Revised taxonomy and stratigraphy of Middle Miocene calcareous nannofossils of the Paratethys

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ABSTRACT: The taxonomy of Paratethyan Middle Miocene calcareous nannofossils is reviewed and revised. Two new species, *Syracosphaera croatica* and *Syracosphaera horvati,* are proposed. Comparative study of coeval Neogene nannofossils from NHM and ODP (Ocean Drilling Project) reference collections give differences and similarities between the investigated areas (first occurrence, their morphology and dimensions). Other studies data on taxonomy are reviewed including palaeoecological and biostratigraphic applications.

INTRODUCTION

The investigated area (text-fig. 1) comprises two basins (Pavelić et al. 2001; Pavelić 2005): the Hrvatsko Zagorje Basin (i.e. north-western Croatian basin) and the North Croatian Basin (Samobor hills, Medvednica Mountain and Slavonian Mountains – Krndija and Dilj). During the Middle Miocene Croatia comprised the south western part of the Central Paratethys. The evolution of the Central Paratethys was controlled by regional tectonic events, sea-level changes and connections with the Mediterranean, Boreal and Indo-Pacific Oceans. These communications were repeatedly disrupted and re-established, resulting in highly variable palaeoenvironments often with distinctive restricted faunas and floras and occasionally with endemic taxa (Steininger et al. 1988). This unusual geodynamic and palaeobiogeographic evolution with development of distinctive Paratethyan assemblages has meant that the region has acquired its' own taxonomic traditions. The existing taxonomy of the Miocene calcareous nannofossil species for the Paratethys (based on available literature) has been published by Bartol (2009), Bóna and Gál (1985), Ćorić and Gross (2004), Fuchs and Stradner (1977), Gerhard and Müller (1972), Lehotayová (1982), Lehotayová and Priewalder (1978), Luljeva (1989), Martini (1977), Mărunţeanu (1997), Mihajlović (1993), Müller (1974, 1998), Nagymarosy (1980), Stradner and Fuchs (1978, 1980), Stradner and Papp (1961), Švábenická (2002), and at the Croatian part by Bajraktarević (1983) and Jerković (1970, 1971).

One of the unusual features of Paratethyan assemblages is that a higher abundance and diversity of *Syracosphaera* and *Rhabdosphaera* species is recorded than is usually the case. Our SEM study verified the presence of these specimens and shows that these Paratethyan facies preserve small and delicate species better than typical deep water pelagic sediments. The preservation is not generally as fine as in the Tanzania Drilling Project (TDP) Palaeogene sediments described by Bown (2005) and Dunkley Jones et al. (2009); however, it is comparable in some ways. As in the TDP sediments the shallower sedimentation depth and high clay content appears to have resulted in less dissolution even if secondary overgrowth has occurred. As a result these sediments provide a window into Middle Miocene coccolithophore diversity of great value for understanding the development of Cenozoic nannofossils.

The objectives of this paper are to review coccolith diversity in the Middle Miocene of the Paratethys, to reconcile regional taxonomic usage with standard taxonomy, and to provide accessible descriptions of the more unusual taxa present with good quality scanning electron microscope (SEM) illustrations.

METHODOLOGY

The standard preparation method used by the Croatian Geological Survey is also applied here with some modifications made at the Natural History Museum in London (NHM). Approximately 1 cm^3 of the sediment is placed in a beaker and treated with 30% concentrated hydrogen peroxide (H_2O_2) to oxidise organic matter for light microscope (LM) analyses of calcareous nannofossils. The sediments are then rinsed with distilled water. Some of the samples were put in an ultrasonic bath for approximately 15 seconds to improve disaggregation (Galović and Bajraktarević 2006). Standard smear slide and SEM stub preparation techniques were used in slide preparation for both LM and SEM analysis. The LM slides were mounted with Norland optical adhesive and exposed to UV light for 3 minutes at the Natural History Museum. For SEM analysis, we selected laminated sediments with good preservation in light microscope and mounted small fragments of sediment on aluminium stubs using epoxy resin. The specimens were gold-palladium coated and studied with a Phillips XL30 Field Emission SEM.

Smear slides were examined using BH2 Olympus and polarised Leitz LM (light microscope) (Croatian Geological Survey, Zagreb), and SEM (scanning electron microscope) JEOL JSM-T330 A (Ivan Rakovec Institute of Palaeontology ZRC SAZU, Ljubljana, Slovenia). Additional analyses for coccoliths taxonomy were done at the NHM, using LM (Zeiss Axioplan) and SEM (Philips XL-30 FEG).

Measurements of the coccoliths were made using ImageJ software. The scale bar of the images on the plates is 2µm unless otherwise indicated. All dark figures at plates are taken in cross polarised light. The morphometric variations of the *Reticulofenestras* are given in text-figure 2 based on lengths of the rim and central area. The length of approximately one hundred randomly selected specimens was measured on the SEM and LM pictures from the samples. The supplementations of Pujos's (1987) extinction figures are also given in it.

SYSTEMATIC PALEONTOLOGY

A revised taxonomy of calcareous nannoplankton based integrating data from extant coccolithophore biology and nannofossil palaeontology has been developed by Young and Bown (1997), Bown (1998) and Young et al (2003). Higher-level classification of coccolithophores (group, order, family) is based primarily on coccolith rim structure, but is well-supported by molecular genetic data (Saez et al. 2004). Fine details of rim construction are reserved for genus- and species-level (Young and Bown, 1997). More information about synonyms and variants of the species can be found on Electronic Calcareous Nannofossils CD-ROM v3 and on the Nannotax website (http://nannotax.org). Terminology used follows Young et al. (1997).

Group Heterococcoliths Young and Bown 1997
Order Zygodiscales Young and Bown 1997
Family Helicosphaeraceae Black 1971

Genus ***Helicosphaera*** Kamptner 1954
{*synonym*: *Helicopontosphaera* Hay and Mohler 1967}

Description: Coccospheres ellipsoidal with a prominent flagellar opening. Coccoliths are arranged spirally round the coccosphere and may vary slightly in size and shape from the antapex to the flagella pole. Coccolith structure - Outer rim (V-units) of the coccoliths are modified into a helical flange, ending in a wing or spike. R-units form the base plate and extend to form blanket of small elements. Central-area bars may be conjunct, disjunct or absent.

Helicosphaera carteri (Wallich 1877) Kamptner 1954
Plate 1, figures 1-8, 17-19

Coccosphaera carteri WALLICH 1877, p. 348, pl. 17, figs. 3, 4, 6, 7, 17
Helicosphaera carteri (Wallich) KAMPTNER 1954, pl. 17, figs. 17-1; tafs. 21-213, 73-74; text figs. 17a-c, 18-19
Helicopontosphaera kamptneri HAY et MOHLER 1967, p. 448, pl. 10, 11, fig. 5

*Description***:** Medium to large size helicoliths with flange ending in a prominent wing. Two small, elongate central openings oriented along (sometimes parallel) the long axis of the central area.

Length: 7-15µm (in our material).

*Stratigraphic occurrence***:** NP25 NN13 for the Paratethys, but in other marine areas NN1–NN21. This is the only common larger *Helicosphaera* species in the mid Miocene of the Paratethys. The species is more common to abundant in assemblages from Karpatian to Sarmatian in North Croatia, as in the most of the Paratethys. The FAD of *Helicosphaera carteri* is reported in the Oligocene (NP 25) of the South Slovakia depression (Holcová, 2005) and at the NN1/NN2 boundary from the Ukraine Carpathians (Savitska, unpublished data). LO (Lower Occurrence) of the species is determined for the end of the Oligocene i.e. Oligocene/Miocene boundary in a nearby Tethyan area of the SE Istria (mine investigations). This is in agreement with the lowest occurrence of the *H*. cf. *carteri* in Lemme-Carrosio Section (near the boundary i.e. in NP25c; Aubry and Villa, 1996).

Locality: Našice, Krndia Mountain.

Helicosphaera walbersdorfensis Müller 1974
Plate 1, figures 9-16, 19-20

Helicosphaera walbersdorfensis MÜLLER 1974, p. 392-393; pl. 2, fig. 15; pl. 4, figs. 35- 37, 45-46.

*Description***:** Small to medium sized. Flange ends in a broad wing. Central-area with two normally oblique pores separated by narrow conjunct bar that is sometimes missing.

Comparison: This medium sized *Helicosphaera* species is readily distinguished from *H. carteri* by its smaller size, oblique slits and different shaped wing. It was described from the Paratethys but has been recorded widely.

*Length***:** (3.5) 4-7µm (known to 8µm in other oceans)

Stratigraphic occurrence: NN4–NN7 (till NN9 in the Eastern Paratethys). *Helicosphaera walbersdorfensis* is common in the Middle Miocene of the Paratethys in contrast to its rather sporadic distribution in the deep sea record.

Locality: Našice, Krndia Mountain, Tromeđa and Kasonja, Dilj Mountain.

Remarks: The species appears to be characteristic of eutrophic, hemipelagic, or partly enclosed marine environments.

Family Pontosphaeraceae Lemmermann 1908

Genus ***Pontosphaera*** Lohmann 1902

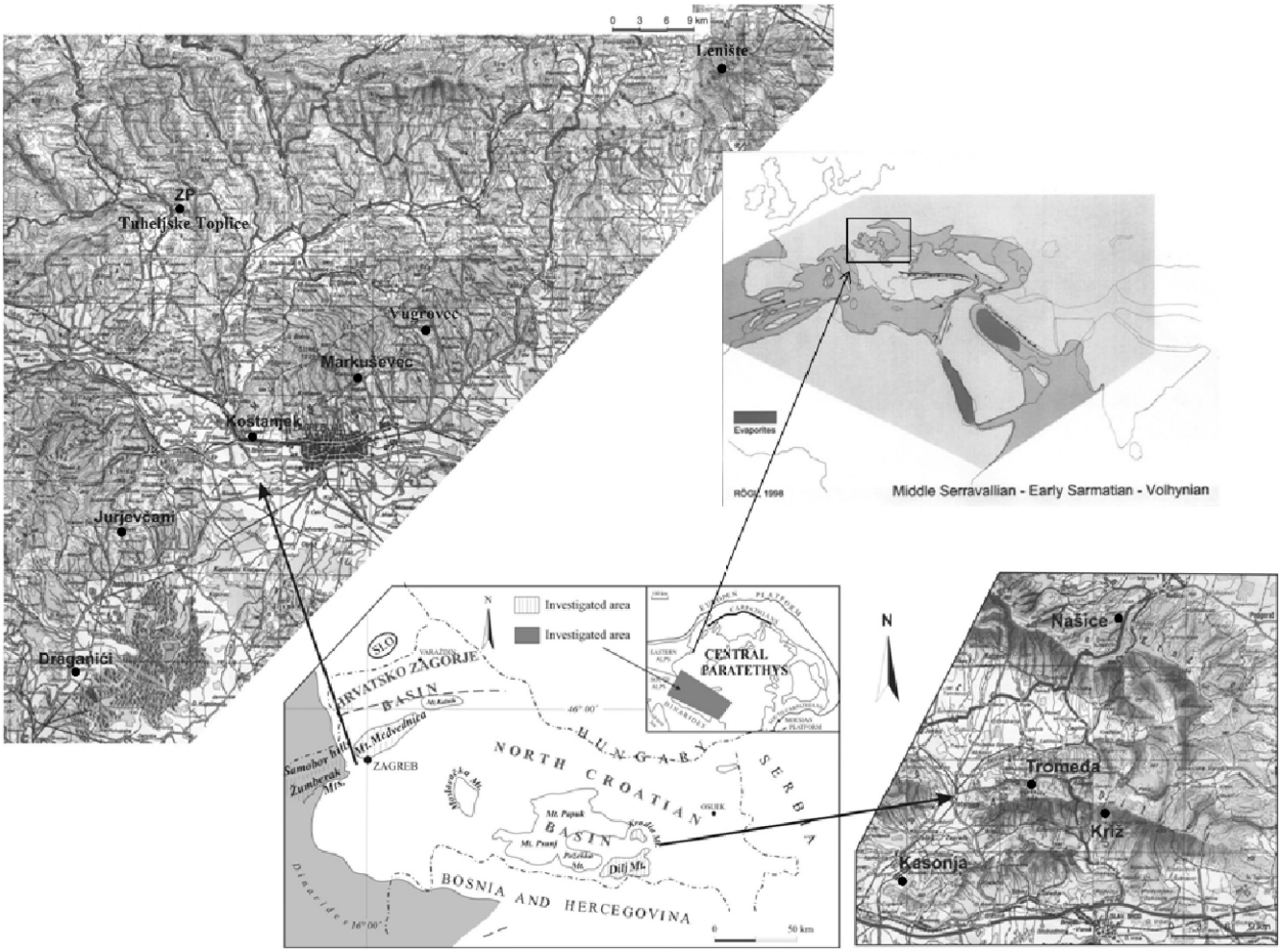
Description: Coccoliths have murolith rims. Central area possesses a variable number of perforations. V-units form narrow anti-clockwise imbricate outer wall, R-units form inner wall and central-area.

Pontosphaera multipora (Kamptner 1948) Roth 1977
Plate 1, figures 21-25

Discolithus multiporus KAMPTNER 1948, pl. 1, figs. 7-8
Discolithina multipora (Kamptner) Martini – STRADNER and EDWARDS 1968, p. 35-37, figs. 7a,b; pl. 32-35. – MARTINI 1977, p. 128; pl. 1, fig. 4. – STRADNER and FUCHS 1981, pl. 4, figs. 7-8
Pontosphaera multipora (Kamptner) ROTH 1977. – FUCHS and STRADNER, p. 25, pl. 4, figs. 2,4,6. – STRADNER and FUCHS 1978, pl. 13, fig. 6 – SVÁBENICKÁ 2002, fig. 7: 21-22, 25-26

Description: Medium-sized, broadly elliptical form with mostly arranged two cycles of pores in the central area. The number of pores is 20 or less in the outermost cycle.

Remarks: The name *P. multipora* is conventionally applied to Neogene *Pontosphaera* coccoliths with large pores, both within the Paratethys and more widely. However, in detail, our species appears somewhat different to the modern *P. multipora*, in particular the central area is normally higher than the rim in the Paratethyan specimens and pores do not extend to the basal plate at Plate 1, figs. 21-22. This may be a consequence of the overgrowth here. The discoliths (Plate 1, fig. 21) show the



TEXT-FIGURE 1
Site map of the investigated area with localites modified after Rögl (1998) and Pavelić (2005).

striation on the proximal side of the rim as in Stradner's specimen.

Length: about 10µm (6-12)

Stratigraphic occurrence: Palaeogene-NN9, but characteristic for the Middle Miocene (till NN21 in other marine areas).

Type localities: Našice, Krndia Mountain and Križ, Dilj Mountain.

Genus ***Scyphosphaera*** Lohmann 1902

Description: Medium to relatively large coccoliths in which the rim is elevated into vase-like structures (lopadoliths) varying in forms.

