CALCAREOUS ALGAE, MICROBIAL STRUCTURES AND MICROPROBLEMATICA FROM UPPER JURASSIC-LOWERMOST CRETACEOUS LIMESTONES OF SOUTHERN CRIMEA

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Abstract The calcareous algal association described in this paper was identified in Kimmeridgian-Berriasian limestones in the Ay Petri and Yalta massifs and near Belogorsk (Crimea). It consists of dasycladaleans, udoteaceans, thaumatoporellaceans, and cyanobacteria accompanied by various encrusting organisms. *Steinmanniporella taurica* has been known in this region since 1925 but the original description was rather inaccurate; this paper provides further details, illustrations and appropriate diagnostic features. It also includes a brief paleontological overview of the algal, cyanobacterial and microproblematical association as a whole.

Keywords: Green algae, Dasycladales, Udoteaceae, Cyanobacteria, Microproblematica, Upper Jurassic, Lower Cretaceous, Crimea

INTRODUCTION

The earliest studies of fossil calcareous algae from southern Crimea date back to 1925 with Pcelincev's publication, followed by Maslov (1958, 1965, 1973). These authors described four new dasycladalean species: *Actinoporella krymensis*, *Kopetdagaria iailensis*, *Tetraporella taurica* and *Triploporella karabiensis*. New material collected in the same region (Krajewski & Olszewska, 2006, 2007; Granier *et al.*, 2009) led us to revise these taxa and to document the associated algal assemblage.

GEOLOGICAL SETTING

The core of the Crimea Mountains is formed by sediments ranging in age from Triassic to Lower Cretaceous that were deformed during the Cimmerian orogenic phases, *i.e.*, near the Triassic-Jurassic transition, in the Callovian and in the Early Cretaceous (Late Berriasian-middle Valanginian) (*e.g.*, Nikishin *et al.*, 1998; Yudin, 1999, 2008; Mileev *et al.*, 2006; Afanasenkov *et al.*, 2007). The study area is located in the southwestern part of the Crimean Mts, in the Yalta and Ay-Petri massifs, as well as further north-east near Belogorsk (Also known as Bilohirsk, Granier et al, 2009) (Fig. 1). The geological structure of the area is dominated by Kimmeridgian, Tithonian and Berriasian rocks (e.g., Gorbatchik & Mohamad, 1997; Mileev *et al.*, 2006; Krajewski & Olszewska, 2007; Anikeyeva & Zhabina, 2009).

All the sedimentary rocks encountered in the area studied are shallow-marine deposits of various environments related to evolution of the Crimean carbonate platform (Krajewski, 2010). The total thickness of these sediments before tectonic movements formed the allochthonous series of the Crimean Mts was probably less than 800 meters. Thicker series currently observed in parts of carbonate massifs probably result from the tectonic stacking of nappes.

The sedimentary rocks of the Yalta and the Ay-Petri massifs studied here rest unconformably upon Middle Jurassic strata and Taurid (Triassic-Lower Jurassic) flysch.

The facies and microfacies of the area require further investigation. In recent years studies have illustrated the diversity of facies which are referred to three main types of platform setting: (i) lower-slope (?) ramp, (ii) platform margin with reefs and oolitic shoals, and (iii) inner platform with lagoons and tidal flats, representing three successive stages of platform development (Krajewski & Olszewska, 2006; Krajewski, 2008, 2010). In the study area, the water depths of these shallow-marine environments did not exceed several tens of meters. Erosional gaps are common, and breccias, (?) vadose crystal-silts and fenestral structures document emergent or sub-emergent environments (Krajewski, 2010). The platform was sited on a continental margin, and siliciclastic material locally occurs as a result of nearby terrestrial erosion. The main factors controlling these shallow-marine environments were probably small oscillations of relative sea-level that resulted in a cyclic deposition accompanied by changes in depositional rate.

The first stage of platform development spans the Kimmeridgian and possibly also the uppermost Oxfordian. Two main facies types were deposited (Krajewski, 2010): bioclastic wackestones with microbolites and *Microsolena*-microbial-sponge boundstones-floatstones. Sedimentation proceeded on a gentle slope, in proximity to land-masses supplying siliciclastic material (Krajewski & Olszewska 2006; Krajewski, 2010).

The second stage too place in Tithonian times and is characterized by a greater diversity of facies, with

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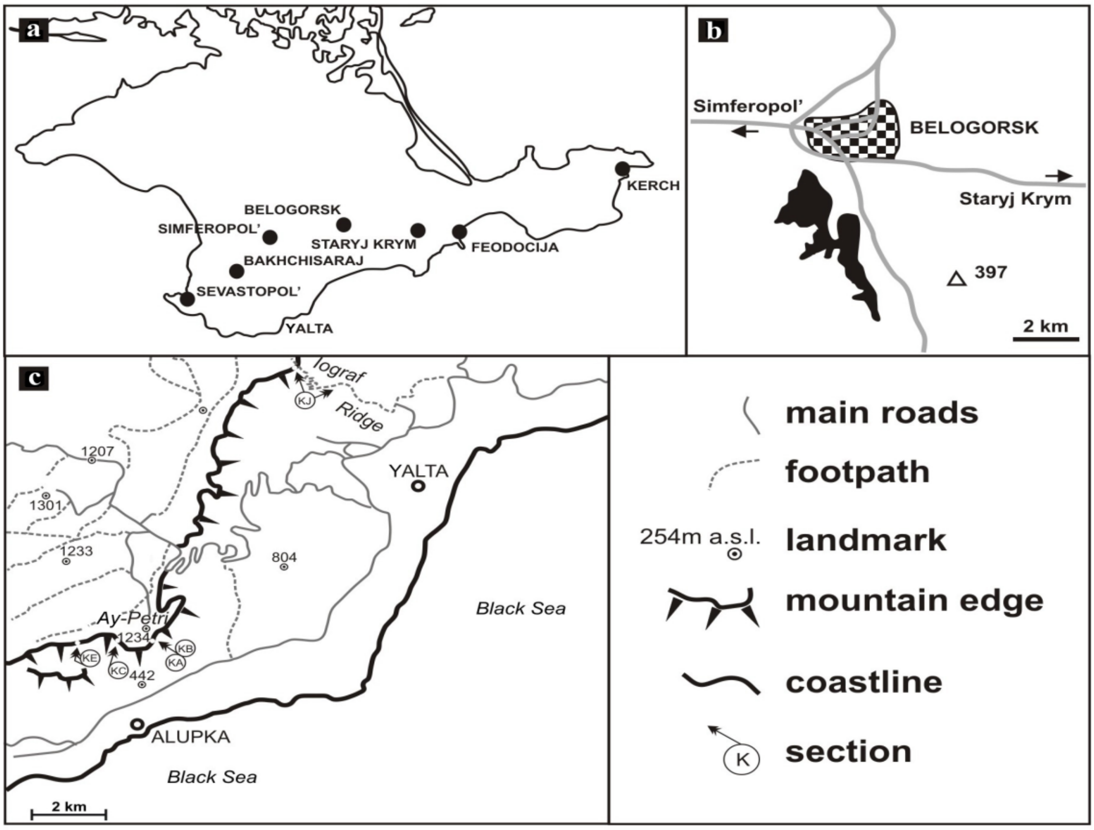

Fig. 1 Location of the areas studied. **a** General sketch of the Crimean Peninsula with the main localities of its southern part. **b** Location of samples collected near Belogorsk (point 397). **c** Location of the samples collected near Yalta.

sediments deposited in marginal platform environments represented mostly by oolitic shoals and reefs built by various organisms: calcareous sponges, chaetetids, corals, algae, calcimicrobes and microencrusters (e.g. *Lithocodium*, *Bacinella*, *Thaumatoporella*, *Crescentiella*). The main types of facies are oolitic-bioclastic grainstones, sponge-coral-microbial boundstones-floatstones, mixed siliciclastic-carbonate and pure siliciclastic facies. Inner platform facies are also represented, and consist of both open and restricted lagoonal facies represented by foraminiferal mudstones-wackestones and oncoidal floatstones (Krajewski, 2010). Small bathymetric oscillations are revealed by facies alternations.

The third and final stage of platform history (Late Tithonian-Berriasian) is dominated by inner platform facies represented by *Bacinella*-oncoid floatstones, sponge-coral floatstones, foraminiferal-gastropod wackestones-mudstones and intertidal mudstone-microbial bindstone with fenestral structures (Krajewski, 2010). At that stage of growth, platform development was interrupted by Cimmerian movements and sedimentation was frequently affected by episodes of emergence and erosion. On the top of Ay-Petri Mountain, reddish, chaotic, karstified conglomerates and neptunian dykes document a significant stratigraphic gap and long-term subaerial exposure from Late Berriasian - mid Valanginian.

The Tithonian-Berriasian limestones of the Yaila series crop out five kilometers south of Belogorsk. They are exploited in a quarry at the foot of a small (379 m) hill (Fig. 1b). Samples were collected there in 1994 during an exploratory mission by one of us (BG).

The microfacies of the limestones in the Belogorsk area range from wackestones to grainstones; the allochems consist mostly of bioclasts (foraminifera and calcareous algae). Diagenetic features, such as voids surrounded by micritic envelopes with sedimentary infills, could document repeated stages of subaerial exposure.

The algal assemblage from the limestones in the Belogorsk area consists of *Diversocallis* sp., *Permocalculus* sp., *Thaumatoporella parvovesiculifera, Terquemella* sp., *Salpingoporella* sp., *Actinoporella podolica, Rajkaella iailensis, Suppiluliumaella* sp. Foraminifers associated with these algae include *Anchispirocyclina lusitanica, Pseudocyclammina lituus, Dobrogelina ovidi, Protopeneroplis ultragranulata, Mohlerina basiliensis*, *Coscinoconus* sp., miliolids, and various agglutinated forms (Gorbatchik, 1971; Krajewski & Olszewska, 2007).

CALCAREOUS ALGAE

Algae from southern Crimea have been studied by Pcelincev (1925) and Maslov (1958, 1965, 1973). Pcelincev (1925) described *Tetraporella taurica*, a species recently transferred to the genus *Steinmanniporella* (Bucur *et al.*, 2010). Maslov described *Actinoporella* sp., *Actinoporella krymensis, Kopetdagaria iailensis* and *Triploporella karabiensis. A. krymensis* was considered a *nomen nudum* by Granier & Deloffre (1993). *K. iailensis* was transferred to the genus *Rajkaella*

(Dragastan & Bucur, 1988), and *T. karabiensis* has the features of a *"Montenegrella"*-type *Suppiluliumaella* (see also Bassoullet *et al.*, 1978: p. 291).

More recently Granier *et al.* (2009) documented an assemblage of calcareous algae from the Yaila Series (Tithonian-Berriasian) of Belogorsk. Some algae of this assemblage are further described and illustrated below.

Field studies of the limestones of South Crimea by Krajewski (Krajewski, 2008, 2010; Krajewski & Olszewska, 2006, 2007) resulted in a large quantity of samples collected from several profiles in the Yalta and Ay-Petri massifs (Fig. 1c). Most of the thin sections (over 90 %) prepared from these samples contain calcareous algae. Figure 2 illustrates the limestone successions in the studied profiles and the location of the samples with algae.

Table 1 presents the algal associations identified in the studied areas. The ages of the algal-bearing limestones are based on benthic foraminifers (Krajewski & Olszewska, 2006, 2007; Granier *et al.*, 2009; Granier & Bucur, 2011; unpublished data from the present study).

