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Stratigraphy and structural position of the type locality of the Phasoula Formation (Upper Triassic, southwestern Cyprus)

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Abstract. The Upper Triassic Phasoula Formation in its type locality in Dhiarizos River valley is interpreted as a large tectonic block incorporated in the Upper Cretaceous Mamonia Mélange. Volcanics of the Phasoula Formation are dated as Upper Triassic based on radiolarian assemblages from chert intercalations within these volcanics, while the clayey matrix of the mélange yields small blocks of red radiolarian cherts which are dated by radiolarians as Cenomanian. According to biostratigraphic and structural data all major localities of the Phasoula Formation (Petra tou Romiou, Akamas, Ayia Varvara, Phasoula) represent large blocks within the Mamonia Mélange.

Key words:
Mamonia Complex, Carnian, Norian, mélange, Cenomanian, cherts.

Апстракт. Горњотријаска формација Phasoula на свом типском локалитету у долини реке Dhiarizos интерпретира се као велики тектонски блок уклопљен у горњокредни Mamonia меланж. Старост вулканита формације Phasoula је горњотријаска и одређена је на основу радиоларија из рожначких интеркалација унутар ових вулканита, док глиновити матрикс меланжа садржи мале блокове црвених рожнаца са радиоларијама, који су, на основу радиоларија, одређени као ценомански. На основу биостратиграфских и структурних података, сви главни локалитети формације Phasoula (Petra tou Romiou, Akamas, Ayia Varvara, Phasoula) представљају велике блокове унутар Mamonia меланжа.

Кључне речи:
Mamonia комплекс, карнијски кат, норијски кат, меланж, ценоман, рожнаци.

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Introduction

The geological structure of southwestern Cyprus is characterized by the widespread occurrence of highly deformed allochthonous sedimentary, igneous and metamorphic rocks of Mesozoic age. These rocks have been grouped together as the Mamonia Complex (Gass, 1960; Lapierre, 1975; Robertson & Woodcock, 1979; Swarbrick & Robertson, 1980; Malpas et al., 1992). The Mamonia Complex is subdivided in two major units:

The Ayios Photios Group (Upper Triassic to lower Upper Cretaceous), consisting of clastic, carbonate and chert deposits (Swarbrick & Robertson, 1980).

The Dhiarizos Group (Upper Triassic to Lower Cretaceous), composed of basic volcanics with sedimentary interlayers and a sedimentary cover (Swarbrick & Robertson, 1980).

Additionally, the Mamonia Complex includes also extensive zones of a tectonic mélange known as the Mamonia Mélange (Geological Survey Department of Cyprus, 2008; 2015; Bragin et al., 2021, 2022, 2024) (Fig. 1). The Mamonia Mélange consists of a sedimentary matrix of highly tectonized siltstones and mudstones from the Ayios Photios Group, mixed with different-sized blocks from various lithologies of the Mamonia Complex and, to a lesser extent from the Troodos Ophiolite (Geological Survey Department of Cyprus, 2008; 2015). The age of the Mamonia Melange is estimated as late Turonian – early Campanian (Bragin et al., 2021; Bragin, 2023).

In more detail, the Dhiarizos Group consists of the Phasoula Formation (Upper Triassic volcanics with chert intercalations) (Swarbrick & Robertson, 1980), Loutra tis Aphroditis Formation (Upper Triassic lava breccias) (Swarbrick & Robertson, 1980), Ayia Varvara Formation (greenschists and amphibolites with Late Cretaceous age of metamorphism) (Malpas et al., 1992; Chan et al., 2007, 2008), Kholetria Member (Upper Triassic to Lower Jurassic pelagic limestones and radiolarian cherts) (Swarbrick & Robertson, 1980; Bragin et al., 2022), Lower Jurassic volcaniclastic sedimentary breccia (Bragin et al., 2022) and the Petra tou Romiou Formation (Upper Triassic reefal limestones which crop out as blocks within the Mamonia Mélange) (Henson et al., 1949; Swarbrick & Robertson,

