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New early Late Carnian (Upper Triassic) radiolarians from the Pindos-Huğlu succession of the South-Taurides ophiolite belt

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Abstract
This article is a continuation of the taxonomic study of the exquisitely preserved and extremely rich Late Carnian (early Tuvalian, *Spongotortilispinus moixi* Zone) radiolarian fauna of the sample G 11 from the Sorgun Ophiolitic Mélange occurring in the Tavusçayiri block, Pindos-Huğlu series, Tauride ophiolite belt, Turkey. 26 species of Spumellaria with spongy test, belonging to 7 genera, are discussed and illustrated. Among them 14 species and two genera (*Staurotortilispinus* n. gen and *Ancoraspongus* n. gen) are introduced as new. The assemblage provides new data on the diversity of the radiolarian fauna of the Tethys during the Late Carnian and contributes to a better understanding of the Mesozoic geodynamic evolution of the Mediterranean region.

Keywords Radiolaria · Tuvalian · Sorgun Ophiolitic Mélange · Turkey

1 Introduction

The ophiolites and deep-sea sedimentary units exposed in the Eastern Mediterranean region provide the most important clues for reconstruction of the geodynamic evolution of the Neotethyan oceanic basin. These NNW-SSE trending units stretch from the Balkan Peninsula (Dinarides-Hellenides) through Taurides-Anatolides orogenic belt to the Himalayas (Fig. 1). One of the most important sedimentary sequences or key geological unit is the classical deep-water Pindos-type series that extends from the Budva Zone in Montenegro through Albania and continental Greece to the Aegean islands. The succession is identical to the Huğlu series in Turkey characterized by widespread occurrence of volcanics, volcanoclastics associated with pelagic limestone and abundant cherts of Middle Triassic to Late Cretaceous age (e.g. Monod 1977; Andrew 2002; Moix et al. 2013). The Huğlu series are exposed in the Lycian Nappes, the Beyşehir-Hoyran Nappes and likely farther east in the Mersin Ophiolite Complex (MOC) and in the Köseyahya Nappe in the Eastern Taurides. This paper is focused on the appearance of Pindos-Huğlu series in the MOC that belongs to the Taurides ophiolite belt (Moix et al. 2013; Parlak 2016). The MOC exhibits oceanic lithospheric remnants with typical ophiolitic series, sub-ophiolitic metamorphic sole and associated infra-ophiolitic mélange (Mersin Mélange). Moix et al. (2011) subdivided this mélange into two major units: the Upper Cretaceous Sorgun Ophiolitic Mélange (SOM) and the Middle to Upper Triassic Hacialani Mélange (Fig. 2a, b). An individual tectonic block of the SOM is the well-developed Tavusçayiri Block (Masset and Moix 2004), which contains a typical Huğlu (-Pindos) succession (Fig. 2c). This block has yielded the best-preserved and most diverse early Tuvalian (Carnian) radiolarian fauna worldwide (Masset and Moix 2004). Thus far, three new families, 15 new genera, and 119 new species and subspecies have been described in a series of papers by Moix et al. (2007), Kozur et al. (2007a, b, 2007c; 2009) and Ozsvárt et al. (2015; Ozsvárt et al. 2017a, b). In this paper, we continue to present the results of taxonomic study with the description of several new spumellarian radiolarians and discuss some implications for the geodynamic reconstruction of the Tethyan realm.

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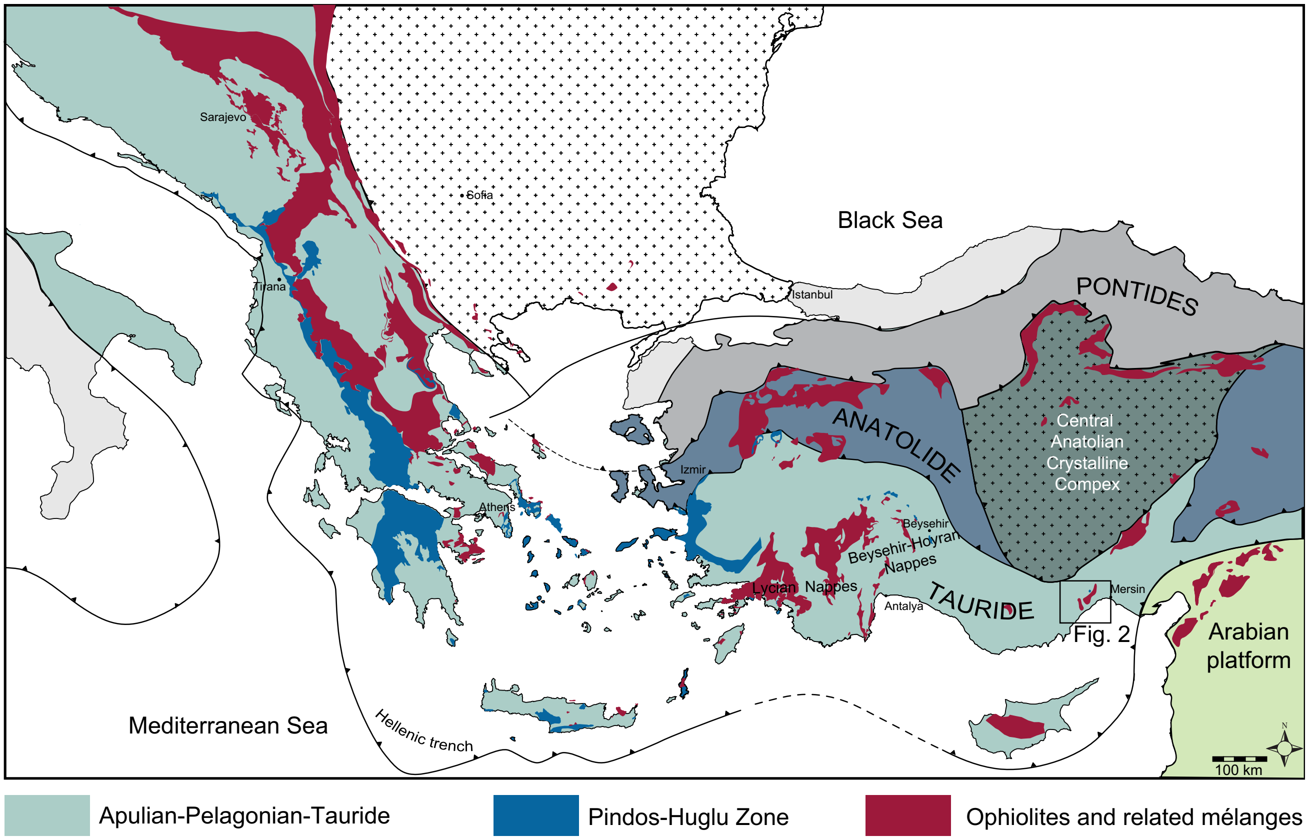


Fig. 1 Schematic tectonic map of the Eastern Mediterranean region. Simplified after Moix et al. (2008) and Schmid et al. (2018)

2 Geological framework

2.1 The Pindos Zone and its extension in the Neotethys

The Pindos Zone is located between the Gavrovo-Tripolitza (carbonate platform)—Ionian Zone (intra-platform rift basin) and the Pelagonian units. The sedimentary successions of this unit have been studied extensively for more than a century (e.g. Phillipson 1892; Brunn 1956; Aubouin 1959; Fleury 1980; Neumann et al. 1996; Degnan and Robertson 1998). It is generally agreed that a classical Pindos-type sedimentary series was formed in a rift basin from the Triassic and became a passive margin during the Mesozoic extending to the early Paleogene. The basal part of the classical Pindos-type series characterized by flysch-type sequences ("Anisian Flysch") mainly with siliciclastics and carbonates [called "détritique triasique" by Fleury (1980) or Priolithos Formation by Degnan and Robertson (1998)] overlain by massive volcano-sedimentary sequence with alternating volcanoclastics, bedded cherts, *Halobia* limestone, cherty limestones and Hallstatt Limestone associated with detrital rocks (Drimos Formation by Degnan and Robertson 1998). Upwards, the carbonate content of the predominantly calcareous Drimos Formation decreases, while the clay and siliceous content increases and the succession become lithologically more heterogeneous with frequent radiolarite and chert beds ("Les Jaspes à Radiolarites" by Aubouin 1959 or Lesteena Formation by Degnan and Robertson 1998). This was followed by decrease of siliceous content and sedimentation became definitely carbonated (Lambia Formation) with appearance of the first flysch-type series (Premier Flysch by Aubouin 1959; Flament 1973) in the Cenomanian–Turonian (Wagreich et al. 1996; Neumann et al. 1996). The sedimentary series of the Pindos Zone terminates by the "Flysch du Pinde" or Pindos Flysch Formation by Degnan and Robertson 1998 that formed during early Cenozoic time (Paleocene to Eocene, Fleury 1980). This classical deep water Pindos-type series is known from the Budva Zone of Montenegro (Goričan 1994) and Krasta-Cukali Zone of Albania (Xhomo et al. 1975), from the continental Greece (Pindos series) and from the Peloponnese (Olonos series), from Crete (Ethia, Mangassa and Lentas series), from Karpathos (Xindothio series), from Rhodes (Prophitis Ilias series), and from Tilos (Kreati series) of the Dodecanese (de Bernoulli et al. 1974; Moix et al. 2013). Eastwards, this characteristic facies succession reappears in the Lycian Nappes (de Bernoulli et al. 1974; Moix et al. 2013), in the Beyşehir-Hoyran Nappes (e.g. Brunn et al. 1971; Monod