Scyphosphaera apsteinii Lohmann 1902
Plate 2, figures 1-2

Scyphosphaera apsteinii LOHMANN 1902 - PERCH-NIELSEN 1985, p. 500, figs. 52 and 54.

Description: Rim terminates simply at distal end or curves slightly inward. Wall has surface ornamentation of thin ribs.

Remarks: This form is not exactly the same as modern *S. apsteinii* but use of this name for *Scyphosphaera* specimens with simple morphology is conventional usage in the nannofossil literature. No *Scyphosphaera* specimens with distinctively different morphologies were observed.

Height: About 16µm (known 10-18µm in other oceans).

Stratigraphic occurrence: NN6 NN8 middle Miocene of Paratethys. Palaeogene Recent globally.

Locality: Tromeđa, Dilj Mountain.

Order Syracosphaerales Ostenfeld 1899
Family Syracosphaeraceae Hay 1977

Genus ***Syracosphaera*** Lohmann 1902

Description: Murolith coccoliths with central area spanned by grill of laths disjunct from the rim and showing tangential crys-

tallographic orientation in cross-polarised light. Spines may be present or absent within coccoliths of a single species (dimorphism). Wall with elements showing clockwise imbrications (that could be seen on SEM and at gypsum view on LM) in some species. Neither obvious exothecal coccoliths nor coccoliths with distal flanges were observed, in contrast to modern *Syracosphaera* species (see Young et al. 2003).

Syracosphaera clathrata Roth and Hay 1967
Plate 2, figures 3-10

Syracosphaera clathrata Roth and Hay 1967. – HAY et al. 1967, p. 449, pl. 7, fig. 9
Syracosphaera cf. *histrica* Kamptner. – STRADNER and FUCHS 1980, pl. 9, fig. 3

Description: In SEM, small *Syracosphaera* with moderately flaring wall, lacking flanges, wall elements show distinct clockwise imbrication, central area with single cycle of robust laths. In LM, similar to *S.pulchra* (4.5-8µm large), but smaller.

Remarks: This species has frequently been recorded in the Paratethys, as *S. histrica* or *S. pulchra*, with SEM illustrations usually referred to *S. histrica* and LM illustrations usually referred to *S. pulchra*. Neither of the identifications is suitable for the observed species since they lack the distal and midwall flanges shown by these two species. Roth and Hay (1967) illustrated in proximal view a *Syracosphaera* species which appears to be identical to this form and called it *S. clathrata* and as such, is used here as the valid name for the taxon.

Dimension: 1-5µm.

Stratigraphic occurrence: NN5-NN7 (known from Oligocene in other marine areas).

Locality: Tromeđa, Dilj Mountain.

Syracosphaera croatica Galović and Young **n. sp.**
Plate 2, figures 11-14, 18-20, 23-24

Description: Similar to *Syracosphaera clathrata* but with more flaring rim and distinct proximal flange. Spine can be present or absent (dimorphism shown in Plate 2, figs. 14 and 23). Specimens without spine have an irregular central ridge formed from upgrowing laths.

Holotype: Stub 660: image 270-62 and slide Nac-I: 4 (NHM collection, London; illustrated in Plate 2, figs. 14, 18-20).

Paratype: Stub 660: images 270-63, 270-68 (NHM collection, London; illustrated in Plate 2, figs. 12-13).

Remarks: This species has not previously been distinguished but our SEM study showed clearly that it is distinct from *S. clathrata*.

Dimension: 1-5µm.

Derivation of name: Named based on the location at which *S. croatica* was first observed, Croatia.

Stratigraphic occurrence: NN6 (Badenian).

Type locality: Našice (sample Nac-I-4), Krndia Mountain, North Croatian Basin.

Syracosphaera horvati Galović and Young **n. sp**.
Plate 2, figures 15-17

Description: A very small *Syracosphaera* species; wall narrow, sub-vertical with weakly imbricate elements; proximal cycle elements well-developed extending about half way up the wall on both inner and outer side and forming weak proximal flange; central area with two concentric cycles of radial laths and a few axial laths; low central spine on some specimens.

Holotype: Stub 653: 268-37 (NHM collection, London; illustrated in pl. 2, figs. 15, 17).

Paratype: Stub 660: 270-69 (NHM collection, London; illustrated in pl. 2, fig. 16).

Remarks: This distinctive species has only been found in one sample but may have been overlooked in LM studies due to its small size.

Length: ca 2µm

Derivation of name: Named after Dr. Aleksander Horvat, micropalaeontologist.

Stratigraphic occurrence: NN6 (Badenian).

Type locality: Našice (sample Nac-I-4), Krndia Mountain, North Croatian Basin.

Syracosphaera* sp.** cf. ***S. nodosa
Plate 2, figures 21-22

Description: Very small murolith with more delicate grill forming plaque in base (proximal view). Shorter wall then previous species with elements showing no or slightly imbrications. On the proximal side possessed flange.

Comparison: Similar to *S. tumularis* but with broad plaque in the central area. It is also very similar to *S monechiae,* but smaller.

Dimension: around 2.5µm

Stratigraphic occurrence: NN6 (Badenian).

Type locality: Našice, Krndia Mountain.

Genus *incertae sedis* ***Coronosphaera*** Gaarder 1977

Description: Murolith coccoliths with radial laths in central area; outer part of the wall (outer rim cycle) has anti-clockwise imbrication, while inner cycle has vertical elements.

Coronosphaera mediterranea (Lohmann 1902) Gaarder 1977
Plate 3, figures 1-10

Coronosphaera mediterranea (Lohmann 1902) Gaarder in Gaarder and Heimdal 1977. – LEHOTAYOVÁ 1982, tab. 30, fig. 1.

Description: Elliptical BCs with laths forming a shelf in central part with spine or not (dimorphic). Inner rim cycle is lower than outer. Our SEM images show forms both with and without spines and the specimens appear to be identical to modern *C. mediterranea*.

Dimension: 1.5-5µm.

Stratigraphic occurrence: NN4-NN6 (till Pannonian in Eastern part of the Paratethys). Species is more common in Badenian sediments than in Sarmatian at SEM, while in LM view, its appearance is very rare in the investigated area.

Type localities: Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Family Calciosoleniaceae Kamptner 1927

Genus ***Calciosolenia*** Gran 1912

Description: Rhombic muroliths without flanges, sometimes termed scapholiths. The rim is predominantly formed of V-units, with small R-units at the basal/inner margin. The central-area has a single lath-cycle; pairs of laths from opposite sides of coccolith meet, forming transverse bars.

Remarks: The group ranges back into the Mesozoic (Lower Cretaceous) and may have evolved from the Stephanolithiaceae (Perch-Nielsen 1985; Bown and Young 1997).

Calciosolenia brasiliensis (Lohmann 1919) Young et al. 2003
Plate 3, figures 11-18

Scapholithus fossilis Deflandre 1954. – PERCH-NIELSEN 1985: p. 452, fig. 12 (1, 2, 5-7).
Calciosolenia sp. BARTOL 2009: pl. 8, figs. 6-10, 16-18.

Description: Slender and elongate coccoliths with short laths generally without median ridge preserved.

Remarks: The extant species *Calciosolenia murrayi* and *Calciosolenia brasiliensis* are primarily separated on the basis of coccosphere morphology-apical spines are present in C. murrayi (Young et al 2003). *C. murrayi* is the more common species and was suggested as the default identification in the fossil record by Young (1998). However, the coccoliths of *C. brasiliensis* are also larger than those of *C. murrayi* and have better separated laths (Young et al. 2003, Malinverno 2004). Our specimens more closely resemble *C. brasiliensis* in size and morphology and so are assigned to that species.

Dimension: 2-6 (very rarely up to 7)µm.

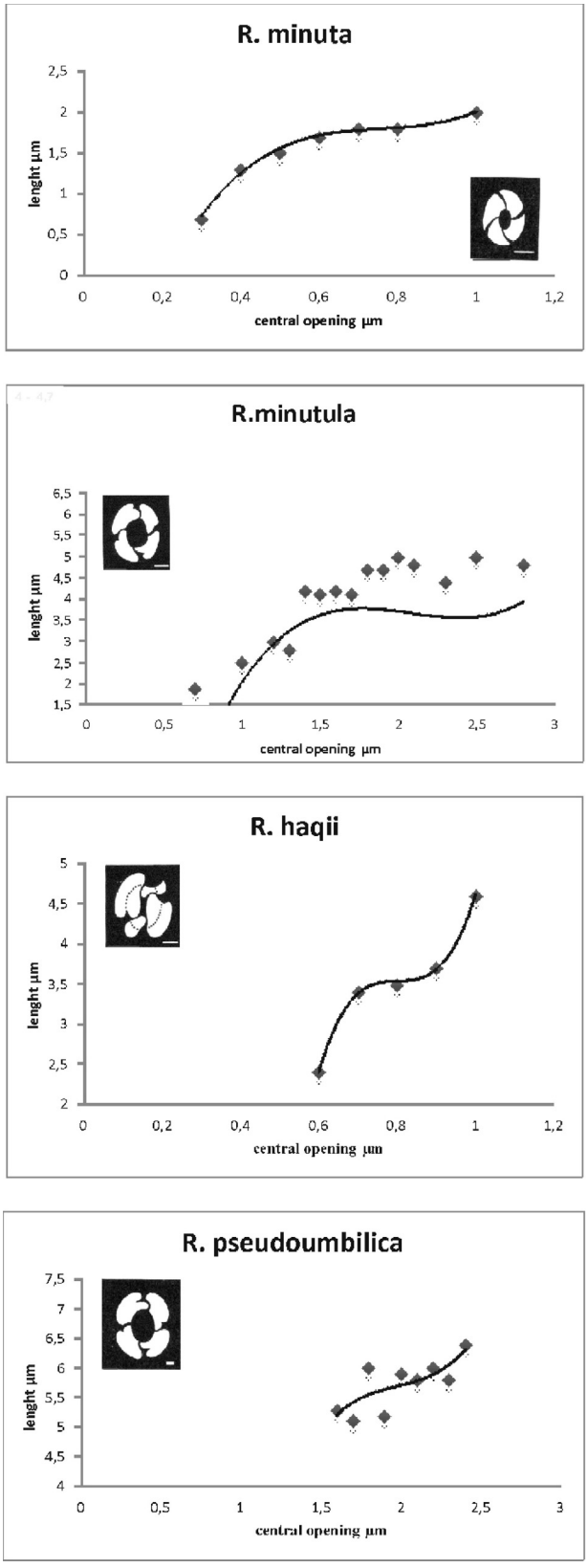
Stratigraphic occurrence: NN5 - NN6 (Lower Cretaceous to Recent in other marine areas). Its rare appearance is characteristic of the NN6d zone (upper Badenian-lower Sarmatian) of the North Croatian Basin. First occurrence of the species in Badenian, zone NN6, of the West Carpathians (Lehotayová, 1982) and. upper Badenian (NN6b-c) of the East Carpathians (Mărunţeanu, 1999). It has also been observed in the NN6 zone of Slovenia (Bartol, 2009) and Northern Bosnia (Jerković and Ćorić, 2006). Fuchs and Stradner (1977) record the species is in zone NN5 of the Vienna Basin, Austria.

Type localities: Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Order Rhabdosphaerales Ostenfeld 1899
Family Rhabdosphaeraceae Lemmermann 1908

Genus ***Rhabdosphaera*** Haeckel 1894
synonym: *Rhabdolithus* Kamptner ex Deflandre in Grass 1952 }

Description: Coccoliths typically disc shaped (planoliths). Rim formed of two cycles of elements: outer rim with non imbricate



TEXT-FIGURE 2
Reticulofenestra species identified using biometric studys and crossed nicols observations.

elements (V unit) and inner rim with obliquity. A lamellar cycle fills central area and forms spine; the radial lath cycle seen in other genera of the Rhabdosphaeraeae is absent. Coccopheres are dimorphic including coccoliths with and without spines (e.g. Young et al. 2003) in the light microscope only the spine-bearing coccoliths can usually be recognised but in the SEM we also observed the forms without spines.

Rhabdosphaera poculi (Bóna-Kernerne 1964) Müller 1974
Plate 3, figures 19

Rhabdolithus poculi BÓNA-KERNERNE 1964, p. 120; pl.5, figs. 15-16.
Rhabdosphaera poculi (Bóna-Kernerne) MÜLLER 1974, p. 394; tab. 2, fig. 18; tab. 4, figs. 31-33, 41-42.

Description: Rhabdoliths with trumpet-like (salpingiform) spine. The wider end of the distal part of the spine terminates in a sharply tapering spine top. The shape of the rhabdoliths at LM is similar to those of the genus *Discosphaera,* but with a distal cover.

Dimension: 5.5-8µm.

Stratigraphic occurrence: NN6-NN7. First appearance of *Rhabdosphaera poculi* is noticed in the lower Badenian of Austria and upper Badenian of Hungary, while in Sarmatian in Rumania (Müller, 1974 and Stradner and Fuchs, 1978). In North Croatian Basin species is very rare from upper Badenian till lower Sarmatian.

Locality: Kasonja, Dilj Mountain.

Rhabdosphaera clavigera Murray and Blackman 1898
Plate 3, figures 20-21, 23-25

Rhabdosphaera clavigera Murray and Blackman 1898. – LEHOTAYOVÁ 1982: 103; pl. 66, fig. 2. – PERCH-NIELSEN 1985: 516, fig. 68 (30, 31).

Description: Spines are robust and composed of vertical, elongate laths formed of five clockwise-spiral sets of elements organizing in a club-shape projection with pentameral terminal papilla at the top. BCs are elliptical/oblong. Spine-bearing coccoliths have wider rim of those without spine (Plate 3, figs. 20 and 22).

Remarks: Rhabdosphaera stylifera Lohmann was regarded as a less calcified variant of *R. clavigera* by Young et al. (2003). However, Kahn and Aubry (2006) showed, that the two morphotpyes are also well-separated by size and almost certainly are discrete species. In Paratethyan sediments isolated *clavigera* type spines are commonly preserved and readily identified in LM. The only picture of the s*tylifera* specimen at SEM is provided by Müller, 1974. In the Paratethyan fossil assemblage this is the first record of the species with a terminal papilla and non spine-bearing coccolith captured at SEM (arrow at Fig. 22, and Fig 20 at Pl. 3).

Note: The specimen shown on fig. 23 belongs to smaller and more delicate taxa with broken spine found in Badenian sediments of the North Croatian Basin.

Dimension.: (3) 6-10µm (BCs about 2,5-4µm)

Stratigraphic occurrence: (?Palaeogene) NN4-NN7 (?NN9) in the Paratethys, to recent in other marine areas.

Type localities: Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Rhabdosphaera procera Martini 1969
Plate 3, figures 26-31

Rhabdosphaera procera Martini 1969. – MÜLLER 1974, p. 394; pl. 4, figs. 38-39. – PERCH-NIELSEN 1985, p. 516, fig. 68 (28, 29).