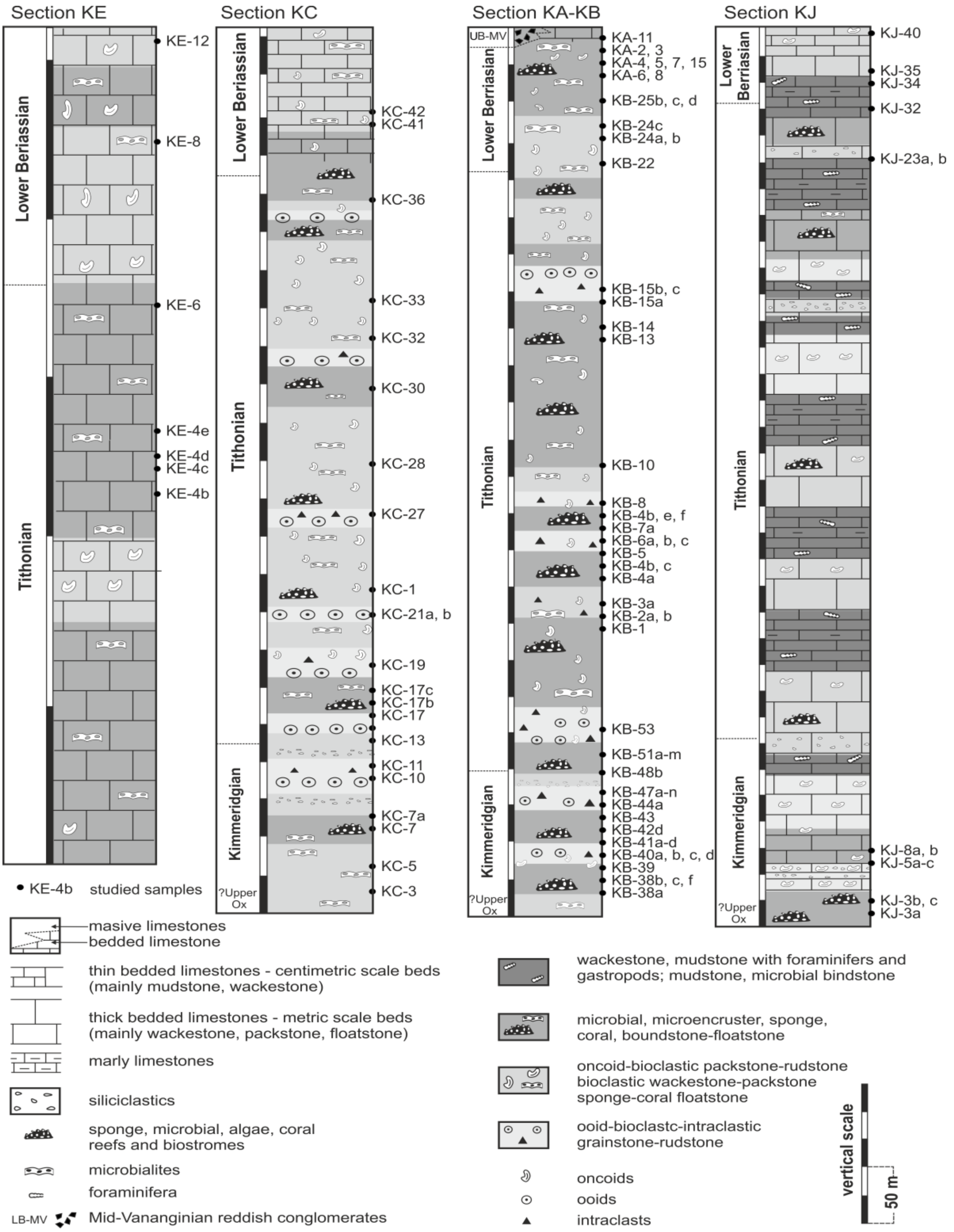

Fig. 2 Succession of the carbonate rocks in the four sections sampled near Yalta, after Krajewski (2008) modified by Krajewski (2010).

Table 1 The algal assemblage from the Upper Jurassic-Lowermost Cretaceous of Southern Crimea.

Algae	Location	Sample	Age	Illustration
Dasycladales				
Actinoporella podolica (Alth)	Belogorsk	003A, 007B, 013C, 014	Latest Tithonian-Berriasian	Fig. 3a-e
Campbelliella striata (Carozzi)	Ay-Petri massif	KB-22, KB-24-1a, KB-24e, KB-25b, KB-25d, KC-28, KC-41, KE-4e, KE-8	Tithonian-Early Berriasian	Fig. 3f-n
Chinianella scheimpflugi Hofmann	Ay-Petri and Yalta massifs	KB-15c, KC-11, KC-27, KE-12, KJ-5a	Kimmeridgian-Early Berriasian	Fig. 4a-f
Clypeina sulcata (Alth)	Ay-Petri massif	KB-22	Early Berriasian	Fig. 3l
?*Clypeina* sp.	Ay-Petri massif	KE-4e	Tithonian	Fig. 14d
?*Clypeina*/*Actinoporella* sp.	Ay-Petri massif	KB-6b, KB-14	Tithonian	Fig. 14 e, i
Griphoporella cretacea (Dragastan)	Ay-Petri massif	KB-7a, KB-7e, KB-38c, KB-40a, KB-40b	Kimmeridgian-Early Berriasian	Fig. 4g-l
?*Humiella* sp.	Ay-Petri massif	KA-8	Early Berriasian	Fig. 14b, f
Neogyroporella? *gawlicki* Schlagintweit	Ay-Petri and Yalta massifs	KB-44a, KJ-5a, KO-3a	Kimmeridgian-Tithonian	Fig.14c, g, h
?*Otternstella* sp.	Ay-Petri massif	KO-3a	Late Tithonian	Fig. 14a
Petrascula sp. cf. *P. bursiformis* Etallon	Belogorsk	004A, 009B	Latest Tithonian-Berriasian	Fig. 13f, g, k
Rajkaella iailensis (Maslov)	Belogorsk, Ay-Petri and Yalta massifs	001, 002A, 006A,012, 014, KF-4, KR-9, KJ-32,	Latest Tithonian-Berriasian	Fig. 5a-o; Fig. 6b-e
Rajkaella bartheli (Bernier)		KA-11, KR-9	Latest Tithonian-Berriasian	Fig. 6a, f
Salpingoporella annulata Carozzi	Ay-Petri and Yalta massifs	KA-7, KE-4a, KE-4b, KJ-5e	Kimmeridgian-Early Berriasian	Fig. 6g-k
Salpingoporella pygmaea (Gümbel)	Ay-Petri massif	KB-5, KB-13, KB-15b, KB-15c, KB-40a, KB-42a, KB-47a, KC-11, KO-3a	Kimmeridgian-Tithonian	Fig. 7a-k
?*Selliporella* sp.	Ay-Petri massif	KB-13	Tithonian	Fig. 14l, n
Steinmanniporella taurica (Pcelincev)	Ay-Petri and Yalta massifs	KB-38a, KB-41a, KB-41b, KB-41d, KB-51K, KB-51L KB-51m, KC-13, Kc-17b, KJ-23a, KJ023b	Kimmeridgian-Tithonian	Fig. 9a-f, Fig.10a-g, Fig. 11a-i

Suppiluliumaella delphica (Carras)	Ay-Petri and Yalta massifs	KB-6b, KB-39, KB-41b, KB-51a, KC-27, , KJ-5c, KJ-23b	Kimmeridgian-Tithonian	Fig. 12a-f
Suppiluliumaella sp.	Belogorsk, Ay-Petri and Yalta massifs	001, 002A, 007B, 008, 010B, 014, KC-27, Kj-23b	Tithonian-Early Berriasian	Fig. 12g-h, Fig. 1a-e, h-j
Terquemella sp.	Ay-Petri massif	KC-33	Tithonian	Fig. 14m
?*Triploporella* sp.	Ay-Petri massif	KC-16	Tithonian	Fig. 14j, k
Bryopsidales - Udoteaceae				
Arabicodium sp.	Ay-Petri and Yalta massifs	KB-7e, KC-11, KJ-23a	Kimmeridgian-Tithonian	Fig. 15a-c
Nipponophycus ramosus Yabe & Toyama	Ay-Petri massif	KB-25c, KB-29	Kimmeridgian-Early Berriasian	Fig. 15d, e
Thaumatoporellales				
Thaumatoporella parvovesiculifera	Ay-Petri massif	KB-7a, KB-7b	Tithonian	Fig. 14o, p
Cyanobacteria				
Girvanella sp.	Ay-Petri massif	KB-38f	Kimmeridgian	Fig.15j, k
Rivulariacean (*Cayeuxia*) type cyanobacteria	Ay-Petri and Yalta massif	KA-6, KB-4e, KB-38f, KB-39, KB-41a, KB-51m, KC-27KE-4c, KF-4, KJ-40	Kimmeridgian-Early Berriasian	Fig. 16a-g
?*Rothpletzella*/*Pseudo-rothpletzella*-like structures	Ay-Petri massif	KB-41a	Kimmeridgian	Fig. 16h-j
Problematica				
Crescentiella morronensis (Crescenti)	Ay-Petri and Yalta massifs	KB-38b, KC-7, KC-7a, KJ-8a	Kimmeridgian	Fig. 15f-i
Koskinobullina socialis Cherchi & Schroeder	Ay-Petri massif	KC-11	Kimmeridgian	Fig. 16k

REMARKS ON THE ALGAE AND DESCRIPTION OF SELECTED DASYCLADALEAN SPECIES

Genus *Actinoporella* Gümbel in Alth, 1881, emend Conrad *et al.*, 1974
Actinoporella gr. *podolica* (Alth, 1878), emend Conrad *et al.*, 1974
Fig. 3 a-e
Specimens of this alga have been found only near Belogorsk. It is a common species throughout the Tethyan realm. Details and extended synonymies are given in Conrad *et al.* (1974), Granier (1994) and Bucur (2011).

Genus *Campbelliella* Radoičić, 1959, emend Bernier, 1974, emend De Castro, 1993
Campbelliella striata (Carozzi, 1954), emend De Castro, 1993
Fig. 3 f-n.

Genus *Clypeina* (Michelin, 1845) Bassoullet *et al.*, 1978
Clypeina sulcata (Alth, 1881)
Campbelliella striata and *Clypeina sulcata* (formerly *C. jurassica*) are common in reef-dominated Upper Jurassic limestones of the Tethyan realm. In a detailed study of *Campbelliella*, De Castro (1993) emended the genus as well as its two species: *C. milesi* Radoičić, 1959, and *C. striata* (Carozzi, 1954). Although details of the thallus morphology are not always revealed, the specimens investigated from the Ay-Petri massif are most likely *Campbelliella striata*. *Clypeina sulcata* is normally easy to identify; nevertheless, currently it can be confused with the recently described *Clypeina langustensis* (Sokač *et al.*, 2014). In the Ay-Petri massif, we have also identified rare *Clypeina sulcata* specimens.

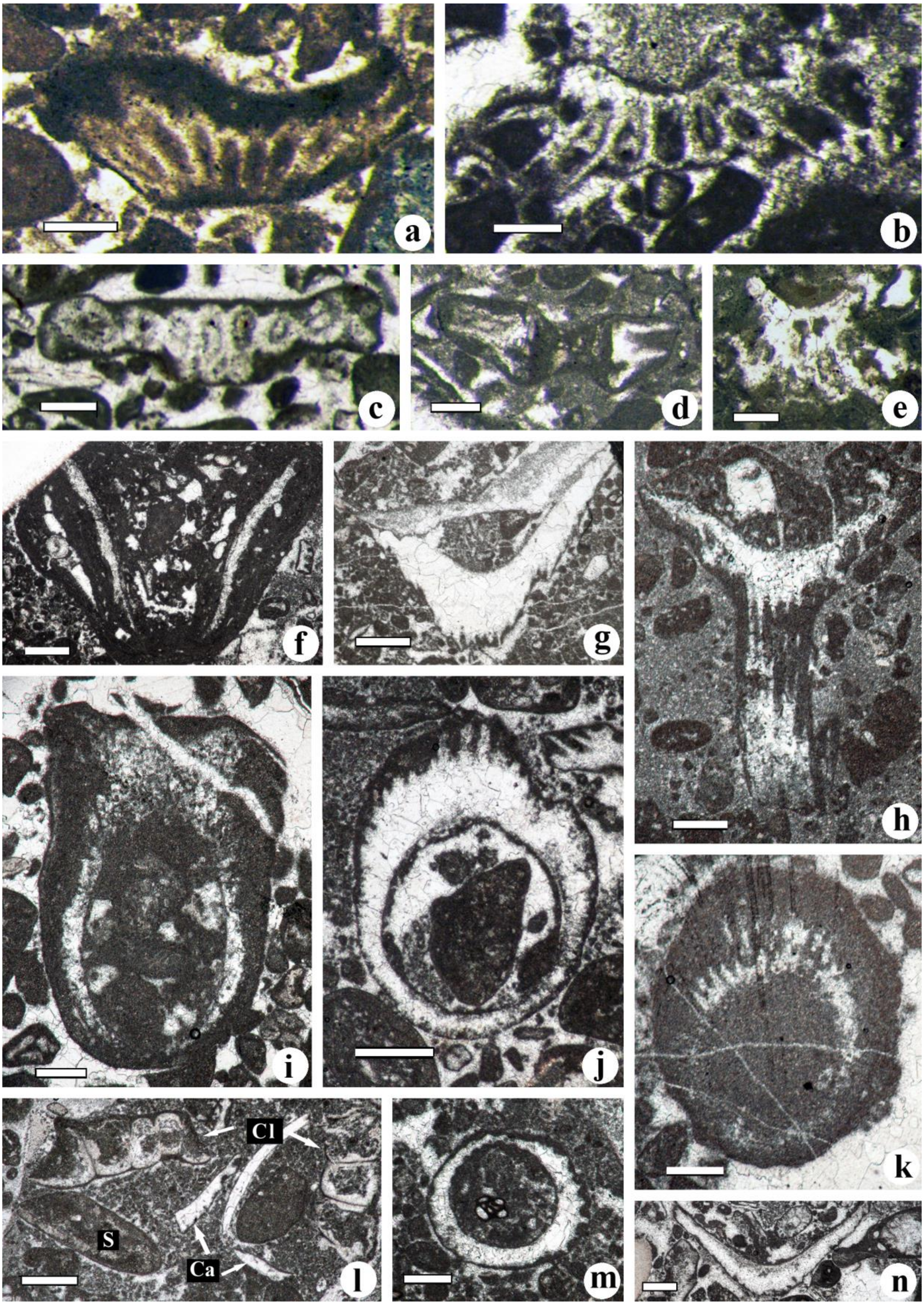

Fig. 3 Calcareous algae (Dasycladales) from the Belogorsk (**a** to **e**) and Yalta-Ay Petri (**f** to **n**) areas, southern Crimea. **a** to **e** *Actinoporella* gr. *podolica* (Alth) in oblique-tangential (a, b), longitudinal-tangential (c) and longitudinal (d) sections. a, sample 003A; b, sample 007B; c, e, sample 013C; d, sample 014. **f** to **k, m, n** *Campbelliella striata* (Carozzi) in longitudinal oblique (f), tangential (g, h, n), oblique-transverse (i, j, k), and transverse (m) sections. f, sample KC-28; g, sample KB-24-1a; h, sample KE-4e; I, sample KC-41; j, sample KB-25b; k, sample KE-8; m, sample KB-24e; n, sample KB-25d. **l** *Clypeina sulcata* (Alth) (Cl), ?*Salpingoporella* sp. (or stipe of *Humiella*?) (S), and fragments of *Campbelliella* (Ca). Sample KB-22. Scale bar: 0.25 mm (a to g, j, n); 0.5 mm (h, i, k, m).