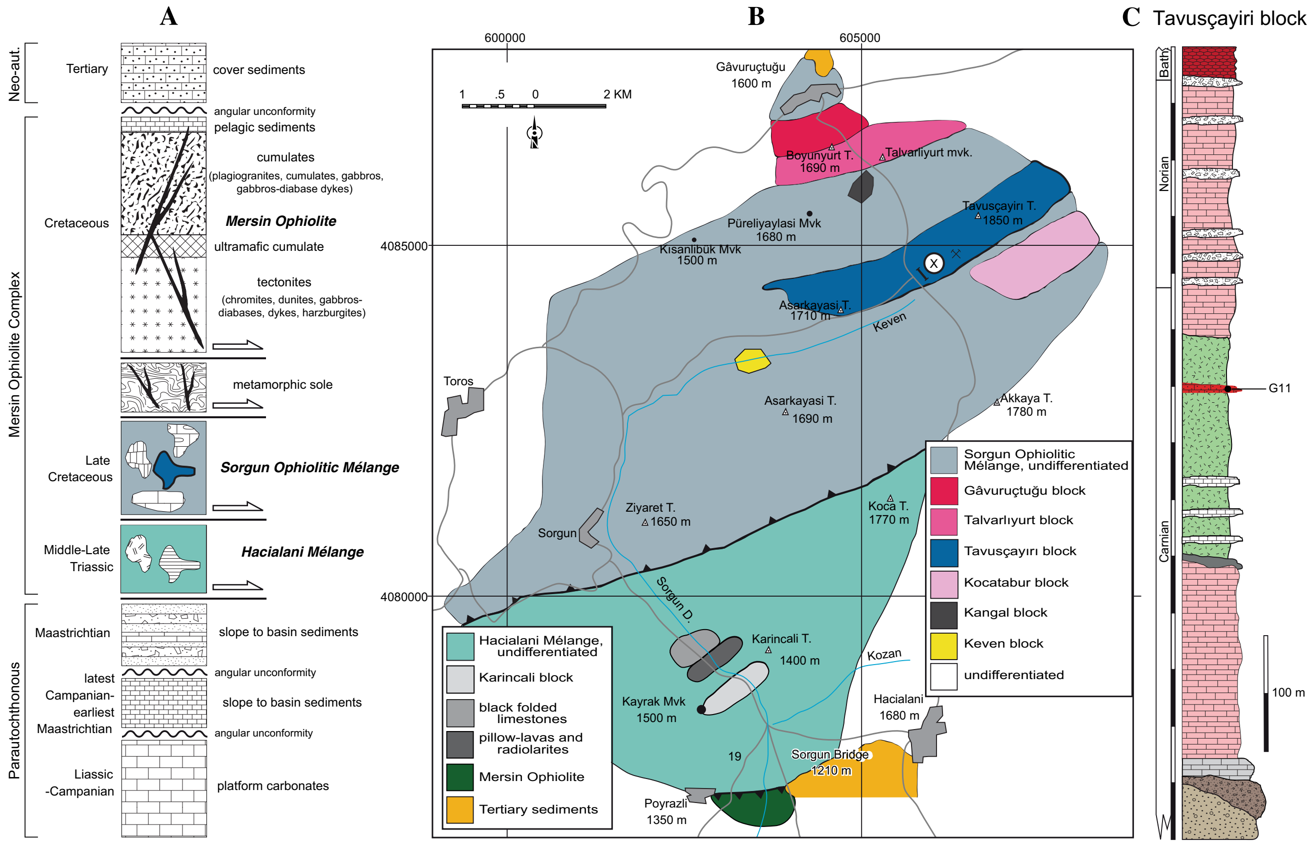


Fig. 2 **a** Composite section (modified from Moix et al. 2011) of the studied area. **b** Simplified geological map of the studied area, showing the location of the Tavusçayiri block within the Sorgun Ophiolitic Mélange. Location of the investigated section is marked by X (see geological map). All the taxa described herein are from a single radiolarian-rich sample (G11) belonging to the early Tuvalian *Spongotortilispinus moixi* Radiolarian Zone (Moix et al. 2007). **c** Lithostratigraphic log of the Tavusçayiri block

1977; Özgül 1997; Tekin 1999; Andrew 2002; Andrew and Robertson 2002) and in the Antalya Nappes (Brunn et al. 1971) as the Huğlu series (or Huğlu Unit which is equivalent to the Dedemli Formation (Özgül 1997) and the Bayirkoy-Ihsaniye Unit by Gökdeniz (1981). Additionally, Huğlu-type series are exposed at the base of the MOC, in the Tavusçayiri block of the SOM (Moix et al. 2007), and comparable sequences are found in the Köseyahya Nappe (Elbistan) in the Eastern Taurides (Tekin and Bedi 2007a, b). The Huğlu series is characterized by the deposition of massive volcano-sedimentary series from the Middle Triassic to the Cenomanian-Campanian (Monod 1977; Gutnic et al. 1979). It consists of more than 1000 m of mafic and intermediate volcanics (Pietra Verde like green tuffs), interspersed by relatively thin ($\sim$ 100 m) pelagic (e.g. *Halobia* limestone and Hallstatt Limestone) and redeposited limestone (Andrew 2002). The pelagic sedimentation continues during the Late Triassic (cherty limestones), and passes to a locally well-developed Toarcian Ammonitico Rosso, itself followed by radiolarites and pelagic limestone ranging in age from the Liassic to the Senonian (Moix et al. 2013).

2.2 Sorgun Ophiolitic Mélange

The Sorgun Ophiolitic Mélange (analogous to the Findikpinari Formation by Özer et al. 2004) belongs to the Mersin Mélange, which lies on the Taurides platform and is tectonically overlain by the Mersin ophiolitic suite (Moix et al. 2011). The SOM occupies the highest tectonic position (Moix et al. 2011) and includes four distinct tectonic blocks (Gavuruçtuğu, Talvarliyurt, Tavusçayiri and Kocatabur blocks) within the mélange (Fig. 2b). The blocks consist of remnants of ophiolitic series, Carboniferous to Upper Triassic carbonates, Ladinian to Coniacian radiolarites and limestone, suggesting that this basin remained open until the Senonian (Moix et al. 2011). The Tavusçayiri block is a 600 m thick series, while its lateral extent is a few kilometers (Fig. 2b). The succession corresponds to the Huğlu-type sequences described by Özgül (1976) in the Bozkir Units and by Monod (1977) in the Beyşehir-Hoyran Nappes. The investigated section is located northeast from the small village of Sorgun (Fig. 2b). The sequence starts with polymictic breccia which is followed by a 60 m of conglomerate (Fig. 2c). It is followed by

15 m of black Middle Triassic (Anisian?) calciturbidites. The series continues with brownish Upper Triassic (Carnian?) limestone which is covered by discontinuous pink nodular limestones (Hallstatt Limestone facies) that yielded middle Carnian fauna (Moix et al. 2007, 2011; Kozur et al. 2009). This Hallstatt Limestone is conformably overlain by 130 m of thin bedded Huğlu-type green tuffites (Fig. 2c). The tuffitic series is interspersed with alternations of micritic limestone and calciturbidites. One micritic level (Sample G11) contains conodonts (Moix et al. 2007), sponge spicules, ostracods (Forel et al. 2018) and an exquisitely preserved and remarkably diverse radiolarian fauna of early Tuvalian age. The tuffitic episode is followed by 300 m of pelagic carbonate series (Fig. 2c). The pelagic limestone sedimentation usually started during the upper Carnian, continues during the Norian and most probably ended during the early Rhaetian (?). The early Rhaetian (?) limestone is overlain by a breccia, followed by late Bajocian brownish radiolarian cherts (Fig. 2c).