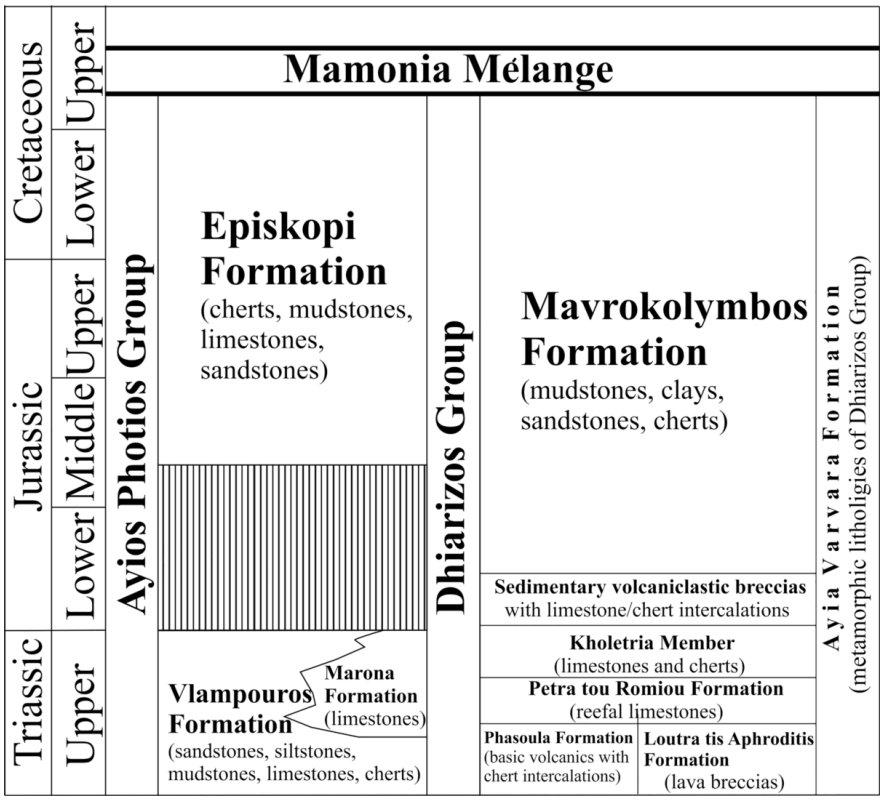

Fig. 1. *Main geological units of the Mamonia Complex (Upper Triassic–Upper Cretaceous (lower Turonian) (Bragin et al., 2021). The hiatus between Vlampouros and Episkopi formations is shown by hatching.*

1980; Bragin et al., 2021). The abovementioned volcaniclastic sedimentary breccias are present as a block within the Mamonia Mélange in the Akamas Peninsula. The Lower Jurassic age of breccias was determined from radiolarian data that were collected from the intercalations of radiolarian cherts (Bragin et al., 2022). This unit represents a previously unknown lower part of the sedimentary cover of the Triassic volcanics (Phasoula Formation, Mamonia Complex). Finally, the Mavrokolymbos Formation, which is composed predominantly of clays and mudstones of a supposed Jurassic to Cretaceous age, is interpreted by previous investigators as the main part of sedimentary cover of the Dhiarizos volcanics (Swarbrick & Robertson, 1980).

The Phasoula Formation is widespread in the southwestern Cyprus and it is usually present as blocks within Mamonia Mélange. Previously we observed such blocks (from several meters to approximately 100-200 m) in Petra tou Romiou (Bragin et al., 2021) and in Ayia Varvara areas (Bragin, 2007; Bragin et al., 2024). Volcanics of the Phasoula formation are dated in these areas as Upper Triassic by radiolarians and bivalves (Halobia) from chert/limestone intercalations. Our special interest was focused to the type section of the Phasoula Formation.

The type section of the Phasoula Formation is located 0.3 km NE of Phasoula Village in the Dhiarizos River valley (Figs. 2, 3) (Swarbrick & Robertson, 1980). It is represented by amygdaloidal or vesicu-

