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FIRST EVIDENCE OF PALAEO-TETHYAN UPPER TRIASSIC CALCAREOUS NANNOFOSSILS IN NORTH DOBROGEAN OROGEN (ROMANIA)

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Keywords: *Prinsiosphaera triassica; Eoconusphaera zlambachensis;* Rhaetian*;* Frecăţei; Borehole 816 LV; Black Sea; Palaeo-Tethys.

Abstract. This study presents the analysis of Upper Triassic sediments from five locations in North Dobrogea (Romania) and the Black Sea. Microfacies analyses on thin sections from the Frecăţei log reveal a shallowing trend and likely an increase in energy upward into the section. The oldest part of the log is characterised by deposition of mudstones transitioning to wackestones, with an increase of bivalves. Similar wackestones are observed in the Izvoarele and Rândunica logs, i.e. microfacies with abundant bivalves, some foraminifera and echinoderms. The offshore boreholes 816 and 817 Lebăda Vest (core CM 9 and CM 31) seem to have been deposited in a basinal or distal marine shelf environment indicated by the presence of mudstones with rare bioclasts. In contrast, sample CM 10 from borehole 816 LV is a micritised grainstone suggesting a deposition in a shallower, higher energy environment. Scanning electron microscope observations reveal a moderate diagenetic alteration in all studied samples, mainly due to dissolution. Two calcareous nannofossil species: *Prinsiosphaera triassica triassica* and *Eoconusphaera zlambachensis* were commonly observed in sample F of the Frecăţei log, allowing for assignment of the sediments to the Rhaetian age. Two coccoliths were also observed in sample F of Frecăţei log and sample CM 9 of the borehole 816 LV indicating the presence of coccolithophorids within the study region. This discovery constitutes the first confirmed record of well-preserved, determinable Upper Triassic calcareous nannofossils in the Palaeo-Tethys Ocean.

Introduction

Calcareous nannofossil assemblages from the Late Triassic are dominated by the incertae sedis *Prinsiosphaera triassica triassica* Jafar, 1983, which is recorded from at least the middle Norian (Alaunian; Fischer et al. 1967). Coccolithophorids are also documented from the middle Norian (Alaunian – *Halorites macer* ammonoid Zone) with *Crucirhabdus minutus* Jafar, 1983 appearing first, followed by *Archaeozygodiscus koessenensis* Bown, 1985 and *C. primulus* Prins, 1969 ex Rood et al., 1973, *emend.* Bown, 1987 occurring from the early Rhaetian (*Paracochloceras suessi* Zone) (Demangel et al. 2020). Conical Eoconusphaeraceae are reported from the early Rhaetian, with first the appearance of *Eoconusphaera hallstattensis* Demangel et al., 2021 and then *E. zlambachensis* Moshkovitz, 1982 Kristan-Tollmann, 1988 (*Vandaites stuerzenbau-*

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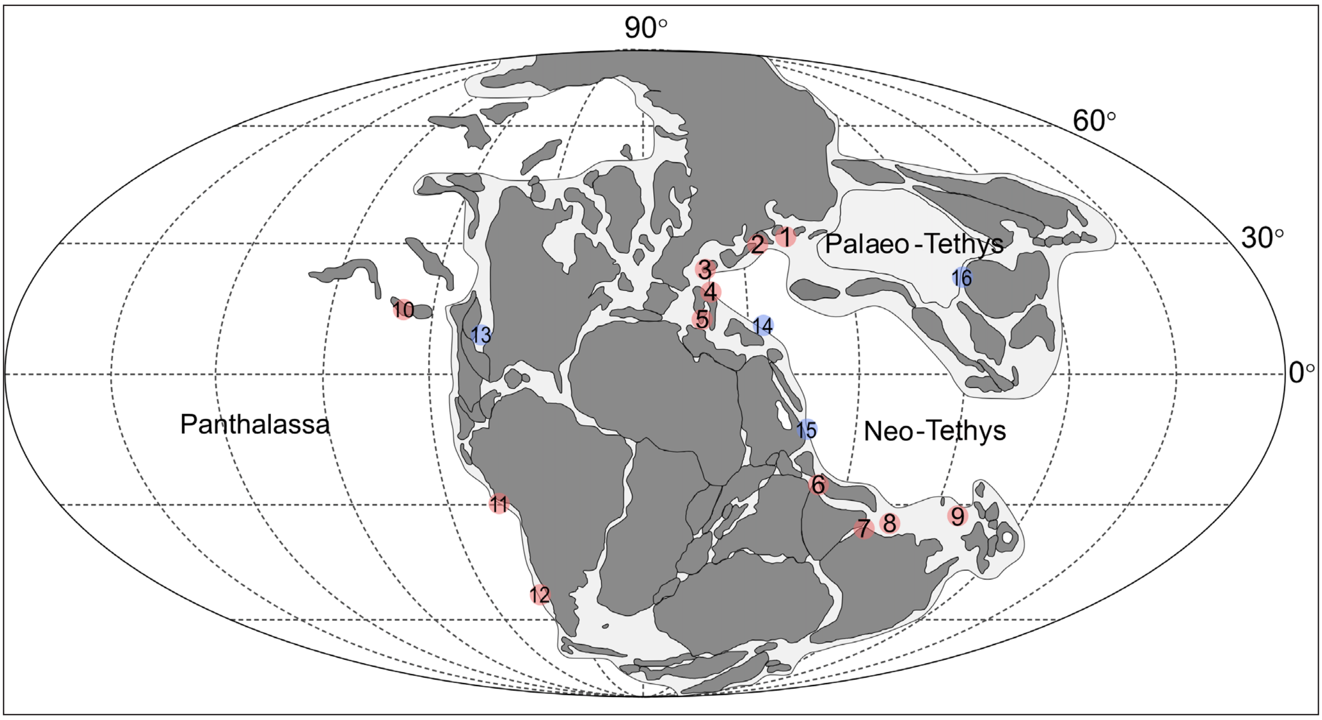


Fig. 1 - Global palaeogeographic reconstruction of the Late Triassic modified after Nakada et al. 2014 and Onoue & Yoshida 2010. The darker grey represents the emerged land and the lighter grey the shallow sea. The red, numbered circles show the area reporting Triassic calcareous nannofossils, with 1: Georgia (Koiava et al. 2015); 2: North Dobrogea, Romania (this study); 3: The Northern Calcareous Alps (Fischer et al. 1967; Moshkovitz 1982; Jafar 1983; Bown 1985; Janofske 1987; Posch & Stradner 1987; Bown & Cooper 1989; Clémence et al. 2010; Gardin et al. 2012; Demangel et al. 2020; Demangel et al. 2021; Demangel et al. 2023); 4: The Southern Alps (Janofske 1992; Bottini et al. 2016; Dal Corso et al. 2020; Rifl & Holcovà 2022); 5: Sicily and Lagonegro, Italy (Bellanca et al. 1993; Preto et al. 2013); 6: India (Rai et al. 2004); 7: Northern Carnarvon Basin, Australia (Demangel et al. 2021); 8: Wombat Plateau, Australia (Bralower et al. 1991); 9: Timor (Bown 1992); 10: Queen Charlotte Island, British Columbia (Bown 1992); 11: Pucará Group, Peru (Pérez Panera et al. 2023a), 12: Neuquén Basin, Argentina (Pérez Panera 2023b). The blue, numbered circles show the area studied for calcareous nannofossils without recovering them: 13: Nevada, USA (Demangel, personal observation); 14: Turkey (Demangel 2022); 15: Oman (Hauser et al. 2001; Demangel 2022); 16: southwestern China (Enos et al. 1998).