3 Radiolarian fauna

All the taxa described in the Systematic paleontology section are from a single radiolarian-rich sample (Fig. 2c) belonging to the lower Tuvalian *Spongotortilispinus moixi* Radiolarian Zone (Moix et al. 2007). This radiolarian zone corresponds to *Paragondolella postinclinata—Paragondolella noah* Conodont Zone. The correlation is based on the occurrence of *Paragondolella noah* in sample G11. An age equivalent radiolarian fauna has been partly described by Ozsvárt et al. (Ozsvárt et al. 2017a) from the Kopría Mélange, Rhodes, Greece (Moix et al. 2008) and by Dumitrica et al. (2010, 2013a, b) and Dumitrica and Hungerbühler (2007) from cherts of the Zulla Formation, Hawasina Complex, Oman.

4 Geodynamic implications

The Tavusçayiri block in the SOM includes sequences comparable to the classical Pindos-type series known from the Pindos Zone (extending from Budva–Krasta–Cukali–Pindos–Olonos) to the Dodecanese islands (Degnan and Robertson 1998; Moix 2010; Moix et al. 2011). The classical Pindos-type series from the Balkan Peninsula is interpreted as an intra-platform rift basin (Obradović and Goričan 1988; Goričan 1994) filled by characteristic volcano-sedimentary series, radiolarites and pelagic carbonates between Apulia and Pelagonia that existed from the Middle–Late Triassic to the Paleogene. The massive Huğlu-type tuff sequences with intercalated carbonates might relate to extensional events (intra-platform rifting) in the Apulian-Pelagonian-Taurides platform. The widespread alkaline volcanism of the Antalya Nappes and MOC (Huğlu series) was probably generated by a small OIB-type mantle plume during the Middle-Late Carnian time interval, connected to early stages of spreading in the Neotethys (Varol et al. 2007). Pelagic sedimentation began in the Middle–Late Anisian in the western end of Neotethys, followed by ocean spreading from the Anisian-Ladinian (Bortolotti and Principi 2005; Bortolotti et al. 2013; Ozsvárt et al. 2012; Ozsvárt and Kovács 2012). However, Triassic oceanic remnants are preserved exclusively in tectonic mélange blocks in the Dinarides–Hellenides belt. Anisian (probably Illyrian) to Norian ages of radiolarites interbedded with basalts suggest a Triassic oceanic crust forming (from early-rift related through rift/ocean transition to MOR-type) from Euboia Island to Meliata (summarized by Bortolotti et al. 2013). These age data clearly demonstrate the westwards propagation of Neotethyan rifting. The identification of Pindos-type succession in different tectonic units of Early Mesozoic Neotethyan oceanic basin, from the Budva and Krasta-Cukali Zone through the external Hellenides and in Dodecanese in the Aegean Sea, and continuing eastward in the Lycian nappes and farther east in the Antalya nappes, as well as in Mersin and in Elbistan, might support the "single ocean model" (e.g. Bernoulli and Laubscher 1972; Neubauer and von Raumer 1993; Schmid et al. 2008; Bortolotti et al. 2013) for the Late Triassic.

5 Systematic paleontology

The studied material is deposited in the collection of the Department of Paleontology and Geology, Hungarian Natural History Museum, Budapest.

Class Radiolaria Müller, 1858

Subclass Polycystina Ehrenberg 1838 emend. Riedel, 1967

Order Spumellaria Ehrenberg, 1875

Family Angulobracchiidae Baumgartner, 1980 emend. Dumitrica et al. 2013a

Subfamily Pseudohagiastrinae Dumitrica and Tekin in Dumitrica et al. 2013a

Genus *Acanthotetrapaurinella* Kozur and Mostler, 2006

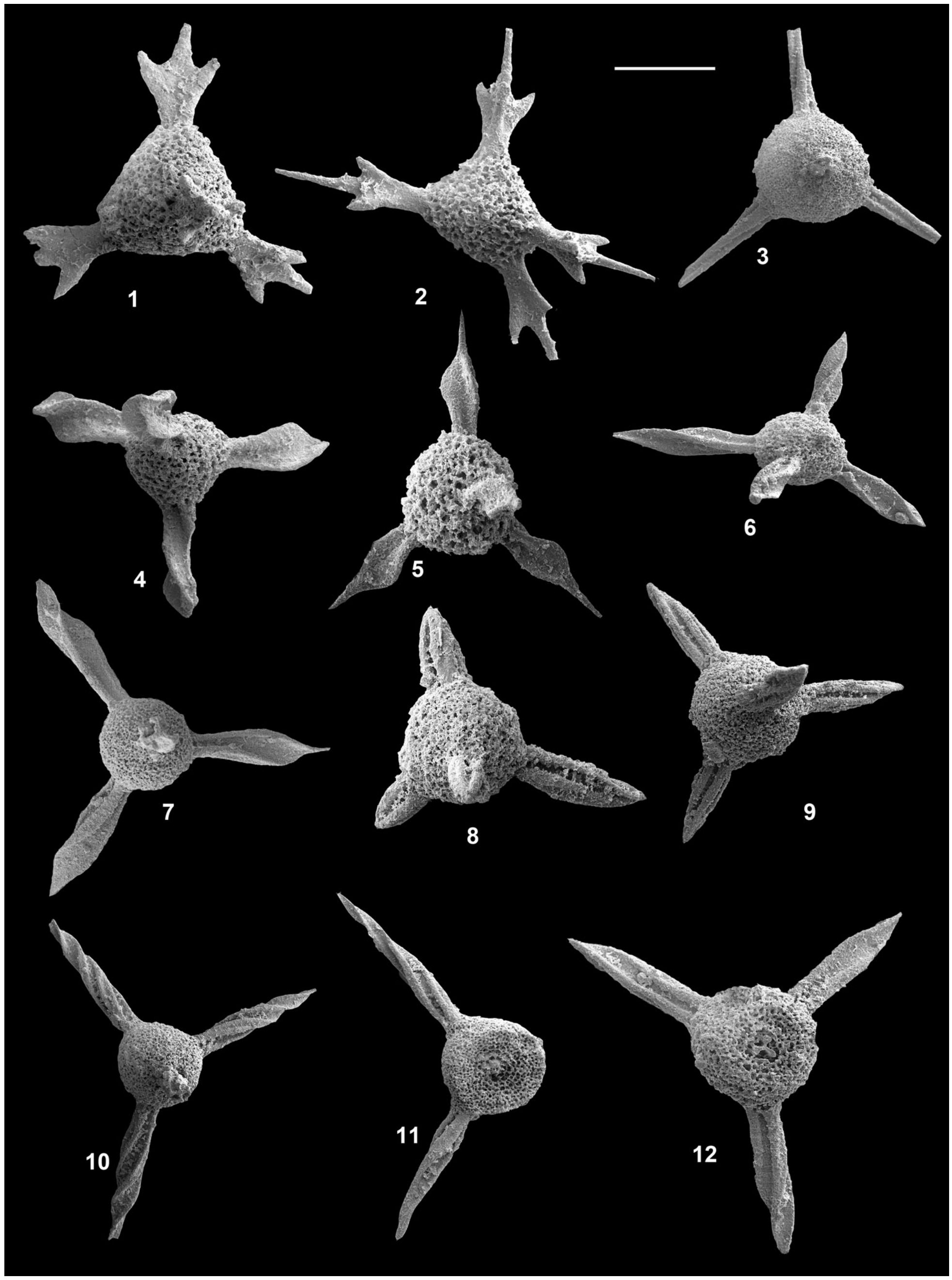
Type species: *Acanthotetrapaurinella variabilis* Kozur and Mostler, 2006

Acanthotetrapaurinella lanceolata Dumitrica and Tekin, in Dumitrica et al. 2013a

Figure 3(1–2)

2013a *Acanthotetrapaurinella lanceolata* Dumitrica and Tekin n. sp.—Dumitrica et al., p. 319, figs. 3d–f.

Fig. 3 1–2: *Acanthotetrapaurinella lanceolata* Dumitrica and Tekin, in Dumitrica et al., 2013a. 3: *Cantalum* cf. *angustispina* Dumitrica and Tekin, in Dumitrica et al., 2013a. 4–5: *Cantalum carterae* Dumitrica and Tekin, in Dumitrica et al., 2013a. 6-7: *Cantalum elegans* n. sp. 8–9: *Cantalum hexacarinatum* n. sp. 10–11: *Cantalum macerum* n. sp. 12: *Cantalum sulcosum* n. sp. Scale bar = 100 µ



Remarks: Spines terminated in a large, relatively long, pointed shaft at some specimens from the Sorgun Ophiolitic Mélange, Turkey.