?*Clypeina* sp.
Fig. 14 d
?*Clypeina*/*Actinoporella* sp.
Fig. 14 e, i
A single specimen that can be assigned to the genus *Clypeina* (Fig. 14 d) was found in Tithonian limestones of the Ay-Petri massif. Another specimen of a "clypeiniform" dasyclad (Fig. 14 e, i), represented by oblique or tangential sections of verticils, could belong either to *Clypeina* or *Actinoporella*.

Genus *Chinianella* Ott ex Granier & Deloffre, 1993
Chinianella scheimpflugi Hofmann, 1994, emend. Schlagintweit, 2011
Fig. 4 a-f
Schlagintweit (2011) recently revised this alga that was first described by Hofmann (1994). The emended diagnosis states that the basal part of the thallus of *C. scheimpflugi* is represented by a well-marked stalk showing only alternating sterile phloiophorous laterals, as well as a more-developed main part with laterals arranged into vertical rows. The Crimean specimens identified by us were also examined and illustrated by Schlagintweit (2011). Currently, *C. scheimpflugi* is only known from 5 sites: Ernstbrunn (Austria) – the type-locality (Hofmann, 1994); Plassen carbonate platform (Northern Calcareous Alps, Austria) (Schlagintweit, 2011), Parnassus (Greece) (Carras, 1995; Schlagintweit, 2011), Outer Carpathians (Poland) (Bucur et al., 2005; Schlagintweit, 2011) and Crimea (Schlagintweit, 2011; this paper).

Genus *Griphoporella* (Pia, 1915) Barattolo *et al.*, 1991
Griphoporella cretacea (Dragastan, 1967) Bucur & Schlagintweit, 2009
Fig. 4 g-l
Initially, Dragastan (1967) described this species as *Pseudoepimastopora cretacea.* In the following decades, it has been successively assigned to several genera: *Epimastoporella* Roux, 1979 (by Bucur, 1992), *Anisoporella* Botteron, 1961 (by Bucur, 1995, 2000) and *Griphoporella* (Pia, 1915) (by Bucur & Schlagintweit, 2009). Attribution to the last genus was already suggested by Bucur *et al.* (2005) following emendation of *Griphoporella* by Barattolo *et al.* (1993). Bucur *et al.* (2005) also emphasized the resemblance between the cap of some *Petrascula* specimens and thallus fragments of *Griphoporella*.

Genus *Humiella* (Sokač & Velić, 1981) emend. Masse *et al*., 1984, emend. Sokač, 1987
?*Humiella* sp.
Fig. 14 b, f
Very rare specimens, represented by sections of laterals, in the Lower Berriasian limestones of the Ay-Petri massif are here doubtfully assigned to this genus.

Genus *Neogyroporella* Yabe & Toyama, 1949
Neogyroporella? *gawlicki* Schlagintweit, 2005
Fig. 14 c, g, h
This species was firstly described by Schlagintweit (2005) from Upper Tithonian-Lower Berriasian deposits in the Northern Calcareous Alps. The specimens illustrated are from Kimmeridgian-Tithonian limestones of the Ay-Petri and Yalta massifs.

Genus *Otternstella* Granier in Granier *et al.*, 1994
?*Otternstella* sp.
Fig. 14 a
A single specimen identified in the Upper Tithonian limestones of Ay-Petri Massif, represented by an oblique-tangential section in which sterile and fertile verticils alternate.

Genus *Petrascula* (Gümbel, 1873) Bernier 1979
Petrascula sp., cf. *Petrascula bursiformis* Etallon, 1859
Fig. 13 f, g, k
Rare specimens in transverse, transverse-oblique or tangential sections were identified from near Belogorsk. With a large number of primary, club-shaped laterals, and a bush of secondary laterals developed at their distal end, they resemble sections through the stipe of *Petrascula bursiformis.*

Genus *Rajkaella* Dragastan & Bucur, 1988
Rajkaella iailensis (Maslov, 1965) Dragastan & Bucur, 1988
Fig. 5 a-o
This is one of the species first described from Crimea (Maslov, 1965), as *Kopetdagaria iailensis*. Afterwards, Conrad & Peybernès (1976) assigned this species to *Griphoporella* and Conrad & Radoičić (1979) to *Pseudoclypeina*. Granier (1988, 1990) considered the species invalid. Dragastan & Bucur (1988) designated a lectotype of the species *K. iailensis* and transferred it to the new genus *Rajkaella*, an assignment accepted by Granier & Deloffre (1993).
Most of the Crimean specimens were identified in the Belogorsk area. Some others, assigned with some uncertainty to *R. iailensis*, were collected from the Ay-Petri and Yalta area (Fig. 6 b-e).

Genus *Salpingoporella* Pia in Trauth, 1918, emend. Carras *et al.*, 2006
Salpingoporella annulata (Carozzi, 1953)
Fig. 6 g-k
Salpingoporella gr. *pygmaea* (Gümbel, 1891) emend. Carras *et al.*, 2006
Fig. 7 a-k
Recently, Carras *et al.* (2006) revised the species of *Salpingoporella.* In the limestones studied from Crimea we identified both *S. annulata* and *S.* gr. *pygmaea*.
S. annulata is common in deposits of the inner platform (Carras *et al.*, 2006), sometimes showing almost monospecific distribution, and is abundant in restricted inner platform environments (Bucur & Săsăran, 2005).
S. gr. *pygmaea* is one of the most common dasycladaleans we have identified in Crimea, being typical of reef environments. Carras *et al.* (2006) included several previously discrete species within this name: *Salpingoporella exilis* and *Salpingoporella johnsoni* (Dragastan, 1971), *Salpingoporella enayi* and *Salpingoporella etalloni* (Bernier, 1984). Carras *et al.* (2006: p.486) suggested that a distinctive feature for the species is the presence of "laterals arranged in

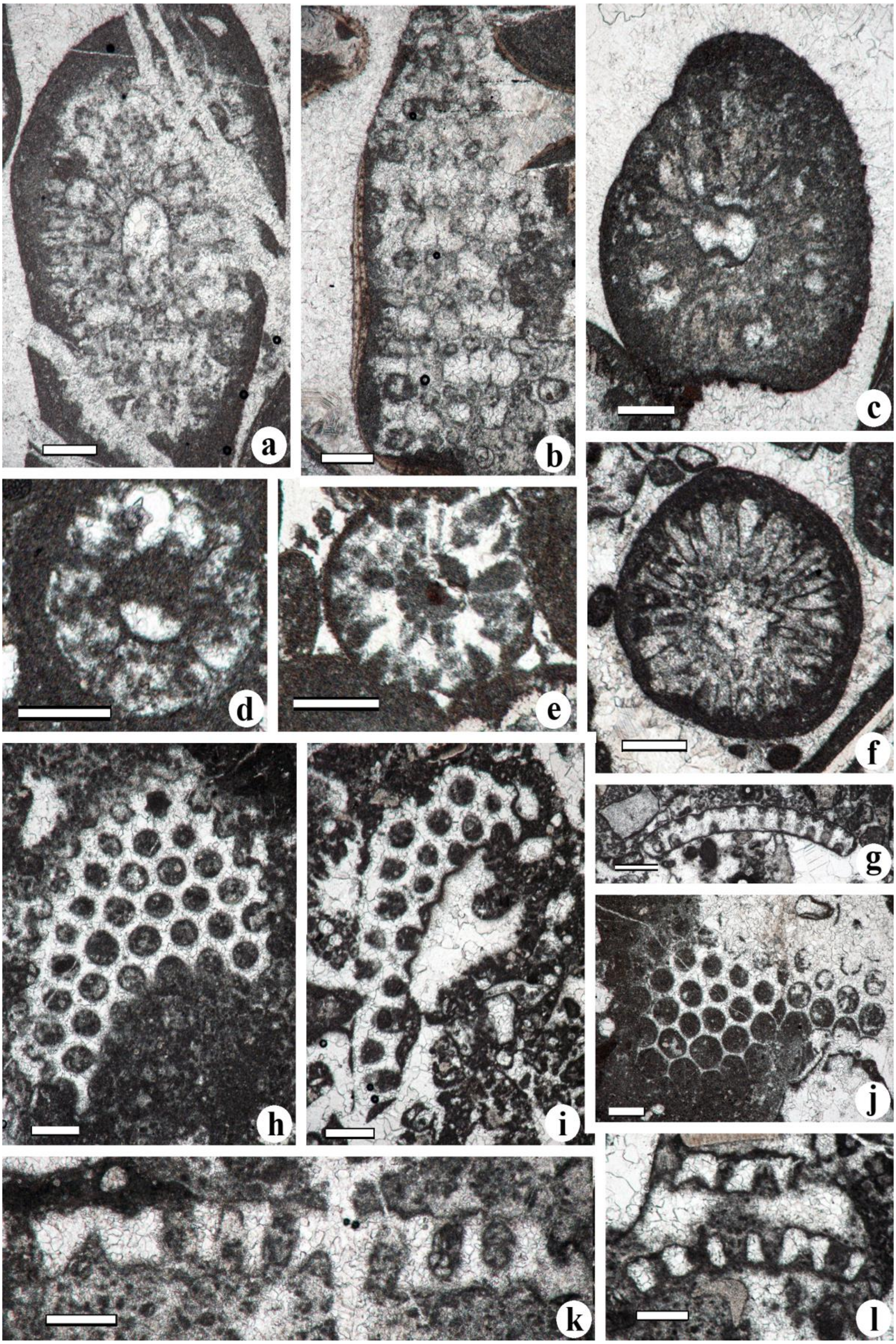

Fig. 4 Calcareous algae (Dasycladales) from the Yalta-Ay Petri area, southern Crimea. **a** to **f** *Chinianella scheimpflugi* Hofmann in oblique (a, c), tangential (b) and transverse (d-f) sections. a, sample KB-15c; b,c, sample KB-27; d, sample KE-12; e, sample Kj-5a; f, sample KC-11. **g** to **l** *Griphoporella cretacea* (Dragastan) in oblique-tangential (h, i), tangential (j), and oblique-longitudinal and longitudinalal (g, k, l) sections. g, sample KB-40a; h, i, sample KB-40b; j, sample KB-38c; k, sample KB-7a; l, sample KB-7e. Scale bar: 0.25 mm (a to f, h to l); 0.5 mm (g).

