *Cylindroporella elitzae* Bakalova, 1971

Bakalovaella? sp.

(Fig. 7.12 pars)

Remarks: Two oblique sections are here tentatively assigned to *Bakalovaella* Bucur, 1993, that has recently been revised by Granier and Bucur (2019). The generic reservation results from the verified occurrence of sterile laterals, otherwise the sections could then belong to the genus *Holosporella* Pia, 1930.

Measurements: D: 0.35-0.64 mm; d: 0.07 mm; h: 0.09 mm; Diameter fertile ampullae: 0.07 mm / 0.11 mm.

Occurrence: Very rare in the Kukebai Formation of the Simuhana section.

Genus *Neomeris* Lamouroux, 1816

Type species: *Neomeris dumetosa* Lamouroux, 1816

Neomeris sp.

(Fig. 6.1-6.3, 6.5, ?6.6)

Remarks: The total diameter (D) of the thalli varies between 0.80 mm and 1.10 mm while the inner diameter (d) ranges from 0.49 mm to 0.6 mm. The latter value however only comprises the preserved calcified part not referable to the main axis that is only seldom preserved in *Neomeris* (*e.g.*, Granier *et al.*, 2013a). Here, one possible specimen of *Neomeris* shows the preserved main axis and inner portion of the laterals (D: 0.98 mm; d: 0.44 mm leading to a d/D ratio of 0.45) (Fig. 6.6). The subspherical fertile ampullae range from 0.11 mm to 0.13 mm in diameter. We refrain from any specific assignments noting the difficulty of addressing all features of thin-section material especially from lower-mid Cretaceous Neomerideae in general and also due to the relatively poor material available from the Kukebai Formation.

Occurrence: Common in the Cenomanian Kukebai Formation of the Simuhana section.

Genus *Cymopolia* Lamouroux, 1816

(Fig. 9.8, ?9.9 pars)

Remarks: One tangential section of ovoid outline is considered here as belonging to *Cymopolia* Lamouroux (Fig. 9.8). The diameter of the fertile ampullae is approximately 0.10 mm in average. Another possible fragment consists of two fertile ampullae (Fig. 9.9). The microfacies refers to high-energy deposits as shown in Figure 4.5 .

Occurrence: Rare in the Campanian Yigeziya Formation of the Tuoyundoke section.