Description: Small, arched, circular to broadly elliptical BCs with medium-sized, robust parallel-sided spine. Central area with fewer more regular plates than in *R. clavigera*.

Comparison: R. procera differs from *R. clavigera* in the shape of the BCs; in the spines having parallel-sides and weakly-developed axial canal; and wit the spines being terminated by hollow (figs. 27, 28) rather than by a papilla.

Dimension: spines 5-12µm long, BCs 3-4,5µm long.

Stratigraphic occurrence: NN4-NN9. Mostly rare but a characteristic middle Miocene species in Austria, Slovenia, Croatia and Bosnia. *Rhabdosphaera procera* is detected in Pannonian of Romanian paratethys.

Localities: Jurjevčani, Samobor hills, Našice, Krndia Mt and Tromeđa, Dilj Mountain.

Rhabdosphaera sicca (Stradner 1963) Fuchs and Stradner 1977
Plate 4, figures 1-3, 5-8

Discolithus phaseolus Black and Barnes - FARINACCI 1969, I; 105.
Rhabdosphaera sicca (Stradner 1963) FUCHS and STRADNER 1977, p. 29, pl. 1, figs. 16, 17. – ANDREYEVA-GRIGOROVICH and SAVYTSKAYA 2000, pl. 1, figs. 13, 14. – ANDREYEVA-GRIGOROVICH and HALÁSOVÁ 2000, pl. 1, fig. 20.
Rhabdosphaera clavigera Murray et Blackman. – LEHOTAYOVÁ 1978, pl.4, fig.6.

Description: Wider, elongate broadly elliptical, convex BCs with a medium-sized hollow spine. The base of the spine which is well separated from the rim is wide and the spine tapers distally.

Comparison: R. sicca differs from *R. claviger* in the absence of pentameral terminal papilla and in the spine tapering distally. It differs from *R. pannonicus* in having has elliptical rather than circular BCs with conical spine without hollow in the central proximal part. *R. pannonicus* (pl. 4, fig. 4) is also a larger and more robust species (7.5-10.5) with smaller BCs (3.5-5µm).

Dimension: about 7µm (BCs 4.5-6.5µm).

Stratigraphic occurrence: NN4-NN7. Rare, but more common middle Miocene Paratethyan species.

Localities: Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Genus ***Discosphaera*** Haeckel 1894

Description: Coccospheres monomorphic with trumpet-like (salpingiform) circular spines. Coccolith bases are broadly elliptical, with normal rhabdosphaeraceae rims, radial lath cycle present. Spine is weakly attached to base above a narrow pore in the centre of the base.

Discosphaera tubifera (Murray and Blackman 1898) Ostenfeld 1900
Plate 4, figures 9-10

Rhabdosphaera tubifera Murray and Blackman 1898. – FARINACCI 1972, V; 184.
Discosphaera tubifera (Murray and Blackman) Ostenfeld 1900. – YOUNG et al. 2003: 56, fig. 12-15.

Description: Small BCs, slightly convex.

Dimension: about 2µm (BCs)

Stratigraphic occurrence: NN6 (NN11 to recent in other marine areas, Young 1998). Very rare forms have been found in SEM images only. The species is detected for the first time in the Paratethys in upper Badenian of the North Croatian Basin (Krndia Mountain).

Locality: Našice, Krndia Mountain

Genus ***Acanthoica*** Lohmann 1903, emend. Schiller 1913 and Kleijne 1992

Description: Coccospheres polymorphic, with differentiated apical and antapical coccoliths. Body coccoliths with well developed radial cycle(s) of rods and laths with openings, lamellar cycle forms low cone, or protrusion. Apical and antapical coccoliths have long tapering spines.

Acanthoica laffitei (Jerković 1971) Aubry 1999
Pate. 4, figures 11-19

Blackites laffitei JERKOVIĆ 1971, 202; figs. 1, 2.
Acanthoica laffitei (Jerković) AUBRY 1999, p. 237-238; pl. 6, figs. 67, 68.

Description: Subcircular to elliptical coccoliths with (conical) central area formed two radial cycles of laths. Rim structure on proximal side also consists of two cycles: second anticlockwise long elements finishing on the first narrow marginal cycle. Lamellar cycle of forms low cone or small spine.

Remarks: Jerković (1971) also described two further species, *Blackites balcanicus* and *Syracosphaera beogradensis*, which Aubry (1999) recombined into *Acanthoica*. The holotypes of both these species are very poorly illustrated and may be specimens of *A. laffittei.* I found one specimen (pl. 4 Fig. 19) with apparently a single cycle of radial alrhs and a well-developed spine, this is similar to *A. beogradiensis,* but may prove to be polymorph of *A. laffitei*.

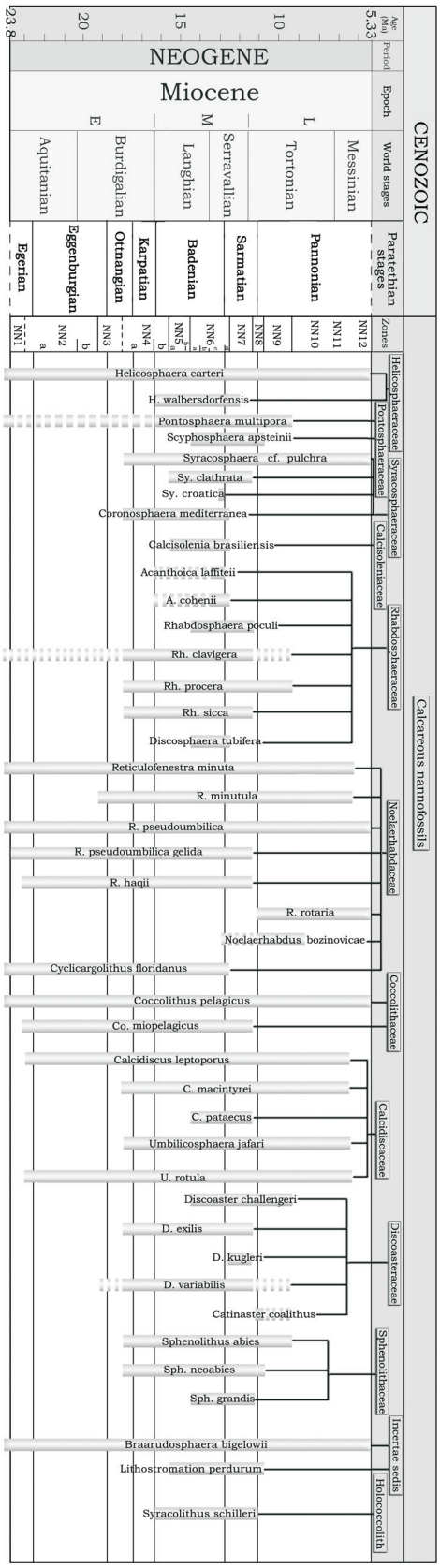
Dimension: 1.5-5µm.

Stratigraphic occurrence: NN6 (Badenian). Common species in SEM analyses of the North Croatian Basin. The species was described by Jerković (1971) as from the Tortonian of Yugoslavia, in current terminology the type level would be placed in the Badeinan and the type locality in Bosnia.

Localities: Našice, Krndia Mountain and Tromeđa, Dilj Mountain

Acanthoica cohenii (Jerković 1971) Aubry 1999
Plate 4, figures 20-22; pl. 5, figures 1-5, 8-10

Syracosphaera cohenii JERKOVIĆ 1971, p. 203; figs. 1, 2.
Acanthoica beogradiensis (Jerković) AUBRY 1999, p. 237-238; pl. 7, figs. 69, 70.



TEXT-FIGURE 3
Stratigraphic distribution of some middle Miocene calcareous nannofossils.

Acanthoica backmanii DUNKLEY JONES, BOWN and PEARSON 2009, p. 35- 36, pl. 9, fig. 10.

Description: Elliptical coccolith with central area fromed radial cycles of rods (laths) separated by narrow slits. First lamellar cycle of rods has clockwise imbrications. Lamellar cycle forms protrusion or spine (dimorphism).

Comparison: Very similar to recent *Cyrtosphaera lecaliae* but with narrower wall.

Dimension: 1-3.5µm.

Stratigraphic occurrence: NN6 (Badenian-Sarmatian). Characteristic middle Miocene species of the North Croatian Basin (this work and Jerković, 1971). It's very rare on LM, but common in SEM analyses. *Acanthoica cohenii* has been also detected in the Sarmatian sediments of the Vienna Basin (Schütz et al., 2007). The species *A. backmanii* recently described from the upper Eocene of Tanzania by Dunkley Jones at al., (2009) appears to be identical to this species and so we regard it as a junior synonym.

Localities: Jurjevčani, Samobor hills; Našice, Krndia Mountain and Tromeđa, Dilj Mountain.

Family **Alisphaeraceae** Young, Kleijne and Cros 2003
Genus ***Alisphaera*** Heimdal 1973

Description: Coccoliths with asymmetrical distal flange. One side is broader with a variable extension. Other side narrower with teeth extending into central area. See Kleijne et al. (2002) and Young et al. (2003) for extended description and discussion.

Alisphaera* sp.** cf. pinnigera*** Kleijne et al. 2002
Plate 5, figures 6-7

Alisphaera pinnigera KLEIJNE et al. 2002. – YOUNG et al. 2003, p. 64; pl. 29, figs. 4-6.

Description: Very small species. Central area with well developed teeth.

Remarks: There are few fossil records of *Alisphaera* but the specimens illustrated can be unambiguously assigned to the genus, thus extending considerably its' known statigraphic range. The specimens seen appear similar to modern *A. pinnigera,* but we did not observe enough specimens to confirm this identification.

Length: ~1.5µm.

Stratigraphic occurrence: NN6-NN7 (Badenian - Sarmatian). The coccoliths are too small to be identified by LM, so the record is based on our SEM observations.

Localities: Našice, Krndia Mountain and Tromeđa, Dilj Mountain.

Order **Isochrysidales** Pascher 1910
Family Noelaerhabdaceae Jerković 1970
Genus *Reticulofenestra* Hay, Mohler and Wade 1966

Reticulofenestra minuta Roth 1970
Plate 5, figures 11-18

Reticulofenestra minuta ROTH 1970, p. 850; pl. 5, figs. 3, 4. – PUJOS 1987, pl. 1, figs. 6-7. – ŠVÁBENICKÁ 2002, p. 204; fig. 18. – DUNKLEY JONES 2009, pl. 1, fig. 8.
Dictyococcites productus (Kamptner) Backman - PUJOS1987, pl. 1, fig. 25.

Description: Very small elliptical placolith with a central grill of 10-15 twisted bars.

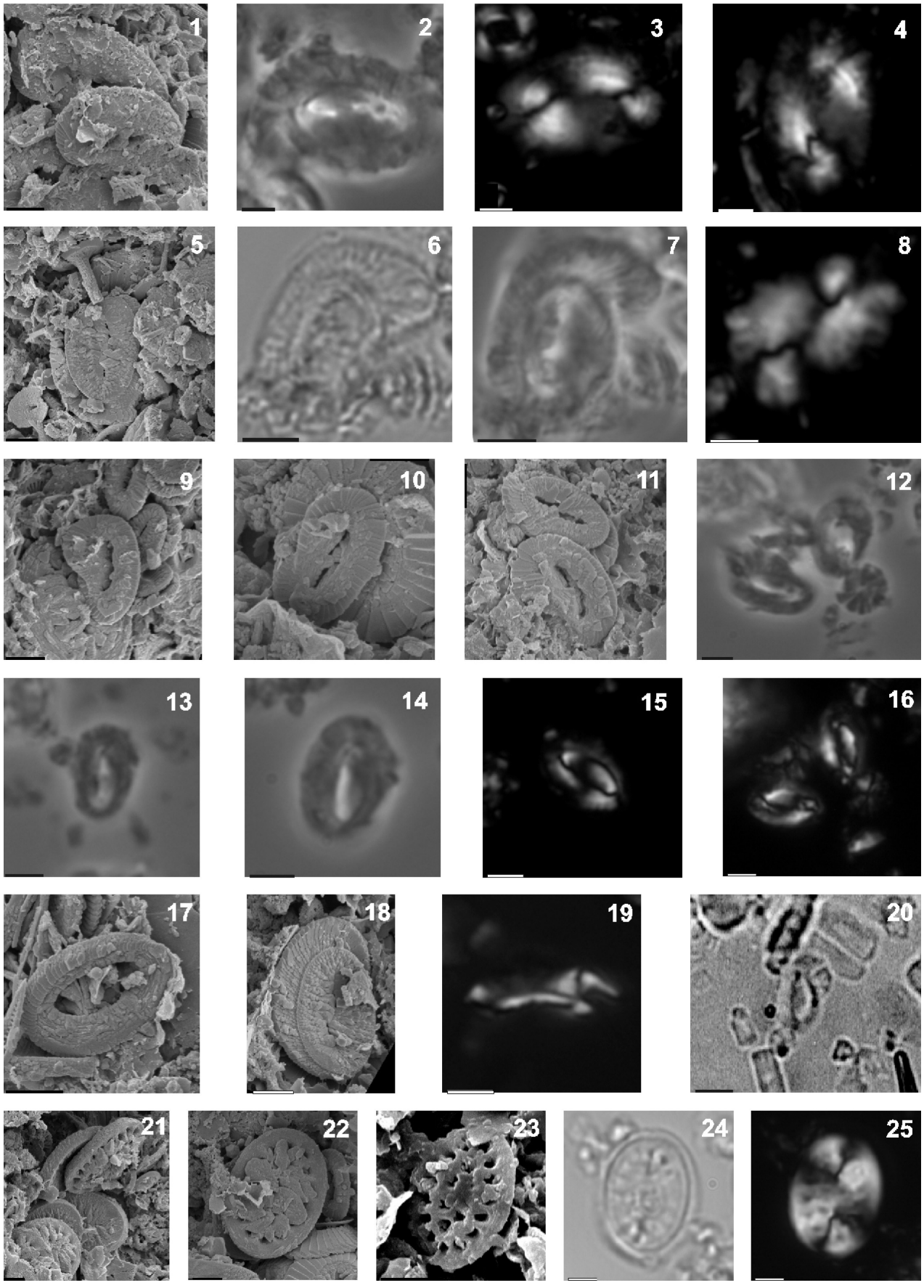
Remarks: The name *R. minuta* is conventionally applied to all very small (mostly <3µm) *Reticulofenestra* specimens and so may include several species (Young et al., 2003). The forms seen in our material consistently have a rather broad central area (≤ 1µm) spanned by a grill formed of a few robust bars. In LM these bars are barely visble, leaving a broad cetral area (figs. 13, 18).

PLATE 1

1-8, 17-19 *Helicosphaera carteri.* Nac-II: 4, Figs. 1, 5, 17 (early growth stage) and 18. SEM, figs. 2-4. and 6-8. LM (2 and 7 phase contrast, and 19 side view).