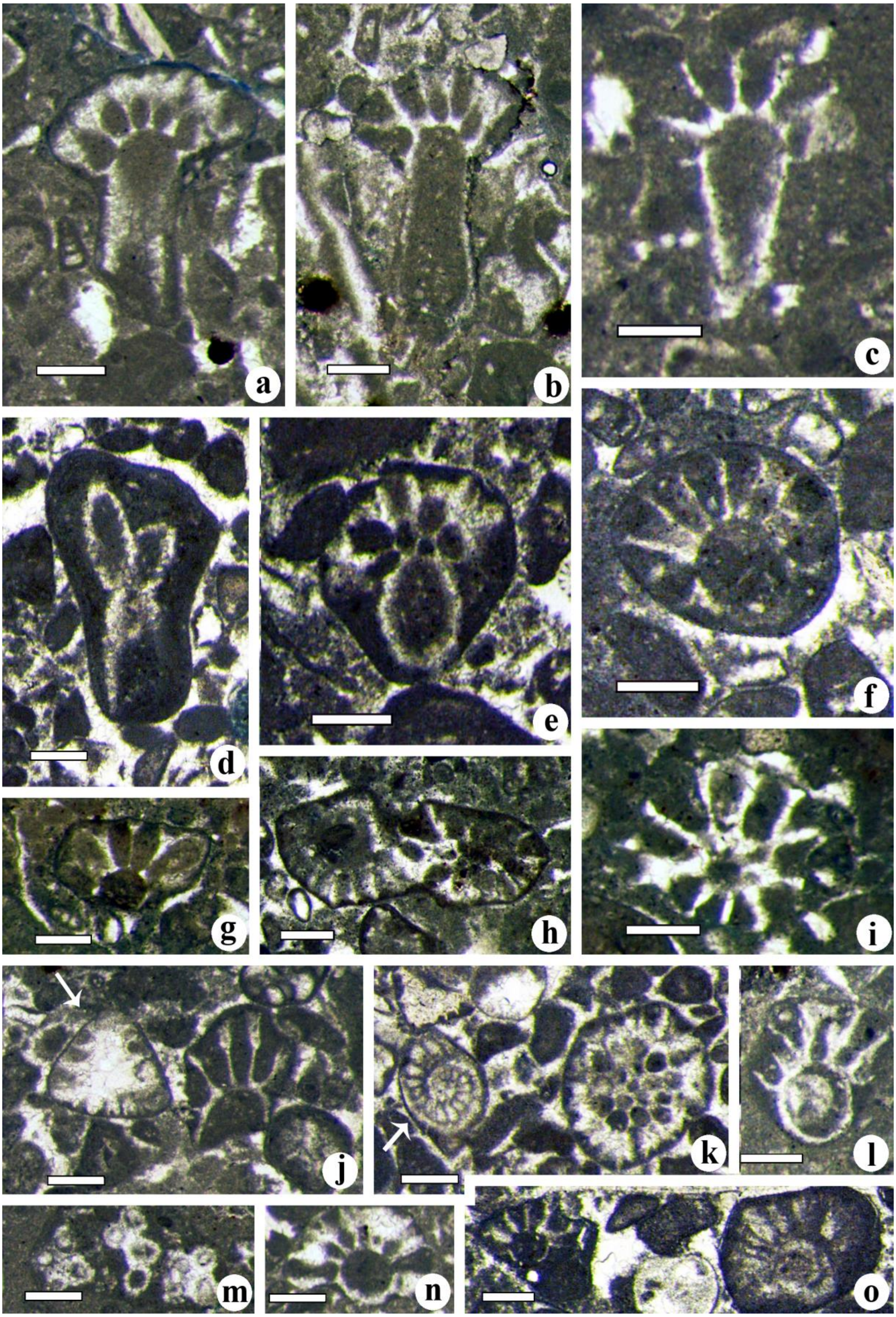

Fig. 5 Calcareous algae (Dasycladales) from the Belogorsk area, southern Crimea. **a** to **o** *Rajkaella iailensis* (Maslov). Sections through primary and secondary laterals (a to e), the distal end of the primary and secondary laterals (f to l, n, o), and tangential section through secondary laterals (m). Note the presence of the foraminifers *Coscinoconus alpinus* (Leupold) (j, arrow) and *Protopeneroplis ultragranulata* (Gorbatchik) (k, arrow). a, b, c, j, l to n, sample 014; d, f, k, sample 002A; e, sample 001; g to i, sample 012; 0, sample 006A. Scale bar: 0.25 mm (a to o).

quincunxes, […] first leaning up narrow and slightly widening out, then subhorizontal, markedly widening out." Nevertheless, not all the specimens illustrated in the references correspond to this description. Sometimes the laterals are short, phloiophorous and slightly inclined, lacking the distal end (*e.g.*, Hofmann, 1991, Pl. 1, figs. 1-3; Senowbari *et al.*, 1994, pl. 3, figs. 6, 9, or the present paper, Fig. 7a).

On the other hand, Carras *et al.* (2006) also emphasized that defining a species based on the ratios between size parameters (cf. Bernier, 1984) is a counterproductive principle that should be abandoned, and this is supported by our diagrams based on the Crimea specimens (Fig. 8a-b).

Genus *Selliporella* Sartoni & Crescenti, 1962

?*Selliporella* sp.

Fig. 14 l, n

Random sections through *Coptocampylodon*-like corpuscles could represent fragments of laterals of a *Selliporella* species.

Genus *Steinmanniporella* Bucur, Granier & Schlagintweit, 2010

Steinmanniporella taurica (Pcelincev, 1925) Bucur *et al.*, 2010

Figs. 9-11

Synonymy

1925 *Tetraporella taurica* n. sp. – Pcelincev, p.85-86, Pl. 2, fig. 5

1965 *Linoporella taurica* (Pcelincev) – Praturlon, p.3-4.

1978 *Tetraporella taurica* Pcelincev – Bassoullet *et al.*, p. 149-150, Pl. 17, fig. 5 (reproduction of the original illustration; considered as synonym of *Linoporella capriotica*)

2005 *Linoporella* (?) *taurica* Pcelincev – Barattolo & Romano, p.238

2010 *Steinmanniporella taurica* (Pcelincev, 1925) nov. comb. – Bucur *et al.*, p. 320, Fig. 1b (reproducing the specimen illustrated by Pcelincev, 1925).

Even though described in 1925, *S. taurica* remains a poorly studied species, as illustrated by the brief list of synonyms. The type-specimen presented by Pcelincev (1925) was collected at the Kukhu-koy locality from "oolitic-like limestones" assigned by the author to the "Lusitanian"-Lower Kimmeridgian interval. Pcelincev (1925: p. 85-86) provided the following species description (translation from Bassoullet *et al.*, 1978):

"In the Kücük-köy oolitic limestones, we frequently meet stalks and fragments of these calcified algae. About their external morphology, they are semicylindrical club-shaped with rounded end. Their maximal diameter is 3.2 mm long and their length is 14 mm. Only the external part of the stalk has been observed. In longitudinal section the internal cavity, appears, where the proper plant lives. From that cavity, primary canals crop outwards which appear, in distinct rings, on the outer part of the fossilized cylinder. When the thin outer layer has been destroyed, the concentric series of canal openings appears with a quantity no more than 30 per segment. On the whole length, the primary cylindrical canal has a constant diameter. Near the outer part of the external layer of the calcareous cylinder, each canal is divided into 4 secondary canals that are arranged on the external part of the cylinder. Small spores are situated principally at the distal end of a primary canal."

The specimens identified by us show cylindrical, non-branched thalli (no club-shaped thalli were noticed, but based on the original description we cannot exclude the presence of such a morphology) with external diameters ranging from 1.6 to 4 mm.

The relatively large axial cavity (about 1/3 of the thallus diameter, from 0.6 to 2.4 mm) is well-defined, commonly outlined by a thin micritic rim (Fig. 9 c, f; Fig. 10 e). The primary laterals show perpendicular arrangement or are slightly tilted towards the axial cavity. They have tubular shapes with rounded transverse sections and relatively constant diameter along the whole length. These laterals build-up relatively widely spaced verticils (Fig. 9 a-d; Fig. 10 a-f; Fig. 11 h). The number of primary laterals within a verticil varies from 38 to 45. Their length ranges from 0.25 to 0.70 mm and the diameter from 0.07 to 0.10 mm. The secondary laterals, ranging from 0.12 to 0.35 mm in length have a tubular proximal part followed by distal expansion (Fig. 9 e; Fig. 10 a, e, f; Fig. 11 a-d). They are attached at the distal end of the primary laterals, each of the primary giving rise to 4 secondary laterals (Fig. 11g, i). The close-up view (Fig. 11 f) clearly illustrates the overall morphology of the primary and secondary laterals. Pcelincev (1925) noted the presence of some "spores" at the distal end of the primary laterals. However, further studies of numerous specimens have failed to confirm this feature.

Calcification consists of a sparitic calcareous sleeve (low-magnesian calcite replacing the original aragonite) surrounding the axial cavity and extending outwards almost to the distal end of the secondary laterals. In specimens from more agitated environments with terrigenous supply the calcareous sleeve is partly eroded (Fig. 9 f; Fig. 10 a, b). In some specimens that constitute the core of bacinellid oncoids (Fig. 9 b), the skeleton is "invaded" by such structures.

The general dimensions for this alga are included in Table 2. Despite providing a useful morphological description, Pcelincev (1925) did not present a diagnosis for this alga. Our observations identify the following diagnostic traits: Cylindrical (or possibly club-shaped), non-branched thallus with large, well-defined axial cavity. Two-orders of laterals displayed into verticils widely-spaced along the axial cavity. The primary tubular, cylindrical laterals are arranged perpendicularly or slightly-inclined with respect to the axial cavity. A bush of 4 phloiophorous secondary laterals is located at their distal end. Reproduction organs unknown, probably located within the axial cavity (endosporous).

Steinmaniporella taurica and *S. kapelensis (*a species identified in deposits of similar age) can be distinguished by observing the arrangement of the primary laterals (perpendicular vs. very steep) with respect to the axial cavity, as well as the inter-verticilar distance, which is smaller in the case of *S. kapelensis*. The general morphological features allow this species to be distinguished from other species of the genus *Steinmanniporella* (Bucur *et al.*, 2010).

Table 2 Dimensional parameters of *Steinmanniporella taurica* (Pcelincev)

Sample	Specimen	L	D	d	d/D	l1	l2	p1	p2	h
KB-4-1a	1		2.2	1	0.45	0.7				
KB-4-1a	2		2.2	1.2	0.54	0.3	0.15	0.08		0.3
KB-10	3		2.25	1.4	0.62					
KB-14	4		4	2.4	0.6					
KB-38a	5	7.68	2.2	1.1	0.5	0.3	0.26	0.08	0.05	0.42
KB-41a	6		2.24	1.22	0.54	0.3	0.26	0.07	0.04	0.42
KB-38a	7									0.35
KB-41a	8		2.3	1.14	0.49	0.3	0.25	0.07	0.05	
KB-41b	9		2.85	1.2	0.42	0.5	0.27	0.07	0.05	0.45
KB-41b	10		2.4	1.1	0.46	0.45	0.25	0.07	0.05	
KB-41d	11		2.64	1.1	0.42	0.45	0.35	0.07	0.04	
KB-41c	12		2.3	1.14	0.49					
KB-51b	13		2.3	1.1	0.48	0.4	0.2	0.08		
KB-51k	14		2.8	1.1	0.39	0.37	0.22	0.08	0.05	
KB-51K	15									0.35
KB-51L	16		2.2	0.6	0.27	0.3	0.2			
KB-51m	17	8.8	2.3	1.02	0.44	0.4	0.25	0.09	0.05	0.35
KB-51m	18		2.1	1	0.48	0.35	0.22	0.08	0.06	
KC-13	19		2.5					0.1		
KC-13	20		2.4	1.05	0.44	0.4	0.25	0.08	0.04	
KC-17b	21	7.58	2.6	1.4	0.54	0.37	0.23	0.085	0.055	0.35
KC-17b	22		2.5	1.2	0.48	0.3	0.2			
KC-17b	23		2.3	1.2	0.52	0.3	0.22			
KC-17c	24		2.1	1	0.48	0.3	0.22			
KC-17c	25		2.1	1.1	0.52			0.1	0.08	0.35
KJ-23a	26	6.6	1.8	1	0.55					
Kj-23a	27		1.8	1.04	0.58	0.25	0.12			
Kj-23a	28		1.6	0.92	0.57					
Kj-23a	29		1.7	1.1	0.65					
Kj-23a	30		2	0.8	0.4					
Kj-23a	31		2	1.1	0.55					
Kj-23a	32		2.5	1	0.4					
Kj-23b	33		1.9	1.1	0.58	0.25	0.18	0.07	0.04	0.38
Kj-23b	34		2	1.14	0.57	0.3	0.18	0.08	0.05	0.4
Total		4	32	31	31	21	20	17	14	11
Min.		6.6	1.6	0.6	0.27	0.25	0.12	0.07	0.04	0.3
Max.		8.8	4	2.4	0.65	0.7	0.35	0.1	0.08	0.45
Average		7.665	2.284	1.1281	0.4974	0.361	0.224	0.0797	0.0504	0.3745
Standard deviation		0.9	0.43	0.2793	0.0797	0.103	0.0488	0.0098	0.0105	0.0437