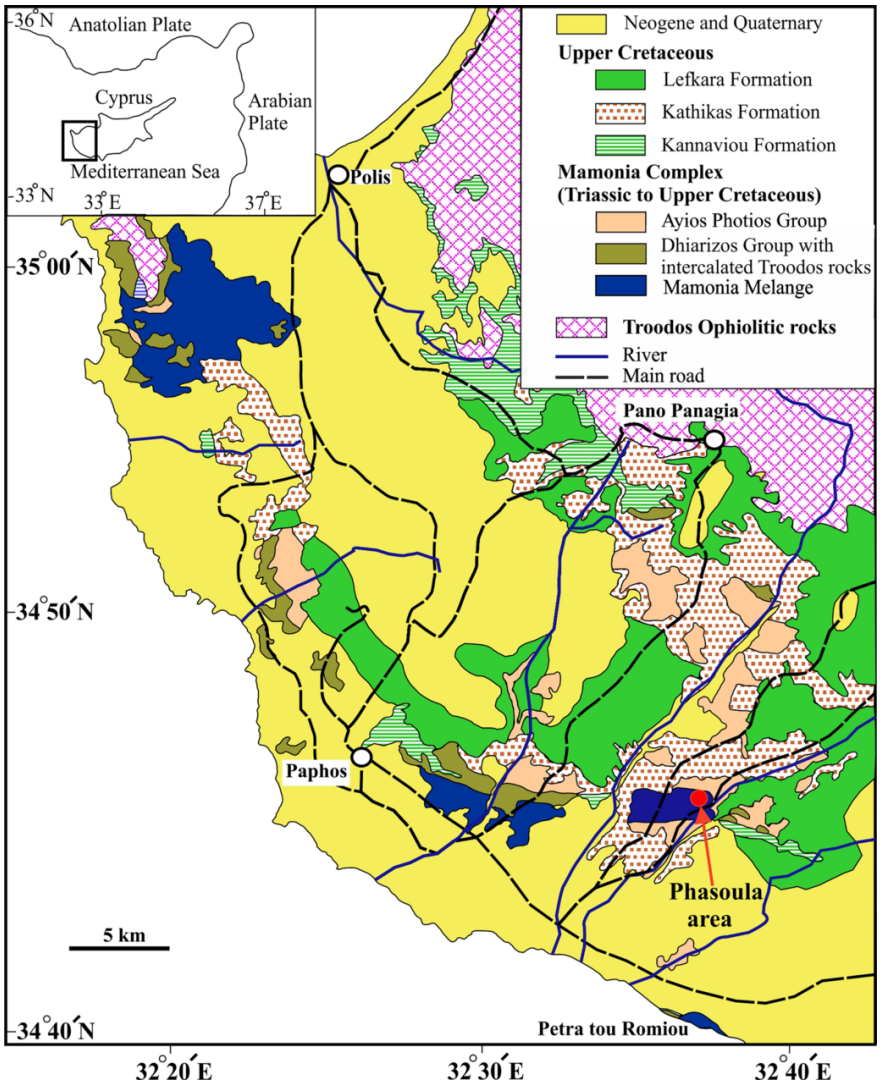

Fig. 2. *Location of the Phasoula Section. Simplified geological map of the Mamonia Complex, compiled from Geological Survey Department Of Cyprus (1995, 2008, 2015) and Chen & Robertson (2019).*

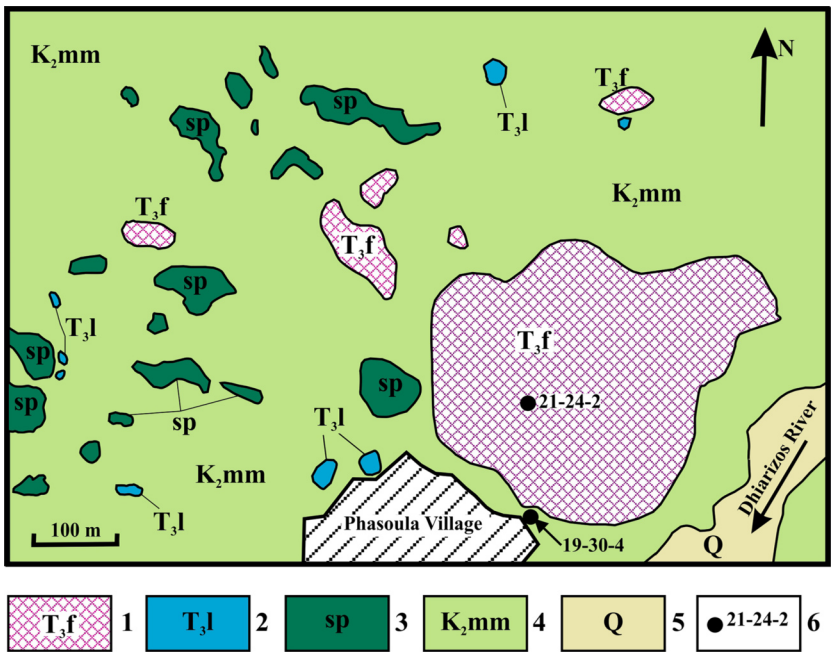

Fig. 3. *Geological map of the right bank of the Dhiarizos River near the Phasoula Village.* ***1.*** *Blocks of volcanics of the Phasoula Formation (Upper Triassic);* ***2.*** *blocks of the Upper Triassic limestones;* ***3.*** *blocks of serpentinites;* ***4.*** *matrix of the Mamonia Mélange;* ***5****. Quaternary alluvial deposits;* ***6.*** *position of sampling and sample number.*

lar porphyritic pillow lavas with interstices filled by pink or grey recrystallized calcilutites. There are rare intercalations of calcilutites and pink to red cherts, with the formation's thickness exceeding 250 m in its type area (Swarbrick & Robertson, 1980). Swarbrick & Robertson (1980) also noted that the Phasoula Formation is frequently structurally associated with large masses of serpentinites, metamorphic rocks, and Troodos igneous rocks.

The objective of this study was to confirm the Triassic age of the Phasoula Formation at its type section and to study its structural position. We recently have studied the Mamonia Complex in the several areas (e.g., Bragin et al., 2021, 2022, 2024). During field works in Phasoula area in 2019 and 2021, samples were collected and studied from sedimentary rocks (calcilutites and cherts) within the Phasoula volcanics and around them. This paper reports newly yielded Triassic radiolarians from the Phasoula Formation and Cretaceous radiolarians from the Mamonia Melange. On that basis, we discuss stratigraphy and structural position of the Phasoula Formation based on the radiolarian age combined with our previous research.