Range and occurrences: Middle Late Ladinian (*S. rarauana* Subzone of *M. cochleata* Zone) from the Eastern Carpathians, Romania (Rarău Mts.) to Carnian (*Tetraporobrachia haeckeli* Zone to *Spongotortilispinus moixi* Zone) of Turkey and Oman.

Genus *Cantalum* Pessagno in Pessagno et al., 1979 emend. Dumitrica et al., 2013

Type species: *Cantalum holdsworthi* Pessagno, 1979

Cantalum cf. *angustispina* Dumitrica and Tekin, in Dumitrica et al., 2013a

Figure 3(3)

cf. 2013a *Cantalum angustispina* Dumitrica and Tekin n. sp.—Dumitrica et al., p. 321, figs. 3k–l.

Remarks: This specimen differs from the holotype of *C. angustispina* Dumitrica and Tekin, 2013a by having significantly dense spongy shell and shorter spines.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

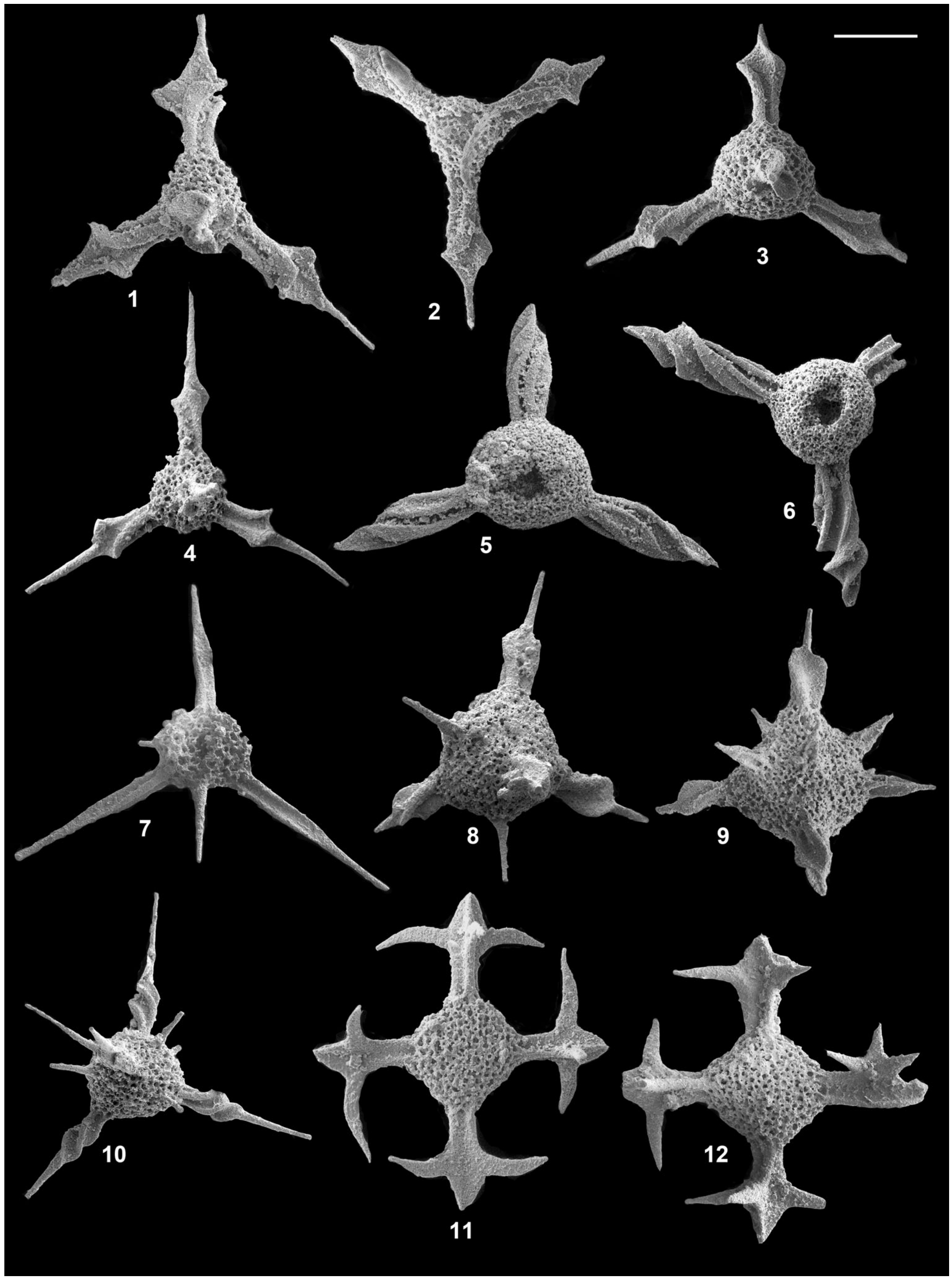


Fig. 4 1–2: *Cantalum petersi* Dumitrica and Tekin, in Dumitrica et al., 2013a. 3–4: *Cantalum sarlaespina* Dumitrica and Tekin, in Dumitrica et al., 2013a. 5–6: *Cantalum hexacarinatum* n. sp. 7: *Cantalum longispinosum* n. sp. 8–9: *Cantalum varispinosum* n. sp. 10: *Cantalum spinosum* n. sp. 11–12: *Tetraspongodiscus longispinosus* Kozur and Mostler, 1979. Scale bar = 100 μ

Cantalum carterae Dumitrica and Tekin, in Dumitrica et al., 2013a

Figures 3(4–5)

2013a *Cantalum carterae* Dumitrica and Tekin n. sp.—Dumitrica et al., p. 321–323, figs. 3o–p.

Remarks: The specimens from Sorgun Ophiolitic Mélange differ from those from the Zulla Formation, Oman, in having spines with longer distal part; the two specimens from Oman on which the species was described have distal part rather blunt.

Range and occurrences: *Spongotortilispinus moixi* Zone from Turkey (Sorgun Ophiolitic Mélange) and Oman (Zulla Formation, Hawasina Complex).

Cantalum elegans Ozsvárt and Dumitrica n. sp.

Figure 3(6–7)

Etymology: Allusion to its nice and elegant look.

Description: Test spherical with very dense spongy meshwork. The four three-bladed spines are slightly broadening distally and decrease fast at the distal end. Blades are slightly twisted dextrally and relatively thin but grooves are deep and wide.

Material: More than 5 specimens.

Holotype: The specimen in Fig. 3(7), HNHM, PAL 2018.6.1.

Dimensions (in µm based on 3 specimens): Diameter of test = 150; length of spines = 220–250.

Remarks: *C. elegans* n. sp. differs from *C. dextrogyrum* Dumitrica and Tekin, 2013a by having a much denser spongy meshwork, less dextrally twisted spines, and spines slightly broadened at the middle part. Generally, all specimens have the spines disposed in a regular tetrahedral position; a single one (Fig. 3(6)) has the spines irregularly disposed.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Cantalum hexacarinatum Ozsvárt and Dumitrica n. sp.

Figures 3(8–9), 4(5–6)

Etymology: Allusion to its six blades on the spines.

Description: Shell spherical to slightly tetrahedral with dense spongy meshwork. The four spines are robust, relatively short, very slightly spindle-shaped, and disposed in a regular tetrahedral position. They are very slightly dextrally twisted and their primary blades are thick and forked longitudinally by secondary grooves so that they have three relatively deep grooves between primary blades and three thin and narrow grooves along the blades.

Material: More than 3 specimens.

Holotype: The specimen in Fig. 3(9), HNHM, PAL 2018.7.1

Dimensions (in µm based on 3 specimens): Diameter of test = 150; length of spines = 125–140.

Remarks: *C. hexacarinatum* n. sp. is well characteristic by its spines.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Cantalum longispinosum Ozsvárt and Dumitrica n. sp.

Figure 4(7)

Etymology: Allusion to its long spines.

Description: Test relatively small, spherical with loose spongy meshwork and four relatively long, thin, three-bladed, and untwisted spines with long, conical and pointed terminal shaft. In the areas among primary spines two or more needle shaped secondary spines may develop.

Material: More than 2 specimens.

Holotype: The specimen in Fig. 4(7), HNHM, PAL 2018.10.1

Dimensions (in µm based on 2 specimens): Diameter of test = 100, length of spines = 200, length of secondary spines = 75.

Remarks: *S. longispinosum* n. sp. differs from other species of *Cantalum* by having long, thin and untwisted main spines and several secondary needle-shaped spines.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Cantalum macerum Ozsvárt and Dumitrica n. sp.

Figures 3(10–11)

Etymology: In allusion to its skinny looks (from the Latin *macerum* = thin, skinny).