9-16, 20 *Helicosphaera walbersdorfensis.* figs. 9-11, 17-18. SEM, Nac-II: 4, figs. 12-16, 19-20. LM, phase contrast (12-14), figs. 12, 14-16, fig. 13, Tro-I: 4/2a, fig. 20. Kas-I: 16/1.

21-25 *Pontosphaera multipora.* figs. 21-23. SEM (21-22 Nac-II: 4, 23 Krž-I: 29/1), figs. 24-25 LM (Nac-II:4).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Dimension*:* <3μm.

Stratigraphic occurrence: Oligocene-NN11 (till NN21 in other marine areas). Common species in the Miocene of the Paratethys, especially concurrent with *Sphenolithus heteromorphus*. According to newest data prevalence of the species over *Coccolithus pelagicus* is useful biomarker for Karpatian/Badenian boundary in Austria and Slovakia too (Andrejeva-Grigorovič et al., 2001, Ćorić et al., 2004). In Hrvatsko Zagorje Basin this event is recognised in NN4b zone. In North Croatia Basin it is characteristic for NN5a zone. In the late Sarmatian in both Croatian basins monofloral developments of the species occur probably reflecting "stress" conditions.

Localities: Jurjevčani, Samobor hills; Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Reticulofenestra producta (Kamptner 1963) Wei and Thierstein 1991
Plate 5, figures 19-20

Dictyococcites productus (Kamptner 1963) Backman. – PERCH-NIELSEN 1985, fig. 59, Figs. 5-6A, 7.
Reticulofenestra minuta Roth. – PUJOS 1987, pl. 1, fig. 1.
Dictyococcites productus (Kamptner) Backman. – PUJOS 1987, p. 248-250; fig. 9; pl. 1, figs. 22-24.

Description: Small reticulofenestrid coccoliths with a nearly closed central area except for a slit along the long axis. Birefringence is simple, the bright field bent at angles to the centre. The shield has many more elements than *R. minuta* (SEM).

Dimension: ‹ 4.5μm.

Stratigraphic occurrence: NN4-NN7. The species occurs sporadically in Miocene sediments of the Paratethys. Based on available literature the first appearance of the species is in the upper part of the NN4 zone in Austria. In North-Western Croatian part is observed in the lowermost NN4, while in North Croatia in NN4b zone. FO of the species is marked around 16 Ma in early mid Miocene of the southern high latitudinal regions (Kameo and Sato, 2000).

Localities: Tuheljske Toplice, Hrvatsko Zagorje and Križ, Dilj Mountain.

Reticulofenestra minutula (Gartner 1967) Haq and Berggren 1978
Plate 5, figures 21-22; plate 6, figures 1-3, 5-7

Coccolithus minutulus GARTNER 1967, p. 3; pl. 5, figs. 3-4, 5a-c.
Reticulofenestra minutula (Gartner) HAQ and BERGGREN 1978, pl. 1, figs. 19-22. – YOUNG 1999, pl. 8.3, fig. 29.
Reticulofenestra minutula minutula PUJOS 1987, pl. 1, figs. 8, 9.

Description: Small *Reticulofenestra* species with a wide central opening (around 1.5μm) spanned by a delicate grill. Shields constructed of numerous imbricate elements (pl. 5, fig. 21 and pl. 6 fig. 1).

Comparison: In cross polarized light the central opening (pl. 5, figs. 13, 18, and pl. 6, fig. 7) is much wider in *R. minutula* than *R. producta*.

Dimension: 2-5μm.

Stratigraphic occurrence: NN3-NN11

Localities: Lenište, Kalnik; Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Reticulofenestra haqii Backman 1978
Plate 6, figures 4, 8-12, 16

Reticulofenestra haqii Backman 1978. – PERCH-NIELSEN 1985, fig. 59, Figs. 5-6B. – ŠVÁBENICKÁ 2002, p. 202; figs. 31, 32.
Reticulofenestra minuta Roth. – PUJOS 1987, pl. 1, fig. 5. – PUJOS 1987, p. 247, fig. 6.
Reticulofenestra minutula minutula (Gartner) Haq and Berggren. – PUJOS 1987, pl.1, fig. 10.
Reticulofenestra minutula haqii (Backman) PUJOS 1987, 247-248; fig. 7, pl. 1, figs. 18-21.
Dictyococcites perplexus Burns. – PUJOS 1987, pl. 1, fig. 27.

PLATE 2

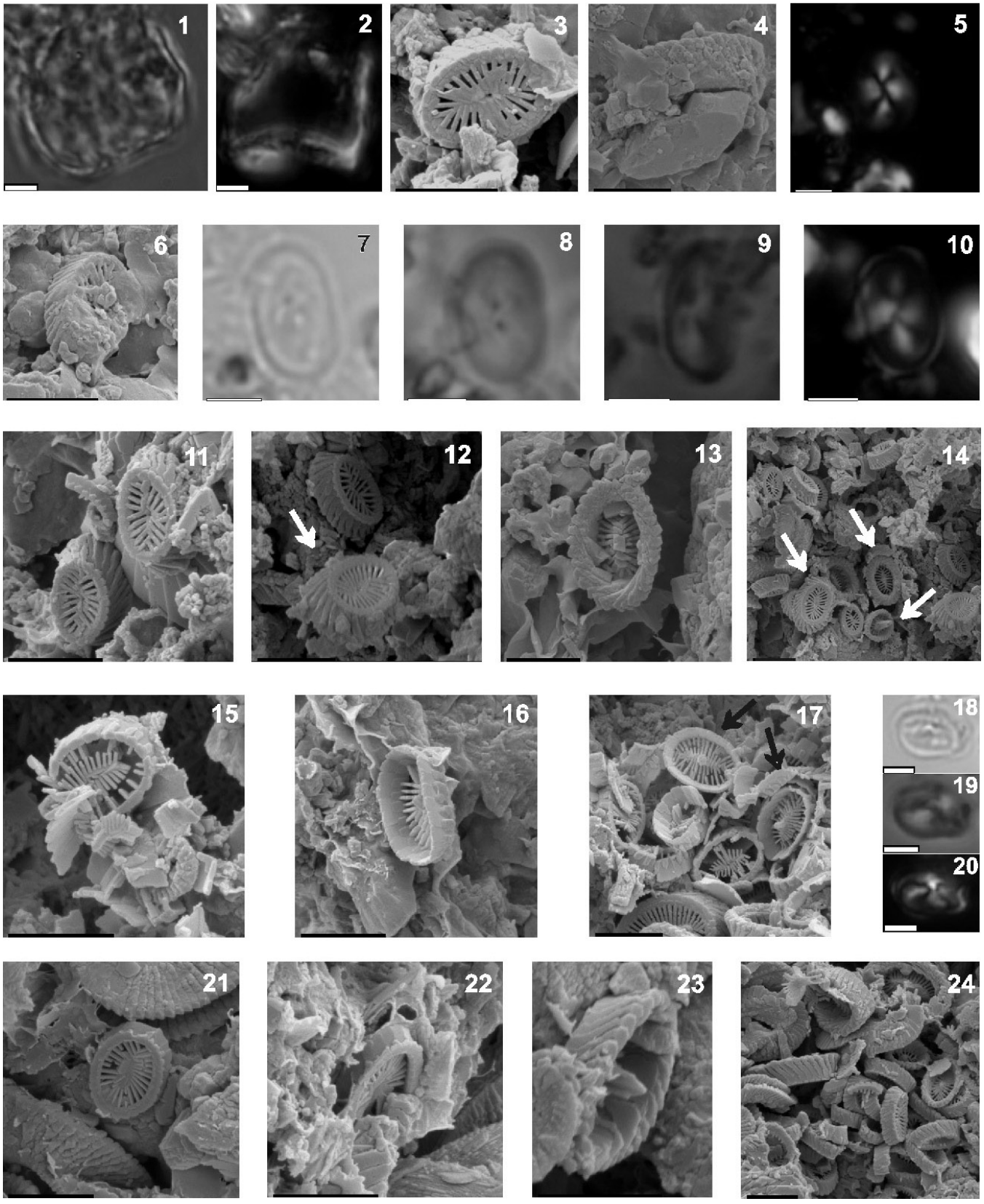
1-2 *Scyphosphaera apsteinii.* LM, Tro-I: 29/2.

3-10 *Syracosphaera clathrata.* figs. 3,4,6 SEM, Tro-I: 4/2a, figs. 5, 7-10. LM (8, 9. phase contrast), Tro-I: 4/2a.

11-14, 18-20, 23-24 *Syracosphaera croatica* n. sp. figs. 11-14, 23-24 SEM and 18-20. LM (19. phase contrast), Nac-II: 4. Holotypes: figs. 14 (white arrow), 18-20. Paratype: figs. 12-13.

15-17 *Syracosphaera horvatiana* n.sp. SEM, Nac-II: 4. Holotype: fig. 16; Paratype: fig. 17 (black arrow).

21-22 *Syracosphaera* sp. cf. *S. nodosa.* SEM, Nac-II: 4.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Description: Small, elliptical to broadly elliptical placoliths with a central opening around 1µm or less, surrounded by a distal collar of coarse, blocky elements.

Comparison: Very similar to *R. pseudoumbilicus* and *R minutula* but with smaller and sometimes almost closed central opening (pl. 6, fig. 9).

Dimension: 2-5µm.

Stratigraphic occurrence: NN2-NN7.

Localities: Tromeđa and Križ, Dilj Mountain and Našice, Krndija Mountain.

Reticulofenestra pseudoumbilicus (Gartner 1967) Gartner 1969
Pate 6, figures 13-15, 17-20

Coccolithus pseudoumbilicus GARTNER 1967, p. 4, pl. 6, figs. 1-2, 3a c, 4a-c.
Reticulofenestra pseudoumbilicus (Gartner) GARTNER 1969, p. 598, pl. 2, fig. 4. – YOUNG 1999, pl. 8.3, fig. 22.
Reticulofenestra pseudoumbilica pseudoumbilica (Gartner) Gartner - PUJOS 1987, pl. 2, figs.13-14, 18b.

Description: Mostly medium to large sized elliptical placoliths with the central opening around 2µm, spanned by delicate grill in well-preserved specimens.

Comparison: The shields of R. *minutula* are narrower relative to the central opening than in *R. haqii and R. pseudoumbilicus* (especially in proximal view at SEM pictures).

Dimension: 4-9µm.

Stratigraphic occurrence: Oligocene-NN15. The Badenian/ Sarmatian boundary is marked by the last occurrence or absence of *Cyclicargolithus floridanus* and prevalence of *Reticulofenestra pseudoumbilicus* in the assemblage (Perch-Nielse 1985). This boundary is sharp in the Hrvatsko Zagorje Basin and North Croatian Basin (Medvednica Mountain) where the beginning of the Sarmatian is characterised by the very abundant to almost monofloral appearance of large *Reticulofenestra pseudoumbilicus* (≥7µm).

Locality: Našice, Krndia Mountain.

Reticulofenestra pseudoumbilicus gelida (Geitzenauer 1972) Wise 1983
Plate 7, figure 1

Coccolithus gelidus GEITZENAUER 1972, 407; pl. 1, figs. 1-2, 5-6.
Reticulofenestra gelida (Geitzenauer) BACKMAN 1978, 112.
Reticulofenestra pseudoumbilicus gelida (Geitzenauer) WISE 1987, Pujos: 253; pl. 2, figs. 18b-c, 19-22.
Reticulofenestra pseudoumbilicus (Gartner) Gartner. – YOUNG 1999 : pl. 8.3, fig. 17.

Description: Medium to large *Reticulofenestra* species with smaller central opening (around 2µm or less). In addition the shields of this form usually show stronger birefringence than typical *R. pseudoumbilicus*, probably indicating that they are more heavily calcified.

Dimension: 6-12µm.

Stratigraphic occurrence: NN1-NN7.

Locality: Tromeđa, Dilj Mountain.

Remarks: According to Backman (1980) *R. pseudoumbilicus gelida* is a winter ecotype of the *R. pseudoumbilicus*. In most of the samples studied here it was easy to differentiate at LM a medium-sized *pseudoumbilicus* with a large central opening and a larger-sized *gelida* with a small central opening.

I found the species in monofloral development with *R. pseudoumbilicus* in lower Sarmatian assemblages at Medvednica Mountain together with abundant prasinophycean algaes (Bakrač, personal communication). Prasinophytes are also com-

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PLATE 3

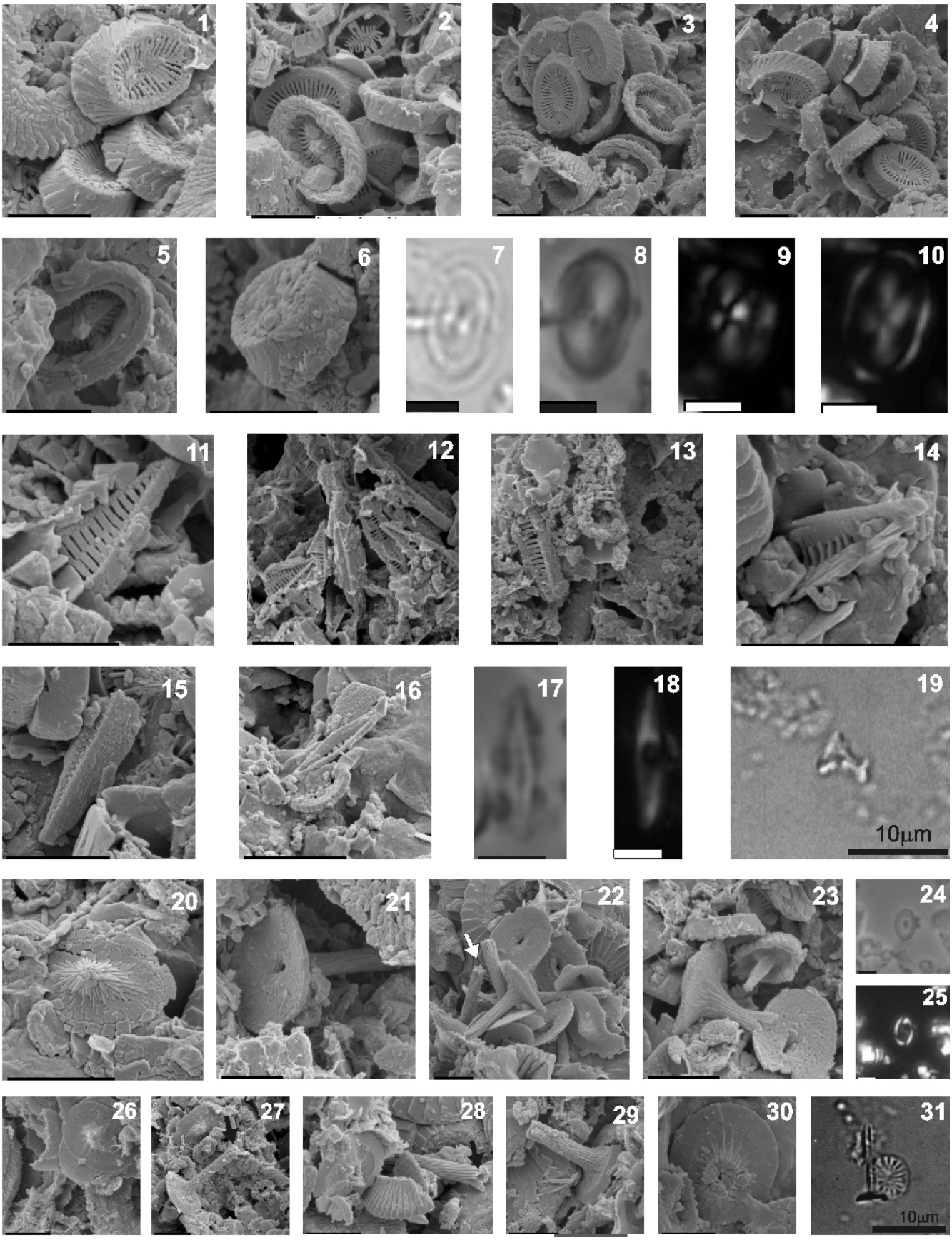
1-10 *Coronosphaera mediterranea*. figs. 1-6. SEM, figs. 1-4 Nac-II:4 and figs. 5-6 Tro-I: 4/2a, figs. 7-10. LM (8. phase contrast), Nac-II:4.