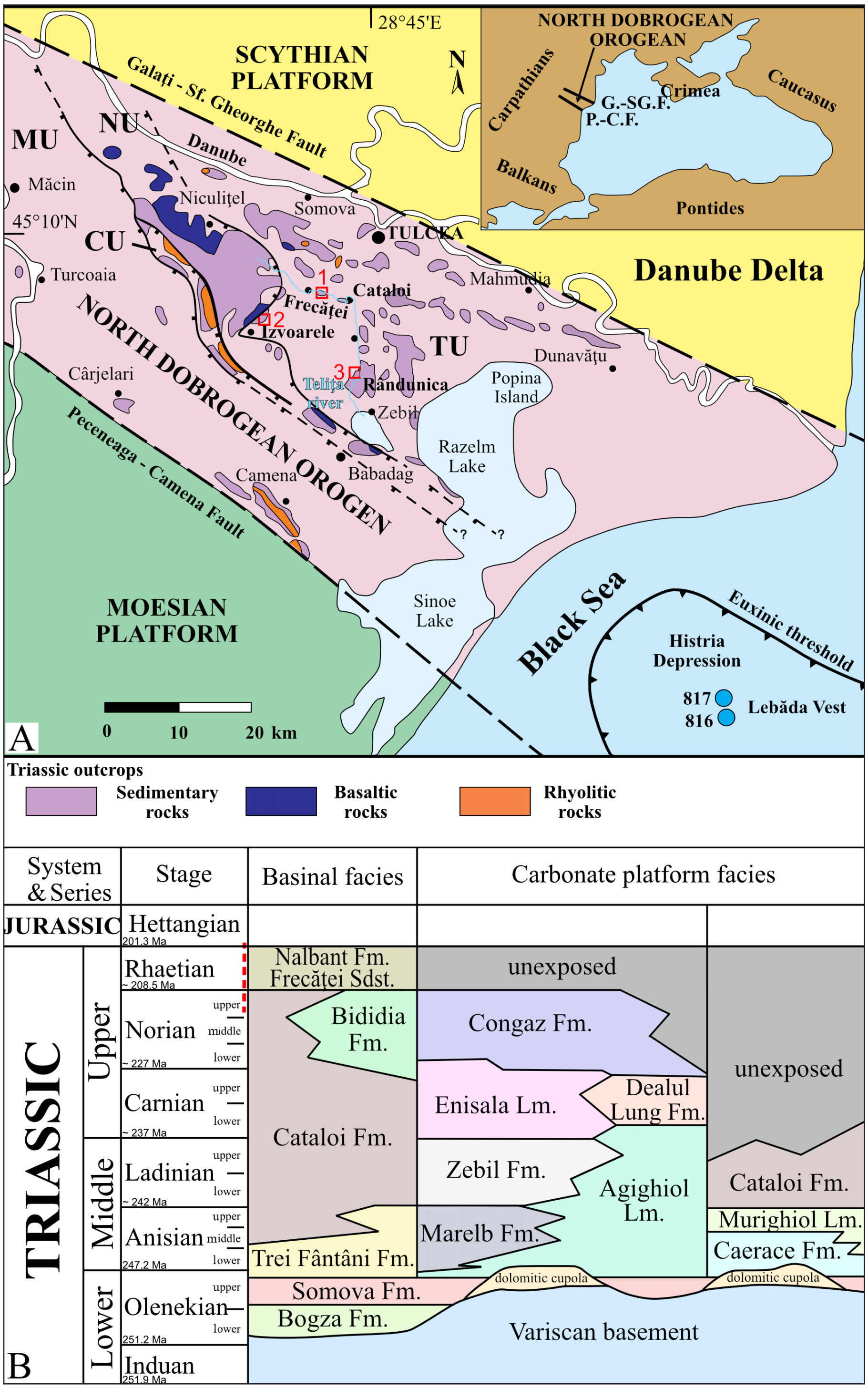
mi Zone) (Demangel et al. 2021). From the middle Rhaetian (*V. stuerzenbaumi* Zone), the sub-species *P. triassica crenulata* Jafar, 1983 emerged (Demangel et al. 2023). In terms of geographical distribution, calcareous nannofossils have been described and reported from the Neo-Tethys Ocean, in both its Western and Southern parts, and in the Eastern Panthalassa Ocean (see references in Fig. 1). However, records of Upper Triassic calcareous nannofossils in Palaeo-Tethys are almost absent (Fig. 1). Only Koiava et al. (2015) reported calcareous nannofossils, including *P. triassica triassica*, *C. minutus* and *C. primulus,* from Georgia (Caucasus). However, the specimens illustrated in Koiava et al. (2015) appear poorly preserved, with overgrowth of calcite crystals, and the specific characteristics of the species reported are indiscernible. Therefore, we investigated five sections in the North Dobrogea region (Romania) to investigate the possible evidence of calcareous nannoplankton in the Palaeo-Tethys during Norian and Rhaetian.

Geological Setting

The North Dobrogean Orogen and the Tulcea Unit

North Dobrogea in Romania, is a fold-and-thrust belt (Săndulescu 1984, 1995), commonly known as North Dobrogean Orogen (NDO). Located south of the Danube Delta and northwest of the Black Sea, this region is tectonically bordered by the Galați-Sfântu Gheorghe Fault to the north and the Peceneaga-Camena Fault to the south (Fig. 2A). The NDO corresponds to a Late Permian-Middle Triassic rifted basin that was inverted during Late Triassic, Jurassic and Early Cretaceous tectonic phases. It is situated at the western extremity of the Palaeo-Tethys, north of the Cimmerian Orogenic System, which extends eastwards with the Mountainous Crimea and North Caucasus, and further continues into the Asian Cimmerides (Şengör 1984, 1986). The NDO is composed of four tectonic

Fig. 2 - A) Tectonostratigraphic map of the North Dobrogean Orogen showing the distribution of Triassic rocks and localities studied. MU: Măcin Unit, CU: Consul Unit, NU: Niculiţel Unit, TU: Tulcea Unit (modified and completed after Grădinaru 2005). 1 - Frecăţei; 2 - Izvoarele; 3 - Rândunica logs are illustrated with red squares and villages with black dots; 816 LV and 817 LV boreholes (blue dots). The inset map shows the regional location of the North Dobrogean Orogen. B) Triassic stratigraphy for the Tulcea Unit, North Dobrogean orogen (Romania) with the succession of interest shown by a red dashed line, modified after Atudorei et al. (1997) and Grădinaru (2000). According to an alternative interpretation, the Frecăţei Sandstone is a member of the Nalbant Formation (including upper Carnian to Upper Jurassic turbidites) (Baltres, in Antonescu and Baltres 1998; Baltres 2003).



units, Măcin, Consul, Niculiţel and Tulcea (Fig. 2A), forming a system of nappes that are overthrusted north-easterly (Săndulescu 1984; Visarion et al. 1990).

The Triassic sedimentary series displays its most extensive development in the Tulcea Unit (Grădinaru 2000), overlaying unconformably a Variscan basement (Fig. 2B). Carbonate sedimentation started in early Spathian and persisted throughout the Middle and Late Triassic. It developed with basinal facies westwards and a complex carbonate platform that extends eastwards in the Tulcea Unit (Fig. 2; Baltres 1976). The Triassic of North Dobrogea is well known for its Tethyan-type facies and richness in various groups of invertebrate and vertebrate fossils (Peters 1867; Arthaber 1906; Kittl 1908; Simionescu 1910, 1913a, 1913b, 1927; Tozer 1984; Mirăuţă & Gheorghian 1975; Mirăuţă & Iordan 1982; Mirăuţă et al. 1984, 1993; Grădinaru 1984, 1995, 2000; Baltres 2005; Crasquin-Soleau &

Grădinaru 1996; Grădinaru et al. 2007; Grădinaru & Sobolev 2006; Sebe et al. 2013; Popa et al. 2014; Cavin & Grădinaru 2014; Nützel et al. 2018; Grădinaru & Gaetani 2019; Forel & Grădinaru 2018, 2020, 2021; Gale et al. 2021; Friesenbichler et al. 2021).