Description: Test spherical with very dense, many-layered spongy meshwork. The four spines are three-bladed, tetrahedrally disposed, long, straight, slim and one turn dextrally twisted. Blades with deep and narrow primary grooves and secondary shallow grooves on blades.

Material: More than 2 specimens.

Holotype: The specimen in Fig. 3(10), HNHM, PAL 2018.8.1

Dimensions (in µm based on specimens): Diameter of test = 200; length of spines = 350–370.

Remarks: *C. macerum* n. sp. differs from *C. tozeri* Dumitrica and Tekin in Dumitrica et al., 2013a by having denser spongy test and spines longer, thinner and with blades divided into two secondary blades by a longitudinal groove.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Cantalum petersi Dumitrica and Tekin, 2013a

Figure 4(1–2)

2013a *Cantalum petersi* Dumitrica and Tekin n. sp.—Dumitrica et al., pp. 324–325, figs. 5c–e.

Remarks: The figured specimens from the Sorgun Ophiolitic Mélange terminatein a longer pointed shaft than those from the Köseyahya section, Elbistan.

Range and occurrences: Middle Carnian (*Tetraporobrachia haeckeli* Zone to *Spongotortilispinus moixi* Zone from Turkey (Köseyahya section, Elbistan and Sorgun Ophiolitic Mélange).

Cantalum sarlaespina Dumitrica and Tekin in Dumitrica et al., 2013a

Figure 4(3–4)

2013a *Cantalum sarlaespina* Dumitrica and Tekin n. sp.—Dumitrica et al., p. 325, figs. 5h–i.

Remarks: A specimen from the Sorgun Ophiolitic Mélange wears spines with a much longer pointed part than the three-bladed one.

Range and occurrences: Middle Carnian (*Tetraporobrachia haeckeli* Zone to *Spongotortilispinus moixi* Zone from Turkey (Köseyahya section, Elbistan and Sorgun Ophiolitic Mélange).

Cantalum spinosum Ozsvárt and Dumitrica n. sp.

Figure 4(10)

Etymology: Allusion to its conical secondary spines.

Description: Test tetrahedral with relatively large, rounded pores. The four three-bladed spines are sinistrally twisted (half turn) and have non subdivided blades but deep grooves and terminate in a long, needle-shaped spinal shaft. Central shell with 5–6 relatively long, straight and needle-shaped secondary spines.

Material: More than 2 specimens.

Holotype: The specimen in Fig. 4(10), HNHM, PAL 2018.12.1

Dimensions (in µm based on 2 specimens): Diameter of test = 150, length of spines = 200, length of secondary spines = 100.

Remarks: *Cantalum spinosum* n. sp. differs from other species of the genus with strongly twisted and three-bladed spines by having needle-shaped secondary spines.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Cantalum sulcosum Ozsvárt and Dumitrica n. sp.

Figure 3(12)

Etymology: In allusion to its deep grooves on spines. From the Latin *sulcosus* = striated.

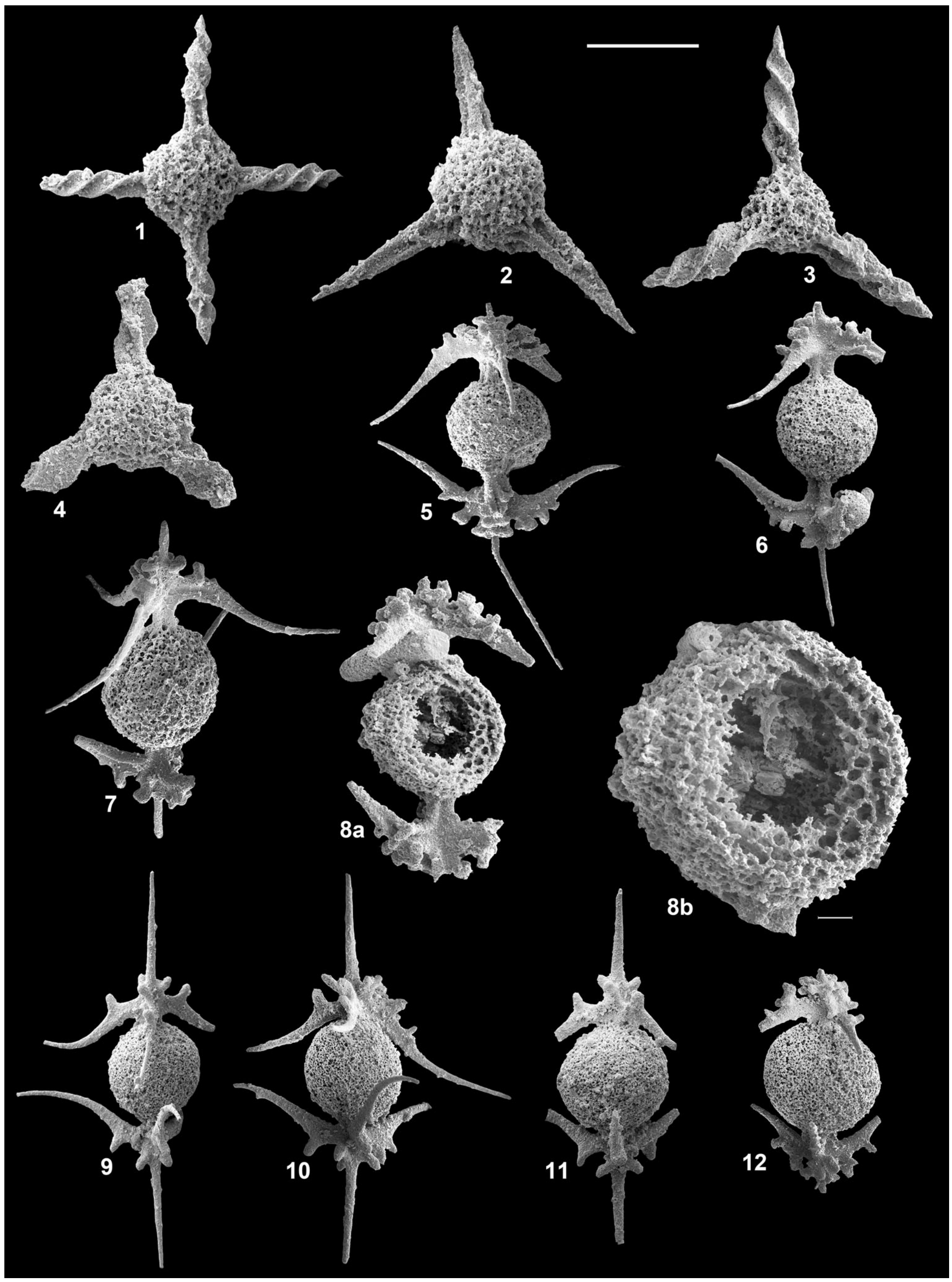


Fig. 5 1: *Plafkerium odogherthyi* Dumitrica and Tekin in Dumitrica et al., 2013b. 2: *Angulopaurinella edentata* Dumitrica and Tekin in Dumitrica et al., 2013b. 3: *Angulopaurinella longicornuta* n. sp. 4: *Angulopaurinella dentispinosa* Dumitrica and Tekin in Dumitrica et al., 2013b. 5–8: *Dumitricasphaera goestlingensis* Kozur and Mostler, 1979. 9–12: *Dumitricasphaera annae* n. sp. Scale bar = 100 µ

Description: Test globular with five, six or more dense spongy layers and four relatively long spines in tetrahedral position. Spines three-bladed, straight, with parallel sides, untwisted or very slightly twisted dextrally. Distal end pointed. Blades with very shallow and weakly visible secondary grooves.

Material: More than 2 specimens.

Holotype: The specimen in Fig. 3(12), HNHM, PAL 2018.9.1

Dimensions (in µm based on 2 specimens): Diameter of test = 150; length of spines = 150–160.

Remarks: *Cantalum sulcosum* n. sp. seems to be very close to *C. hexacarinatum* n. sp., from which it differs by having wider primary grooves, absence of secondary grooves and thinner and longer spines.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Cantalum varispinosum Ozsvárt and Dumitrica n. sp.

Figure 4(8–9)

Etymology: In allusion to its variable secondary spines (from the Latin *variatus*—variable).

Description: Globular to tetrahedral dense spongy test with four short three-bladed and sinistrally (counterclockwise) twisted spines with massive, thin blades. Spines increasing slightly in breadth distally, terminated in an obtuse angle (100°–110°) and bearing a long, pointed, needle-like shaft. Some areas corresponding to faces of tetrahedron may have one needle-like or bladed secondary spine in their center.

Material: More than 6 specimens.

Holotype: The specimen in Fig. 4(8), HNHM, PAL 2018.11.1.

Paratype: The specimen in Fig. 4(9), HNHM, PAL 2018.11.2.