Geological setting

At the key locality, the Phasoula Formation is represented exclusively by various volcanics, of reddish-brown to greenish-brown color, porphyritic and amygdaloidal texture, with sporadic pillow structures, which are commonly strongly altered and sometimes highly tectonized (Fig. 4a). In contrast, sedimentary rocks are rare and are represented by white, light-grey and pinkish-grey recrystallized limestones that form thin (up to 2–5 cm thick) discontinuous intercalations in the volcanics (Fig. 4b), and by greenish-grey to pinkish-grey or rarely red cherts that form small lenses (up to 5–7 cm thick) in the volcanics. One chert lens was identified at sample point 19-30-2 [34° 45' 35.3'' N, 32° 37' 34.0'' E (Fig. 4c)]. This chert yielded moderately preserved Triassic radiolarians that were used to determine the age of the volcanics (Plate 1).

All the outcrops of the Phasoula Formation are located in the prominent hill northeast of Phasoula Village (Fig. 3).) The surrounding area is characterized by isolated small hills exposing various rocks, including serpentinites, limestones, volcanics, and

Fig. 4. *Outcrops of the Phasoula Formation and Cretaceous radiolarian cherts;* ***a*** *– pillow volcanics of the Phasoula Formation;* ***b*** *– Phasoula volcanics with intercalations of light-grey to pinkish-grey recrystallized limestones;* ***c*** *– Phasoula volcanics with a small lens of greenish-grey chert with Triassic radiolarians (sample 21-24-2);* ***d*** *– clayey matrix of the Mamonia Mélange with a block of red cherts with Cretaceous radiolarians (sample 19-30-4).*

cherts (Fig. 3). The landscape is similar to areas associated with the Mamonia Mélange, as previously described in multiple publications (Bragin et al., 2021, 2022, 2024).

Reddish-brown clays and mudstones of the Mavrokolymbos Formation are not observed on top of the Phasoula lavas in the broader area of the Phasoula village. The first type section of this formation is located in the valley of Mavrokolympos River (Swarbrick & Robertson, 1980); at that locality the Mavrokolymbos Formation has no contact with the Phasoula Formation. The second type section of the Mavrokolymbos Formation is located in the valley of the Xeros River, 1.5 km SW from the Kholetria Village (Swarbrick & Robertson, 1980). In this area the presumed Mavrokolymbos Formation has a tectonic relation with the Phasoula volcanics, and a mid-Cretaceous (Albian-Turonian) age according to radiolarian assemblages from rare chert beds within the clayey section (Bragin et al., 2000).

In a roadcut near the southwestern part of the Phasoula Formation key locality, at sample point 19-30-4 (34° 45’ 41.1’’ N, 32° 37’ 37.9’’ E), a contact between highly tectonized greenish-brown volcanics (Phasoula Formation) with reddish-brown mudstones and siltstones, and a block of red cherts (Fig. 4d) was observed. These cherts are characterized by well-preserved Upper Cretaceous (middle to upper Cenomanian) radiolarians (Plate 2). The observed mudstones and siltstones can be interpreted as the matrix of the