Within the Tulcea Unit, a few locations expose Norian and Rhaetian carbonate rocks in isolated outcrops. Norian and Rhaetian carbonate rocks have also been identified in boreholes. In this study, three successions from the Tulcea Unit were analysed: the Frecăţei, Izvoarele and Rândunica logs. The Frecăţei log outcropping along the right bank of the Teliţa river, from west of Cataloi to east of Frecăţei villages (Fig. 2A) (Grădinaru 1984; Mirăuţă et al. 1993). The Izvoarele log exposes uppermost Norian to Rhaetian sediment, occurring as a narrow strip underlying the frontal part of the Niculiţel Unit, mainly north of the Izvoarele village (Fig. 2A; Grădinaru 2011). The Rândunica log, located south of Rândunica village (Fig. 2A), exposes Norian and Rhaetian sediments (Mirăuţă & Gheorghian 1975). In addition, two offshore boreholes, i.e. 816 and 817 Lebăda Vest (Fig. 3A, B), in the Black Sea were studied.

Material And Methods

A total of sixteen samples from three different locations in North Dobrogea and two boreholes in the Black Sea western shelf (Fig. 2) were analysed for their calcareous nannofossil content using both light microscope (LM) and Scanning Electron Microscope (SEM). Seven samples are from the Frecăţei log (A1, A2, B, C, D, E, F), two samples are from the Izvoarele log (144 with 2 pieces and 237), and one from the Rândunica log. Three samples come from the borehole 817 LebădaVest (LV), drill core CM 31 (depth interval 2623.85 – 2623.90 m, 2623.90 – 2624.00 m, 2623.00 – 2625.00 m), and three from the borehole 816 LV, core CM 9 (2650.20 – 2650.25 m), core CM 10 (2699.30 – 2699.55 m) and core CM 11 (2807.70 – 2808.00 m). All samples are stored at the Department of Geology at Lund University (Sweden).

Smear slides were prepared according to the method described by Bordiga et al. (2015). A fresh rock surface was powdered and dried overnight, 0.05 g of powder was added to 50 mL of buffered ammonia. After shaking, 1500 μL of the solution were put on the coverslip previously humidified. The solution was slowly dried below 50°C to avoid aggregates of sediments. The coverslip was mounted on the slide using Norland Optical Adhesive and fixed with a UV lamp. Observations of the smear slides were performed using an Olympus BX50 light microscope with a magnification of x2500. Illustrations were taken using an Olympus SC50.

SEM samples were prepared according to the method described by Demangel et al. (2020). Fresh surfaces of 1 cm^2 were cut perpendicular to the bedding and polished with powder at 800 mesh per inch using distillate water. The blocks were etched for 15 seconds in 0.1% HCl and briefly cleaned in the ultrasonic bath with distillate water. The samples were dried overnight at 50° C and coated with 1 nm of platinum/palladium using Cressington Sputter Coater 208HR. SEM observations were performed with a TESCAN MIRA 3 electron microscope at Lund University (Sweden).

Additionally, uncovered thin sections (28 x 48 mm) were produced and then analysed with a Canon slide scanner (9600 dpi) and an Olympus BX50 optical microscope equipped with an Olympus SC50 digital camera.

Results

Detail descriptions of fossiliferous logs

Frecăţei log - The Frecăţei log, located approximately 1.5 km east of the village, is exposed in a ravine on the right bank of the Teliţa river (Fig. 2A). This location provides a continuous succession from the Norian to the lower Pliensbachian, offering a unique opportunity in North Dobrogea to study the transition from basinal facies of the Upper Triassic carbonate succession to Lower Jurassic deep-water siliciclastic turbidite (Grădinaru 1984; Grădinaru 2005). The Frecăţei log exposes, around the Triassic-Jurassic boundary, the following succession, in ascending stratigraphic order (Fig. 3C):

1 - An alternance of grey, nodular, marly limestones, and marlstones, with a maximum thickness of 5 metres. It contains black shells of crushed ammonoids, commonly represented by arcestids, rare specimens of *Paracladiscites multilobatus* Bronn, 1832, and nautiloids such as *Proclydonautilus spirolobus* Dittmar, 1866. Mirăuţă et al. (1993) reported rich foraminiferal and ostracod assemblages indicative of a late Norian age. In other outcrops, situated in the Muchea Verde area, near the Poşta village, the presence of the ammonoid *Sagenites quinquepunctatus* Mojsisovics, 1873 – 1902, together with bivalves of *Monotis* (*Monotis*) *salinaria-haueri* Kittl, 1912 group, is diagnostic for the *Sagenites quinquepunctatus* Zone of the upper Norian, which corresponds to the lower Sevatian (= Sevatian 1) (Krystyn 2008; Grădinaru & Sobolev 2010). Samples Frecăţei A1-2 and B come from this part of the log.

2 - A maximum 1-metre thick grey-mauvish, sandy limestone bed with frequent microscopic, cubic, crystals of pyrite. Mirăuţă et al. (1993) reported the occurrence of the conodont *Norigondolella steinbergensis* Mosher, 1968, and a rich upper Norian foraminiferal assemblage including "*Vidalina*" sp., *Ophthalmidium fusiforme* Trifonova, 1962, *Ophthalmidium* sp., and frequently *Tolypamminidae* sp. (Mirăuţă