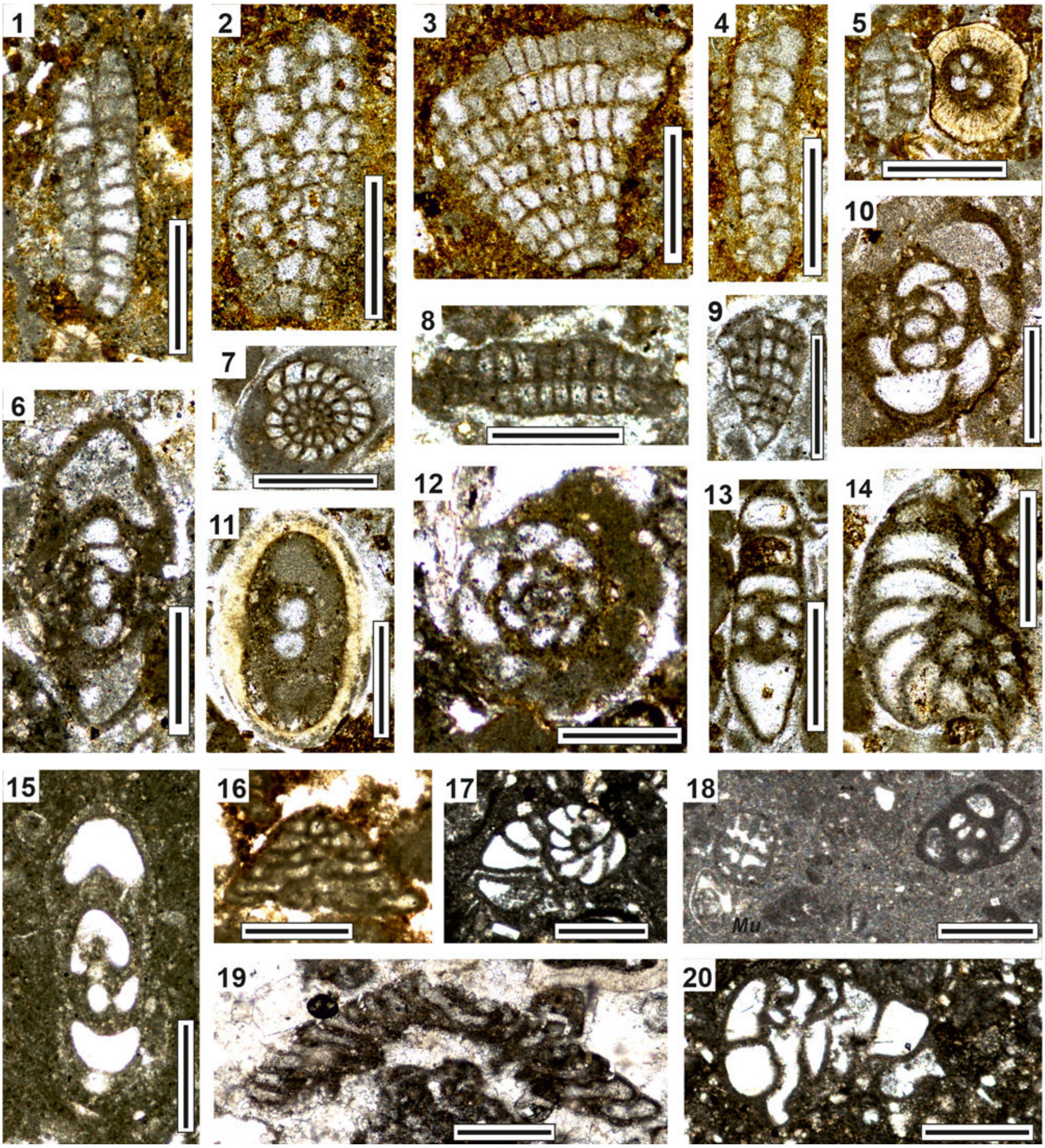

Figure 5: Benthic foraminifers from the Cenomanian Kukebai Formation of the Simuhana section, (1-14), Cenomanian-pro parte Turonian? Kukebai Formation of the Akqiy section (15, 17-18, 20) and the Campanian Yigeziya Formation of the Tuoyunduke section (16, 19), SW Tarim Basin, China. (1-5, 8-9) *Cuneolina compressa* SCHLAGINTWEIT; transverse sections (1, 5, 8), oblique longitudinal section (2), longitudinal section parallel to plane of biseriality (3), longitudinal section perpendicular to plane of biseriality (4). (6, 10-12, 15) *Charentia cuvillieri* NEUMANN; axial section (6), oblique section (10), subaxial sections (11: juvenile specimen showing oolitic envelope; 15), equatorial section (12). (7) Unknown planispirally coiled taxon in equatorial section (*Biconcava*? sp.). (13-14) *Comaliamma* sp.; subaxial section (13), oblique section (14). (16, 19) *Dictyopselloides*? *tarimensis* SUN & SCHLAGINTWEIT; subaxial sections; possible microspheric specimen in 19. (17, 20) *Nezzazatinella picardi* (HENSON); oblique sections. (18) *Quinqueloculina* sp. (right) and *Murgeina apula* (LUPERTO SINNI) (*Mu*). Scale bars = 0.30 mm. Samples: sm41 (1-5), sm88 (6), sm45 (7, 9), sm91 (8, 12), sm84 (10), sm42 (11, 13-14), AK80 (15), TY65 (16), AK58 (17-18, 20), TY31 (19).

Family Triploporellaceae (PIA, 1920)

Tribe Dissocladelleae ELLIOTT, 1977

Genus *Dissocladella* PIA, 1936

Type species: *Dissocladella savitriae* L.R. RAO & PIA, 1936

Dissocladella ondulata (RAINERI, 1922) PIA, 1936

(Fig. 7.9-7.11, 7.12 pars, 7.13-7.14)

1922 *Neomeris cretacea* var. *ondulata* var. nov. – RAINERI, p. 75, Pl. 3, figs. 5-11.
1936 *Dissocladella undulata* (RAINERI) - PIA, p. 18, Figs. 12-16.
2005 *Dissocladella bonardii* n.sp. - RADOIČIĆ *et al.*, p. 313, Pl. 1, figs. 4-17 (with synonymy).
2017 *Dissocladella ondulata* - GRANIER *et al.*, Fig. 1B-F.
2024 *Dissocladella ondulata* (RAINERI) - SCHLAGINTWEIT *et al.*, p. 494, Fig. 4A-F.

Remarks: Thalli of *D. ondulata* represent a common element in oolitic packstones (partly grainstones) associated with rare *Bakalovaella*? sp. and *Neomeris* sp., as well as some bryozoans. Benthic foraminifers are represented by a few specimens of *Charentia cuvillieri* and *Cuneolina compressa*. For discussion about taxonomic problems associated with the Libyan type material of *Dissocladella ondulata* see RADOIČIĆ *et al.* (2005) and GRANIER *et al.* (2017). *D. ondulata* is known from Cenomanian to Santonian strata (BARATTOLO, 2002).

Measurements: D: 0.34-0.45 mm; D: 0.15-0.26 mm; d/D: 0.40-0.65; p: 0.04-0.05 mm; p': 0.03-0.04 mm; w: 8 (1 value); h: 0.07 mm (1 value); Lmax: ~2.0 mm.

Occurrences: Common in the Kukebai Formation of the Simuhana section.

Tribe Triploporelleae PIA, 1920

Genus *Trinocladus* RAINERI, 1922

Trinocladus sp.

(Fig. 9.4)

Remarks: One transverse section (D = 0.70 mm, d = 0.25 mm, d/D = 0.36, w = ?7) with presumably three orders of laterals. The inner part of the skeleton shows micritization thereby masking the primary laterals. *Trinocladus* sp. occurs in high-energy oolitic shoal facies associated with gen. and sp. indet. 3, 4, and *Morelletpora sinica* sp. nov. and bryozoans.

Occurrence: Very rare in the Turonian? Kukebai Formation of the Akqiy section.

Tribe Morelletporeae VARMA, 1950

Genus *Morelletpora* VARMA, 1950

Type species: *Morelletpora nammalensis* VARMA, 1950

Morelletpora sinica sp. nov.

(Figs. 4.4-4.5, 8.1-11)

Origin of the name: Named from the Latin '*Sinica*' for 'from China, Chinese'.

Holotype: Fig. 8.11, thin-section TY31.

Type locality: Tuoyunduke section (Fig. 3 right).

Type stratum: Campanian Yigeziya Formation.

Description: Elongated to club-shaped segments occasionally in connection and marked by an incision along the longitudinal axis (Fig. 8.11). The individual segments have a length of 1.8 mm to 3.5 mm and a ratio length/width of ~1.7 to ~2.4. Calcification includes the main axis and the laterals. The common type of preservation is represented by a mass of homogeneous sparry (whitish) calcite. This type appears to be of secondary origin ('secondary collective sheaths', DE CASTRO, 1997) while the primary type shows a calcification with an individual calcareous envelope of light-brownish colour covering each lateral (Fig. 8.4) ('individual sheaths', DE CASTRO, 1997). The laterals are arranged perpendicular to slightly oblique towards the longitudinal axis and in alternating position (Fig. 8.6). Proximally, the laterals are rather narrow, tubular and connected to the main axis by a pore. Along their length, they widen continuously and become more enhanced and funnel-like towards the periphery.

Measurements: D: 1.25-2.20 mm (mostly between 1.40 and 1.50 mm); d: 0.64-0.81 mm (approximately 0.70 mm in average); d/D: 0.42-0.56; l: 0.37-0.80 mm; p: 0.15-0.17 mm; h: 0.19-0.23 mm; w: ~15 to ~25.