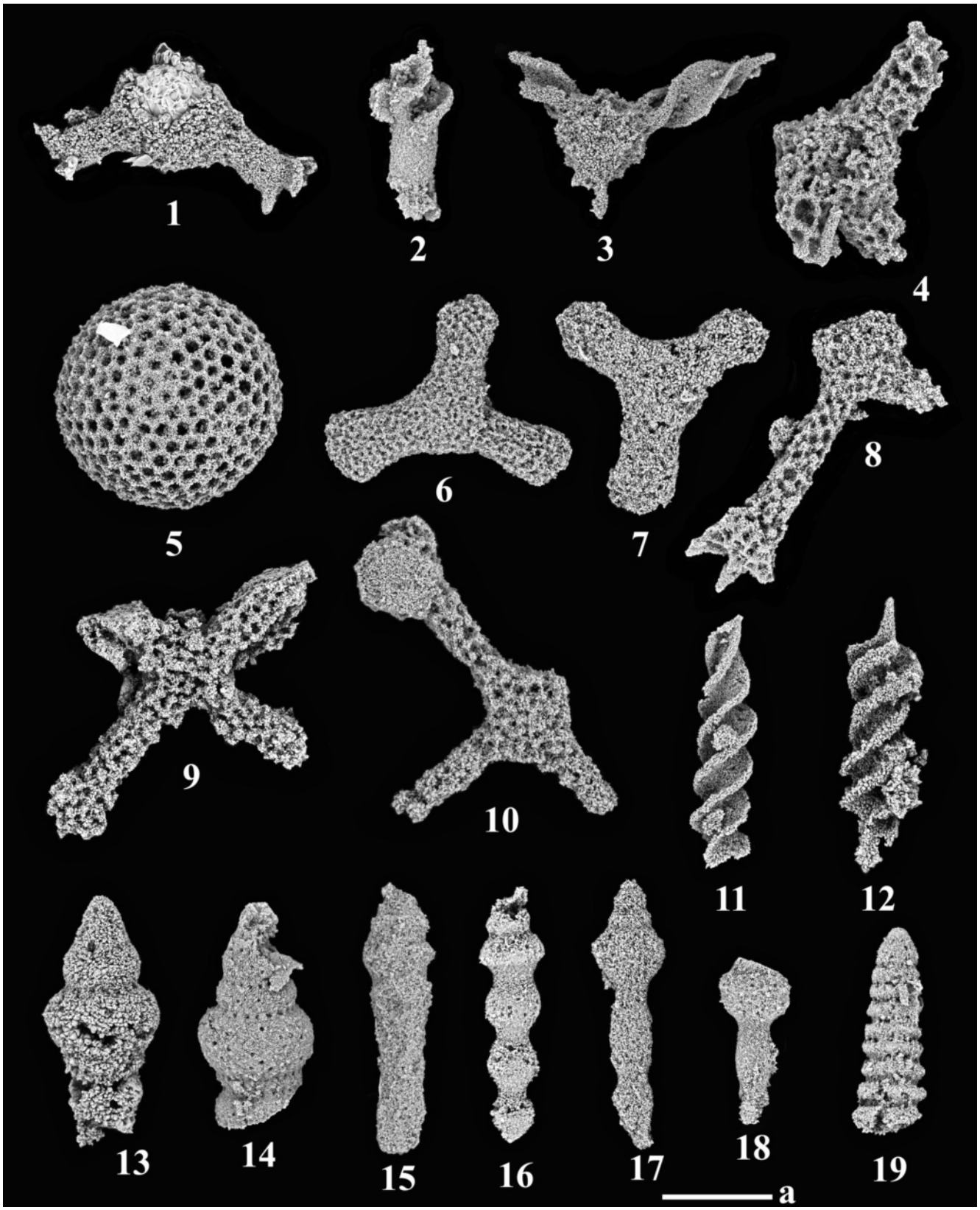

Plate 1. *Triassic Radiolaria. 1. Capnuchosphaera* sp. cf. *C. tricornis* De Wever; *2. Capnuchosphaera* sp. cf. *C. triassica* De Wever; *3. Sarla* sp.; *4. Icrioma* sp.; *5. Archaeocenosphaera* sp.; *6, 7. Paronaella* sp. cf. *P. nuda* (Kozur & Mostler); *8. Triassocrucella* sp. cf. *T. triassica* (Kozur & Mostler); *9, 10. Triassocrucella* sp.; *11, 12. spiral spines, probably Spongotortilispinus tortilis* (Kozur & Mostler)*; 13–15. Xiphothecaella* sp.; *16. Xiphothecaella longa* (Kozur & Mock); *17, 18. Xiphothecaella karpenissionensis* (De Wever); *19. Annulotriassocampe* sp. *Scale bar 100 μm for all images.*