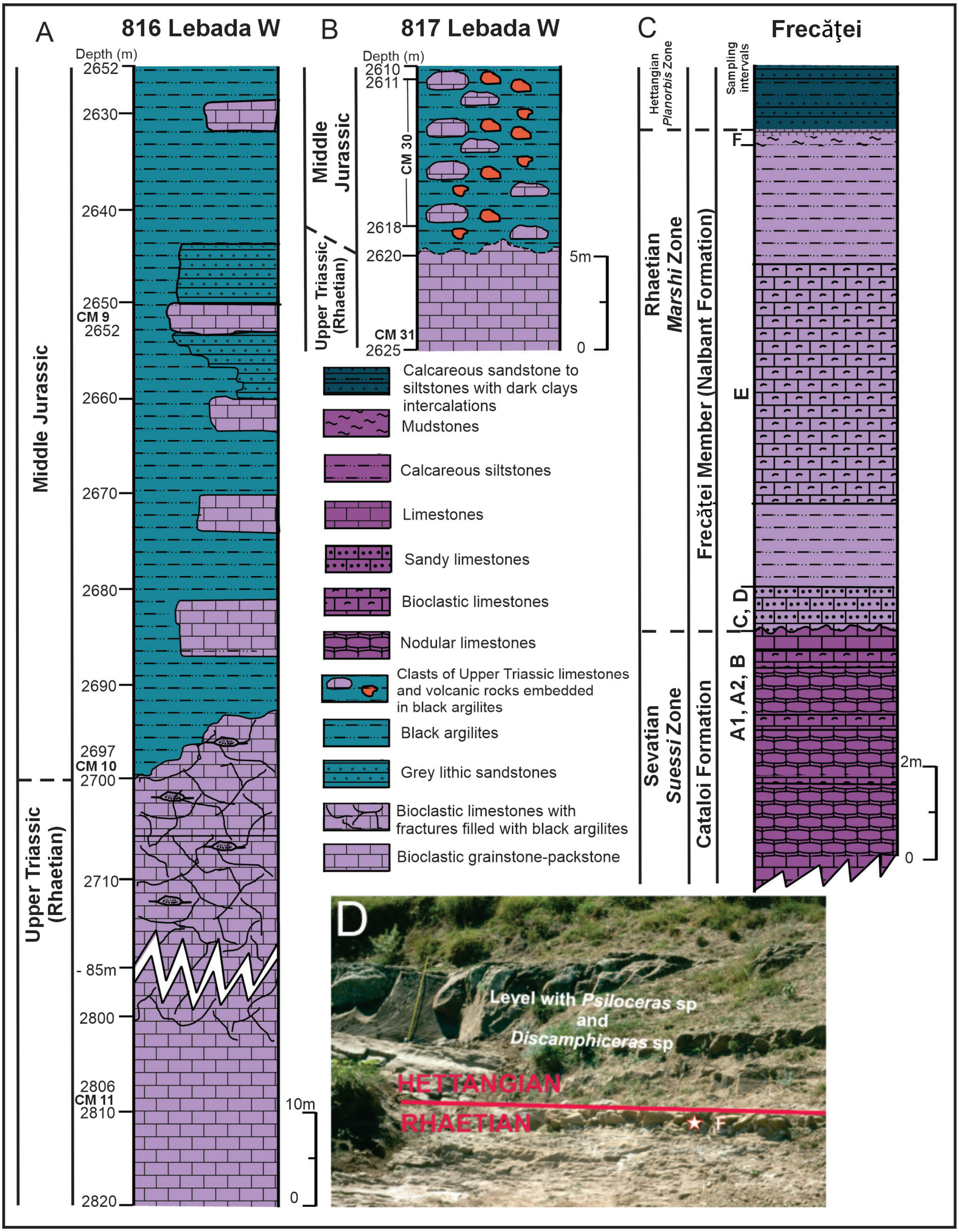


Fig. 3 - Stratigraphic columns of the studied logs within the North Dobrogea region recovering Upper Triassic calcareous nannofossils with A) The Black Sea offshore borehole 816 Lebăda Vest, showing the position of the cores CM 9, CM 10, CM 11 (compiled from Grădinaru et al. 1989); B) The Black Sea offshore borehole 817 Lebăda Vest, and the position of the core CM 31 (modified from Forel & Grădinaru 2020); C) The Frecăţei log with the position of the samples A1, A2, B, C, D, E, and F (modified from Grădinaru 1984); D) Photo of the Rhaetian/Hettangian boundary at Frecăţei, showing the detail location of the sample F (star).

et al. 1993). Samples Frecăţei C and D are from this part of the log.

3 – Around 10 metres thick, of grey, calcareous siltstones with *Zoophycos*-type traces, which exposes a coquina, around 5.5 metres thick bed, with the Rhaetian bivalve *Otapiria marshalli alpina* Zapfe, 1973. Sample Frecăţei E is from this part of the log.

4 – A 0.25 metre thick grey mudstone bed, whitish on weathering surfaces, with black bioturbations, bearing nodules of reddish limestone at its upper part from where sample Frecăţei F was collected (Fig. 3D).

5 – A succession of thick-bedded, light greyish, fine-grained calcareous sandstone to siltstone, from 1.0 to 1.40 metres thick, with *Zoophycos*-type bioturbations, separated by thin layers of dark grey clay. Poorly preserved specimens of Hettangian ammonoids, identified as *Psiloceras* sp. and *Discamphiceras* sp, document this start of the Lower Jurassic succession. This succession continues upwards with terrigenous turbidites, comprised of grey-greenish, thick-bedded, fine-grained sandstones to argillaceous siltstones and rare intercalations of black clays. A few levels with ammonoids provide evidence of the Sinemurian to early Pliensbachian age (Fig. 3D).

Boreholes 816 and 817 Lebăda Vest - In the eastwards offshore extension of the NDO into the western continental shelf of the Black Sea, Triassic carbonate rocks were crossed in several boreholes drilled during the 1980s (Grădinaru et al. 1989). Rhaetian carbonate rocks drilled by boreholes 816 and 817 Lebăda Vest were investigated.

Lithological and stratigraphical relationships show that the Rhaetian carbonate rocks drilled in the boreholes 816 and 817 Lebăda Vest (LV) are allochthonous, with exotic blocks of different sizes being incorporated within Middle Jurassic black argillites (Grădinaru et al. 1989).

The borehole 816 Lebăda Vest (LV) crossed carbonate deposits from 2650 m (top of core CM 9). However, exotic blocks of limestone occur in the upper part of core CM 8 (interval 2600-2604 m) on a thickness of about 60 cm, included, along with other smaller enclaves, in the highly tectonised black micaceous argillites. The contacts between the yellowish limestones and argillites are sharps, and likely correspond to tectonic breccia formed on Middle Jurassic argillites and Triassic limestones, as indicated by biostratigraphic data (Grădinaru et al. 1989).

Upper Triassic sediment of borehole 817 LV corresponds to 5 m thick, light grey limestones, encountered at a depth of 2620 m below Middle Jurassic black argillites (Forel & Grădinaru 2020; Gale et al. 2021). Within those Jurassic sediments, the base of the drill core CM 30 includes clasts of rhyolites and Triassic limestones (Grădinaru et al. 1989). The core CM 31 drilled into the Upper Triassic sediments represents a 2 m thick limestones from depths 2623 m to 2625 m (Gale et al. 2021). A rich assemblage of ostracod and foraminifera constrained a Rhaetian age for the drill core CM 31 in the borehole 817 LV (Grădinaru et al. 1989; Forel & Grădinaru 2020; Gale et al. 2021). A Rhaetian age is also supported by the brachiopod fauna, which includes *Euxinella anatolica* (Bittner, 1892), *Fissirhynchia fissicostata* (Suess, 1854), and *Rhaetina pyriformis* (Suess, 1854). Both in terms of lithofacies as well as brachiopod and foraminiferal assemblages, the Rhaetian limestone drilled in the Lebăda Vest is comparable to the allochthonous Rhaetian limestones occurring in the Mountainous Crimea, which has been studied by Dagys (1974), Kotlyar et al. (1999) and Korchagin et al. (2003).

Microfacies analyses

Sample CM 9 from the offshore boreholes 816 LV is a mudstone with few bioclasts, including recrystallised calcispheres (Fig. 4A). In contrast, sample CM 10 is a micritised grainstone (Fig. 4B). Sample CM 31 from the borehole 817 LV is a mudstone with rare bivalves (Fig. 4C). The sample from the Rândunica log is a wackestone with high abundance of bivalves belonging to the genus *Otapiria*, some foraminifera and echinoderms along with glauconites and lithoclasts (Fig. 4D). The sample from the Izvoarele log reveals a muddy wackestone with high abundance of bivalves, few ostracods, rare foraminifera, and echinoderms (Fig. 4E). Thin sections from Frecăţei log reveal that samples A and B are mudstones with rare and no bivalves, respectively, and a low amount of silt (Fig. 4F, G). Sample Frecăţei C is a mudstone with an increased silt content and bivalves, along with some ostracods and gastropods (Fig. 4H). Therefore, some areas of this sample C could be characterised as wackestone. Sample Frecăţei D is a silty wackestone, with bivalves and ostracods as well as some pyrite (Fig.