Comparisons: The genus *Morelletpora* VARMA is known from the Aptian to the Thanetian (BARATTOLO, 2002; BUCUR *et al.*, 2016) including the three species *M. nammalensis* (VARMA, 1950), *M. turgida* (RADOIČIĆ, 1975, non 1965) BARATTOLO, 2002 (Cenomanian of Croatia), and *M. dienii* PARENTE, 1997 (Maastrichtian of Italy). *M. nammalensis* from the Paleocene of Pakistan shows comparable dimensions, but differs from *M. sinica* significantly by the shape of the laterals with a rather long and thin tubular part that widens abruptly forming a 'sporangium' with a distal rounded end, well discernible in the specimen shown in VARMA (1955: Pl. 1, fig. 2) and his thallus reconstruction of Figs. 18-20 therein. Unfortunately, the specimens from the Yigeziya Formation of the Tarim Basin do not show exactly the morphology of the distal lateral end (widening outwards or forming a rounded end within the calcareous sheeth. In any case, also the size of the segments is different with a length of 4-5 mm (or more?) in *M. nammalensis*. Based on the biometric data from rich material of Iran (BUCUR *et al.*, 2016) *M. turgida* from can be distinguished from *M. sinica* by some of its morphometric parameters such as a reduced main axis (d/D about 0.33), or a reduced whorl spacing (h mean 0.136 mm). Also the segment morphology is different; barrel-shaped in *M. turgida* versus elongated club-shaped in *M. sinica*. *M. turgida* was originally described from the Cenomanian of Serbia but has a rather wide distribution in Aptian-Albian strata (see synonymy in BUCUR *et al.*, 2016). *M. dienii* was originally described from the Maastrichtian of southern Italy. This species also shows barrel- to slightly pear-shaped segments with an axial cavity morphologically similar to the

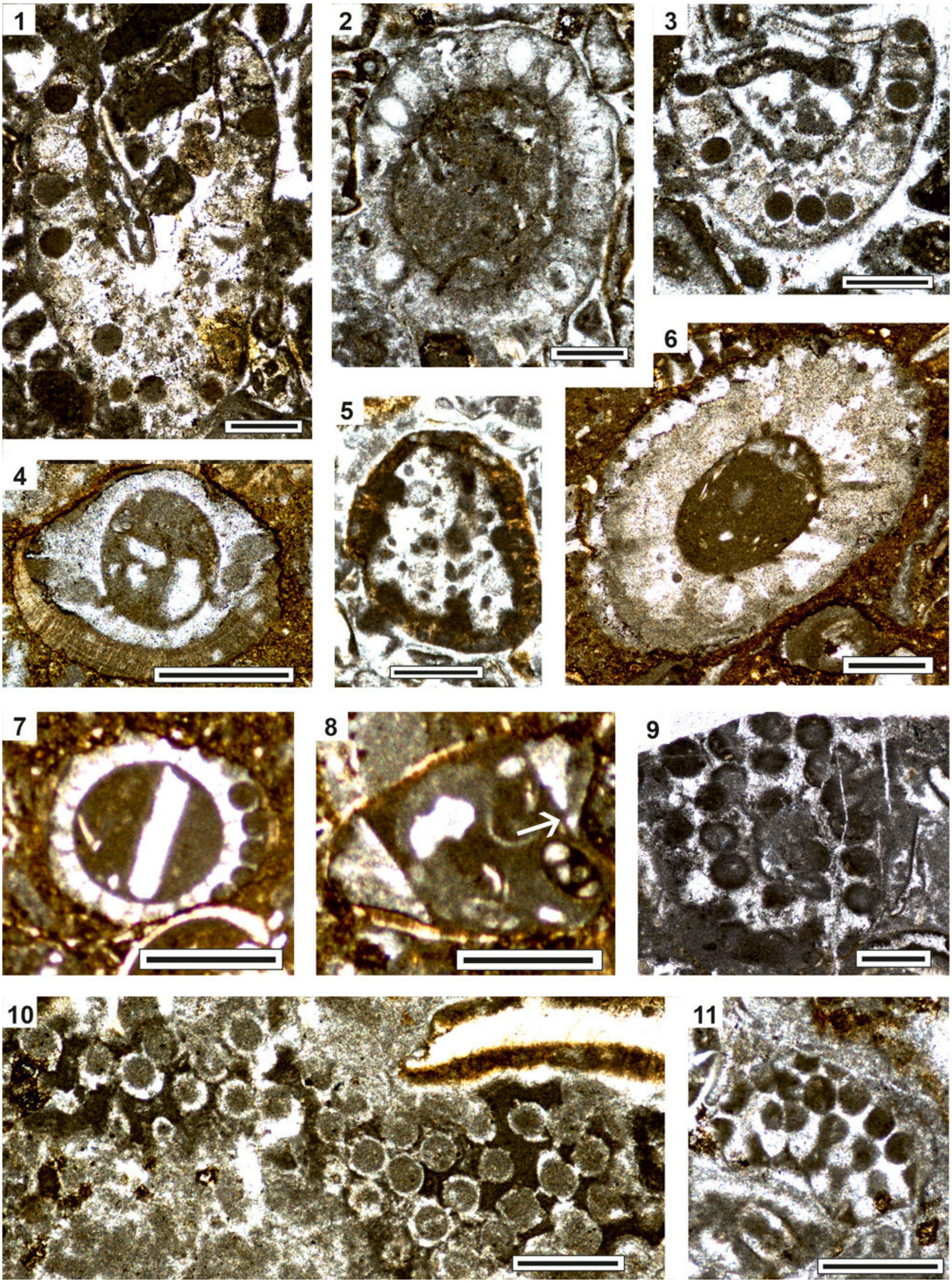

Figure 6: Dasycladalean algae from the Cenomanian of the lower Kukebai Formation of the Simuhana section, SW Tarim Basin, China. (1-3, 5, ?6) *Neomeris* sp. (4, 7-8) *Clypeina* sp. (arrow in 8: Connection of lateral with the main axis). (9-11) Gen. and sp. indet. 1. Scale bars = 0.30 mm. Samples sm94 (1), sm45 (2, 5, 8, 10-11), sm90 (3), sm43 (4, 6-7), sm86 (9).