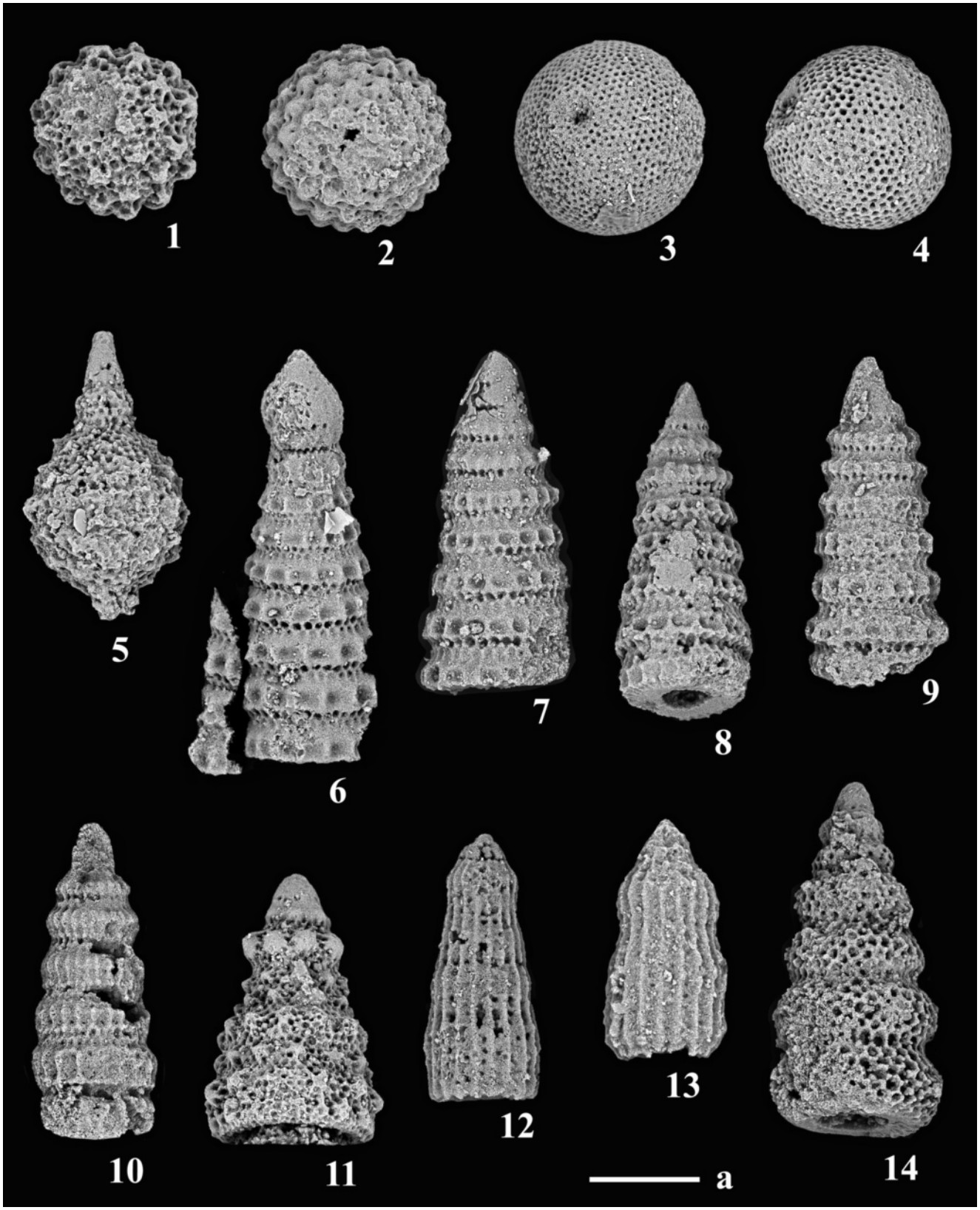

Plate 2. *Cretaceous Radiolaria. 1. Praeconocaryomma universa* Pessagno*; 2. Holocryptocanium geysersense* Pessagno*; 3, 4. Holocryptocanium barbui* Dumitrica*; 5. Pseudoeucyrtis spinosa* (Squinabol)*; 6. Pseudodictyomitra pseudomacrocephala* (Squinabol)*; 7–9. Pseudodictyomitra nakasekoi* Taketani*; 10. Pseudodictyomitra quasilodogaensis* Bragina*; 11. Novixitus weyli* Schmidt-Effing*; 12, 13. Thanarla veneta* (Squinabol)*; 14. Parvimitrella communis* (Squinabol)*. Scale bar 100 μm for all images.*

Mamonia Mélange. Thus, it can be concluded that the volcanics of the Phasoula Formation in its key locality, represent a huge block within the mélange.

Materials and methods

Chert samples were collected from intercalations within the Phasoula volcanics and from blocks within the Mamonia Mélange, during a fieldwork in 2021. The radiolarian assemblages were extracted from the chert samples by using diluted (5%) hydrofluoric acid (HF) for twelve (12) hours, and the residues were rinsed with water and then dried out.

They were studied using a light microscope (LOMO-MBS-10), then the microfossils were collected, mounted on stubs, and analyzed in detail. Scanning electron microscopes (TESCAN 2300 at the Geological Institute RAS, Moscow, and TESCAN VEGA-II XMU at the Paleontological Institute RAS, Moscow) were used for imaging. The radiolarian assemblages are stored in the Geological Institute RAS, Moscow, Russia.

Radiolarian data and their interpretation

Triassic Radiolaria

The assemblage of Triassic radiolarians is characterized by moderate to poor preservation. Radiolarian tests are commonly recrystallized and some important morphological features such as pores and pore frames, are almost or completely destroyed. Some radiolarian remains are fragmented, including spiral spines of Triassic Spumellaria (Plate 1, figs. 2, 11, 12). Due to these conditions, the Triassic radiolarians can be determined mostly in open nomenclature or at generic level. Nevertheless, the assemblage was dated to the middle Carnian–middle Norian interval based on the concurrent presence of taxa such as *Xiphothecaella longa* (Kozur & Mock), *X. karpenissionensis* (De Wever), *Capnuchosphaera* sp. cf. *C. tricornis* De Wever and *C.* sp. cf. *C. triassica* De Wever (Fig. 5). Species *Xiphothecaella longa* (Kozur & Mock) is known from the upper Carnian of Turkey (Tekin, 1999) and Oregon (Yeh, 1989) and from lower Norian of Cyprus (Bragin, 2007), and British Columbia (Carter & Orchard, 2000). *X. karpenissionensis* (De Wever) is known from upper Carnian of Croatia (Halamič & Goričan, 1995) and Turkey (Uzuncimen et al., 2011) and from upper Carnian-lower Norian of British Columbia (Carter & Orchard, 2000), *Capnuchosphaera tricornis* De Wever and *C. triassica* De Wever have their first appearance in the base of upper Carnian radiolarian zone Capnuchosphaera theloides (Bragin, 2000), and are indicated as important taxa for lower Norian radiolarian zone Capnodoce ruesti (Kozur & Mostler, 1994). These results are in accordance with previous conclusions that suggested an Upper Triassic stratigraphic interval for the Phasoula Formation (Lapierre, 1975; Robertson & Woodcock, 1979; Swarbrick & Robertson, 1980; Lapierre et al., 2006).