Dimensions (in µm based on 2 specimens): diameter of test = 150, length of spines without distal spine = 100.

Remarks: *C. varispinosum* n. sp. differs from *C. spinosum* n. sp. by thickness of spines and less than half turn of twisting. Although the secondary spines vary from needle-shaped to bladed we include both varieties in the same species because the shapes of test and of primary spines are similar and we consider that the primary spines may have greater priority in taxonomy than the secondary ones.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Family Veghicycliidae Kozur and Mostler, 1972

Subfamily Tetrapaurinellinae Dumitrica et al., 2013b

Genus *Plafkerium* Pessagno in Pessagno et al., 1979

Type *Species: Plafkerium abbotti* Pessagno, 1979.

Plafkerium odoghertyi Dumitrica and Tekin in Dumitrica et al., 2013b

Figure 5(1)

2013b *Plafkerium odogherthyi* Dumitrica and Tekin n. sp.—Dumitrica et al., p. 378, figs. 10c–d.

Remarks: The illustrated specimen is rather similar to the holotype and paratype from the Elbistan section.

Range and occurrences: Early Carnian (late Julian, *Tetraporobrachia haeckeli* Zone) to early late Carnian (early Tuvalian, *Spongotortilispinus moixi* Zone) from SE Turkey (Köseyahya section, Elbistan, and Sorgun Ophiolitic Mélange).

Genus *Tetraspongodiscus* Kozur and Mostler, 1979

Type species *Tetraspongodiscus longispinosus* Kozur and Mostler, 1979

Tetraspongodiscus longispinosus Kozur and Mostler, 1979

Figures 4(11–12)

1979 *Tetraspongodiscus longispinosus* n. sp.—Kozur and Mostler, p. 81, pl. 11, fig. 1.

1984 *Tetraspongodiscus longispinosus* Kozur and Mostler—Lahm, p. 60–61, pl. 10, fig. 9. 2013b *Tetraspongodiscus longispinosus* Kozur and Mostler–Dumitrica et al., p. 379, figs. 10o–p.

Remarks: The illustrated specimen in Fig. 4(11) from the Sorgun Ophiolitic Mélange, Turkey has slightly inward curved verticil of branches. The specimen in Fig. 4(12) is pathological, suggesting a reparation after a break of the distal end of one spine.

Range and occurrences: Late Early Carnian (late Julian) from Göstling and Großreifling, Austria, and from Köseyahya section, Elbistan and early Late Carnian (Tuvalian) from the Sorgun Ophiolitic Mélange, Turkey.

Family Tritrabidae Baumgartner, 1980 emend. Dumitrica and Tekin, 2013a

Subfamily Intermediellinae Lahm, 1984 emend. Dumitrica and Tekin, 2013a

Genus *Angulopaurinella* Kozur and Mostler, 2006

Type species: *Angulopaurinella crassa* Kozur and Mostler, 2006

Angulopaurinella edentata Dumitrica and Tekin in Dumitrica et al., 2013b

Figure 5(2)

2012 *Angulopaurinella edentata* Dumitrica and Tekin n. sp.—Stockar et al. 2012, p. 412, Pl. 8, f. 6.

2013b *Angulopaurinella edentata* Dumitrica and Tekin–Dumitrica et al., p. 359, figs. 1h, 3d, 4p-r.

Range and occurrences: Latest Anisian (Vicentinian Alps, Northern Italy) to Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Angulopaurinella longicornuta Ozsvárt and Dumitrica n. sp.

Figure 5(3)

Etymology: From having long horns by comparison with other species of the genus.

Description: Test spongy, small, triangular with convex sides and 3 equal spines. Spines three-bladed, gradually narrowing distally, twisted sinistrally about one turn and pointed. Blades are very thin with sharp margin.

Material: More than 2 specimens.

Holotype: The illustrated specimen in Fig. 5(3), HNHM, PAL 2018.13.1

Dimensions (in µm based on 2 specimens): Diameter of shell = 75, length of spines = 125, maximum diameter of spines = 25.

Remarks: This species, of which we have a single specimen, differs from the other species of the genus by having longer, slender and more twisted spines.

Range and occurrences: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Angulopaurinella dentispinosa Dumitrica and Tekin, in Dumitrica et al., 2013b

Figure 5(4)

2013b *Angulopaurinella dentispinosa* Dumitrica and Tekin n. sp.—Dumitrica et al., p. 358, figs. 4. n–o.

Remarks: The illustrated specimen has a more globular test and slightly shorter and less-twisted spines.

Range and occurrences: Upper Julian (*Tetraporobrachia haeckeli* Zone) from Elbistan to Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Family Spongotortilispinidae Kozur and Mostler in Moix et al., 2007

Type genus. *Spongotortilispinus* Kozur and Mostler in Moix et al., 2007

Genus *Dumitricasphaera* Kozur and Mostler, 1979

Type species: *Dumitricasphaera goestlingensis* Kozur and Mostler, 1979

Dumitricasphaera goestlingensis Kozur and Mostler, 1979

Figure 5(5–8)

1979 *Dumitricasphaera goestlingensis* n. sp.—Kozur and Mostler, p. 60, pl. 3, fig. 1.

1984 *Dumitricasphaera goestlingensis* Kozur and Mostler–Lahm, p. 70–71, pl. 12, figs. 7–8.

2005 *Dumitricasphaera goestlingensis* Kozur and Mostler–Feng et al., 2005, p. 243, pl. 1, figs. 13–15.

2007 *Dumitricasphaera goestlingensis* Kozur and Mostler–Tekin and Göncüoğlu, 2007, pl. 1.2.

Remarks: Due to the good preservation, the inner structure is visible in some specimens. Test is spongy but the cortical part is more massive. Inside it, the spongy framework is looser and less massive and most part destroyed by fossilization. The conical root of one polar spine preserved and illustrated in one specimen (Fig. 5 (8a, b)) exhibits remains of the dissolved initial part of this framework, which look like irregularly disposed tiny thorns. The three branches of the verticil of the spines are three-bladed, recurved but their thin needle-like distal ends are curved in lateral direction. Their spinules present on the external blades are double around the polar axis and knob-like; they are disposed perpendicularly on the branches of the verticil and their size reduces distally along them.

Range and occurrence: Cosmopolitan in the Carnian.

Dumitricasphaera annae Ozsvárt and Dumitrica n. sp.

Figure 5(9–12).

Etymology: Dedicated to Anna Ozsvárt, Péter Ozsvárt's daughter, Szentendre (Hungary).

Description: Central test spherical to slightly ellipsoidal with very dense, spongy meshwork and two polar spines. Stem of spines extremely short bearing a verticil of three, long, slender, and distally recurved branches; branches very close to the shell surface and rounded in cross section. Shaft of spines very long and needle-shaped. Its base is surrounded by 3 short and blunt spines each one situated in the spaces between the branches of the verticil. At a certain distance from the spinal shaft each branch bears a short blunt spinule.

Material: More than 10 specimens.

Holotype: The specimen in Fig. 5(10), HNHM, PAL 2018.14.1.

Dimensions (in µm based on 3 specimens): Diameter of test = 150–180; length of spines = 160–260.

Remarks: *Dumitricasphaera annae* n. sp. differs from *D. goestlingensis* Kozur and Mostler by having spines with a very short stem, the branches of the verticil not bladed, and by having also a single short blunt spinule on branches.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Genus *Spongotortilispinus* Kozur and Mostler in Moix et al., 2007

Type species: *Spongotortilispinus moixi* Kozur and Mostler in Moix et al., 2007

Spongotortilispinus asymmetricus Ozsvárt and Dumitrica n. sp.

Figure 6(2–3)

Etymology: In allusion to the asymmetry of polar spines.

Description: Central test globular with dense, spongy meshwork. Polar spines relatively short, straight and dissimilar. One is longer, straight on the proximal half and twisted dextrally on the distal half, the other one is shorter, straight, not twisted or slightly twisted and pointed. Blades of both spines are thicker on the margin and partly divided into two secondary blades by a very weakly visible secondary groove. Primary grooves of both spines are deep and narrow.

Material: More than 10 specimens.