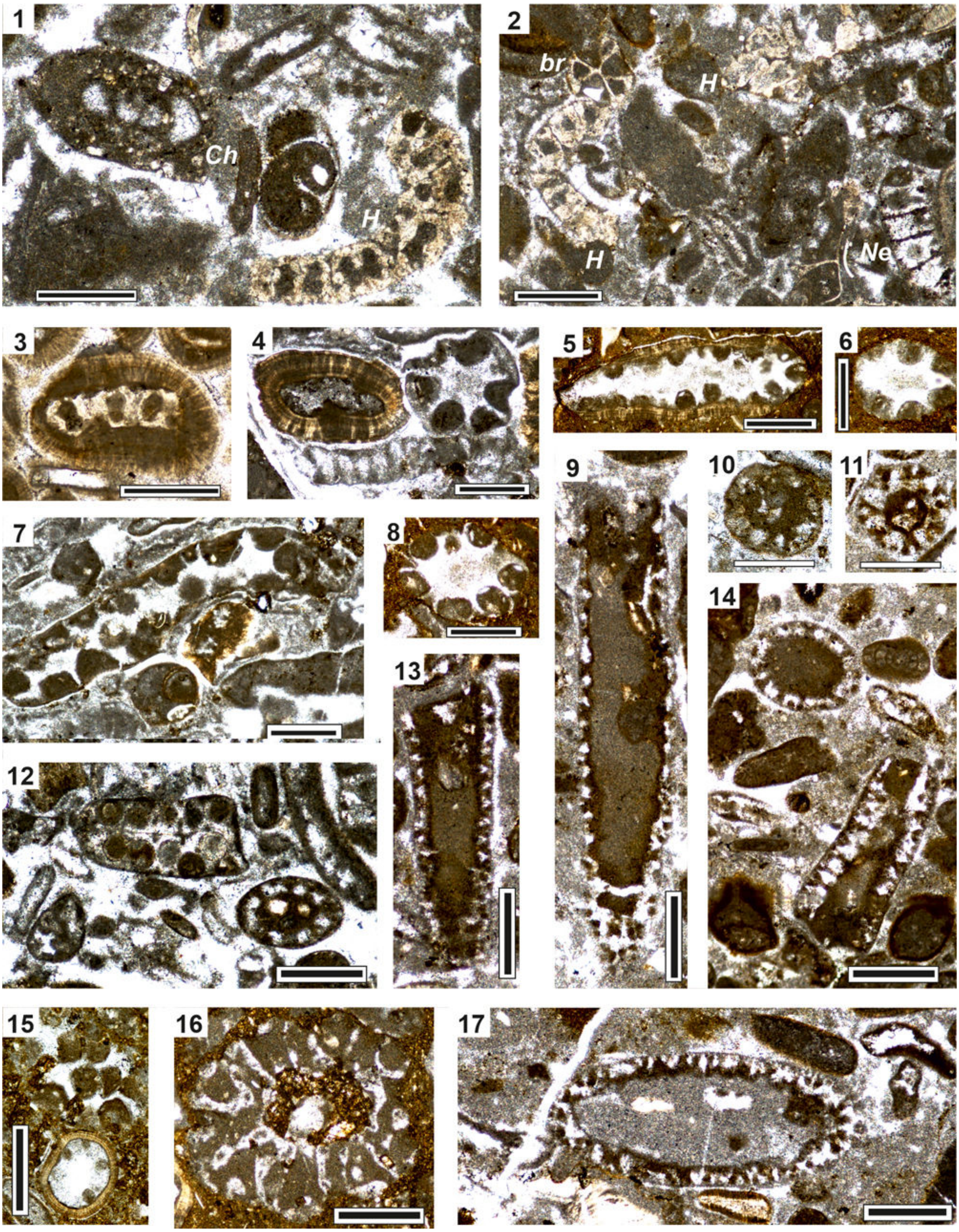

Figure 7: Dasycladalean algae from the Cenomanian of the lower Kukebai Formation of the Simuhana section, SW Tarim Basin, China. (1-3) *Heteroporella lepina* (PRATURLON); debris in grain-packstones with ooids, bryozoans (br), *Charentia cuvillieri* NEUMANN (*Ch*), and *Neomeris* sp. (*Ne*) (1-2), and as core of ooids (3). (4-8) *Acicularia macropora* KUSS. (9-14, 17) *Dissocladella ondulata* (RAINERI) together with *Bakalovaella*? sp. (in 12). (15-16) Gen. and sp. indet. 2. Scale bars = 0.30 mm. Samples: sm89 (1-2), sm84 (3), sm45 (4, 7), sm43 (5-6, 8, 15-16), sm86 (9, 11, 13-14, 17), sm46 (10), sm90 (12).