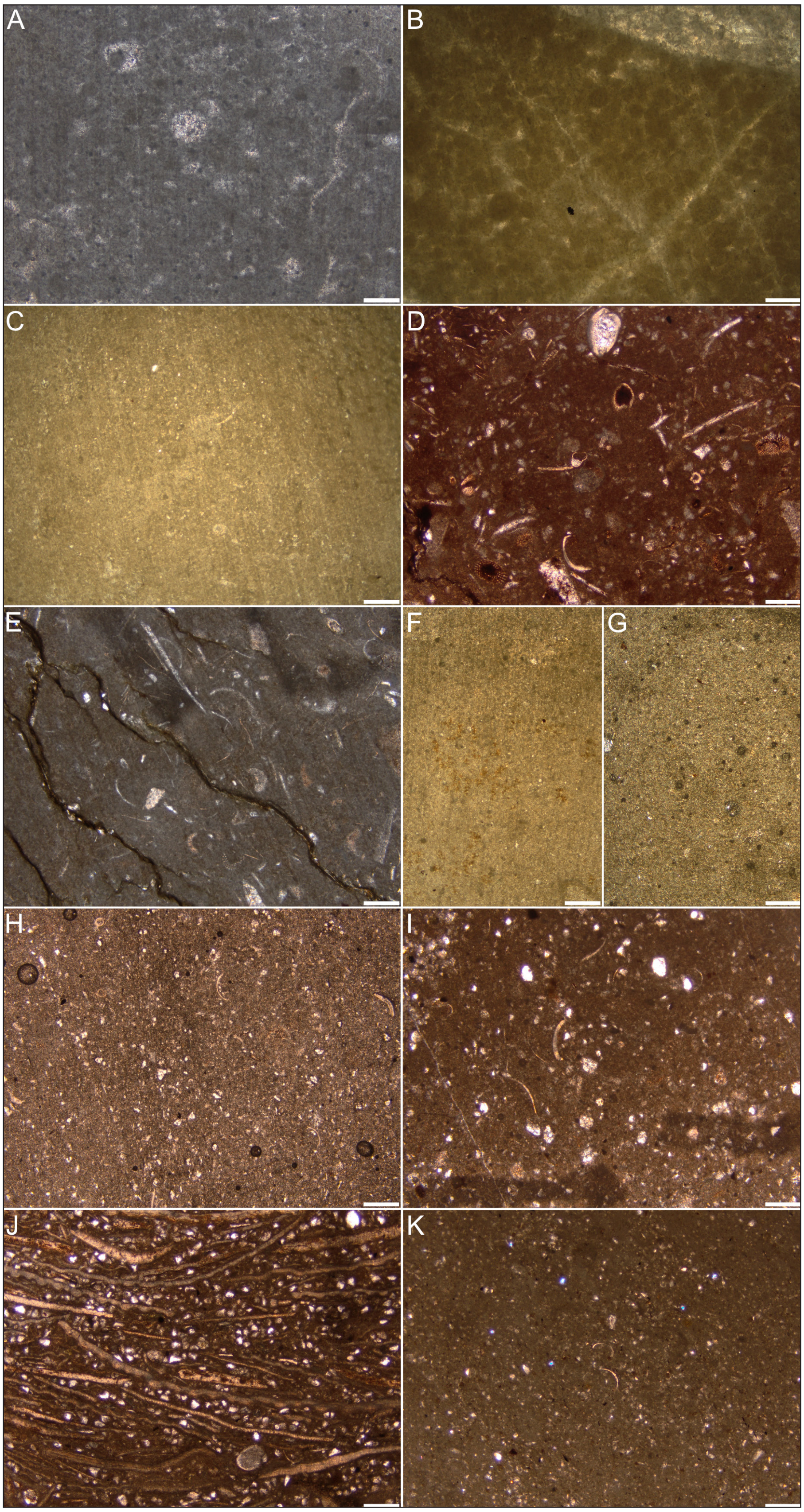


Fig. 4 - Microphotographs of the thin sections from the North Dobrogean logs with A) Sample CM 9 (offshore borehole 816 Lebăda Vest), mudstone with few bioclasts; B) Sample CM 10 (borehole 816 LV), a micritised grainstone; C) Sample CM 31 (borehole 817 LV), a mudstone with rare bivalves; D) Sample from the Rândunica log, a wackestone with abundant bioclasts, mainly of the bivalve *Otapiria* and lithoclasts; E) Sample 237 from the Izvoarele log, a muddy wackestone with abundant bioclasts; F) Sample A from the Frecăţei log, a mudstone with rare bivalves; G) Sample B from the Frecăţei log, a mudstone; H) Sample C from Frecăţei log, a mudstone, partly wackestone in some area with silt and bioclasts; I) Sample D from Frecăţei log, a wackestone with silt, bioclasts and pyrite; J) Sample E from Frecăţei log, a calcsiltstone with quartz, higher amount of silt, abundant bioclasts mainly of the bivalve *Otapiria*; K) Sample F from Frecăţei log, a wackestone with high amount of fine silt and rare bioclasts. Scales = 500 µm.

4I). Sample Frecăţei E is a calcsiltstone with a high abundance of bivalves from the genus *Otapiria*, a few ostracods, and rare foraminifera and gastropods (Fig. 4J). Sample Frecăţei F is a wackestone with a high amount of fine silt and rare bivalves, foraminifera, and gastropods (Fig. 4K).

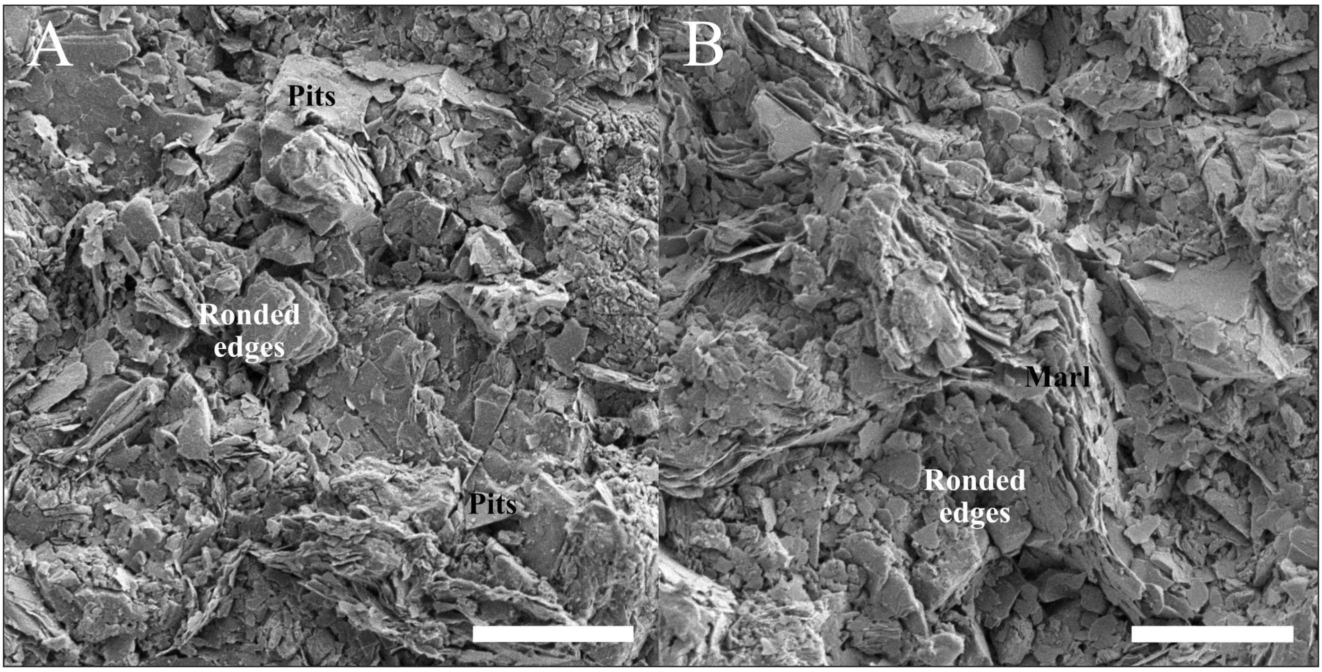


Fig. 5 - Scanning electron microscope images from Frecăţei log, sample F illustrating A) Dissolution patterns on the matrix such as the rounded edges on the calcite crystals, pits on the surface and cracks; B) Clay layer covering the surface of the observed sample. Scale bar = 5 μm.