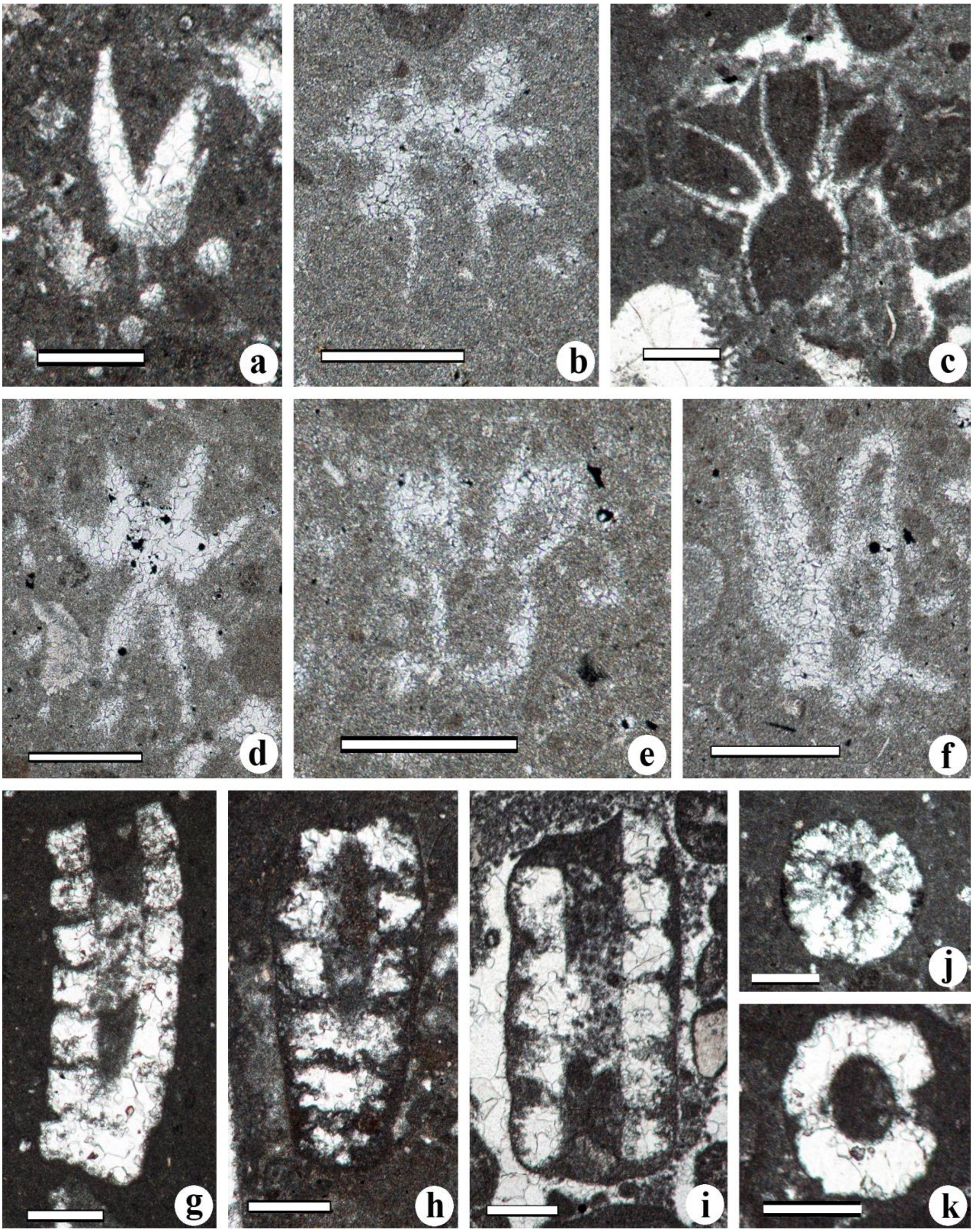

Fig. 6 Calcareous algae (Dasycladales) from the Yalta-Ay Petri area, southern Crimea. **a, f** *Rajkaella* sp. Sections through secondary laterals. a, sample KA-11; f, sample KR-9. **b** to **e** *Rajkaella* cf. *iailensis* (Maslov). Distal part of primary laterals and secondary laterals in longitudinal-oblique section. b, sample KE-4; c, sample KJ-32; d, e, sample KR-9. **g** to **k** *Salpingoporella annulata* Carozzi in longitudinal-oblique (g), oblique (h), longitudinal (i), transverse (j) and transverse-oblique (k) sections. g, sample KE-4d; h, sample KJ-5e; i, sample KA-7; j, k, sample KE-4b. Scale bar: 0.25 mm (a to k).

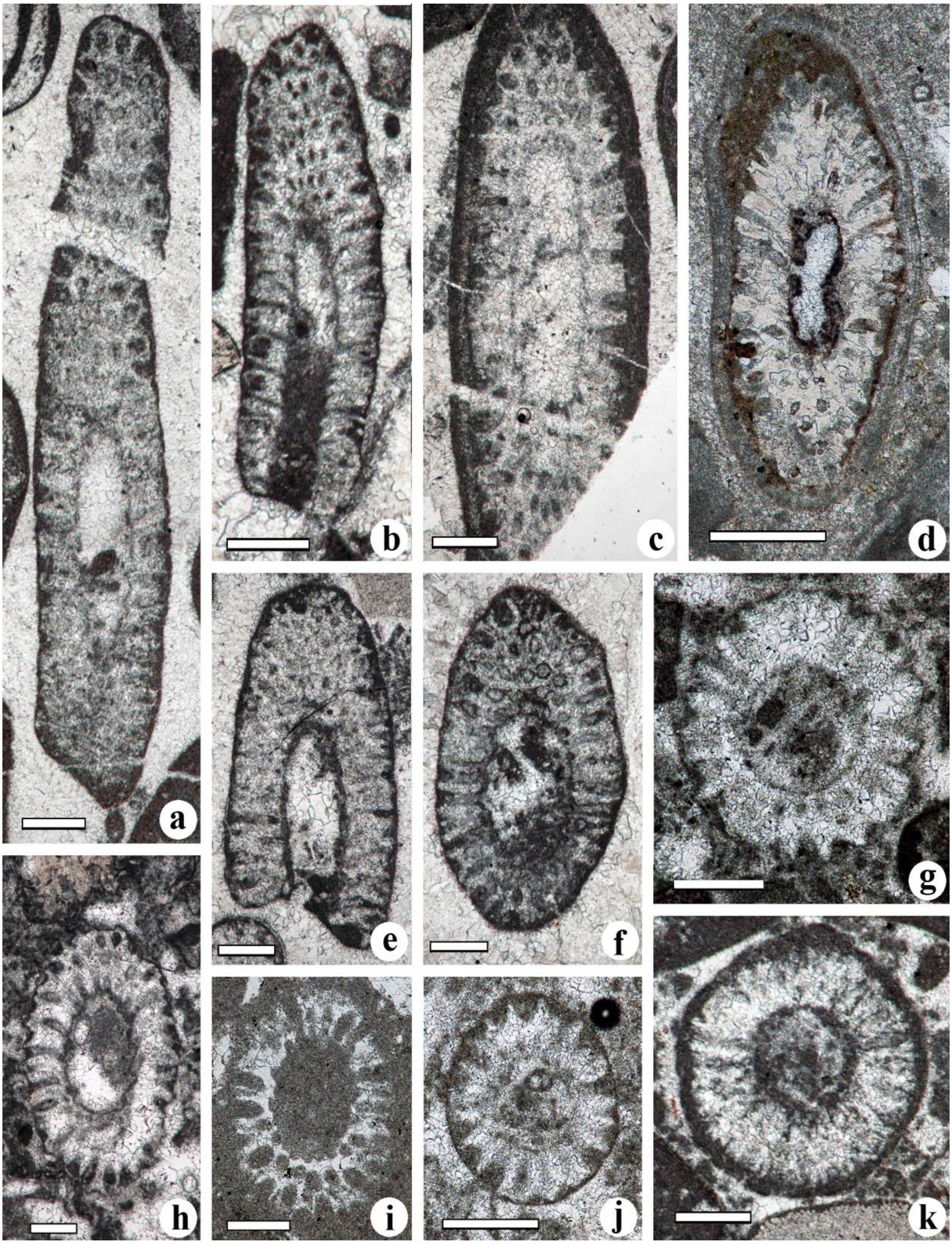

Fig. 7 Calcareous algae (Dasycladales) from the Yalta-Ay Petri area, southern Crimea. **a** to **k** *Salpingoporella* gr. *pygmaea* (Gümbel) in longitudinal oblique and oblique (a to f) sections, and transverse-oblique and transverse (g to k) sections. a, c, sample KB-15b; b, sample KC-11; d, sample KB-47a; e, sample KB-6b; f, sample KB-5; g, sample KB-40a; h, sample KB-42d; i, sample KO-3a; j, sample KB-13; k, sample KB-15c. Scale bar: 0.25 mm (a to k).

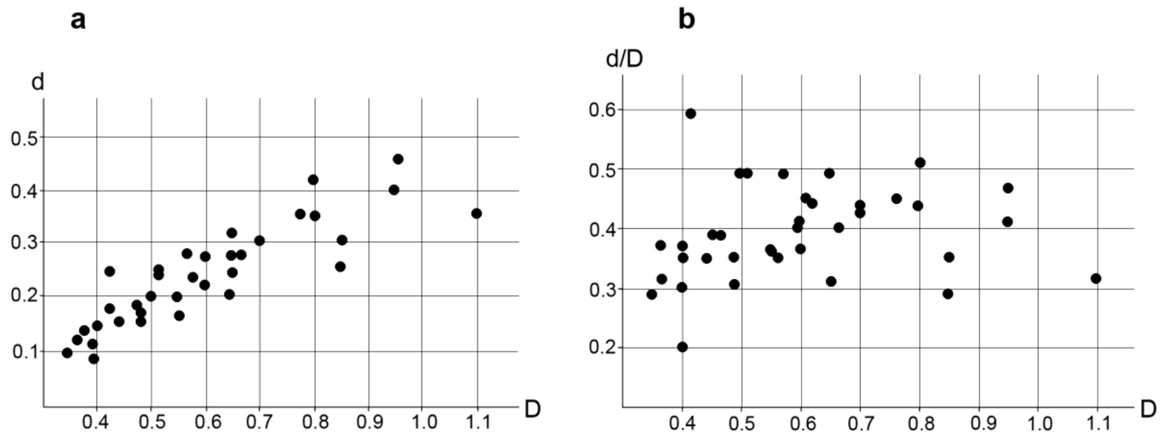

Fig. 8 Diagram showing variation of D (external diameter) in relation to a (diameter of the axial cavity) (**a**) and to the ratio d/D (**b**) in *Salpingoporella* gr. *pygmaea*.

In the study area, *S. taurica* was mainly identified in high energy environments (grainstones, probably bioclastic bars) associated with reef facies, as well as in reef facies with sponges, of Kimmeridgian-Tithonian age.

Associated microfossils: *Salpingoporella* gr. *pygmaea*, *Griphoporella* sp.,? *Clypeina*/ *?Actinoporella* sp., "sole-noporaceans", rivulariacean cyanobacteria, *Mohlerina basiliensis*, *Troglotella incrustans*, *Coscinophragma* sp., *Ammobaculites* sp., *Acruliammina* sp., *Crescentiella morronensis*, *Lithocodium aggregatum*, bacinellid structures.

Genus *Suppiluliumaella* Elliott 1968
Suppiluliumaella delphica (Carras, 1989) Senowbari-Daryan *et al.*, 1994
Fig.12 a-f
This dasycladalean alga was assigned by Carras (1989) with doubt to *Clypeina*. Senowbari *et al.* (1994) transferred the species to *Suppiluliumaella* based on the presence of short secondary laterals in a few specimens.

This feature is rarely present, mainly due to common erosion of the outer surface of the calcareous skeleton, but probably also to the incomplete calcification of the distal part of the laterals. We also assume the presence of short secondary laterals in the case of the specimen illustrated in Fig. 12 f (arrow). We identified *S. delphica* in Kimmeridgian-Tithonian limestones from the Ay-Petri and Yalta massifs.

Suppiluliumaella sp.
Fig. 12 g, h; Fig. 13 a-e, h-j
This alga is relatively common in limestones from the Belogorsk area, but is poorly preserved; it also occasionally occurs in deposits from the Ay-Petri and Yalta massifs. It shows a wide central cavity, and primary club-shaped laterals with bushes of phloiophorous secondary laterals at their distal end. The type of connection between the primary and the secondary laterals is very similar to that in "*Montenegrella*" (Sokač & Nikler, 1973).
Genus *Terquemella* Munier-Chalmas ex L. et J. Morellet, 1913
Terquemella sp.
Fig. 14 m
Rare specimens identified in the upper Tithonian limestones of the Ay-Petri massif

Genus *Triploporella* Steinmann 1880
?*Triploporella* sp.
Fig. 14 j-k
Illustrated by a partial section through a thallus showing the primary laterals, hosting a large number of sparitic corpuscles with round sections, probably representing reproductive cysts. The assignment to *Triploporella* is doubtful, partly because of the lack of secondary laterals, and also because the cysts are more likely simple and not cyst-containers – as they are in *Triploporella* (sensu Barattolo, 1980).

Thaumatoporellales
Genus *Thaumatoporella* Pia, 1927
Thaumatoporella parvovesiculifera (Raineri, 1922) Pia, 1927
Fig. 14 o, p
Well-known species related mostly to reefal facies, associated with bacinellid structures.

Bryopsidales
Udoteaceae
Genus *Arabicodium* Elliott, 1957
Arabicodium sp.
Fig. 15 a-c
Rare specimens identified in the Kimmeridgian-Tithonian limestones of the Ay-Petri massif.

Genus *Nipponophycus* Yabe & Toyama, 1928
Nipponophycus ramosus Yabe & Toyama, 1928 emend. Senowbari-Daryan *et al.*, 1994
Fig. 15 d, e
Nipponophycus is another alga frequently identified in the reefal facies of the Upper Jurassic-Lower Cretaceous of the Tethyan realm. It occurs in the Kimmeridgian-Berriasian limestones of the Ay-Petri massif.