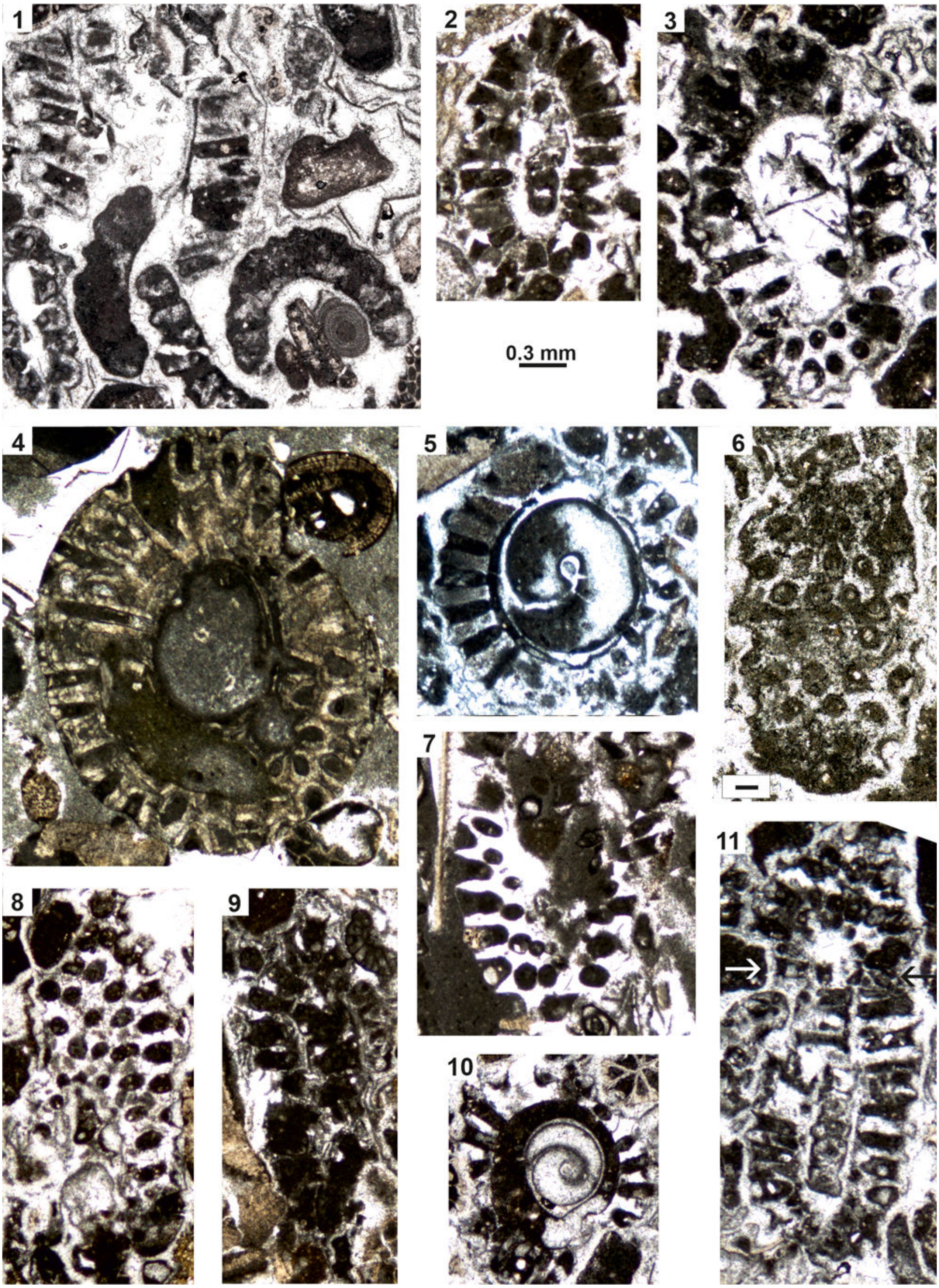

Figure 8: *Morelletpora sinica* sp. nov. from the Turonian? Kukebai Formation of the Akqiy section (4) and the Campanian Yigeziya Formation of the Tuoyunduke section (all others), SW Tarim Basin, China. (1) Debris of diverse sections; sample TY31. (9, 11) Longitudinal sections; note the incision along the thallus axis of the holotype (11) marking the conjunction between two segments (arrows); samples TY32 and TY31. (2-4, 6-7) Oblique sections; samples TY32: 2, 7, TY31: 3, 6; AK28: 4). (5, 10) Slightly oblique transverse sections; sample TY31. (8) Tangential section; sample TY32. Scale bars = 0.30 mm. Samples: TY31 (1, 3, 5-6, 10-11) TY32 (2, 7-9), AK28 (4).

external shape. *M. dienii* has a comparably high number of laterals per whorl (w = 34-41) and a reduced whorl spacing (h = 0.07-0.12 mm).

Occurrence: Turonian? Kukebai Formation of the Akqiy section (rare); Campanian Yigeziya Formation of the Tuoyunduke section (common to abundant).

Family Thyrsoporellaceae
GRANIER & BUCUR in GRANIER *et al.*, 2013b

Genus *Heteroporella* (PRATURLON, 1967) GRANIER *et al.*, 1994

Type species: *Heteroporella lepina* PRATURLON, 1967

***Heteroporella lepina* (PRATURLON, 1967) GRANIER *et al.*, 1994**

(Fig. 7.1 pars, 7.2 pars, 7.3).

1967 *Heteroporella lepina* n.gen., n.sp. – PRATURLON, p. 202, Pls. 51-52.

1990 *Heteroporella lepina* PRATURLON - GUŠIĆ & JELASKA, Pl. 3, fig. 1; Pl. 7, fig. 5.

1992 *Heteroporella lepina* PRATURLON – SCHLAGINTWEIT, Pl. 2, fig. 10.

1994 *Heteroporella lepina* PRATURLON - GRANIER *et al.*, p. 129, Pl. 1, figs. 1-8 (with synonymy).

1999 *Heteroporella lepina* PRATURLON - ENSSLIN & SCHLAGINTWEIT, p. 478, Pl. 1, figs. 1-3, 5.

2000 *Heteroporella lepina* PRATURLON - J.-P. MASSE & ISINTAK, p. 370, Pl. 1, figs. 7-8.

Remarks: The debris of *H. lepina*, typically showing the yellowish calcification (GRANIER, 2012, for details), has been observed as cores of individual ooids in oolitic grainstones (Fig. 7.3) and together with bryozoans and some benthic foraminifers (*e.g.*, *Charentia cuvillieri*) in grainstones-packstones. The fragmentary state of preservation is not only due to the high-energy facies but also the modular thallus organization of the alga consisting of individual rhombohedral shields facilitating breakage (GRANIER *et al.*, 1994: Fig. 1). *Heteroporella lepina* is typically recorded from open lagoonal external platform facies and occurs also resedimented in slope carbonates (PRATURLON, 1967).

Occurrence: Rare to common in the Kukebai Formation of the Simhuana section.

Family Polyphysaceae KÜTZING, 1843

Forma genus *Acicularia* ARCHIAC, 1843

Type species: *Acicularia pavantina* ARCHIAC, 1843

***Acicularia* cf. *macropora* KUSS, 1994**

(Fig. 7.4-7.8)

1994 *Acicularia macropora* n. sp. - KUSS, p. 304, Fig. 6, Pl. 3, figs. 12-16.

Remarks: Large-sized, elongate, often bended spicules displaying well calcification. The shape of the spicules is often club-shaped with a thicker rounded and a narrower tapering end (Fig. 7.5). In transverse section there are 7 to 8 globular sporangial cavities. *A. macropora* was described by KUSS (1994) from the upper Turonian of Egypt. The specimens from the Cenomanian Kukebai Formation display larger dimensions than the Egyptian type material while other parameters (number of sporangial cavities) are equal. These differences are here not considered as being of specific importance.

Dimensions (data from KUSS, 1994 in brackets): Length of spicules: up to 1.8 mm (0.8 mm to 1.2 mm); Diameter of spicules 0.40-0.67 mm (0.32-0.48 mm); Diameter of sporangial cavities: 0.14-0.16 mm (0.10-0.14 mm); Number of sporangial cavities: 7-8 (7-8).

Occurrence: Common in the Kukebai Formation of the Simuhana section.

Forma genus *Terquemella* MUNIER-CHALMAS ex. L. & J. MORELLET, 1913

Type species: *Terquemella parisiensis* MUNIER-CHALMAS ex. L. & J. MORELLET, 1913.

***Terquemella*? *antiqua* (PIA, 1936)**

(Figs. 7.15, 9.9-9.10)

1936 *Acicularia antiqua* sp. nov. - PIA, p. 8, Pl. 3, figs. 1-14.

Remarks: Small-sized spiculae (diameter 0.25-0.45 mm) with numerous tiny sporangial cavities (diameter 0.035-0.045 mm). Occurring in high-energy shoal facies, the spicules often occur as ooid cores (Fig. 9.9). The forma species is treated as possibly belonging to *Terquemella* (PIA *et al.*, 1937, p. 232) while others retain it in the original description (BARATTOLO, 2002). *T.*? *antiqua* is given a general Upper Cretaceous age (Cenomanian-Maastrichtian; GRANIER & DELOFFRE, 1993).