11-18 *Calcisolenia brasiliensis.* figs. 11-16. SEM, figs. 17-18. LM figs. 11-14., 17. Nac-II:4, figs. 15-16., 18. Tro-I: 4/2a.

19 *Rhabdosphaera poculi.* LM, Kas-I: 16/1.

20-25 *Rhabdosphaera clavigera.* figs. 20-23. SEM, figs. 24-25. LM. figs. 20 and 24-25. Tro-I: 4/2a, figs. 21-23. Nac-II: 4.

26-31 *Rhabdosphaera procera.* figs. 26-30. SEM, fig. 31. LM, figs. 26-29. Nac-II: 4, fig. 30. Tro-I: 4/2a and fig. 31. Nac-II:1.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monly reported to be associated with low temperature, enhanced productivity and a stratified water column exhibiting brackish or low-salinity surface waters overlying low oxygen to anoxic bottom waters (Tyson, 1987). Dominance of prasinophyte algae has also been recorded from some restricted lagoon and shallow water carbonate facies (Tyson, 1995). All observations are in agreement with previous interpretations of the environment based on diatoms (Galović and Bajraktarević, 2006).

Reticulofenestra rotaria Theodoridis 1984
Plate 7, figures 2-4, 6-8

Reticulofenestra rotaria Theodoridis 1984. – YOUNG 1998, p. 247-248; fig. 11-12.

Description: Medium sized, circular coccoliths with wide central-area.

Dimension: about 6µm (5-7).

Stratigraphic occurrence: Upper Miocene (Pannonian). In Hrvatsko Zagorje Basin (and elsewhere in the Paratethys) it is very common and occurs earlier than in the Mediterranean.

Locality: Jurjevčani, Samobor hills.

Genus ***Cyclicargolithus*** Bukry 1971

Description: Circular to broadly elliptical placolith with small central area.

Cyclicargolithus floridanus (Roth and Hay 1967) Bukry 1971
Plate 7, figures 5, 9-12

Cyclicargolithus floridanus (Roth and Hay 1967) Bukry 1971. – FUCSH and STRADNER 1977, p. 23, pl. 3, figs. 7-9. – STRADNER and FUCSH 1980, pl. 5, figs. 10, 12. – LEHOTAYOVÁ 1982, pl. 32, figs. 2-3. – DUNKLEY JONES 2009, pl. 1, figs. 1-3.
Reticulofenestra doronicoides (BLACK and BARNES) PUJOS 1987, pl. 1, fig. 13.

Description: Medium-sized sub-circular reticulofenestrids with small central opening.

Remarks: In some cases central area of Paratethyan specimens occupy 1/3 of the coccolith size (Lehotayová, 1982). Slightly elliptical specimens with a larger central opening occur in the Middle Miocene and are possibly intermediate with *R. pseudoumbilicus gelida* (figs. 10-12).

Dimension: 4.5-8µm.

Stratigraphic occurrence: Palaeogene-NN6/7. Present but less common in the basal Sarmatian and rare towards its' last occurrence (LO). The LO is very useful as an indicator of NN6/7 boundary, although some overlap between *Discoaster kugleri* and *C. floridanus* is observed (O. Varol pers. comm.).

Localities: Jurjevčani, Samobor hills, Tuheljske Toplice, Hrvatsko Zagorje and Našice, Krndia Mountain.

Genus ***Noelaerhabdus*** Jerković 1970

Description: Placolith coccoliths similar to *Reticulofenestra* but with spine formed from a few elements of the inner tube.

Noelaerhabdus bozinovicae Jerković 1970
Plate 7, figures 13-20

Noelaerhabdus bozinovicae JERKOVIĆ 1970, p. 468-470; figs. 1-8. – MĂRUNĆEANU 1997, p. 98; pl. 1, figs.6-7, pl. 2, figs. 1-3. – BÓNA and GÁL 1985, pls. 66-68, figs.1-4.
Noelaerhabdus braarudii JERKOVIĆ 1971, p. 207; fig. 1.
Noelaerhabdus tegulatus BÓNA and GÁL 1985, pls. 69, figs.1-2, pl. 77, fig. 3.
Reticulofenestra pseudoumbilica (Gartner). – BÓNA and GÁL 1985, pl. 71, figs.1-2, pl. 72, fig. 1.
Noelaerhabdus bekei Jerković. – MĂRUNŢEANU 1997, p. 97; pl. 10, figs. 4-5. – CHIRA and MALACU 2008, pl. 4, figs. 9-11, 14, 16.
Noelaerhabdus mehadicus MĂRUNŢEANU 1997, p. 99, pl. 11, figs. 6-7.
Reticulofenestra tegulata (Bona and Gál) ĆORIĆ and GROSS 2004, p. 12; abb. 2; pl. 1, figs. 1-16.

PLATE 4

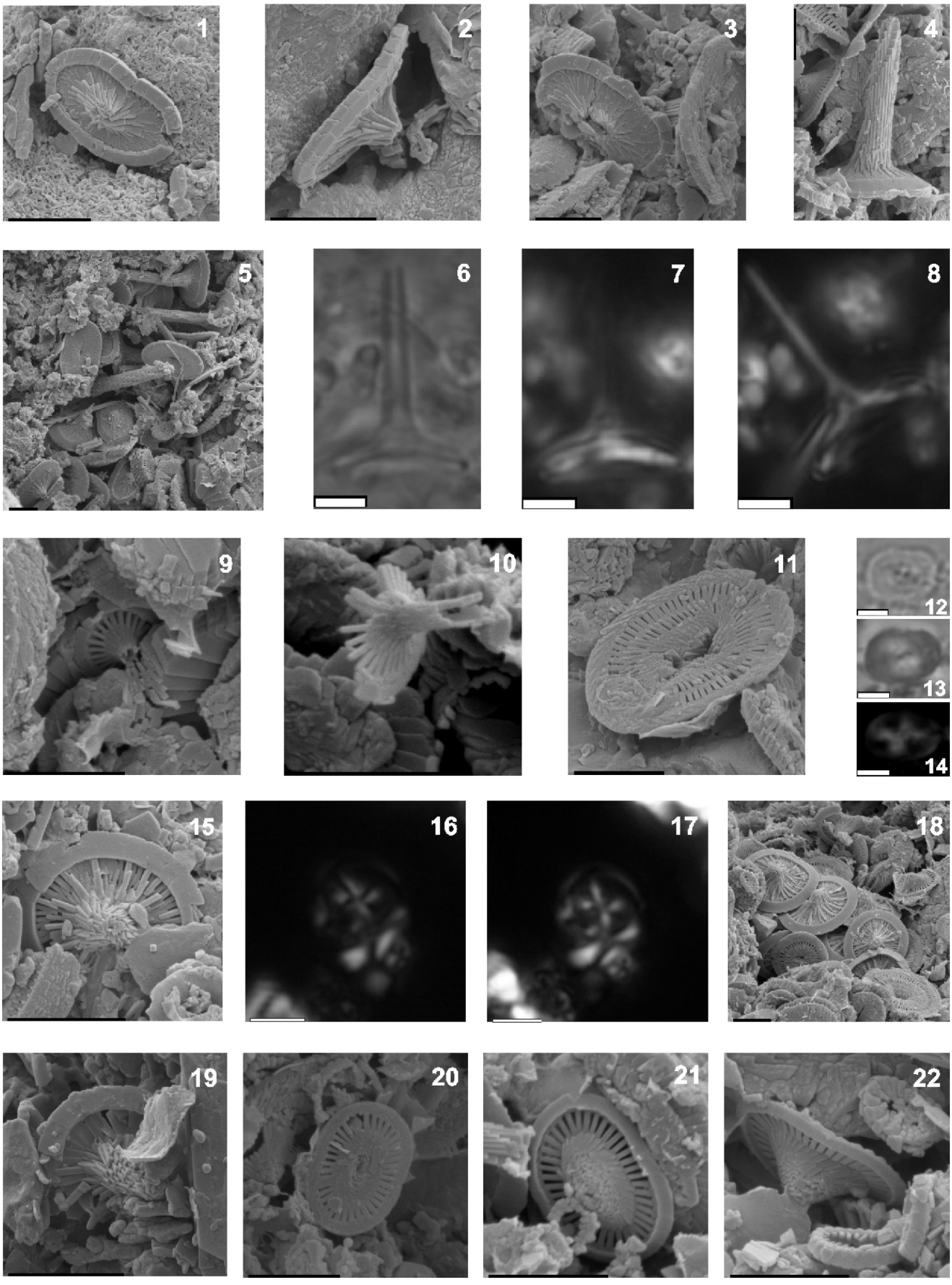
1-3, 5-8 *Rhabdosphaera sicca.* figs. 1-5. SEM, Figs. 6-8. LM. figs. 1-3. and 6-8. Tro-I: 4/2a, fig. 5. Nac-II: 4.

4 *Rhabdosphaera pannonicus.* SEM, Nac-II: 4.

9-10 *Discosphaera tubifera* SEM, Nac-II: 4.

11-19 *Acanthoica laffitei.* figs. 11, 15 and 18. SEM and figs. 12-14 (13. phase contrast) and 16-17 LM, figs. 11, 15-17. Tro-I: 4/2a, figs. 12-14. Jur-I: 1, fig. 18. Nac-II: 4. and fig. 19. Jur-II: 34.

20-22 *Acanthoica cohenii.* SEM, Nac-II: 4.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Description: Medium-sized elliptical placoliths. Proximal shield is significantly smaller than distal shield. Central area spanned by a grill of narrow bars that join to form an axial ridge. The spine is tall, often of similar height to the placolith length, and ends in a bifurcate calyx in well-preserved specimens.

Remarks: Numerous species of Noelaerhabdus have been described, however, they are poorly differentiated and we regard them as synonyms, see also discussion on nannotax website (http://nannotax.org/content/noelaerhabdus-bozinovicae). *Reticulofenestra tegulata* is also regarded as a synonym since it is essentially identical to N. bozinovicae but without the spine. In our material spines are sometimes broken or missing, which could be the result of dimorphism or incomplete growth.

Dimension: 4-9 (with spine 12)µm.

Stratigraphic occurrence: Badenian/Sarmatian-Pannonian. This is a typical Pannonian species, but in the North Croatian Basin I found its' first occurrence in marly sediments of Krndia Mountain, Slavonia at the Badenian/Sarmatian transition. The form is very abundant, often forming near monopecific assemblages in the upper Pannonian of Hrvatsko Zagorje and North Croatian Basins. The species was described from Pannonian sediments in the area of Beograd, Serbia (Jerković, 1970). It has been recorded as common in the lower Pannonian of Styrian Basin, Austria, in middle Pannonian of Pannonian and Transylvanian Basin on Romanian territory and in Pannonian of Hungary (Ćorić and Gross, 2004, Mărunţeanu, 1997, Bóna and Gál, 1985).

Locality: sample ZP-119, Hrvatsko Zagorje.

Order Coccolithales Schwarz 1932 sensu Jordan et al. 2004
Family Coccolithaceae Poche 1913 emend Young and Bown 1997

Genus ***Coccolithus*** Schwartz 1894

Description: Placolith coccoliths with simple central area and coccolithaceae rim structure: V-unit forms distal shield and lower cycle of central-area, while R-unit forms proximal shield and upper cycle of central-area.

Coccolithus miopelagicus Bukry 1971
Plate 8, figures 1-4

Coccolithus miopelagicus Bukry 1971, emend. WISE 1973, p. 310; pl. 2, figs. 6-9.

Description: Large, broadly elliptical placoliths. Proximal shield is markedly smaller than the distal shield.

Remarks: This species is primarily distinguished from *C. pelagicus* by its very large size. In addition the rim is wide relative to the central area and the central opening is narrow.

Dimension: > 13µm.

Stratigraphic occurrence: NN2-NN7/8 (from Oligocene in other marine areas). It is a useful marker within the Sarmatian. In particular, LO (last occurrence) of this species is observed at the NN7/NN8 boundary in the Paratethys.

Locality: Markuševec, Medvednica Mountain.