Calcareous nannofossils analyses

SEM observations revealed a moderate diagenetic alteration for all studied samples with dissolution patterns (e.g., pits, cracks, and rounded edges) (Fig. 5A). Recrystallisation or overgrowth patterns on calcite crystals were not observed. Calcareous nannofossils were difficult to identify due to poor preservation of the sediments and the presence of clay-forming layers on the surface analysed (Fig. 5B).

In the Frecăței log, samples A1, A2, B, D and E were barren of calcareous nannofossils. In sample C, a single specimen of *P. triassica triassica* was observed (Fig. 6). In sample F a single coccolith was observed together with two Upper Triassic nannoliths, *P. triassica triassica* (Fig. 7) and *E. zlambachensis* (Fig. 8). The latter was recognised by the characteristic oblique inner lamellae (Demangel et al. 2021). Those calcareous nannofossils were observed with relatively bad preservation showing dissolution features. Both species present a low abundance in the studied samples with less than 20 specimens per transect of smear slide (24 mm) and SEM transect (1 cm).

In the Izvoarele and Rândunica logs, as well as in the 817 LV borehole, all investigated samples were barren. In the borehole 816 LV, samples CM 10 and 11 were barren whereas a single coccolith was observed in sample CM 9. The preservation of the two coccoliths observed in sample CM 9 of the borehole 816 LV and sample F of the Frecăței log did not enable the identification of the genus.

Discussion

The present-day remote location of the North Dobrogean Triassic, situated outside the Mediterranean Alpine-type Triassic, is interpreted as the result of post-Triassic large-scale horizontal displacements of the Tethyan terranes due to the opening of the West Black Sea Basin (e.g., Grădinaru 1988; Okay et al. 1994; Banks & Robinson 1997; Gaetani et al. 2000). During the Late Triassic, North Dobrogea (Romania) was located in the Palaeo-Tethys Ocean enclosed between Laurasia and Cimmeria, to the north of the Neo-Tethys Ocean. According to Stampfli & Kozur (2006) and Kovács et al. (2011), sedimentation took place during the Late Triassic on the Laurasian margin of the Pangea, including the current territory of North Dobrogea, which was situated between 35° N (early Norian) and 50° N (latest Rhaetian).

Microfacies analyses of the Frecăței log suggest an evolution from a low-energy environment

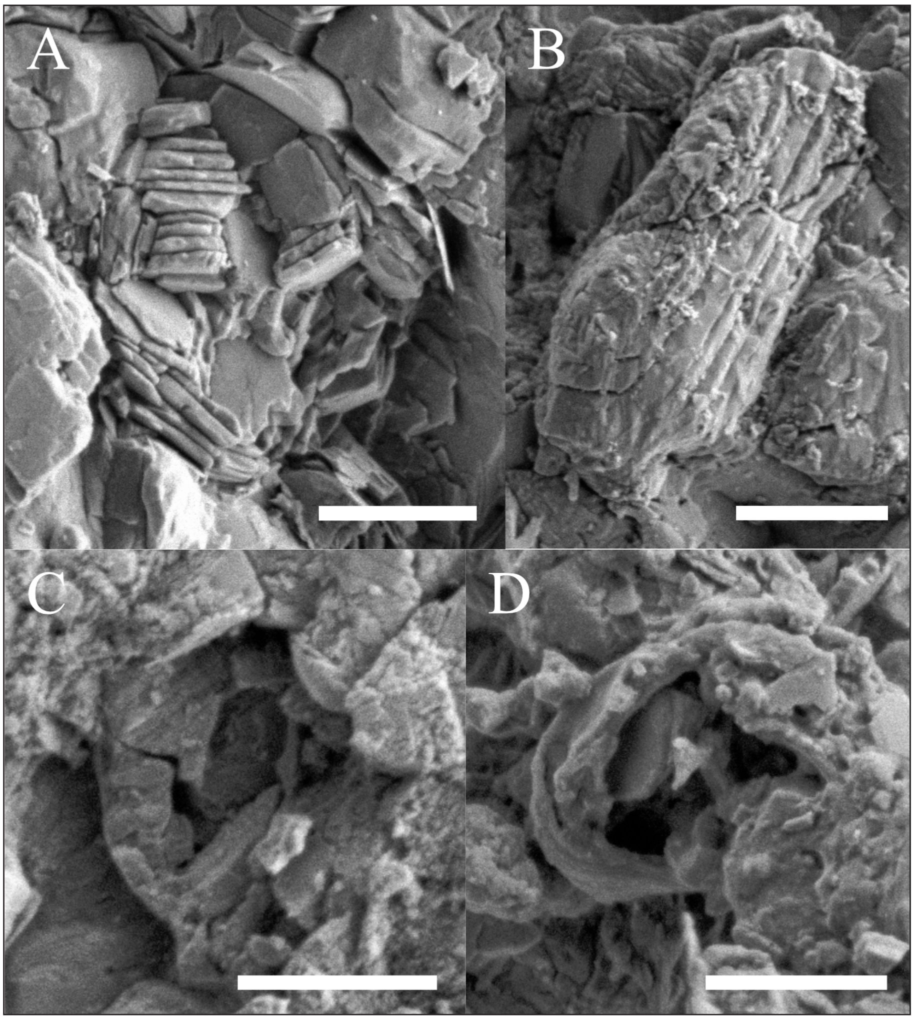


Fig. 6 - Scanning electron microscope pictures representing A) *Prinsiosphaera triassica triassica* from the Frecăţei C sample; B) Outer lamellae of an *Eoconusphaera* sp. from the borehole 816 LV - Core CM 9; C) Coccolith from the borehole 816 LV - Core CM 9; D) Coccolith from Frecăţei F sample. Scale bar = 2 μm.