Occurrences: Common in the Kukebai Formation of the Simuhana section and the Yigeziya Formation of the Tuoyunduke section.

Genus *Clypeina* MICHELIN, 1845

***Clypeina* sp.**

(Fig. 6.4, 6.7-6.8)

Description: The thallus debris consists of isolated verticils characterized by a large main axis bearing numerous relatively short tubular (= uncompressed) laterals. They arise from the main axis by means of a small stalk then widening abruptly and thereby bending upwards (Fig. 6.8).

Remarks: Among the Upper Cretaceous *Clypeina* species, the form from the Tarim Basin is differentiated from those bearing laterals arranged perpendicular (horizontal) to the axis such as *C.*? *alrawii* RADOIČIĆ, 1978, *C. pastriki* RADOIČIĆ, 1983, or *C. dusanbrstinai* RADOIČIĆ, 1997. Upper Cretaceous species with inclined laterals include *C. croatica* Gušić in DELOFFRE & RADOIČIĆ, 1978, and *C. sahnii* VARMA, 1952. The poor material from the Cenomanian Kukebai Formation does not allow more detailed comparisons.

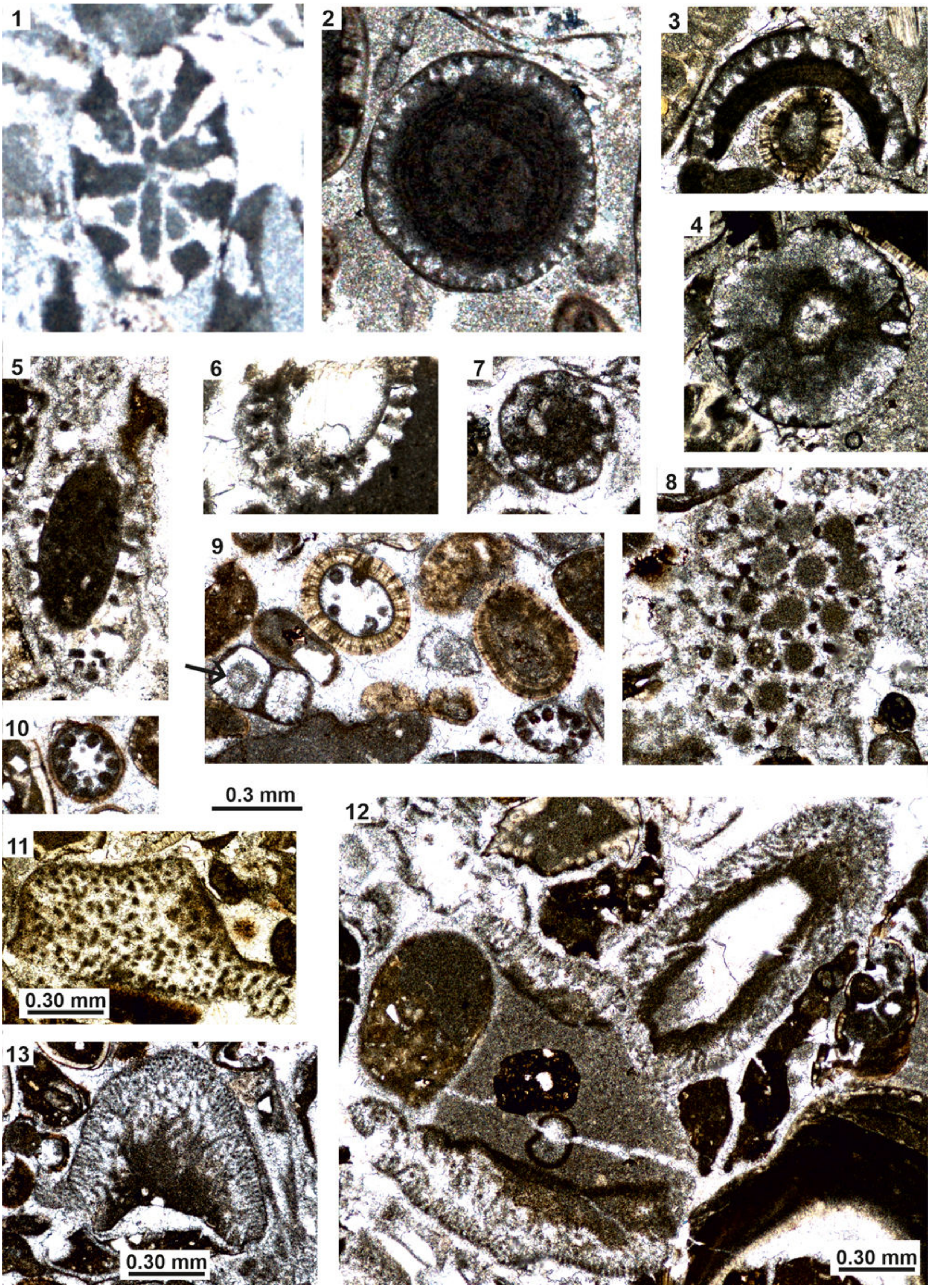

Figure 9: Dasycladales and Bryopsidales from the Turonian? Kukebai Formation of the Simuhana section (1-4) and the Campanian Yigeziya Formation of the Tuoyunduke section (5-12), SW Tarim Basin, China. (1) Gen. and sp. indet. 3. (2-3) Gen. and sp. indet. 4. (4) *Trinocladus* sp. (5-6) Gen et sp. indet. 5. (7) Gen. and sp. indet. 6. (8) *Cymopolia*? sp. (9) *Terquemella*? *antiqua* (PIA) (middle and right below) and *Cymopolia*? sp. (left below; arrow = fertile ampulla). (11-13) Debris of *Arabicodium* sp. Scale bars = 0.30 mm. Samples: AKk28 (1-4), TY32 (5-6), TY31 (7), TY36 (8, 12), TY37 (9-11, 13).

Measurements: D: 0.63-0.88 mm; d: 0.28-0.38 mm d/D: 0.43-0.64; pmax: 0.064-0.070 mm; w: about 26. These biometric data are based on three specimens only. The outer diameter may be larger than in the preserved fragments and should therefore be considered as tentative.