Coccolithus pelagicus (Wallich 1877) Schiller 1930
Plate 8, figures 5-20

Coccosphaera pelagica WALLICH 1877, 348; pl. 17, figs 1, 2, 5, 11d, 16

PLATE 5

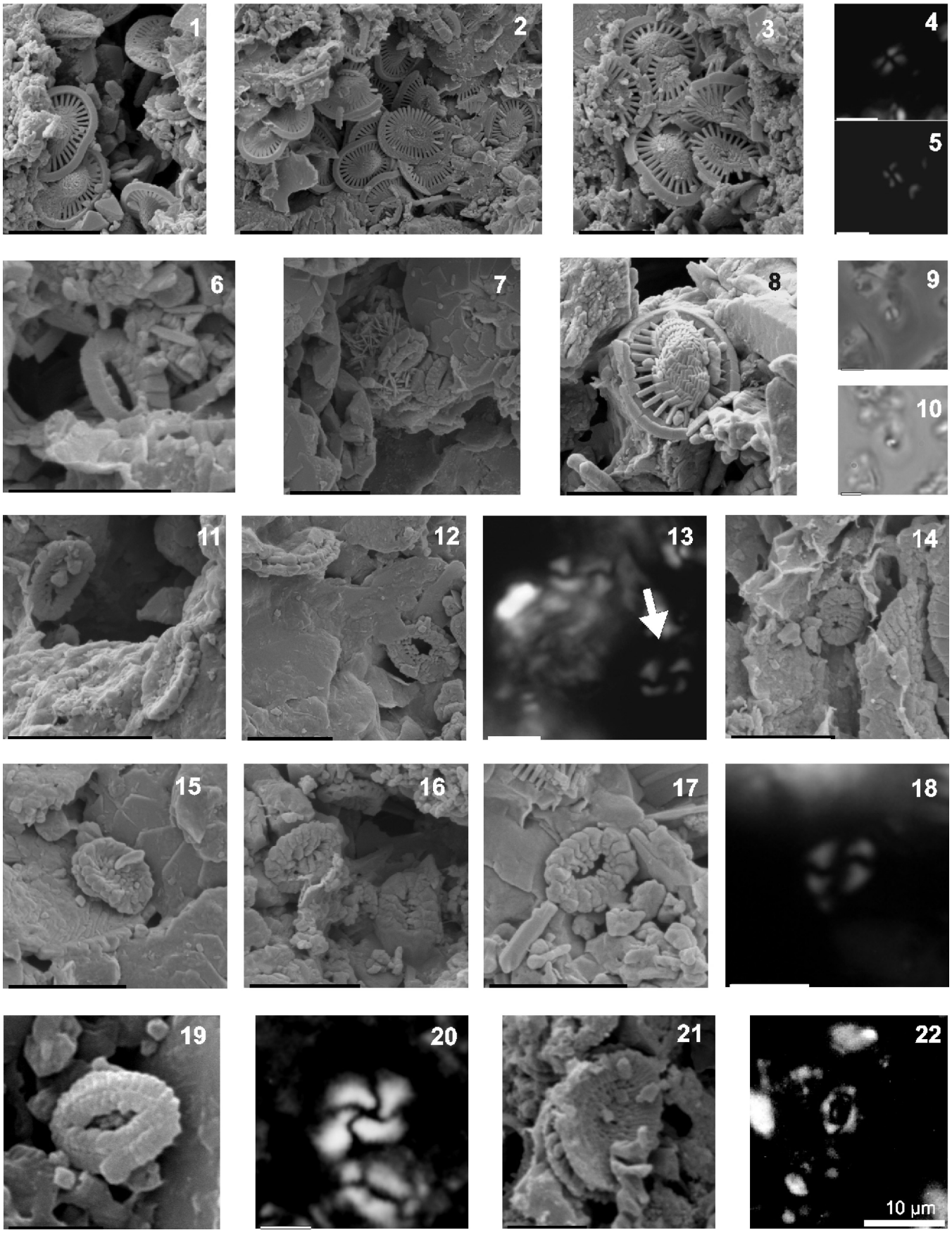
1-5, 8-10 *Acanthoica cohenii.* figs. 1-3, 8. SEM, figs. 4-5, 9-10. LM (9. phase contrast), figs. 1-3, 9-10. Nac-II:4, figs. 4-5, Tro-I: 4/2a, fig. 8. Jur-II: 34.

6-7 *Alisphaera* sp. cf. *pinnigera*. SEM, fig. 6. Nac-II:4, fig. 7. Tro-I: 29/2.

11-18 *Reticulofenestra minuta.* figs. 11-12,14-17. SEM, 13 and 18. LM, fig. 11, Jur-II: 34, figs. 12 and 15. Jur-I: 1, figs. 13, 18. Tro-I: 29/2, figs. 14 and 16, Nac-II: 4, fig. 17., Tro-I: 4/2a.

19-20 *Reticulofenestra producta.* fig. 19. SEM, Krž-I: 59/1, fig. 20. LM, TuT-II: ZK-480/1.

21-22 *Reticulofenestra minutula.* fig. 21. SEM, Nac-II: 4, fig. 22. LM, Le-I: 4.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Coccolithus pelagicus (Wallich) SCHILLER 1930, p. 246, fig. 123, a, c, d.
Cruciplacolithus tenuiforatus CLOCCHIATTI and JERKOVIĆ 1970, pl. 1, figs. 1-3, pl. 2, figs. 1-6.

Description: Mostly medium-sized elliptical placoliths with open central area or spanned by a disjunct structure on the proximal side.

Remarks: In SEM a delicate cross (3rd row of pictures) is often seen in the central area of *C. pelagicus*, specimens from the Paratethys. These specimens were placed in *Cruciplacolithus tenuiforatus* by Clocchiatti and Jerković (1970), recombined as *Coccolithus tenuiforatus* by Wise 1983. We suspect that the presence of a cross in the centre is primarily a result of absence of dissolution in the sediments and include such forms in *C. pelagicus.* The last row represents an early growth-stage of the species. The cross is rarely visible in LM.

Dimension: < 13µm (usually about 7µm).

Stratigraphic occurrence: Palaeogene-Pliocene. Very common species in all Miocene sediments.

Type localities: Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Family Calcidiscaceae Young and Bown 1997
Genus ***Calcidiscus*** Kamptner 1950
synonym: *Cyclococcolithus* Bukry 1971

Description: Circular to subcircular coccoliths. Central area is closed or with narrow opening. Proximal shield is formed from V-unit and birefringent, while distal shield from R-unit and is not birefringent, and has curved sutures.

Calcidiscus leptoporus (Murray and Blackman 1898) Loeblich and Tappan 1978
Plate 9, figures 1-4, 8, 12

Coccosphaera leptopora MURRAY and BLACKMAN 1898, p. 430, 439, pl. 15, figs 1-7.
Coccolithophora leptopora (Murray and Blackman) LOHMANN 1902, p. 137, pl. 5, figs 52, 61-64.
Coccolithus leptoporus (Murray and Blackman) SCHILLER 1930, p. 100, 101, 245, figs 9a, b, 10, 121, 122.
Cyclococcolithus leptoporus (Murray and Blackman) KAMPTNER 1954, p. 23, fig. 20.
Calcidiscus leptoporus (Murray and Blackman) LOEBLICH and TAPPAN 1978, p. 1391.

Description: Medium-sized circular-subcircular placoliths.

Dimension: 5-9,5µm.

Stratigraphic occurrence: NN2-NN11 (common middle Miocene species).

Localities: Tromeđa, Dilj Mountain and Jurjevčani, Samobor hills.

Calcidiscus macintyrei (Bukry and Bramlette 1969) Loeblich and Tappan 1978
Plate 9, figures 5-7

Cyclococcolithus macintyrei BUKRY and BRAMLETTE 1969, p. 132, pl. 1, figs. 1-3.
Calcidiscus macintyrei (Bukry and Bramlette) LOEBLICH and TAPPAN 1978, p. 1392.

Description: Larger, circular placoliths with small central opening.

Dimension: 6-11µm

Stratigraphic occurrence: NN4-NN11 (common middle Miocene species).

Localities: Kasonja and Križ, Dilj Mountain.

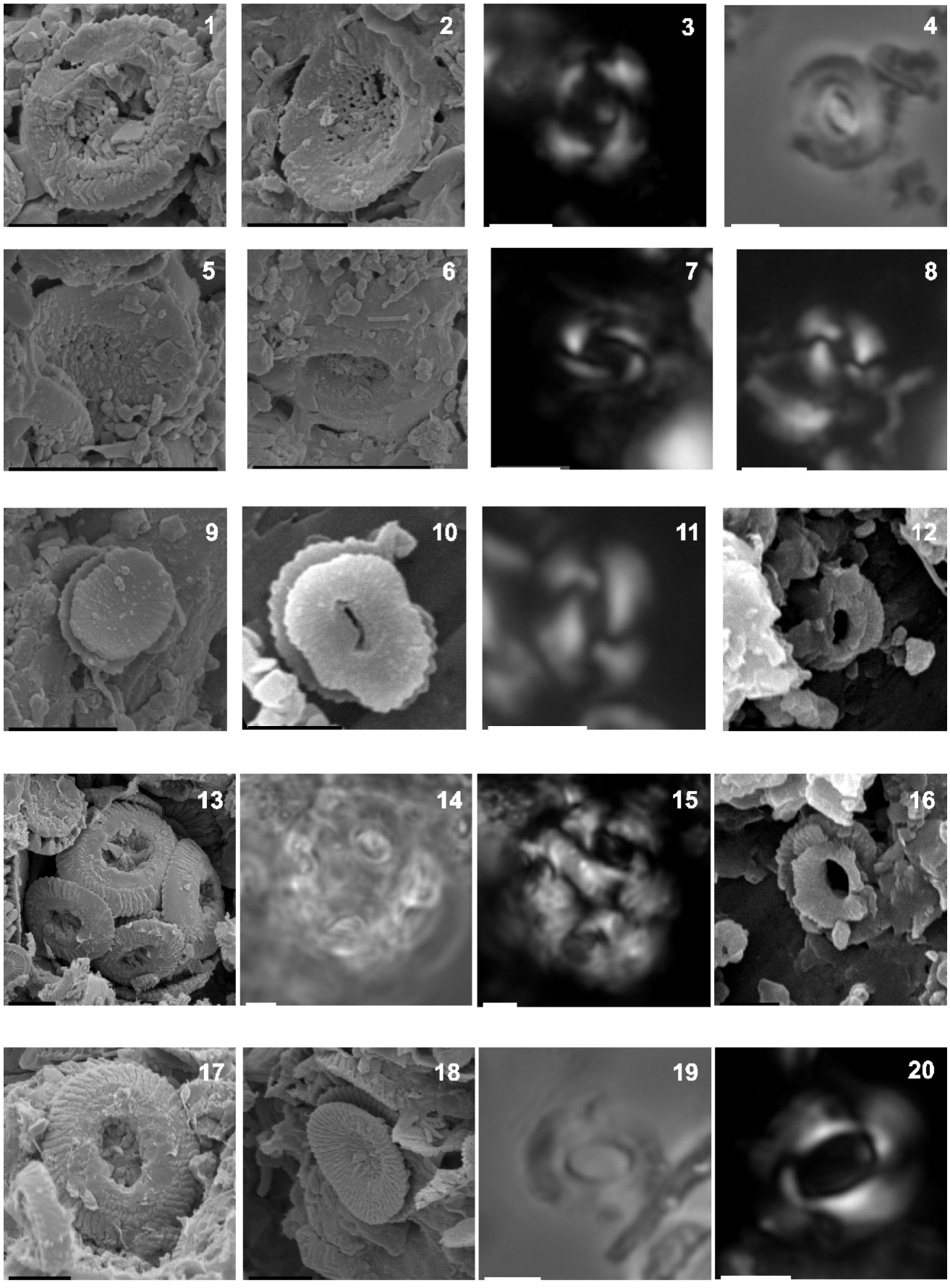
Calcidiscus pataecus (Gartner 1967) de Kaenel and Villa 1996
Plate 9, figures 9-12

PLATE 6

1-3, 5-7 *Reticulofenestra minutula.* figs. 1-2, 5-6. SEM, figs. 3, 7. LM, figs. 1-6 Tro-I: 4/2a, fig. 7. Nac-II: 4.

4, 8-12, 16 *Reticulofenestra haqii.* figs. 9-10, 12, 16. SEM, figs. 4, 8, 11. LM (4. phase contrast), fig. 4, Nac-II: 4, figs. 8-9, 11. Tro-I: 29/2, figs. 10, 12, 16., Krž-I: 59/1.

13-15, 17-20 *Reticulofenestra pseudoumbilicus.* Nac-II: 4, figs. 13, 17-18. SEM, figs. 14-15, 19-20, LM (14, 19. phase contrast).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Calcidiscus pateacus GARTNER 1967, p. 4, pl. 5, figs. 6, 7a, b, 8a, 8b. – DE KAENEL and VILLA 1996, p. 123.

Description: Smaller, broadly elliptical placoliths.

Dimension: < 5µm.

Stratigraphic occurrence: NN6-NN7. The first occurrence (FO) of *Calcidiscus pataecus* differs within the Paratethys. Its FO in the Transylvanian Basin is characteristic of the end of the Badenian NN6d zone (Chira and Mărunţeanu, 2000) as in North Croatian Basin too (Slavonian Mts.). In the Vienna Basin FO of *C. pataecus* is noticed at the beginning of Sarmatian (S. Ćorić, pers. commun.). The first abundant appearance of *C. pataecus* in the Croatia occurs at the beginning of the Sarmatian (NN6d zone).

Localities: Jurjevčani, Samobor hills, Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Genus ***Umbilicosphaera*** Lohmann 1902

Description: Circular coccoliths with *Calcidiscus* structure and open central area. Distal shield elements usually show complex kinked sutures. Proximal shield is monocyclic in fossil species.

Umbilicosphaera jafari Müller 1974
Plate 9, figures 13-16

Umbilicosphaera jafari MÜLLER 1974, p. 394-395, pl. 1, figs. 1-3; pl. 4, figs. 43-44.

Description: Small circular placolith with narrow central area. Distal shield is slightly wider than proximal shield. .

Dimension: 2.5-5µm.

Stratigraphic occurrence: NN4 - NN11. First appearance is detected in the Karpatian of Austria and Croatia. Characteristic warm, oligotrophic species for the middle Miocene of the Paratethys. It has last appearance in upper Miocene of the Romania.

Localities: Našice, Krndia Mountain and Tromeđa, Dilj Mountain.

Umbilicosphaera rotula (Kamptner 1948) Varol 1982
Plate 9, figures 17-20, Plate 10, figures 1-4

Tremalithus rotula KAMPTNER 1948, p. 8; tab. 2, fig. 15.
Cyclococcolithus rotula (Kamptner) KAMPTNER 1956, p. 7.
Geminilithella rotula (Kamptner) BACKMAN, 1980
Umbilicosphaera rotula (Kamptner) VAROL 1982, p. 251.

Description: Coccoliths with wide central area and narrow rim. Tube is well developed and separates shields of similar size.

Remarks: A range of morphotypes are included in *U. rotula* and it possibly includes more than one species. Some speciemens rather closely resemble modern *U. sibogae* (plate 9/17-20).

Dimension: 5-8µm.

Stratigraphic occurrence: NN2 - NN11. First less frequent and small occurrence is detected in the West Carpathian and then in the Karpatian of the Austria, Croatia and Romania. The larger forms are known from the middle Miocene of the mentioned area and also from Slovenia, Bosnia and Czech. It has last appearance in upper Miocene of the Romania.

Locality: Tromeđa, Dilj Mountain.