with deeper settings resulting in deposition of mudstones (samples A to C) to a slightly higher energy and shallower environment, probably above the storm wave base with deposition of bioclastic wackestones (sample D to F; Flügel 2010). Wackestone samples of the Rândunica and Izvoarele logs are composed of bivalves, foraminifera, and echinoderms, suggesting a marine, relatively shallow-water environment with moderate energy. Samples of the offshore boreholes 816 have been studied in detail by Grădinaru et al. (1989) and described as micritic limestones with dismicritic areas and tiny pellets (below 5%) and very rare foraminifera (*Nodosinella* sp.) (sample CM 9). Our analysis of the thin section from sample CM 9 revealed a mudstone with rare bioclasts. Both descriptions suggest a low-energy environment in deeper marine settings such as a basin or distal marine shelf. Grădinaru et al. (1989) described sample CM 10 as a biopelletal limestone with ooids and micritised bioclasts, foraminifera, echinoderm plates and crinoid stems, with microsparite-cemented cracks. Our observations of sample CM 10 showed a micritised grainstone and therefore suggest a higher energy and shallower environment. Finally, sample CM 11 corresponds to a peloidal wackestone with rare ooids and echinoderm plates, echinoderms, along with a silt fraction with angular quartz grains (15%) in a microsparitic cement (Grădinaru et al. 1989). This variation of microfacies within the borehole 816 LV has been explained by the presence of allochthonous Rhaetian blocks (Grădinaru et al. 1989). Sample CM 31 of the borehole 817 LV shows a bioclastic wackestone with fragments of brachiopods, bryozoans, crinoid stems, foraminifera, calcareous algae, calcispongiae, globochaete and rare quartz grains in a micritic matrix (50%) (Grădinaru et al. 1989). Forel and Grădinaru (2020) described a sample from the core CM 31 as a burrowed bioclastic wackestone, locally a packstone with skeletal grains (sponges, echinoderms, brachiopods, bivalves, ostracods, foraminifera, bryozoans and rare juvenile gastropods; Forel & Grădinaru 2020; Gale et al. 2021). Our analysis of a sample from

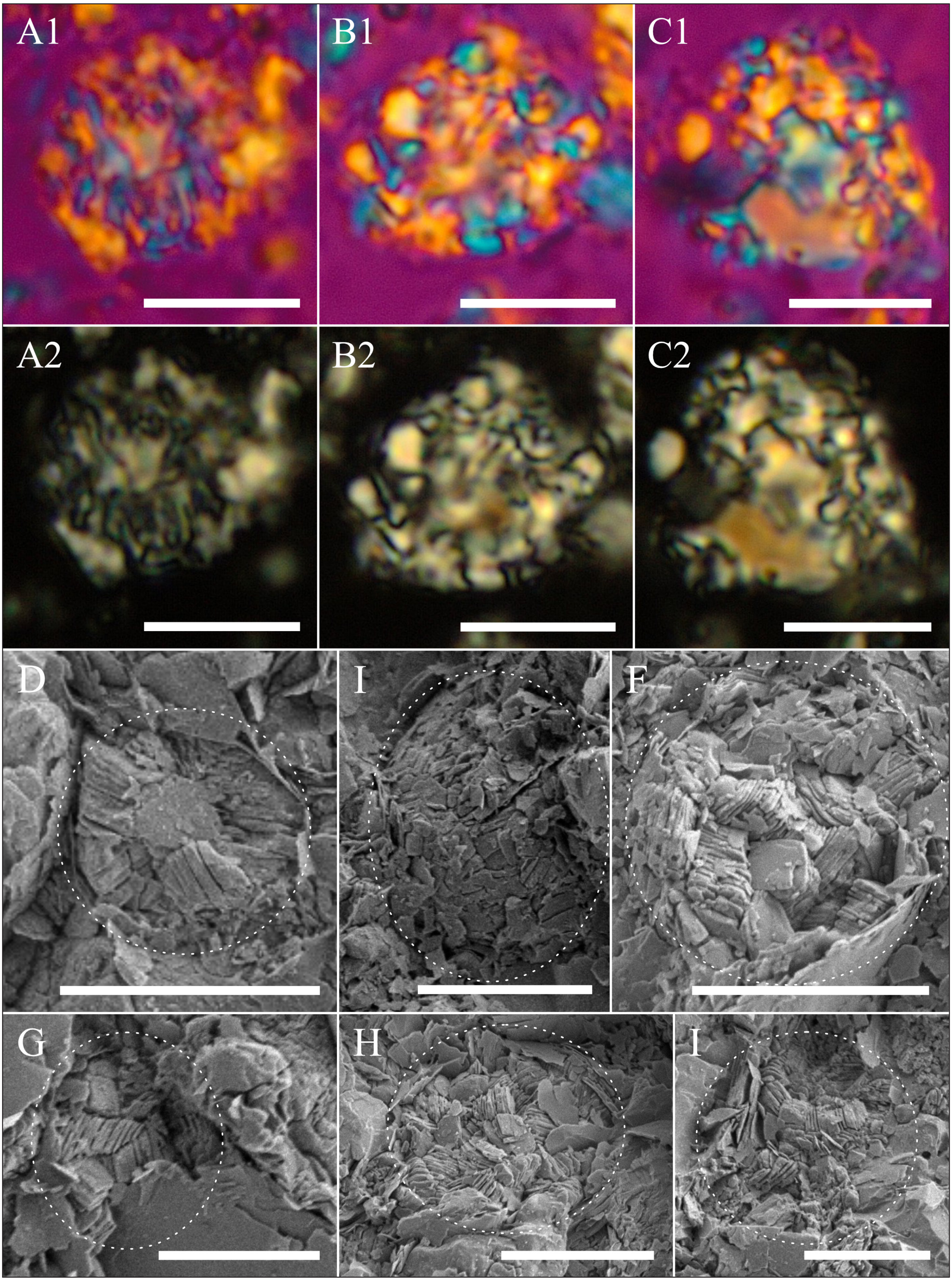


Fig. 7 - Photographs of *Prinsiosphaera triassica triassica* from Frecăţei log, sample F under the light microscope (A-C) with polarised-light and phase contrast (1), polarised-light (2) and under the scanning electron microscope (D-I). Scale bar = 5 µm.