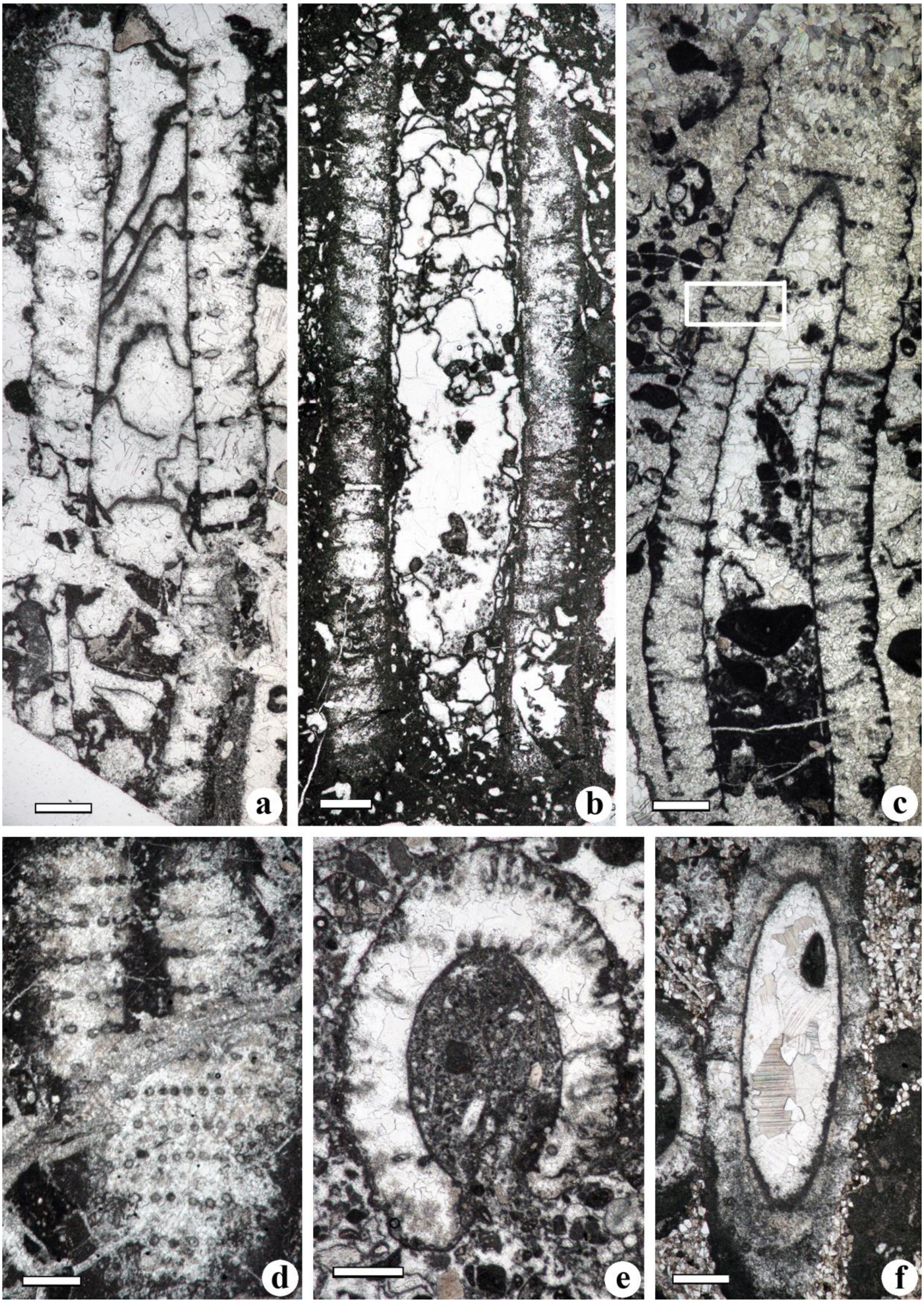

Fig. 9 Calcareous algae (Dasycladales) from the Yalta-Ay Petri area, southern Crimea. a to f *Steinmanniporella taurica* (Pcelincev) in longitudinal (a, b), longitudinal, slightly oblique (c), oblique tangential (d) and oblique (e, f) sections. White square area in c is enlarged in Fig. 11f. a, sample KB-51m; b, sample KC-17b; c, sample KB38a; d, sample KC-13; e, sample KB-51L; f, sample KJ-23a. Scale bar: 0.5 mm (a to f).

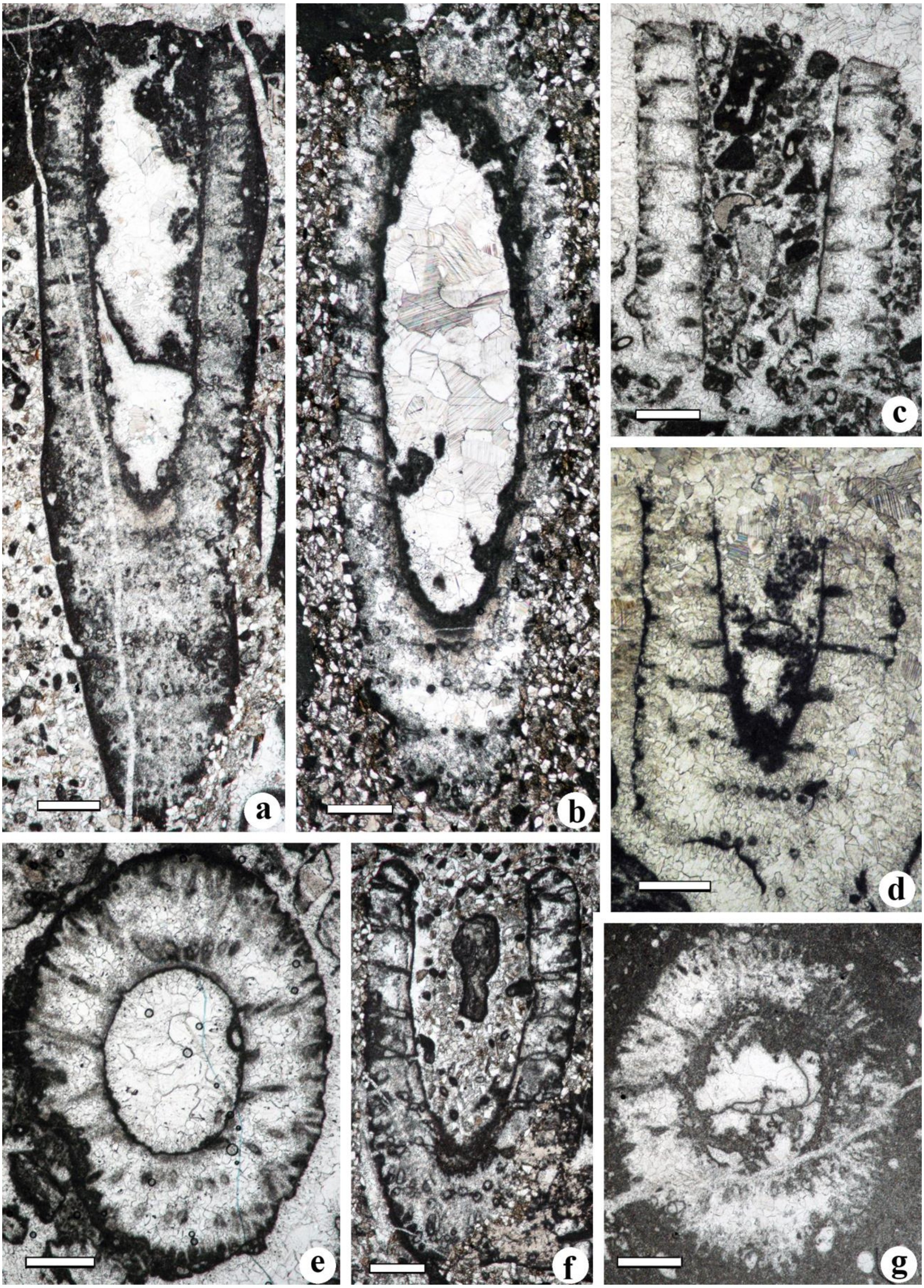

Fig. 10 Calcareous algae (Dasycladales) from the Yalta-Ay Petri area, southern Crimea. **a** to **g** *Steinmanniporella taurica* (Pcelincev) in longitudinal-oblique (a to d, f), oblique (e) and transverse-oblique (g) sections. A, sample KJ-23a; b, sample KJ-23b; c, sample KB-41a; d, sample KB-38a; e, sample KB-41b; f, sample KJ-23b; g, sample KC-17b. Scale bar: 0.5 mm (a to g).

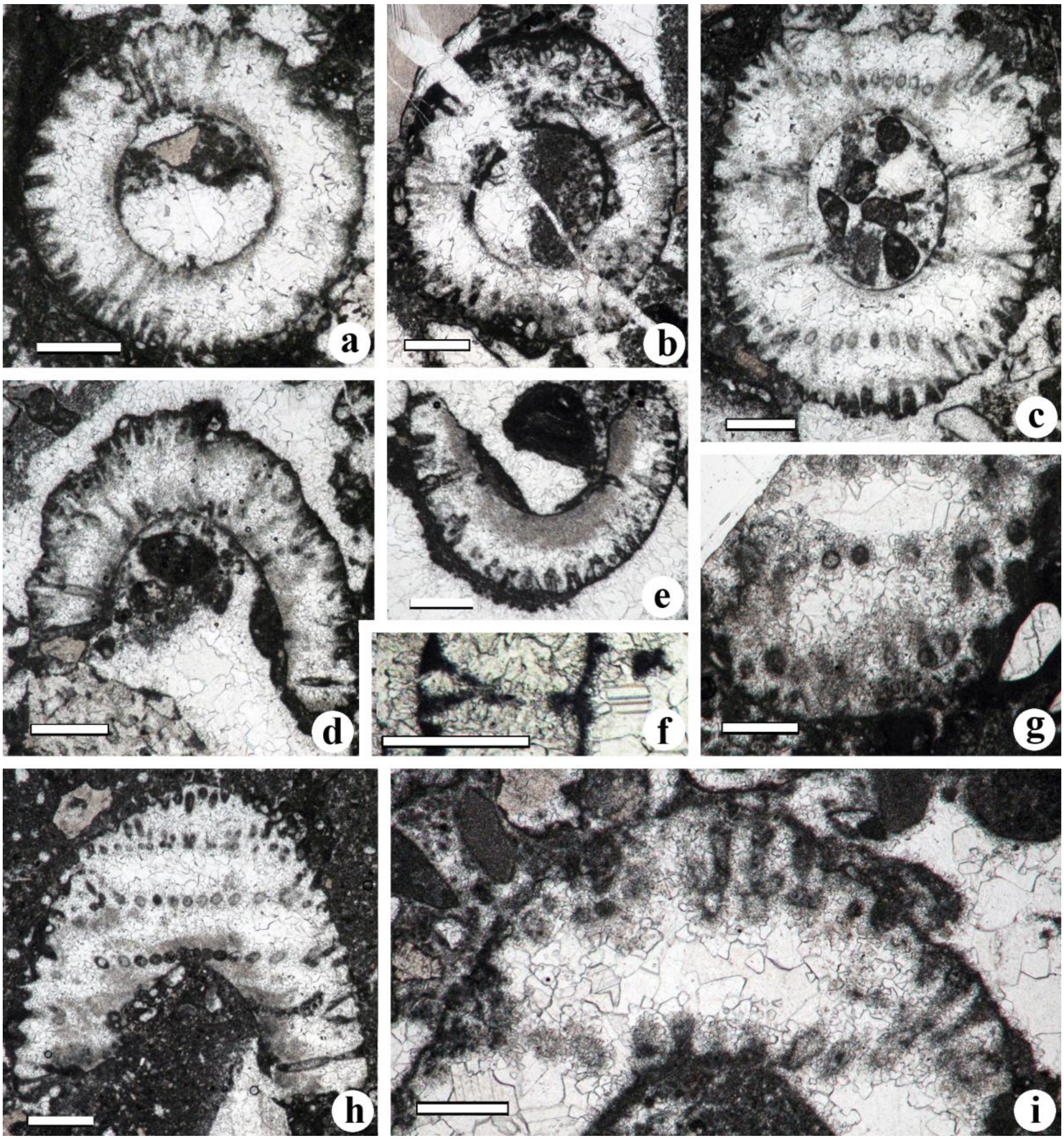

Fig. 11 Calcareous algae (Dasycladales) from the Yalta-Ay Petri area, southern Crimea. a to i *Steinmanniporella taurica* (Pcelincev) in transverse (a, b, e), oblique (d), tangential (g) and oblique-tangential (h) sections. f represents a close-up view of the specimen in Fig. 9c (white square) showing the shape of the laterals, and i represents a close-up view of the specimen in Fig. 9 e (upper part) showing the transition from primary to secondary laterals. a, sample KM-51m; b, g, sample KB-51k; c, sample BK-41d; d, sample KB-41a; e, sample KB-51b; f, sample KB-38a; h, sample KB-41b; i, sample KB-51L. Scale bar: 0.5 mm (a to f, h); 0.25 mm (g, i).