Group Nannoliths Young and Bown 1997
Order Discoasterales Hay 1977
Family Discoastersceae Tan 1927

Genus ***Catinaster*** Martini and Bramlette 1963

Description: Basked or cup shaped nannoliths. They have six-fold radial symmetry and the same crystallographic orientation as discoasters. The cup was probably formed by fusion of the bifurca-

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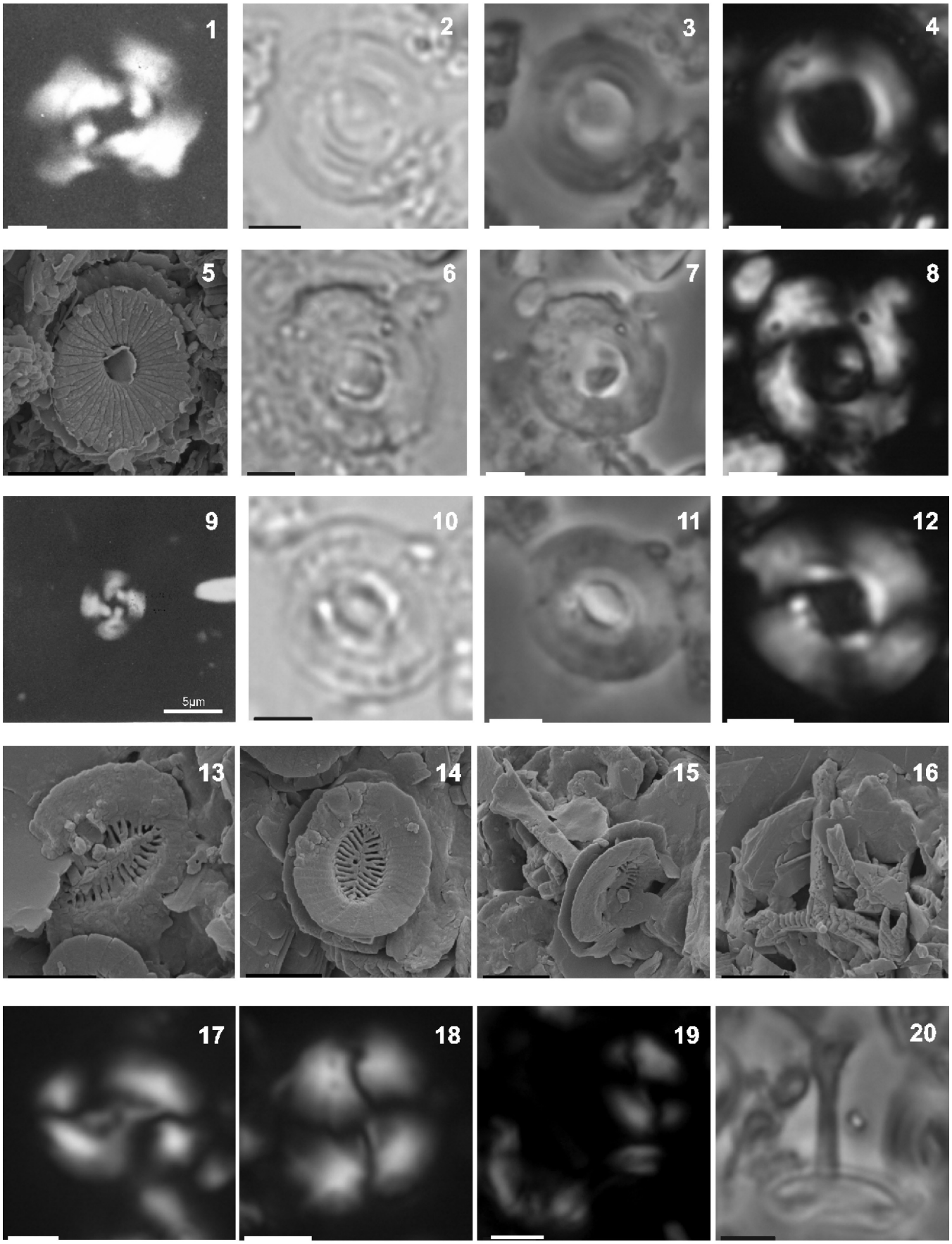
PLATE 7

1 *Reticulofenestra pseudoumbilicus gelida.* LM, Tro-I: 18/3.

2-4, 6-8 *Reticulofenestra rotaria.* LM, Jur-I: 1.

5, 9-12 *Cyclicargolithus floridanus.* fig. 5, SEM, Jur-II: 34., figs. 9-12. LM (11. phase contrast), fig. 9. TuT-II: 17/1, figs. 10-12. Nac-II: 4.

13-20 *Noelaerhabdus bozinovicae.* ZP-119, figs. 13-16. SEM, figs. 17-20. LM (20. phase contrast).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tions of a small discoaster (Martini and Worsley 1971, Peleo--Alampay et al. 1998, http://nannotax.org/content/catinaster).

Catinaster coalitus Martini and Bramlette 1963
Plate 10, figures 5-6

Catinaster coalitus MARTINI and BRAMLETTE 1963, p. 851; pl. 103, figs. 7-9.

Description: Form with rays on the distal side that do not extend beyond the rim. The rim continues to the proximal pole producing a circular to hexagonal basket-like body.

Dimension: 4.5-8μm.

Stratigraphic occurrence: NN8 zone. Very rare Paratethyan zonal species known from Romania and Croatia.

Localities: Kostanjek, Medvednica Mountain and Našice, Krndia Mountain.

Genus ***Discoaster*** Tan 1927

Description: Radiate nannoliths with star shaped rays. Rays show numerous variations. Discoaster are rare in Paratethyan sediments and predominantly 6 rayed discoasters with bifurcations of limited stratigraphic value.

Discoaster challengeri Bramlette and Riedel 1954
Plate 10, figures 7-8

Discoaster challengeri BRAMLETTE and RIEDEL 1954, p. 401; pl. 39, fig.10. – STRADNER and PAPP 1961, Pl. 17, Fig. 2a, Pl. 18, Fig. 2.

Description: Species with 5-7 rays that terminate at about 120 angles into equally cylindrical bifurcations.

Dimension: 4-18μm (mostly about 10μm).

Stratigraphic occurrence: NN6-NN9. Less common middle Miocene species. Mostly represented in Austria, Romania and Croatia.

Locality: Križ, Dilj Mountain.

Discoaster exilis Martini and Bramlette 1963
Plate 10, figure 9

Disoaster exilis MARTINI and BRAMLETTE 1963, p. 852; Tab. 104, Figs. 1-3.

Description: Species with 5-6 long rays with knob in the central-area. The end of each ray shows slightly bifurcation.

Dimension: 11-18μm.

Stratigraphic occurrence: NN4-NN7. Common middle Miocene species of the Paratethys.

Locality: Križ, Dilj Mountain.

Discoaster kugleri Martini and Bramlette 1963
Plate 10, figure 10

Discoaster kugleri MARTINI and BRAMLETTE 1963, p. 853; Pl. 102, Figs. 11-13.

Description: The specimen has short rays and wide, flat central area. Rays end with notch, sometimes slightly angled.

Dimension: 8-11μm.

Stratigraphic occurrence: NN7. The poor occurrence of the zonal species that referred to *Discoaster kugleri* has been found in Poland and typical *D. kugleri* forms in Romania, Hungary and Croatia.

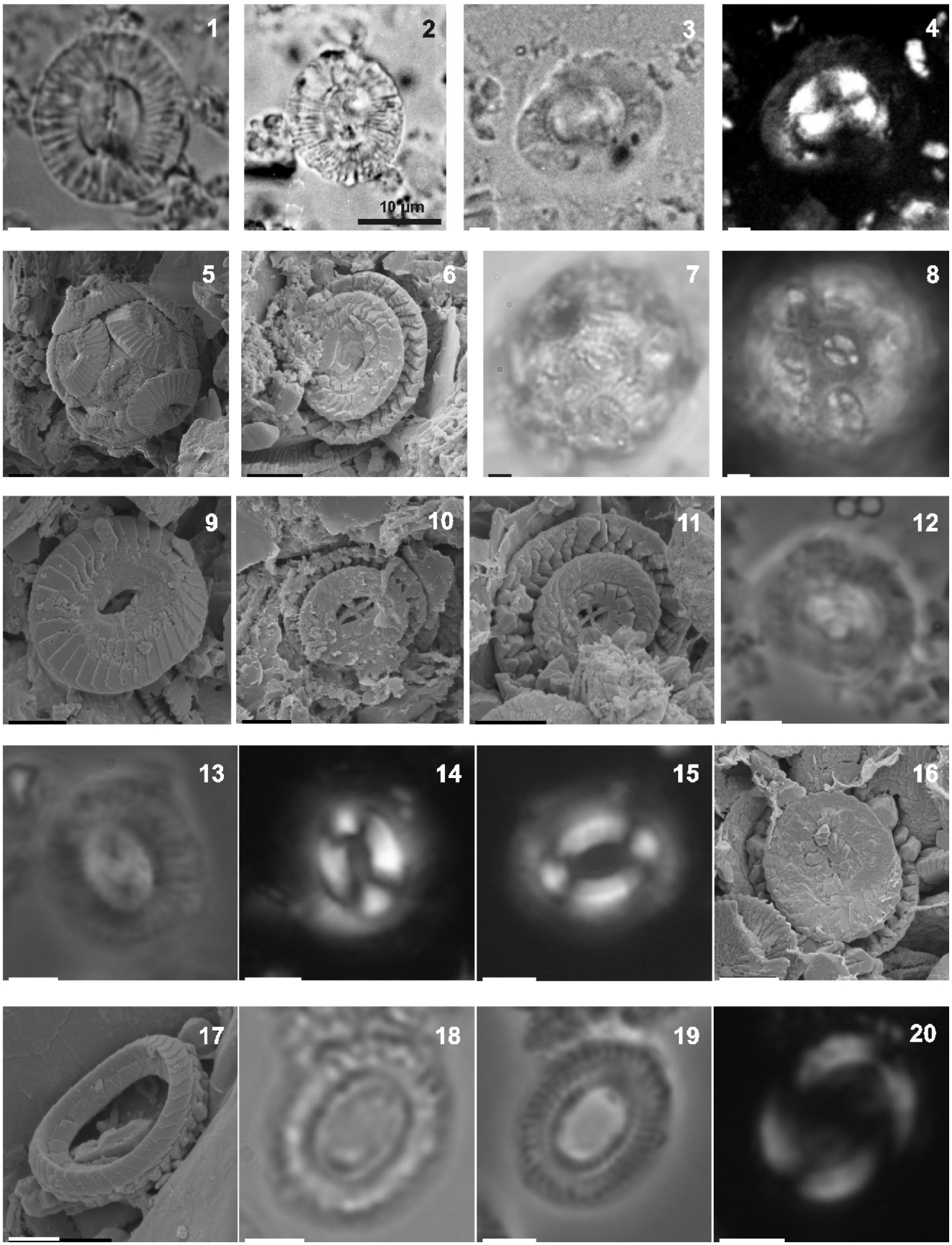
Locality: Križ, Dilj Mountain.

Discoaster variabilis Martini and Bramlette 1963
Plate 10, figure 11

PLATE 8

1-4 *Coccolithus miopelagicus.* LM, figs. 1-2. Mar-I: 1b, figs. 3-4. Ped-2b.

5-20 *Coccolithus pelagicus.* figs. 5-6, 9-11,16-17. SEM, figs. 7-8, 12-15, 18-20. LM (12-13, 19. phase contrast), figs. 5-6, 9,12-15, 17. Tro-I: 4/2a, figs. 7-8, 10-11, 16, 18-20. Nac-II: 4.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Discoaster variabilis MARTINI and BRAMLETTE 1963, p. 854; tab. 104, figs. 4-8.

Description: Nannolith with 3 - 6 rays that bifurcate about 90° at the ends. Central area has ridges and knob in its centre.

Dimension: 9-19.5µm.

Stratigraphic occurrence: (NN3) NN4 NN7 (NN9). Common middle Miocene species of the Paratethys.

Locality: Križ, Dilj Mountain.

Family Sphenolithaceae Deflandre 1952

Genus ***Sphenolithus*** Deflandre 1952

Remarks: In the Paratethys, species seem to appear earlier than in other marine areas.

Sphenolithus abies Deflandre 1954
Plate 10, figures 12-14

Sphenolithus abies Deflandre 1954. – LEHOTAYOVÁ and MOLČÍKOVÁ 1978, pl. 7, fig 5. – LEHOTAYOVÁ 1982, p. 104; pl. XL, fig. 1. – BARTOL 2009, pl. 20, figs. 1,9.

Description: "Moderately elevated sphenolith with cuspate outline and with extinction line going down long axis of spine".

Remarks: Both species *Sph. neoabies* and *Sph. grandis* belong to the variants of the *Sph. abies*. *Sphenolithus abies* differs from *S. moriformis* by its triangular profile. It is not possible to distinguish the species in apical view. *S. neoabies* and *S. grandis* are regarded as variants of *S. abies* by Young (1998).

Dimension: 3.8-5µm.

Stratigraphic occurrence: NN4-NN9, but in other marine areas from NN7-NN15. Common Middle Miocene species.

Type localities: Vugrovec, Medvednica Mountain, Križ, Dilj Mountain and Našice, Krndia Mountain.

Sphenolithus neoabies Bukry and Bramlette 1969
Plate 10, figures 15-16

Sphenolithus neoabies BUKRY and BRAMLETTE 1969, p. 140; pl. 3, figs. 9-11.
Sphenolithus moriformis Bramlette and Wilcoxon. – BARTOL 2009, pl. 20, figs. 4,6.

Description: Smaller and less conical form with less extended apical spine.

Dimension: < 3.8µm.

Stratigraphic occurrence: NN4-Pannonian. *Sphenolithus neoabies* has been found for the first time in the NN4 zone of the Hrvatsko Zagorje Basin (Croatia) and in NN5 of the Mura Depression (Slovenia). The last common appearance is detected in Pannonian of the same area. The species is noticed from NN6 till Pannonian in North Croatian Basin.

Type localities: Križ, Dilj Mountain and Našice, Krndia Mountain.

Sphenolithus grandis Haq and Berggren 1978
Plate 10, figures 17-18

Sphenolithus grandis HAQ and BERGGREN 1978, p. 1192; pl. 3, figs. 17-20.

Description: Larger form with separated spines arising from a narrow base.

Dimension: about 10µm.

Stratigraphic occurrence: NN6 - NN7. The rare appearance of the species has been found for the first time in the North Croatian Basin of Paratethys.