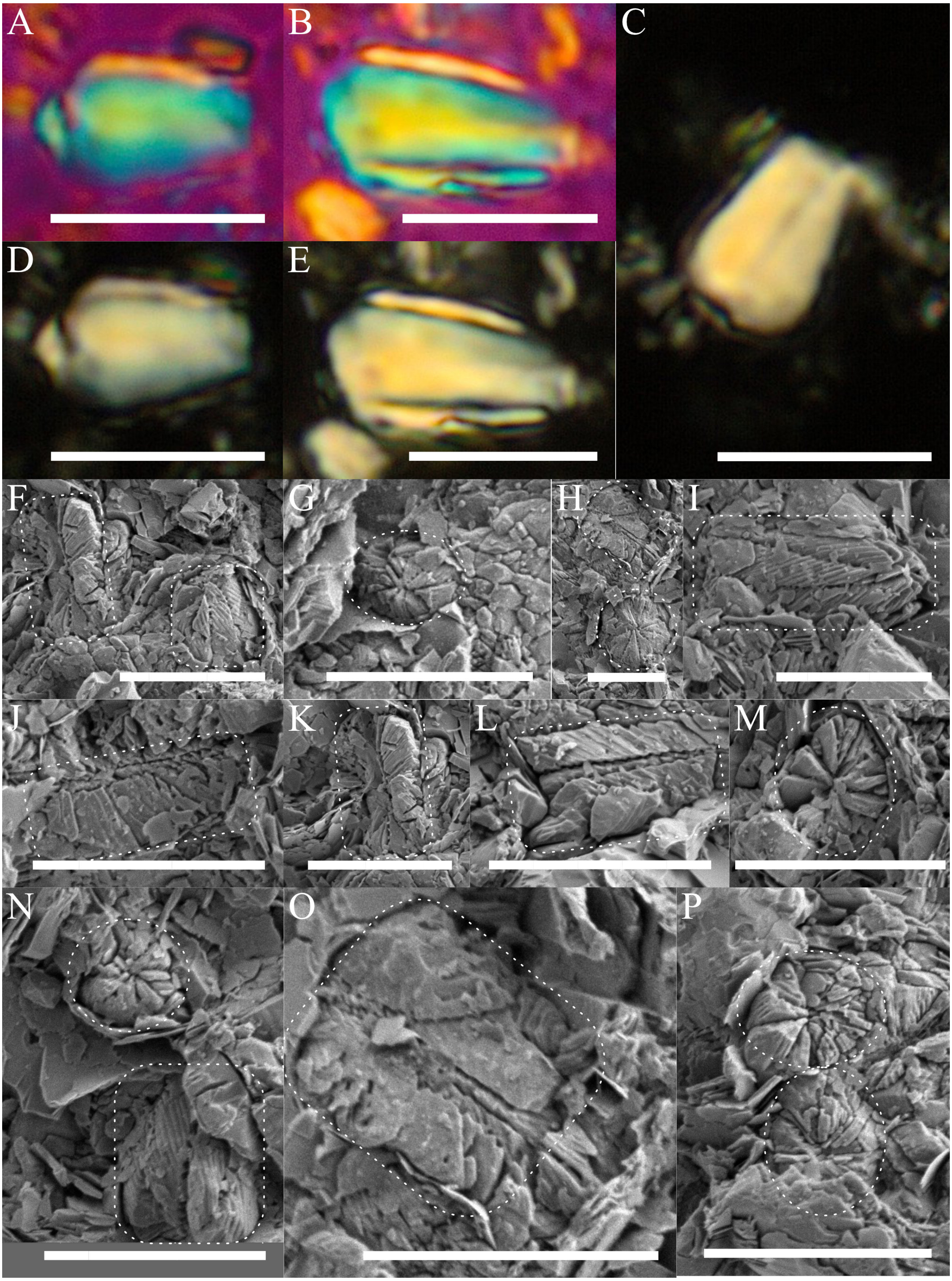


Fig. 8 - Photographs of *Eoconusphaera zlambachensis* from Frecăţei F sample (Rhaetian) observed under the optical microscope (A-E) with polarised-light and phase contrast (A-B) and with polarised light (C-E) and observed under the scanning electron microscope (F-P). Scale bar = 5 μm.

the same drill core revealed a mudstone with rare bioclasts. Such a difference in microfacies within 2 metres thick drill core highlights the allochthonous origin of the Rhaetian sediments in the borehole 817 LV as well. Grădinaru et al. (1989) suggest a deposition in a shallow carbonate platform, with high hydrodynamic energy evidenced by the presence of oolitic deposits.

Upper Triassic calcareous nannofossils are well-documented in the Western Neo-Tethys Ocean. Nevertheless, they are also known to occur outside the Neo-Tethyan Realm in Western Canada (Bown 1992), Peru (Pucará Group; Pérez Panera et al. 2023a) and western Argentina (Neuquen Basin; Pérez Panera et al. 2023b). Koiava et al. (2015) reported calcareous nannofossils from Georgia (Caucasus; Palaeo-Tethys Ocean), however, the specimens of *P. triassica triassica* (see Plate 1, 1-6 in Koiava et al. 2015) described lack the characteristic circular structure and inner calcite lamellae. Similarly, specimens 16 and 18 (see Plate 1 in Koiava et al. 2015), identified respectively as *C. minutus* and *C. primulus,* do not exhibit a coccolith rim and inner structure. Specimen 17 (see Plate 1 in Koiava et al. 2015), reported as *C. primulus*, displays an oval shape with a size consistent with the Upper Triassic coccoliths, but the inner structure is not visible. Additionally, poor preservation of specimens and low image quality prevent identification of this oval shape as a coccolith rim. This study presents the first evidence of Upper Triassic calcareous nannofossils in the Palaeo-Tethys Ocean (North Dobrogea, Romania).

Despite poor preservation, *P. triassica triassica* was identified by its characteristic inner part composed of randomly oriented groups of parallel, thin tabular, rhombohedral calcite crystals (Fig. 7). *E. zlambachensis* was observed with only the inner part preserved, thanks to inclined lamellae that differentiate this species from *E. hallstattensis* presenting vertically arranged lamellae (Demangel et al. 2021). In sample F of the Frecăței log, the specimens were observed with only the inner parts preserved, showing inclined lamellae as characteristic of *E. zlambachensis*. The Norian/Rhaetian boundary is not yet defined with two global stratotype sections and point (GSSP) candidates: Pignola-Abriola in Italy (Bertinelli et al. 2016) and Steinbergkogel in Austria (Krystyn et al. 2007). Well-defined bio-events of different calcareous nannofossil species were established for Austrian sections, including Sommeraukogel, Steinbergkogel, and Zlambach (Demangel et al. 2021, 2023) and could be used for correlation with the Frecăței log. In the Neo-Tethyan domain, *E. zlambachensis* is known from the middle Rhaetian (*Vandaites stuerzenbaumi* Zone) (Demangel et al. 2021) and is not observed after the end-Triassic mass extinction. Based on this range of occurrence, the sample from Frecăței F can be dated from the middle to late Rhaetian (Demangel et al. 2021). In the absence of a defined GSSP for the Norian-Rhaetian boundary, the Triassic/Jurassic boundary in the Frecăței log may be located between the grey/whitish mudstones and the succession of dark grey thick-bedded fine-grained sandstones to calcareous siltstones that delivered ammonoids dating the base Hettangian.

From our understanding, calcareous nannoplankton first appeared in the western part of the Neo-Tethys Ocean during the Carnian (Cordevolian; Janofske 1992). The carbonate platform systems located in subtropical latitudes recorded the highest abundance and diversity of calcareous nannoplankton during the Late Triassic. From the Norian, the calcareous nannoplankton had spreadoutside the Neo-Tethys Ocean as evidenced by reports of *Orthopithonella geometrica* Jafar, 1983 Janofske, 1987, *Thoracosphaera wombatensis* Bralower et al., 1991, *P. t. triassica*, *E. zlambachensis* and *C. minutus* in the Panthalassa Ocean (Bown 1992; Pérez-Panera et al. 2023a, b). In the Southern Neo-Tethys Ocean, almost all Upper Triassic calcareous nannofossils are recorded from the Rhaetian stage only. Considering the abundance and diversity of the calcareous nannofossil reported in the Southern Neo-Tethys Ocean, this diachronism in their first occurrence seems to be due to the lack of study on Carnian or Norian sediments for this region, rather than a late spreading of the calcareous nannoplankton toward the south of the Neo-Tethys Ocean. In the Palaeo-Tethys Ocean, only the two nannoliths *P. t. triassica* and *E. zlambachensis* and two isolated coccoliths have been observed from the Rhaetian only (this study). These observations could suggest a late spreading of the calcareous nannoplankton toward the north, or that rather more investigations are needed to better constrain the assemblage and first occurrence of calcareous nannoplankton in the northern regions.

Conclusions

The investigation of Upper Triassic sediments from North Dobrogea and boreholes in the Black Sea offshore reveals occurrence of calcareous nannofossils. An isolated specimen of *P. t. triassica* was observed in sample C of the Frecăţei log. One specimen of *Eoconusphaera* sp. and a coccolith was observed in the offshore Black Sea borehole 816 LV sample CM 9. The sample F of the Frecăţei log records in slightly higher abundance *P. triassica triassica* and *E. zlambachensis,* two Upper Triassic nannoliths. Using the known range of occurrence of this assemblage in the Neo-Tethys ocean, the sample was dated to the late Rhaetian. Findings of the Upper Triassic nannoplankton in North Dobrogea are the first well-documented for the Palaeo-Tethys regions and further investigation would enable better stratigraphic correlations between oceans to use the Upper Triassic calcareous nannofossil as a biostratigraphic tool.

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