Cyanobacteria

Genus *Cayeuxia* Frollo, 1935

Rivulariacean-like cyanobacteria

Fig. 16 a-g

These cyanobacteria are common in Kimmeridgian-Berriasian shallow-water, often restrictive, facies in the Ay-Petri and Yalta massifs. In spite of the typical aspect of distinctive morphological features, species-assignment is difficult and beyond the goal of this study.

Genus *Girvanella* Nicholson & Etheridge, 1878

Girvanella sp.

Fig. 15 j-k

In Kimmeridgian oncoidal facies of the Ay-Petri massif, *Girvanella* forms the thick cortex of some oncoids.

Genus *Rothpletzella* Wood, 1948/Genus *Pseudorothpletzella* Schlagintweit & Gawlick, 2007

Rothpletzella/*Pseudorothpletzella*-like structures

Fig. 16 h-j

Some crusts identified in the Kimmeridgian limestones of the Ay-Petri massif have a structure similar to that of representatives of the genera *Rothpletzella* and *Pseudorothpletzella*.

Microproblematica

Genus *Crescentiella* Senowbari-Daryan *et al.*, 2008

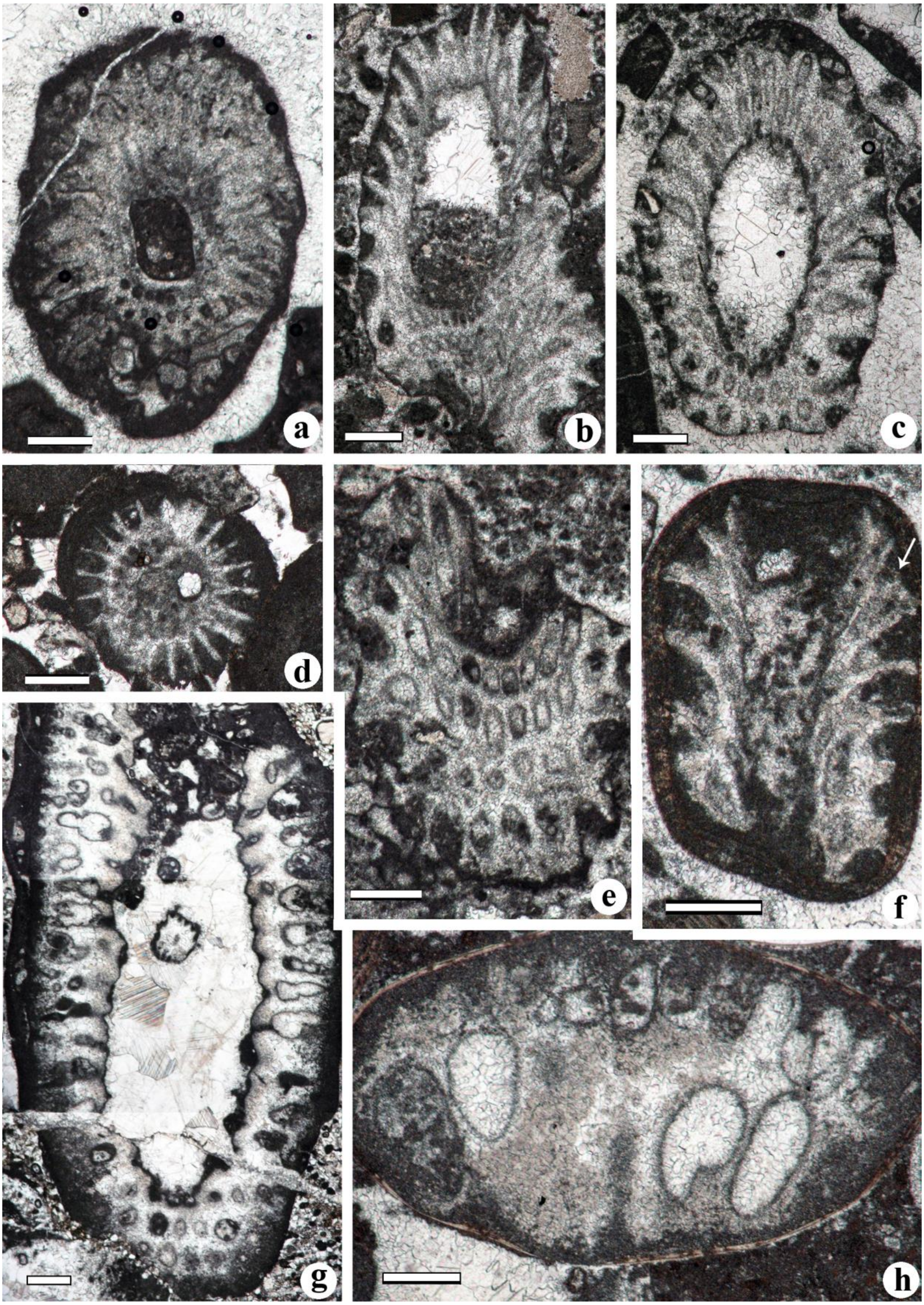

Fig. 12 Calcareous algae (Dasycladales) from the Yalta-Ay Petri area, southern Crimea. **a** to **f** *Suppiluliumaella delphica* (Carras) in oblique (a, c, e), transverse (d) and longitudinal (f) sections. a, f, sample KB-39; b, sample KB-41b; c, sample KB-6b; d, sample KJ-5c; e, sample KB-51a. **g, h** *Suppiluliumaella* sp. In oblique (g) and longitudinal-oblique (h) sections. g, sample Kj-23b; h, sample KC-27. Scale bar: 0.25 mm (a to f, h); 0.5 mm (g).

Crescentiella morronensis (Crescenti, 1969) Senowbari-Daryan *et al.*, 2008
Fig. 15 f-i
Previously known as *Tubiphytes morronensis*, this problematic microorganism was assigned by Senowbari-Daryan *et al.* (2008) to a new genus, *Crescentiella*. It is common and well-known in Upper Jurassic-Lower Cretaceous limestones. In the study area it was identified in Kimmeridgian limestones in the Ay-Petri massif.

Genus *Koskinobullina* Cherchi & Schroeder, 1979
Koskinobullina socialis Cherchi & Schroeder, 1979
Fig. 16 k
Together with *Crescentiella*, *Koskinobilluna* is another microproblematicum frequently identified in reefal limestones of the Tethyan Upper Jurassic (e.g., Schlagintweit & Gawlick, 2008; Pleş *et al.*, 2013).

CONCLUSIONS

Upper Jurassic-lowermost Cretaceous limestones from South Crimea contain a rich association of calcareous algae (dasycladaleans, bryopsidaleans-udoteaceans), thaumatoporellaleans, cyanobacteria and problematic microorganisms. Of these, the dasycladaleans display the largest taxonomic diversity and are present in most of the facies types within the investigated succession. Cyanobacteria and microencrusting organisms are typical for the reef facies.
This association is described in detail here for the first time. These results should be used in regional correlations and in paleogeographical reconstructions at regional/global scale.

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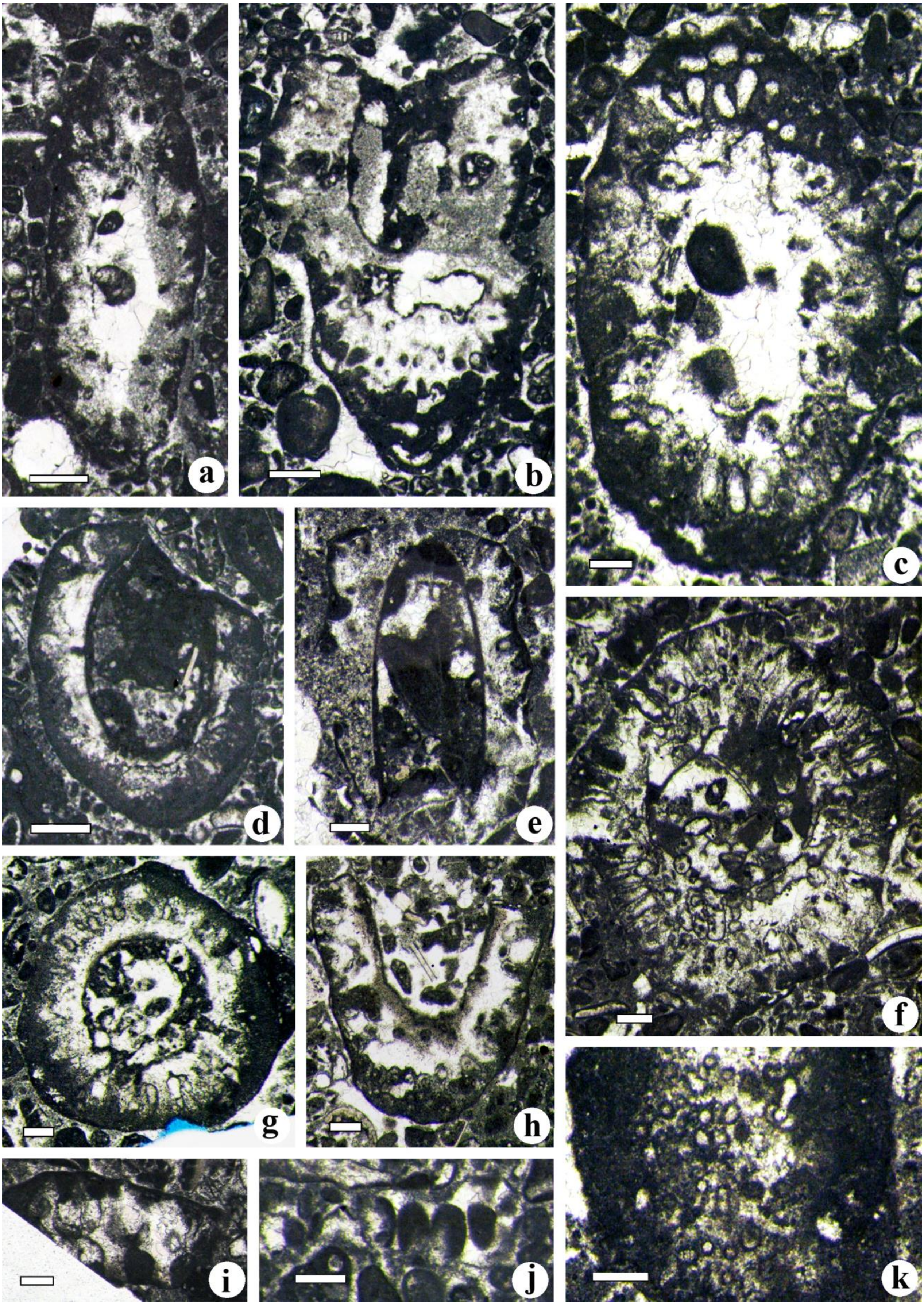

Fig. 13 Calcareous algae (Dasycladales) from the Belogorsk area, southern Crimea. **a** to **e**, **h** to **j** *Suppiluliumaella* sp., in oblique sections. a, sample 001; b, sample 002A; c, i, sample 007B; d, j, sample 008; e, sample 010B; h, sample 014. **f, g, k** ? *Petrascula* sp. cf. *Petrascula bursiformis* (Etallon) in transverse-oblique (f), transverse (g) and tangential (k) sections through the stipe. f, k, sample 009B; g, sample 004A. Scale bar: 0.5 mm (a, b, d,); 0.25 mm (c, e to k).