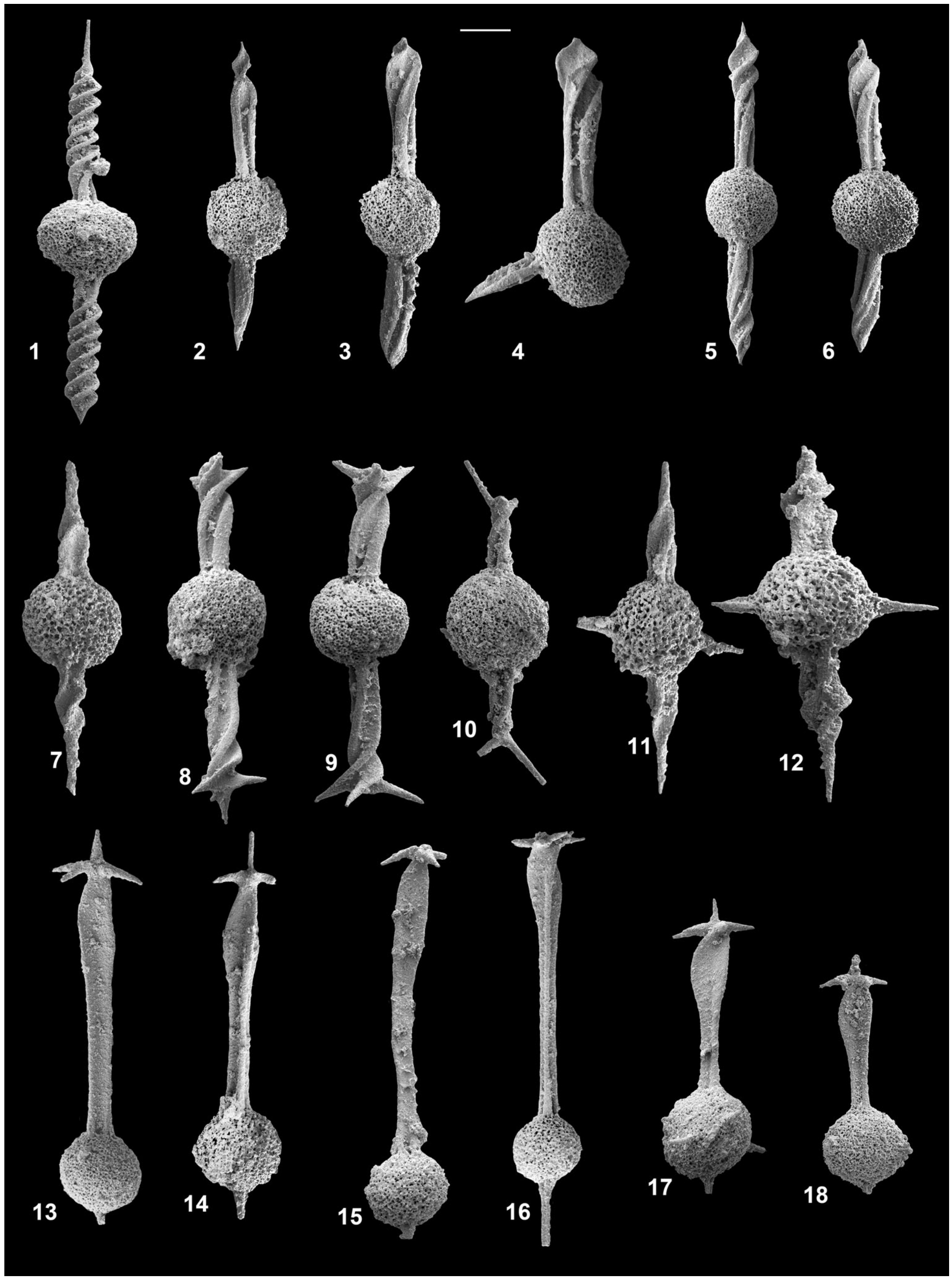


Fig. 6 1: *Spongotortilispinus tortilis* (Kozur and Mostler, 1979). 2–3: *Spongotortilispinus asymmetricus* n. sp. 4: Pathological *Spongotortilispinus* sp. 5–6: *Spongotortilispinus subtortilis* n. sp. 7: *Spongotortilispinus slovenicus* (Kolar-Jurkovšek), 1989. 8–10: *Spongotortilispinus verticillatus* n. sp. 11–12: *Staurotortilispinus kovacsi* n. sp. 13–18: *Ancoraespongus sugiyamai* n. sp. Scale bar = 100 µ

Holotype: The specimen in Fig. 6(2), HNHM, PAL 2018.15.1

Dimensions (in µm based on 3 specimens): Diameter of test = 150–180; length of spines = 160–260.

Remarks: *Spongotortilispinus asymmetricus* n. sp. differs from *S. subtortilis* n. sp. by shorter polar spines and one of them is untwisted, the twisted spine wears less turns.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Spongotortilispinus slovenicus (Kolar-Jurkovšek), 1989

Figure 6(7)

1989 *Pseudostylosphaera slovenica* n. sp.—Kolar-Jurkovšek, 1989, p. 158, figs. 2.1–3.

1989 *Spongostylus* sp. A—Yeh, 1989, p. 67, pl. 13, figs. 7, 22.

1989 *Spongostylus* sp. B—Yeh, 1989, p. 67, pl. 13, fig. 9.

1990 *Spongopallium?* sp. A—Goričan and Buser, 1990, p. 157, pl. 4. fig. 5.

?2005 *Spongostylus bosniensis* n. sp.—Tekin and Mostler, 2005, p. 26–28, pl. 1, figs. 8–9, non 4–7.

2011 *Spongotortilispinus subtilis* n. sp.—Bragin, p. 753, pl. 10, figs. 2–5.

Remarks: The two the Upper Ladinian species of *Spongostylus bosniensis* Tekin & Mostler mentioned in the synonymy list are close to *S. slovenicus* from which they differ in having spines with a much longer straight and untwisted proximal portion.

Range and occurrence: Cosmopolitan and, it seems long-ranged species from Lower Ladinian (Slovenia) and upper Ladinian (*Spongoserrula fluegeli* Subzone) of Bosnia and Herzegovina to lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey. Upper Carnian of Kotel'nyi Island, Siberia to Norian of East-Central Oregon, USA is reported, as well.

Spongotortilispinus subtortilis Ozsvárt and Dumitrica n. sp.

Figure 6(5–6)

Etymology: In allusion to its slightly twisted polar spines.

Description: Test spherical and spongy with two slightly dissimilar and straight polar spines. Both spines twisted dextrally and having 3 deep and narrow grooves on the proximal part, which slowly widen distally. Blades of spines have wide and flat margin on the proximal portion, which start thinning and sharpening on twisted portion. Spines twist only one turn on the distal part. Longer polar spine is wider on the twisted portion, whereas the shorter spine is thinner, but it wears secondary grooves on ridges. Spines terminate in a short, pointed needle-like spine.

Dimensions (in µm based on 3 specimens): Diameter of test = 150–190; length of spines = 350–400.

Material: More than 10 specimens.

Holotype: The specimen in Fig. 6(5), HNHM, PAL 2018.16.1

Remarks: *Spongotortilispinus subtortilis* n. sp. differs from *S. tortilis* (Kozur and Mostler, 1979) by having a single turn on polar spines. *S. asymmetricus* n. sp. differs from *S. subtortilis* n. sp. especially by having the smaller spine practically untwisted.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Spongotortilispinus tortilis (Kozur and Mostler, 1979)

Figure 6(1)

1979 *Spongostylus tortilis* n. sp.—Kozur and Mostler, p. 56, pl. 4, fig. 2; pl. 11, fig. 6; pl. 18, fig. 2.

1981 *Spongostylus tortilis* Kozur and Mostler–Kozur and Mostler, 1981, p. 69, pl. 40, fig. 2; pl. 56, fig. 3.

1984 *Spongostylus tortilis* Kozur and Mostler–Lahm, p. 68, pl. 12, fig. 3.

1997 *Spongostylus* sp.—Knipper et al., 1997, pl. 1, figs. 5–6.

1999 *Spongostylus tortilis* Kozur and Mostler–Bragin and Krylov, 1999, p. 553, fig. 8A.

1999 *Spongostylus tortilis* Kozur and Mostler–Tekin, p. 67, pl. 2, fig. 8. non! fig. 7.

2002 *Spongostylus tortilis* Kozur and Mostler–Wang et al., 2002, p. 330, pl. 2, figs. 24–26.

2007 *Spongostylus tortilis* Kozur and Mostler–Bragin, 2007, p. 990, pl. 8, fig. 5.

Remarks: Generally the polar spines are straight, dextrally twisted, of the same diameter all along the spines, and terminate quickly in a pointed spine, although at some specimens from the Sorgun Ophiolitic Mélange, Turkey, the strongly twisted and straight polar spines have a long, straight, needle-like distal spine. Length of polar spines: 375–400 µm; length of terminal, straight, untwisted, needle-like spines: 160–190 µm.

Range and occurrence: Cosmopolitan from late Ladinian (Middle Triassic) to early Norian (late Triassic).

Spongotortilispinus verticillatus Ozsvárt and Dumitrica n. sp.