PLATE 9

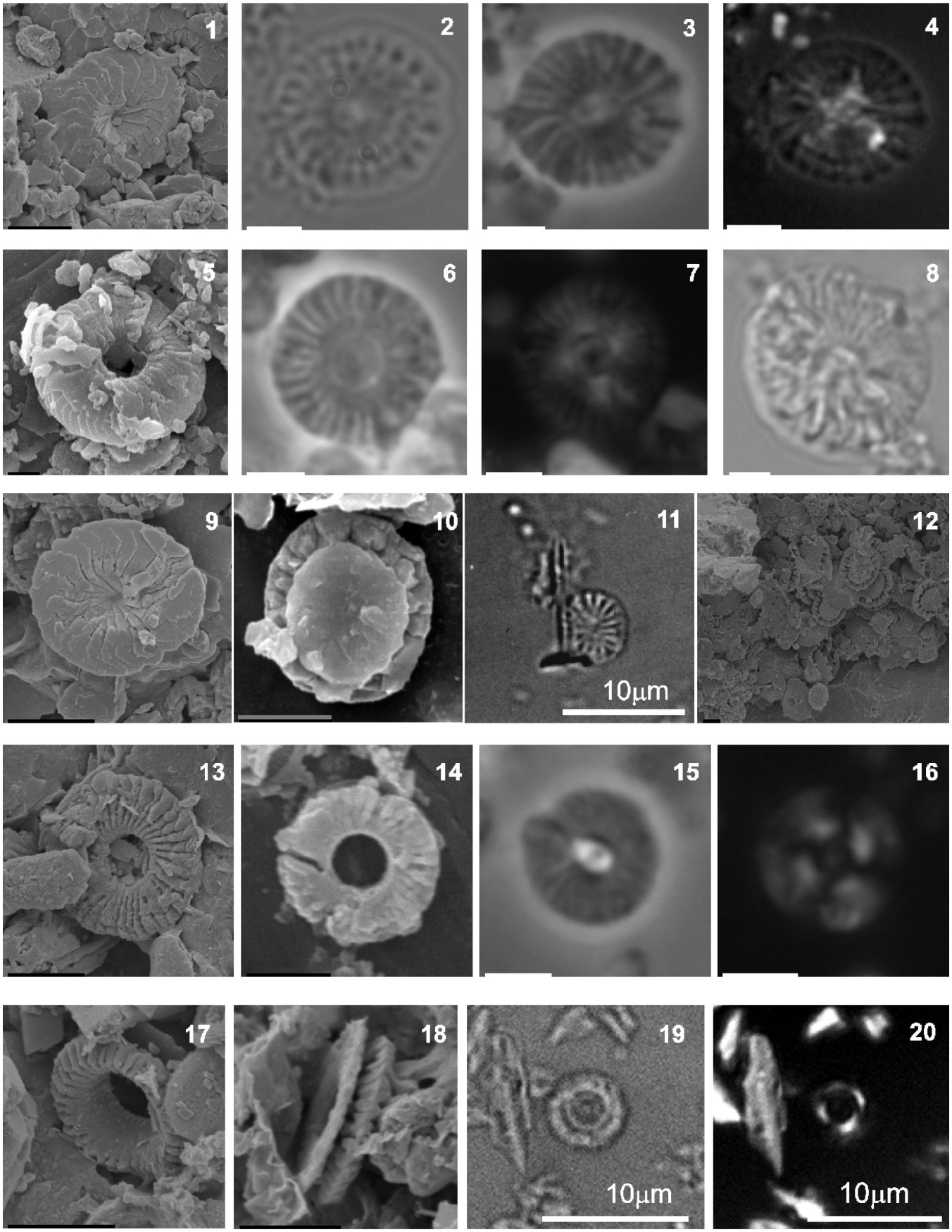
1-4, 8, 12 *Calcidiscus leptoporus.* fig. 1. SEM, Jur-I: 1., figs. 2-4, 8, LM, Tro-I: 29/2 and fig. 12 (SEM).

5-7 *Calcidiscus macintyrei.* fig. 5. SEM, Krž-I: 59/1, figs. 6-7. LM, Kas-I: 16.

9-11 *Calcidiscus pataecus.* figs. 9-10. SEM, Jur-I: 1, fig. 11. LM, Nac-I: 1.

13-16 *Umbilicosphaera jafari.* fig. 13, 14 SEM, figs. 15, 16. LM, figs. 13, 15-16. Tro-I: 29/2, fig. 14. Nac-II: 4.

17-20 *Umbilicosphaera rotula.* figs. 17-18. SEM, fig. 17. Tro-I: 29/2, fig. 18. Nac-II: 4, figs. 19-20. LM, Dra-I: 0/2.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Locality: Jurjevčani, Samobor hills.

Order Incertae sedis sensu Young and Bown 1997
Family Braarudosphaeraceae Deflandre 1947
Genus *Braarudosphaera* Deflandre 1947

Braarudosphaera bigelowii (Gran and Braarud 1935) Deflandre 1947
Plate 10, figures 19-20

Braarudosphaera bigelowii (Gran and Braarud 1935) Deflandre 1947. – STRADNER and PAPP 1961, p. 116-117, pl. 37, figs. 1-3, 7-8. – FUCHS and STRADNER 1977, p. 31, pl. 1, figs. 26-27, pl. 6, figs. 8-9. – LEHOTAYOVÁ and MOLČIKOVÁ 1978, pl. 4, fig. 1. – STRADNER and FUCHS 1978, pl. 16, fig. 18. – NAGYMAROSY 1980, pl. 2, fig. 4. – STRADNER and FUCHS 1980, pl. 1, figs. 1-2, pl. 2, figs. 1-6, pl. 3, figs. 2, 5, pl. 4, figs. 10-11. – MĂRUNŢEANU 1999 pl. 2, figs. 6a-b. – ANDREJEVA- GRIGOROVIĆ and HALÁSOVÁ 2000, fig. 48. – ANDREJEVA-GRIGOROVIĆ and SAVYTSKAYA 2000, pl. 1, fig. 16. – ŠVÁBENICKÁ et al. 2003, pl. 1, figs. 12, 18. – BARTOL 2009, pl. 18, figs. 12-13.

Description: Medium to large sized pentalith with trapezoidal segments and sutures that intersect the flat sides of the pentagon.

Dimension of the side: 2.5-12μm.

Stratigraphic occurrence.: (Jura) Palaeogene-NN13.

Localities: Tromeđa, Dilj Mountain and Markuševec, Medvednica Mountain.

Remarks: The species is thought to be indicative of warm, shallow marine conditions with reduced surface salinity (27-33 ‰) Bukry (1974), Beaufort and Heussner (2001) and Sprovieri et al. (2003).

Family Lithostromationaceae Deflandre 1959
Genus *Lithostromation* Deflandre 1942

Lithostromation perdurum Deflandre 1942
Plate 10, figure 21

Lithostromation perdurum Deflandre 1942. – MÜLLER 1974, pl. 2, fig. 10. – FUCHS and STRADNER 1977, 35, pl. 6, fig. 12. – LEHOTAYOVÁ and MOLÈIKOVÁ 1978, pl. 9, fig. 2. – BARTOL 2009, pl. 18, figs. 1-3, 24-25.
Lithostromation triangularis (Gardet). – NAGYMAROSY 1980, pl. 3, fig. 2.

Description: Triangular, with six rounded perforations on the central body arrange in two pears along each side of the triangle. The perforations are separated by ridges built up as central upper structure on both sides of the plate.

Dimension of the side: 6-21μm.

Stratigraphic occurrence: NN5-NN8. Some bigger species from usually 14μm have been found in North Croatian Basin.

Locality: Markuševec, Medvednica Mountain.

Remarks: In North Croatian Basin I found species in assemblages that are characteristic for nearshore Gulf Coast like Perch Nielsen (1985) in the Middle Miocene too.

PLATE 10

1-4 *Umbilicosphaera rotula.* Tro-I. 29/2, fig. 1. SEM, figs. 2-4. LM (2. phase contrast).

5-6 *Catinaster coalitus.* LM, fig. 5. Kst-I: 10, fig. 6. Nac-I: 2.

7-8 *Discoaster challengeri.* fig. 7. SEM, Krž-I: 29/1, fig. 8. LM, Krž-I: 15/2.

9 *Discoaster exilis.* LM, Krž-I: 29/1.

10 *Discoaster kugleri.* LM, Krž-I: 59/1.

11 *Discoaster variabilis.* LM, Krž-I: 18/1.

12-14 *Sphenolithus abies.* figs. 12-13. SEM, fig. 14. LM, fig. 12. Nac-II: 4, fig. 13, Krž-I: 59/1, fig. 14. Vug-I: 1.

15-16 *Sphenolithus neoabies.* fig. 15. SEM, Krž-I: 299/1, fig. 16. LM, Nac-II: 4.

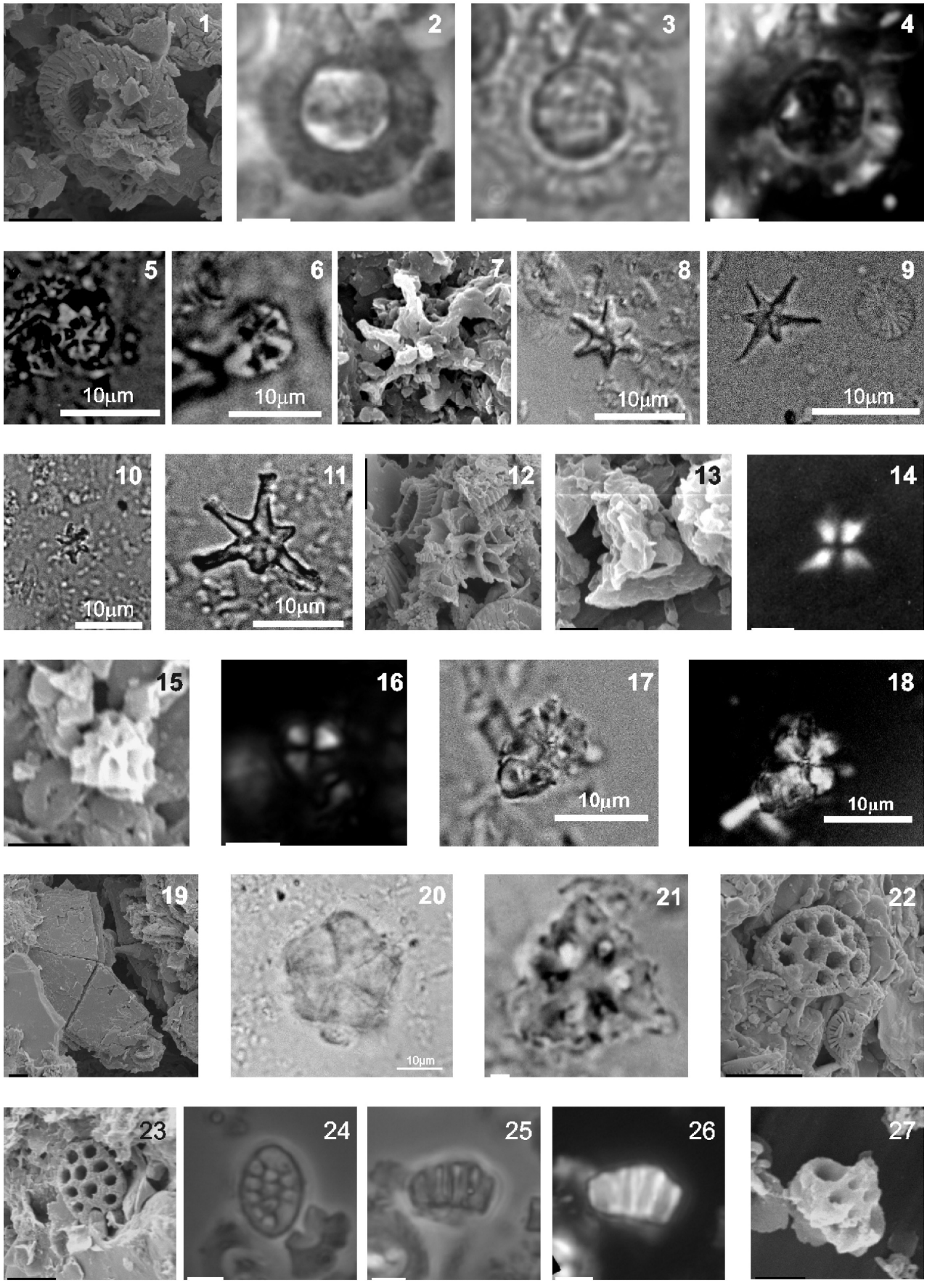
17-18 *Sphenolithus grandis.* LM, Jur-II: 12.

19-20 *Braarudosphaera bigelowii.* fig. 19. SEM, Tro-I: 4/2a, fig. 20. LM, Mar-I: 14.

21 *Lithostromation perdurum.* LM, Mar-I: 14.

22-26 *Syracolithus schilleri.* figs. 22-23. SEM, figs. 24-26. LM (25-26. side view), figs. 22, 24-26. Tro-I: 4/2a, fig. 23. Nac-II: 4.

27 *Syracolithus* cf. *dalmaticus.* SEM, Nac-II: 4.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Group **Holococcoliths** Young and Bown 1997
synonym: Calyptrosphaeraceae Boudreaux and Hay 1969

Description: Holococcoliths are formed of numerous small (0.1µm) rhombohedral calcite crystals of uniform size and shape. In cross-polarized light, specimens show varying degrees of birefringence.

Genus ***Syracolithus*** Deflandre 1952

Description: Open-topped tube with internal septae.

Syracolithus schilleri (Kamptner 1927) Loeblich and Tappan 1963
Plate 10, figures 22-26

Discolithus macroporus (Deflandre) - FARINACCI 1969, II, 124.
Holodiscolithus macroporus (Deflandre) Roth-FUCHS and STRADNER 1977, p. 30. – LEHOTAYOVÁ and MOLČÍKOVÁ 1978, pl. 5, fig. 4. – STRADNER and FUCHS 1981, pl. 9, fig. 5. – MĂRUNĆEANU 1999, pl. 3B, fig. 7.

Description: Coccoliths with open tubes and internal walls (septae) showing hexagonal shaping of crystals that birefringent in LM plain view. Upper surface of coccolith is convex and higher in the centre than edges.

Remarks: Similar to *S. quadriperforatus* but liths are larger and have more than 6 pores. Since *S. quadriperforatus* has been shown to be a holococcolith phase of *Calcidiscus* (Geisen et al. 200) it had been predicted that *S. schilleri* would belong to the Calcidiscaceae but Frada et al. (2009) showed that modern *S. schilleri* is formed by *Scyphosphaera apsteinii*.

Dimension: 3 - 4µm like in recent species, but according to Stradner and Fuchs up to 8µm.

Stratigraphic occurrence: From Pg, but characteristic species for Middle Miocene of the Paratethys.

Type localities: Tromeđa, Dilj Mountain and Našice, Krndia Mountain.

Syracolithus cf. ***dalmaticus*** (Kamptner1927) Loeblich and Tappan 1966
Plate 10, figure 27

Syracolithus cf. *dalmaticus* (Kamptner 1927) Loeblich and Tappan 1966 . – LEHOTAYOVÁ and MOLČÍKOVÁ 1978, pl. 9, fig. 6.
Syracolithus dalmaticus (Kamptner) Loeblich and Tappan. – BARTOL 2009, pl. 17, figs. 10-12, 20.

Description: Similar to *Syracolithus schilleri* but, smaller, with less pores and central area is higher and sometimes without pores.

Dimension: 1-4µm.

Stratigraphic occurrence: NN6 (Badenian).

Locality: Našice, Krndia Mountain.

ACKNOWLEDGMENTS

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