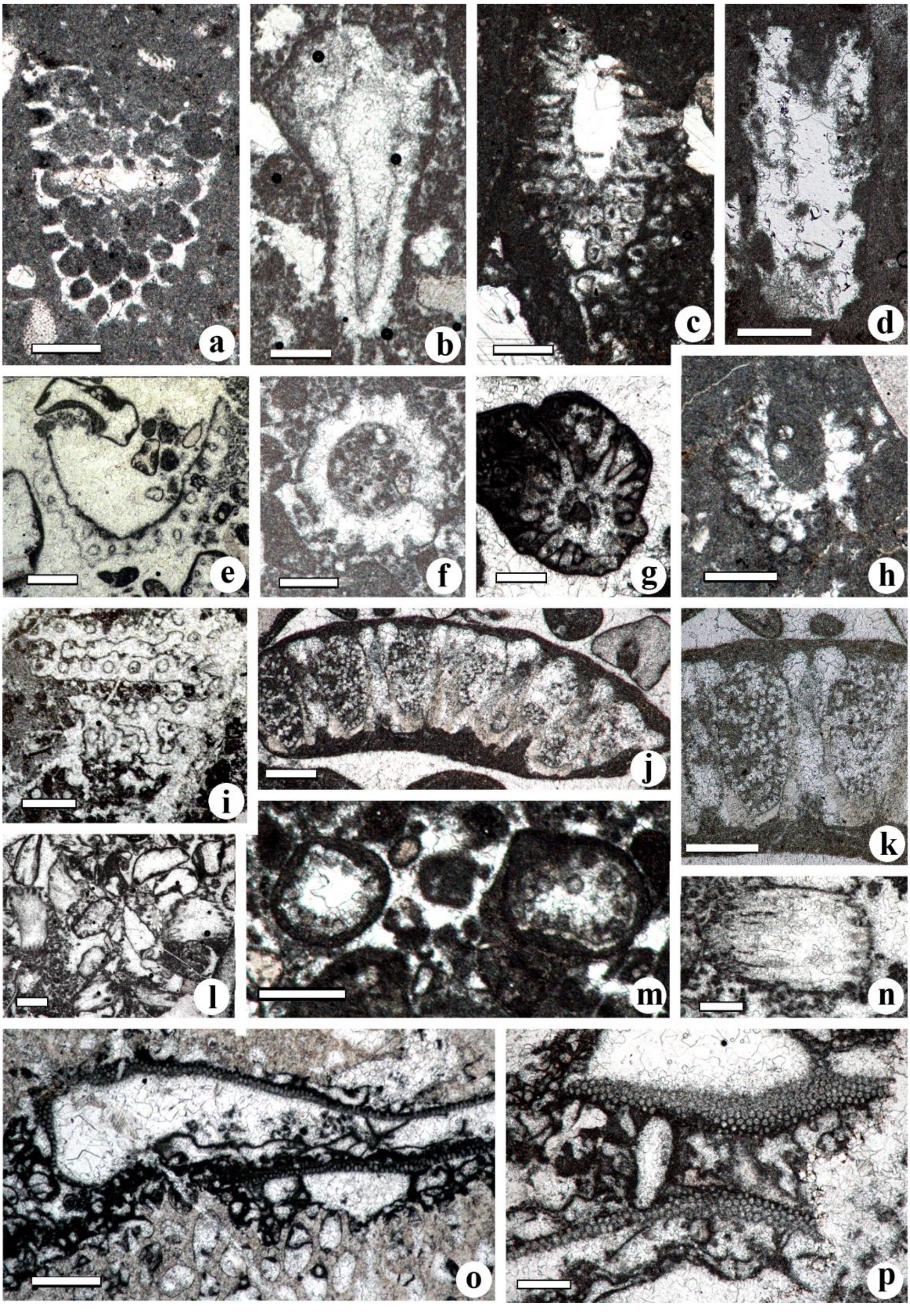

Fig. 14 Calcareous algae (Dasycladales, Thaumatoporellales) and Microproblematica from the Yalta-Ay Petri area, southern Crimea. **a** ?*Otternstella* sp. in oblique-tangential section; sample KO-3a. **b**, **f** ?*Humiella* sp. longitudinal section (b) and transverse section (f) through laterals; sample KA-8. **c**, **g**, **h** *Neogyroporella*? *gawlicki* Schlagintweit in oblique (c), transverse (g), and transverse-oblique section; c, sample KJ-5a; g, sample KB-44a; h, sample KO-3a. **d** ?*Clypeina* sp. in longitudinal-oblique section; sample KE-4e. **e**, **i** *Clypeina/Actinoporella* sp. in oblique (e) and tangential (i) sections; e, sample KB-6b; i, sample KB-14. **j**, **k** Reproductive cysts inside laterals of a triploporellacean alga; sample KC-16; k, enlargements of j. **l**, **n** *Coptocampylodon*-like fragments; possibly lateral fragments of *Selliporella* cf. *neocomiensis* ; sample KB-13. **m**, *Terquemella* sp. (reproductive structures from a large triploporellacean alga); sample KC-33. **o**, **p** *Thaumatoporella parvovesiculifera* (Raineri); o, sample KB-7a; p, sample KB-7b. Scale bar: 0.25 mm (a ton, p; 0.5 mm (o).

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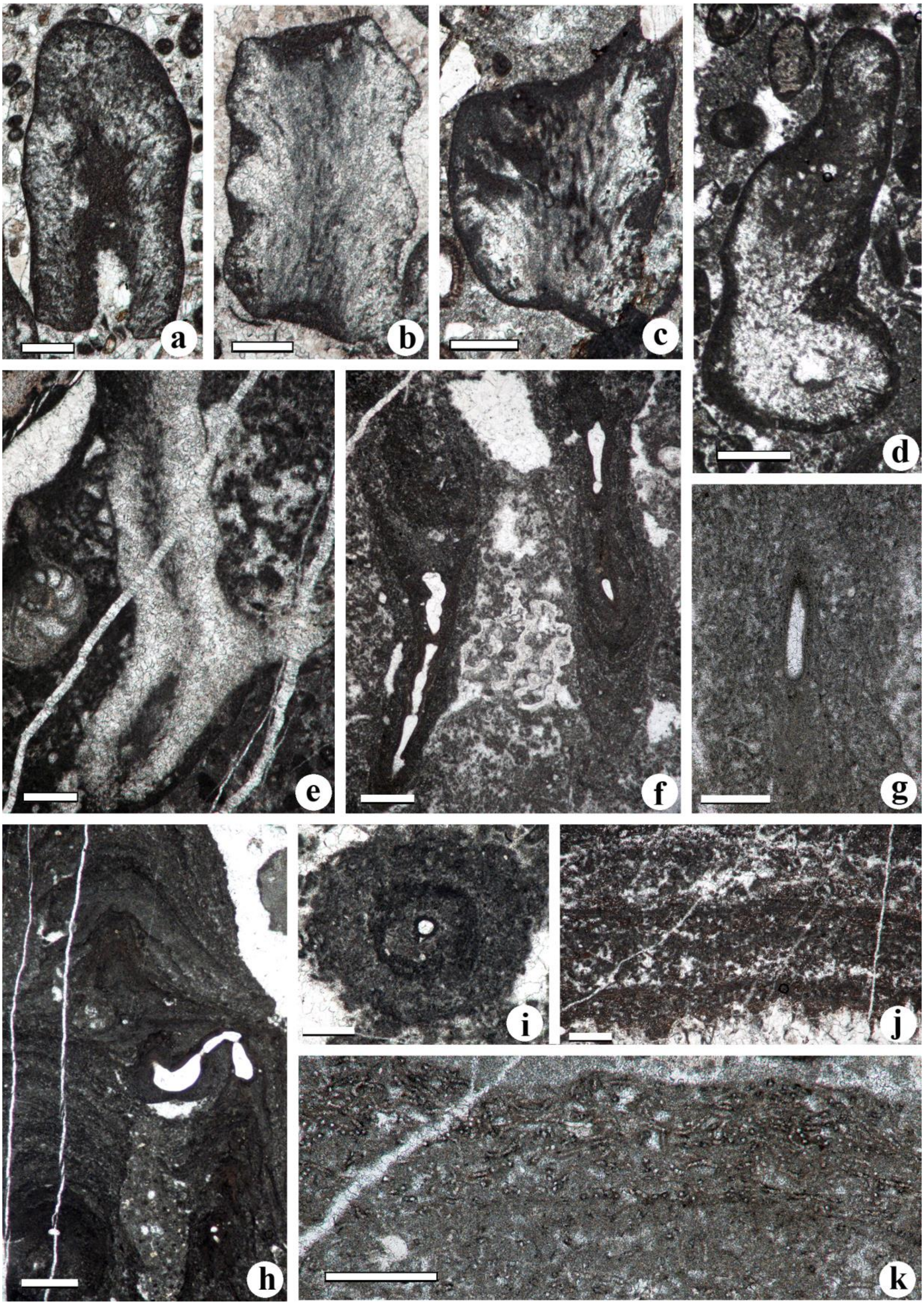

Fig. 15 Calcareous algae (Udoteaceae), Cyanobacteria, and Microproblematica from the Yalta-Ay Petri area, southern Crimea. **a** to **c** *Arabicodium* sp. in longitudinal oblique sections. a, sample KJ-23a; b, sample KC-11; c, sample KB-47a. **d**, **e** *Nipponophycus ramosus* Yabe & Toyama in oblique and transverse oblique (d) and longitudinal (e) sections; d, ample KB-25c; e, sample KB-39. **f** to **i** *Crescentiella morronensis* (Crescenti) in longitudinal and longitudinal-oblique (f-h) and transverse (i) sections; f, g, sample KC-7a; h, sample KB-38b; i, sample KC-7. **j**, **k** *Girvanella* sp. Sample KB-38f (k, enlargement of j). Scale bar: 0.25 mm (a-c, e, g, i-k); 0.5 mm (d, f, i).

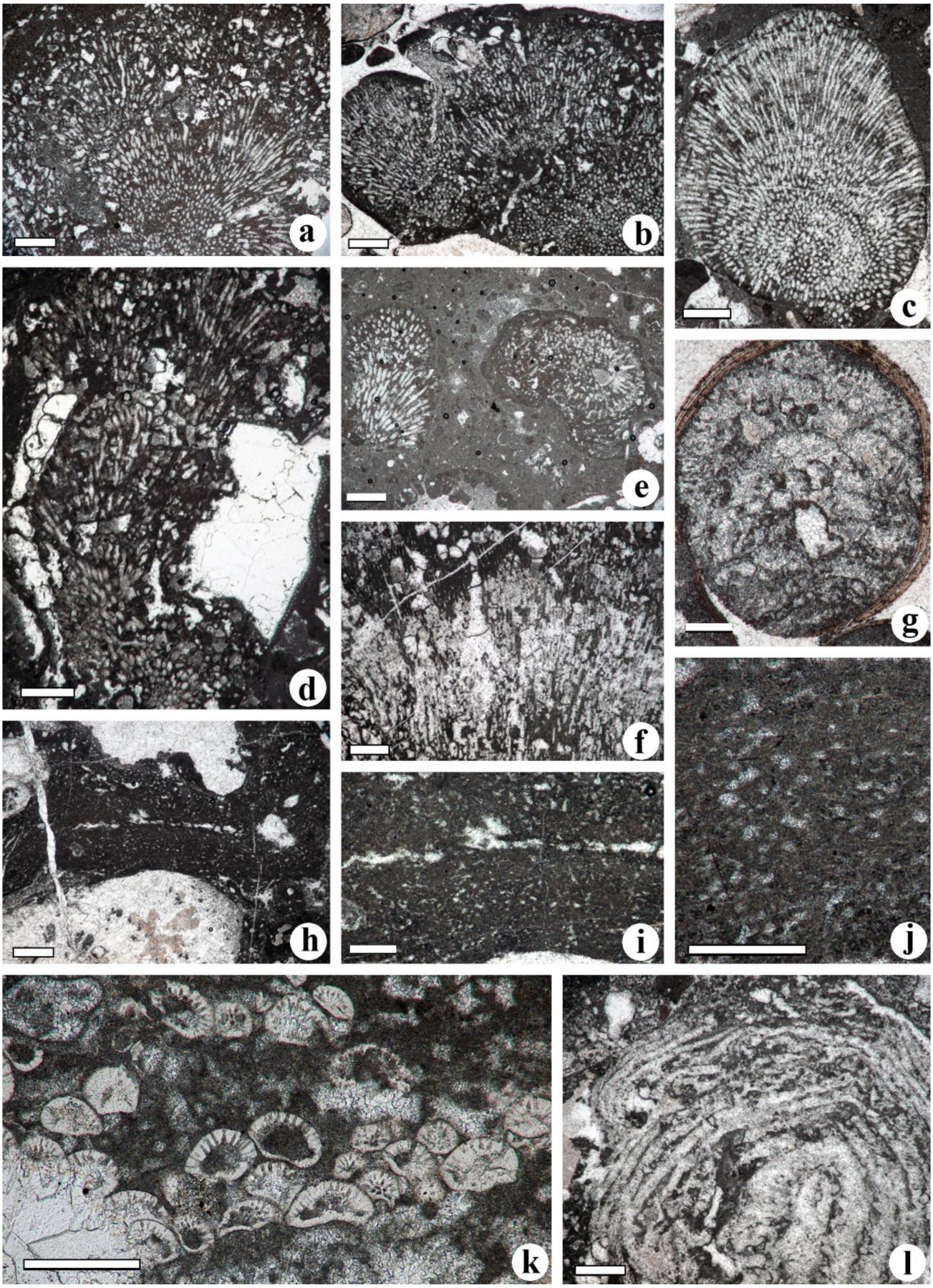

Fig. 16 Cyanobacteria, microbial structures and Microproblematica from the Yalta-Ay Petri area, southern Crimea. **a** to **g** Rivulariacean-like cyanobacteria (mostly *Cayeuxia* sp. type). a, sample KA-6; b, sample KB-39; c, sample KB-38f; d, sample KE-4c; e, sample KF-4; f, sample KB-51m; g, sample KC-27. **h** to **j** Microbial coating on large bioctast; somewhat *Rothpletzella*-like tubular structure; sample KB-41a. **k** *Koskinobullina socialis* Cherchi & Schroeder; sample KC-11; **l** Oncoid made up of thin micritic crusts separated by sparitic bands; sample KB-47n. Scale bar: 0.5 mm (a-f, h, l); 0.25 mm (g, i-k)

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