Figure 6(8–10)

Etymology: In allusion to its distal verticil of three spinules on polar spines.

Description: Globular test with dense, spongy meshwork and two twisted polar spines. Spines three-bladed with deep grooves and simple blades with thickened margin. They are straight or very slightly twisted dextrally on the proximal half and much faster on the distal half, and each blade terminates in a spine, which is laterally directed forming together a verticil of three spinules. Maximum twisting is 180° or a little more.

Dimensions (in µm based on 8 specimens): Diameter of test = 150–190; length of spines = 200–300. Length of spinules = 100–120.

Material: More than 10 specimens.

Holotype: The specimen in Fig. 6(9), HNHM, PAL 2018.17.1

Remarks: One of the illustrated specimens assigned to this species (Fig. 6(10)) differs from the other two in having thin polar spines and thin and long and obliquely distally directed spinules in the distal verticils. In spite of these differences it is considered an extreme variant of the normal specimens. *Spongotortilispinus verticillatus* n. sp. differs from *S. trispinosus* (Kozur and Mostler, 1979) by having twisted polar spines, distal spinules shorter and no distal shaft. Bragin (2011) published a new species as *Dumitricasphaera arbustiva* Bragin from the Upper Carnian of Kotel'nyi Island, Siberia. That species has sinistral coiling at terminal part of the polar spines, but probably it belongs to the genus *Spongotortilispinus*, as well.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey and Kopría Mélange, Rhodes, Greece.

Pathological *Spongotortilispinus* sp.

Figure 6(4)

Remarks: This specimen has two dissimilar polar spines as *Spongotortilispinus asymmetricus* n. sp., but the untwisted spine is laterally displaced suggesting an anomaly. The twisted spine has deep narrow grooves; its proximal part is straight, untwisted, the distal part is twisted dextrally, slightly broader and its blades are thinner.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Genus *Staurotortilispinus* Ozsvárt and Dumitrica n. gen.

Type species: *Staurotortilispinus kovacsi* Ozsvárt and Dumitrica n. gen., n.sp

Etymology: Allusion to its resemblance with the genus *Spongotortilispinus,* and the cross shaped test.

Description: Globular or slightly compressed test with many-layered meshwork. Shell with two strong and twisted three-bladed polar spines and two significantly smaller, three-bladed secondary spines in a cross-shaped position.

Remarks: *Staurotortilispinus* n. gen. differs from the genus *Spongotortilispinus* by having two opposite secondary spines perpendicular on the polar spines suggesting that it belongs to another phylogenetic lineage.

Occurrences: Lower Tuvalian, *Spongotortilispinus moixi* Zone of the Sorgun Ophiolitic Mélange, Turkey.

Staurotortilispinus kovacsi Ozsvárt and Dumitrica n. sp.

Figures 6(11–12)

Etymology: In honor of the late Dr. Sándor Kovács for his outstanding work on Triassic conodonts and general geology of the Alpine-Carpathian and Dinarides-Hellenides system.

Description: Test spherical to slightly compressed with latticed, dense polygonal meshes. Polar spines three-bladed and dextrally twisted (one or two turns). Grooves deep between sharp ridges. The short and pointed secondary spines are three-bladed, in equatorial position, and perpendicular to or slightly inclined to the polar axis.

Dimensions (in µm based on 3 specimens): Diameter of test = 100–120; length of polar spines = 150–170; length of secondary spines = 50–70.

Material: More than 3 specimens.

Holotype: The specimen in Fig. 6(12), HNHM, PAL 2018.18.1

Remarks: Although the spines of the two illustrated specimens seem rather different and belonging to two different species, in the present article we assign them to a single species in the absence of additional specimens.

Range and occurrence: Lower Tuvalian (*Spongotortilispinus moixi* Zone) of the Sorgun Ophiolitic Mélange, Turkey.

Genus *Ancoraspongus* Ozsvárt and Dumitrica n. gen.

Type species: *Ancoraspongus sugiyamai* Ozsvárt and Dumitrica n. gen., n. sp.

Etymology: From the Latin *ancora*—anchor, with which this genus resembles.

Description: Small spongy globular test with two opposite three-bladed unequal polar spines: a long main polar spine with a characteristic morphology represented by a distal rosette of 6 spinules, and a very small and simple opposite secondary spine.

Remarks: Due to the inequality of the two polar spines this genus could be assigned to the family Oertlispongidae Kozur and Mostler where such an inequality is common. However all genera of this family have the main spine circular or elliptical in cross section, never three-bladed. Consequently, the best assignment of *Ancoraspongus* n. gen. is in the family Spongotortilispinidae that contains both genera with three-bladed and unequal spines.

Since the spongy shell consists of a very delicate meshwork, which is usually dissolved, the main polar spine is the only skeletal element that normally can be found in fossil state and on which the species are recognized. The extraordinary preservation of radiolarians in the sample G11 is until present the only happy case when this delicate shell was preserved in a few specimens, permitting to reconstruct the entire skeleton.

Range and occurrences: According to Sugiyama (1997, pp. 114–115, 129) the range of the type species and probably of the genus comprises the interval of his zones TR 5B to TR 7 representing the upper Carnian (FAD of *Poulpus carcharus* Sugiyama) to Middle Norian (*Lysemelas olbia* zone). The occurrence of the type species in the *Spongotortilispinus moixi* Zone of the Sorgun Ophiolitic Mélange, Turkey, suggests that the FAD of the genus precedes that of *P. carcharus*, a species that does not occur in the sample G 11. The genus seems to be common in the Tuvalian of the Tethys; at this level it was cited in Japan (Sugiyama, 1997), and is known to occur also in the in the early Tuvalian of the Kopría Mélange in Rhodes, Greece, and in the Tuvalian of the of the Chert Member of the Zulla Formation exposed on the Wadi Bani Khalid section, Oman.

Ancoraspongus sugiyamai Ozsvárt and Dumitrica n. sp.

Figure 6(13–18)

1997 Spine B4—Sugiyama, p. 139, figs. 35.11a–b.

Etymology: The species is dedicated to Dr. Kazuhiro Sugiyama who illustrated and described for the first time the main spine of this species.

Description: Central test relatively small, globular, spongy, many-layered with very small circular or subcircular pore frames. Main polar spine long to very long, three-bladed, straight or slightly dextrally twisted distally. On proximal and middle parts its sides are parallel but on the distal third or half of its length it starts widening then suddenly narrowing and terminates in a thin axial spine of variable length and a verticil of three bifurcated spinules directed more or less perpendicularly on the axis of the spine. Secondary polar spine three-bladed, thin, pointed and short. Specimens with shorter main spines (Fig. 6(17–18)) may bear a few very small additional spines on shell.

Material: More than 10 complete specimens.

Holotype: The specimen in Fig. 6(13), HNHM, PAL 2018.19.1

Dimensions (in µm based on 8 specimens): Diameter of test = 140–150; length of spines = 500–600.

Remarks: Sugiyama (1997, fig. 35, 11a–b) illustrated very well the morphology of the main polar spine with its distal twisted part and the verticil of three bifurcated spinules in a plane perpendicular on the axis of the spine. With the specimens illustrated in this paper this rosette of 6 spinules is not well visible because all spines are illustrated in lateral view, but it is present to all spines. As mentioned above, in fossil state and especially in cherts the species is only represented by its main polar spine, a few specimens occurring in the sample G 11 being the only entire specimens with complete skeleton that permitted the description of the species and its family assignation.

Range and occurrence: See under the genus.

6 Conclusions

The Upper Cretaceous Sorgun Ophiolitic Mélange (Mersin Ophiolitic Complex) from the South-Taurides ophiolite belt contains one of the most diverse and perfectly preserved Carnian (lower Tuvalian *Spongotortilispinus moixi* zone) radiolarian fauna of the world. Radiolarians come from a thin-bedded Huğlu-type tuffitic series which is interspersed with alternations of micritic limestone layers and calciturbidites. These green tuffs belong to a 600-m-thick characteristic transgressive series (Tavusçayiri block) which shows high similarity to typical Pindos facies successions from the Dinarides and Hellenides. Most of the spumellarian radiolarian species described herein are present in some other Neotethyan subbasins as well (Lagonegro basin in Southern Apennines, Italy; Rhodes Island, Greece; Köseyahya Nappe, Elbistan, Turkey, and Hawasina Complex, Oman). Up to now, 3 new families, 19 new genera and 133 new species and subspecies have been described from a single layer of the Tavusçayiri block from the Sorgun Ophiolitic Mélange, Turkey. Consequently, this unique blooming event and accelerated evolutionary innovation in the late Julian and early Tuvalian indicates a particularly important period in the evolutionary history of Tethyan radiolarians.

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