Cretaceous Radiolaria

The Cretaceous radiolarian assemblage is well-preserved, allowing for detailed identification (Plate 2). Its stratigraphic position is estimated as Cenomanian (Fig. 5) based on the concurrent ranges of several species. *Holocryptocanium geysersense* Pessagno and *Pseudodictyomitra nakasekoi* Taketani have first appearance level in the base of lower Cenomanian radiolarian zone Patellula spica (Bragina, 2016; Bragina & Bragin, 2021). *Pseudodictyomitra quasilodogaensis* Bragina is present in the upper Cenomanian (Bragina, 2004). *Thanarla veneta* (Squinabol) extinct in the top of Cenomanian Dactyliosphaera silviae radiolarian zone (O'Dogherty, 1994; Musavu-Moussavou et al., 2007). *Pseudoeucyrtis spinosa* (Squinabol) is known in the middle Albian–Cenomanian of Mediterranean regions (O'Dogherty, 1994) and in the lower Cenomanian of Crimea (Bragina & Bragin, 2021). These findings are consistent with previous data on Upper Cretaceous blocks within the Mamonia Mélange and its estimated age (Bragin et al., 2021, 2024).

Discussion and conclusions

The Phasoula Formation was proposed by Swarbrick & Robertson (1980) as consisting of thick (up to 250 m) amygdaloidal to vesicular porphyritic pillow

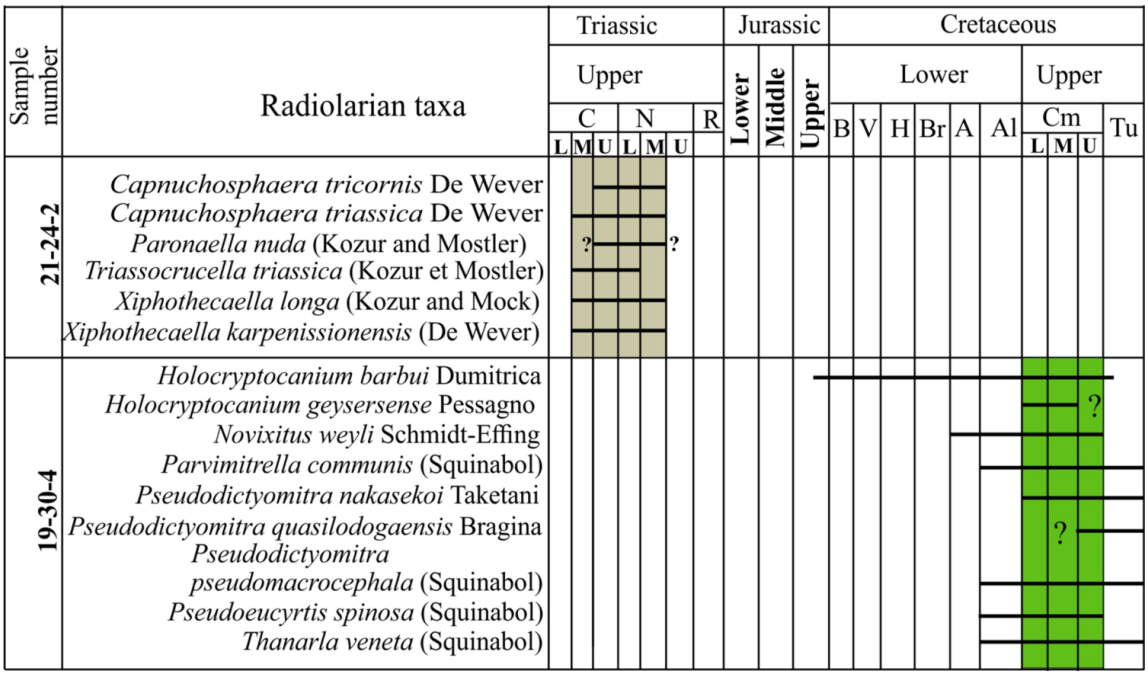

Fig. 5. *Age ranges of the Triassic (sample 21-24-2) and Cretaceous (sample 19-30-4) radiolarian assemblages. Stratigraphic ranges of the Triassic Radiolaria are shown according to published data (Bragin, 2007; Carter & Orchard, 2000; Halamic & Goričan, 1995; Tekin, 1999; Uzuncimen et al., 2011; Yeh, 1989). Stratigraphic ranges of the Cretaceous Radiolaria are shown according to published data (Bragina, 2004; Bragina & Bragin, 2021; Musavu-Moussavou et al., 2007; O'Dogherty, 1994).*