Occurrence: Rare to common in the Cenomanian Kukebai Formation of the Simuhana section.

Taxa of unknown genera and species

Gen. and sp. indet. 1

(Fig. 6.9-6.11)

Remarks: Thallus fragments showing close set laterals or ampullae (diameter 0.05-0.15 mm) in an alternating position. We note similarities to tangential sections of *Brasiliporella nkossaensis* (P. Masse, 1995) emend. Granier *et al.* (2013b) described from Albian-Cenomanian strata of Congo and Brazil (*e.g.*, Granier *et al.*, 2013b: Fig. 5e).

Occurrence: Rare to common in the Kukebai Formation of the Simuhana section.

Gen. and sp. indet. 2

(Fig. 7.15 pars, 7.16 pars)

Remarks: One oblique section (D = ~0.82 mm, d = ~0.3 mm) showing laterals of at least two orders. The swollen first order laterals have a diameter of 0.085-0.11 mm; the second order laterals have a diameter of ~0.043 mm. The uncertainty about the number of orders of laterals (two or three) does not allow a detailed discussion. We also note resemblance to the oblique section of *Fourcadella sintraensis* described by Granier and Berthou (2002: Pl. 1, fig. 4) from the Albian?-Cenomanian of Portugal.

Occurrence: Very rare in the Cenomanian Kukebai Formation of the Simuhana section.

Gen. and sp. indet. 3

(Fig. 9.1)

Remarks: One oblique section of a well calcified dasycladalean alga exhibiting a narrow main axis (D = 056 mm, d = ~0.08 mm). There is presumably just one order of trumpet-shaped laterals of relatively low number within a whorl (less than 10).

Occurrence: Very rare in the Turonian? Kukebai Formation of the Akqiy section.

Gen. and sp. indet. 4

(Fig. 9.2-9.3)

Remarks: One complete transverse section and a fragment of a slightly oblique transverse section (D = ~0.78). The alga shows a rather wide central hollow (filled with micrite) that most likely does not correspond to the main axis thus reflecting a secondary preservational stage. There are at least two orders of laterals in high numbers (>20). The material from the Campanian of the Tarim Basin shows some similarities to the Paleocene *Dissocladella savitriae* Pia *in* L.R. Rao & Pia, 1936, described from the Paleocene of India.

Occurrence: Rare to common in the Turonian? Kukebai Formation of the Akqiy section.

Gen. and sp. indet. 5

(Fig. 9.5-9.6)

Remarks: Two oblique sections of a dasycladalean algae (D = 0.45-0.55 mm, d = 0.26-0.29, d/D = 0.53-0.58) of unknown orders of laterals (presumably just one).

Occurrence: Rare in the Yigeziya Formation of the Tuoyunduke section.

Gen. and sp. indet. 6

(Fig. 9.7)

Remarks: One slightly oblique transverse section (D = 0.41 mm, d = 0.22 mm, d/D = 0.54) with unknown shape and order(s) of laterals. Gen. and sp. indet. 6 occurs in high-energy microfacies with debris of halimedaceans, *Terquemella*? *antiqua* (Pia), and bryozoans.

Occurrence: Rare in the Yigeziya Formation of the Tuoyunduke section.

Order Bryopsidales Schaffner, 1922

Family Halimedaceae Link, 1831

Genus *Arabicodium* Elliott, 1957

***Arabicodium* sp.**

(Fig. 9.11-9.13)

The comparable size of the medullary and cortical filaments discernible in the debris material suggests assignment to the genus *Arabicodium* Elliott, 1957 (*e.g.*, Bucur, 1994). We refrain from assigning the debris material recovered here to any of the described species (see Table 1 in Bucur, 1994).

Occurrences: Common in the Cenomanian-Turonian Kukebai Formation of the Simuhana and Aksay sections and common to abundant in the Campanian Yigeziya Formation.

5. Discussion

Mu (1993) reported 'an important algal flora of Late Cretaceous age' (...) that 'has been found from western Tarim Basin, NW China (ca. 40° N) which is of significance for the delineation of the northern boundary of the Tethyan Realm in Asia. This flora is rather diverse, composed of about 33 species in 22 genera, belonging to the Dasycladales, Halimedaceae, Corallinaceae, Solenoporaceae, Gymnocodiaceae, Peyssonneliaceae, Cyanophyta and other taxa, showing close Tethyan affinities' (*op. cit.*, p. 339). Unfortunately, details of this data have never been published so that the actual assemblages and the lithostratigraphc occurrences (formations) are unknown. Mu (1993: Table 1) only listed genera such as *Acicularia*, *Clypeina*, *Heteroporella*, *Neomeris*, *Salpingoporella*, *Tarimporella*, and *Terquemella*. *Tarimporella* reported by Mu (1993) has to be regarded as *nomen nudum* lacking a taxonomic description in an official publication. It is noteworthy that an identically-named genus has been established dec-