lavas (alcali basalts or trachybasalts) with intercalations or interstices of micritic limestones, cherts and volcaniclastic siltstones. They indicated that "In SW Cyprus, the Phasoula Formation is frequently structurally associated with major masses of serpentinite, Troodos igneous rocks and metamorphic rocks. Phasoula lavas are also known as large detached blocks in the Moni Formation of S Cyprus". Furthermore, large areas in Akamas Peninsula, Ayia Varvara, Petra tou Romiou and Dhiarizos Valley areas were previously mapped as the Dhiarizos Group (Geological Survey Department of Cyprus 1995).

Recent works revised our understanding of the stratigraphy and structural position of the Phasoula Formation and of the Driarizos Group as a whole. Rocks of volcaniclastic sedimentary breccias occuring as blocks within the Mamonia Mélange have been identified and studied in the Akamas Peninsula (Bragin et al., 2022), and an Early Jurassic age was determined in the intercalations of radiolarian cherts. This unit has no name for the moment and represents a previously unknown lower part of the sedimentary cover of the Triassic volcanics (Phasoula Formation, Mamonia Complex), being apparently younger that the Kholetria Member.

Studies in Petra tou Romiou and Ayia Varvara areas (Bragin et al., 2021, 2024) show that all bodies of the Phasoula Formation in these areas, should be interpreted as blocks within the Upper Cretaceous (upper Turonian to lower Campanian) Mamonia Mélange which contains a tectonized siltstone-mudstone matrix supporting a high variety of blocks, including all the lithologies of the Mamonia Complex, as well as subordinate blocks of Troodos lithologies.

The outcrop of the Phasoula Formation in its type area is seemingly the biggest known in SW Cyprus. In this area, it is identified as a large detached block surrounded by the Upper Cretaceous Mamonia Mélange which contains a wide variety of Mamonia and Troodos lithologies (Fig. 3). This allows us to discuss the stratigraphy and structural position of the Dhiarizos Group as a whole.

The Phasoula Formation, as well as other Lower Mesozoic units of the Dhiarizos Group (Loutra tis

Aphroditis and Petra tou Romiou formations) have no stratigraphic relations with the Mavrokolymbos Formation (Swarbrick & Robertson, 1980), which was proposed as the stratigraphic cover of the Dhiarizos Group volcanics. There is no direct evidence that the unit which was described as the Mavrokolymbos Formation represents the upper part of the Dhiarizos Group or the sedimentary cover of the Dhiarizos volcanics. It may be a part of the Ayios Photios Group due to high similarity with their lithologies.

The stratigraphy of the Dhiarizos Group can be presented as follows: Upper Triassic Phasoula, Loutra tis Aphroditis and Petra tou Romiou formations with a sedimentary cover which is represented by Upper Triassic to Lower Jurassic micritic limestones and cherts (Kholetria Member) and Lower Jurassic volcaniclastic sedimentary breccias, locally exposed in the Akamas Peninsula (Bragin et al., 2022).

The Phasoula Formation is dated as Upper Triassic at its type area. All major localities of the Phasoula Formation represent blocks of volcanics and related sediments, which are incorporated in the Upper Cretaceous Mamonia Mélange. Therefore, the structural position of the Dhiarizos Group is determined by the structural position of the Mamonia Mélange.

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Резиме

Стратиграфија и структурна позиција типског локалитета формације Phasoula (горњи тријас, југозападни Кипар)

Горњотријаска формација Phasoula заступљена је на свом типском локалитету у долини реке Dhiarizos у виду лавичних излива велике дебљине (до 250 м), амигдалоидне до везикуларне порфиритне јастучасте лаве (pillow лава) (алкални базалти или трахибазалти) са интеркалацијама микритских кречњака, рожнаца и вулканокластичних алевролита. Горњотријаска формација Phasoula на свом типском локалитету интерпретирана је као велики тектонски блок уклопљен у горњокредни Mamonia меланж.

Вулканити формације Phasoula датирани су као горњотријаски на основу радиоларија представљених врстама: *Xiphothecaella longa* и *X. karpenissionensis* из рожначких интеркалација унутар ових вулканита, док глиновити матрикс меланжа који окружује блокове вулканита Phasoula садржи мале блокове црвених рожнаца са радиоларијама, чија је старост на основу радиолараија одређена као горњокредна (ценоман) на основу присуства врста *Pseudodictyomitra nakasekoi*, *Thanarka veneta* и других таксона. Према биостратиграфским и структурним подацима, сви главни локалитети формације Phasoula (Petra tou Romiou, Akamas, Ayia Varvara, Phasoula) представљају велике блокове унутар Mamonia меланжа.

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