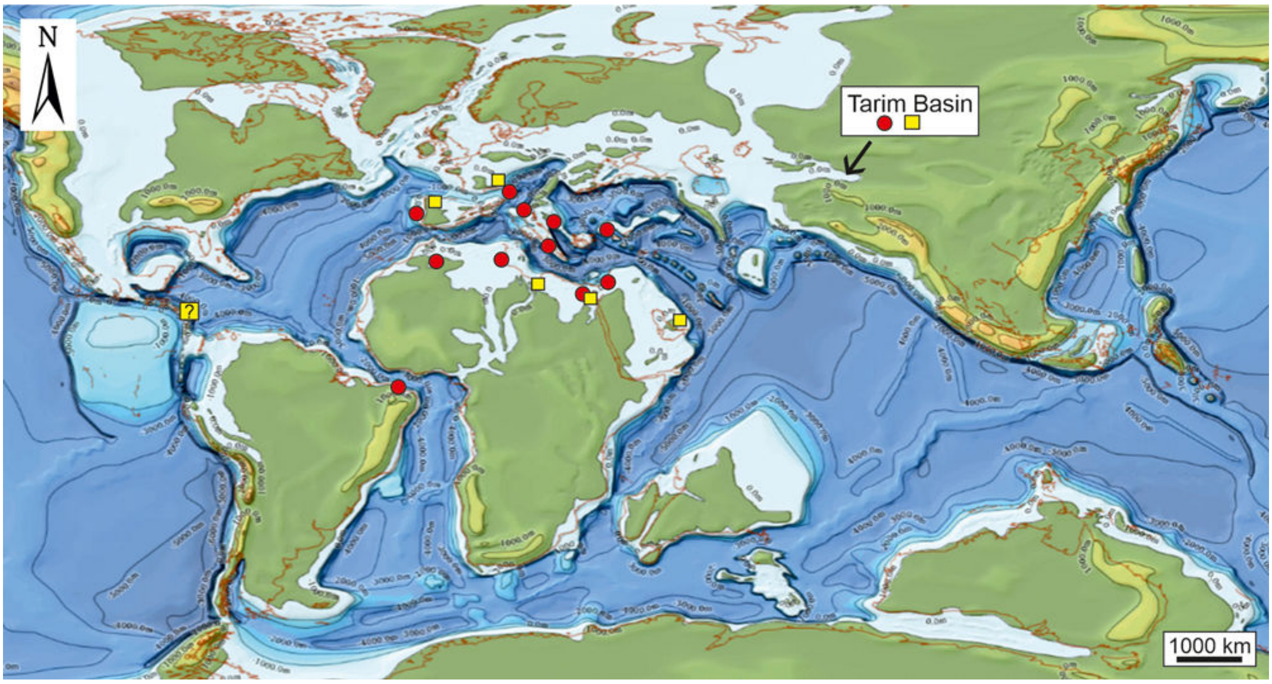

Figure 10: Global palaeogeographic map during the Cenomanian (courtesy of Halliburton) showing the distribution of *Heteroporella lepina* (PRATURLON) (red dots) and *Dissocladella ondulata* (RAINERI) (yellow squares). Brazil (Sergipe-Alagoas Basin, BENGTSON & BERTHOU, 1983), Egypt (KUSS, 1994), Germany (Bavaria, Northern Calcareous Alps, SCHLAGINTWEIT, 1992), Italy (type locality, PRATURLON, 1967), Croatia (GUŠIĆ & JELASKA, 1990), Jordan (KUSS & CONRAD, 1991), Morocco (ENSSLIN & SCHLAGINTWEIT, 1999), Portugal (eastern north Atlantic margin; LAUVERJAT & POIGNANT, 1978), Tarim Basin, China (this work), Tunisia (BISMUTH *et al.*, 1981). Note that for simplicity, the Cenomanian map has been used although some occurrences are from Turonian-Coniacian strata.

ades later by JIANG and ZHANG (2022) from the Cambrian of the Tarim Basin as a dasycladalean alga. The poorly preserved material however does not in our opinion allow an accurate description justifying the erection of a new genus. Moreover, the debris of '*Tarimporella*' does not refer to dasycladales but halimedaceans. The other genera reported by MU (1993) are well represented in our material. Alltogether, 16 different taxa of dasycladalean algae are reported herein, including 9 from the Cenomanian and 1 from the Turonian? Kukebai Formation, and 8 from the Campanian Yigeziya Formation with 2 shared taxa (Table 2).

Cenomanian shallow-water carbonates from Neotethys are typically characterized by highly diverse assemblages of small and larger benthic foraminifers (SCHROEDER & NEUMANN, 1985; CHIOCCHINI *et al.* 2012; SIMMONS & BIDGOOD, 2023). In fact, with respect to the Phanerozoic diversity of agglutinated foraminiferal taxa, the Cenomanian stands alongside the Holocene as the stage with the maximum number of reported taxa (KAMINSKI *et al.*, 2008; SCHLAGINTWEIT & YAZDI-MOGHADAM, 2023: 'Cenomanian megadiversity'). In contrast hereto, the microfauna recovered from the lower Kukebai Formation of the Tarim Basin can be considered as extremely low diversity (Fig. 5). In particular the lack of any typical larger benthic foraminifers (*e.g.*, alveolinoids, orbitolinids) is striking. The greatest diversity reported from Cenomanian carbonates as reported above however is attained in inner platform facies while at least the upper part of the lower Kukebai Formation containing echinoids, bryozoans, and *Heteroporella lepina* (*e.g.*, samples 23sm86 to 94, Fig. 2) can be ascribed to open marine shoal facies that usually contains only a low diversity microfauna. The Cenomanian calcareous algae of the Tarim Basin with at least 9 different taxa, however, can be considered as well diversified against the background of that from Cenomanian strata elsewhere, where only a reduced number of taxa were described (BASSOULLET *et al.*, 1978; BUCUR, 1999; BARATTOLO, 2002: twenty species; AGUIRRE & RIDING, 2005). In their analysis of biodiversity through time, AGUIRRE and RIDING (2005, p. 581) concluded that palaeotemperature and sea-level were the main influencing factors meaning that 'Dasycladaleans were most diverse when their main habitats—warm shallow seas—were most extensive'. In fact, the epicontinental Tarim Gulf must have been a very warm shallow sea evidenced by the occurrences of gypsum and dolostones in the Upper Cretaceous strata including the Kukebai Formation (*e.g.*, XI *et al.*, 2016; ZHANG *et al.*, 2018). Also the calcareous algae of the Yigeziya Formation with at least 8 different taxa can be considered as comparably well diversified bearing in mind that also from the Campanian a relatively low number of species is known worldwide (*e.g.*, seven species in BARATTOLO et al., 2002). Another reason might be the poor inventory of Upper Cretaceous limestones and the related lack of petrographic thin sections.

The calcareous algae from the Upper Cretaceous Tarim Basin compares favourably with other general Neotethys assemblages, exemplified by the distribution of *Heteroporella lepina* and *Dissocladella ondulata* (Fig. 10).

6. Conclusions

A well diversified assemblage of calcareous green algae consisting mainly of Dasycladales is described for the first time from Upper Cretaceous strata of the southwestern Tarim Basin, China. The occurrence of the algae, associated with some (larger) benthic foraminifers, corresponds to two carbonate units within two transgressive cycles, the Cenomanian-Turonian Kukebai Formation and the Campanian Yigeziya Formation. The foraminiferal-algal assemblages described here provide some additional data to the present biostratigraphic inventory indicated in the existing literature. It is expected that wider and more detailed investigations of the Upper Cretaceous shallow-water carbonates of the Tarim Basin will identify additional taxa for both groups than are currently known.

Acknowledgements

Thanks to Mike SIMMONS (London) for providing the Cenomanian palaeomap and permission for illustration. Helpful remarks were provided by the two reviewers Bruno GRANIER (Brest) and Ioan BUCUR (Cluj-Napoca). Mike BIDGOOD (Oldmeldrum) assisted with the English.

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