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LARGE BENTHIC FORAMINIFERA OF THE PALEOGENE DEPOSITS OF THE GREEK THRACE BASIN: BIOSTRATIGRAPHIC AND PALEOENVIRONMENTAL REMARKS

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CHAPTER 1. INTRODUCTION

1.1 GENERAL INFORMATION

1.1.1 Historical background

In the 5th century B.C., Herodotus mentioned for the first time the presence of Large Benthic Foraminifera (LBF) into the rocks of the Egyptian pyramids; considering them as lentils and food relics of the labor-builters. Later, the latin name of species, *Nummulites* were applied to Herodotus findings. Later on, ancient-philosophers (Rliny, Strabo) and scientists (Lineé) also referred to their existence. Nevertheless, the first comprehensive classification was introduced by d’ Orbigny in 1826, including them among the cephalopods. Almost a decade later, Dujardin (1835) recognized foraminifera as protozoa. The following years, a plethora of studies were performed by numerous researchers and in 1872 the first scientific oceanographic research expedition took place. The voyage of H.M.S. Challenger allowed many scientists, including H.B. Brady, to work on the ocean sea floor samples. Brady in 1884 published a monograph of foraminifera that constitutes the fundamental reference until these days.

1.1.2 Morphology

Foraminifera are unicellar organisms characterized by subcellular components or organelles that are responsible for numerous functions (Haynes 1981; Goldstein 1999). All these organelles are surrounded/enclosed by a test that can be architectonically simple or complicated (Haynes 1981; Goldstein 1999). The test may be composed of organic, agglutinated or calcareous material. Foraminifera with organic tests made of chitin, reflect the primitive forms. Genera with agglutinated walls built their tests using the available material which is attached on the organic membrane and cemented with calcareous material. However, most foraminifera possess calcareous test which are divided into three categories: porcelaneous, micrognanular and hyaline (Brasier 1980; Goldstein 1999; Haynes 1981; Hottinger 2000; Loeblich and Tappan 1964). Foraminifera show a variety of test morphologies and chamber arrangements. Tests can be unilocular and consist only of one chamber with an opening (aperture), or they can be multilocular. In this case, the test is made of more than one chamber and presents different kinds of arrangements such as planispiral, fusiform, uniserial, biserial, triserial, milioline, polymorphine, or trochospiral. In these multilocular forms, the test growth is periodic and often the new chamber is bigger than the previous one and they are divided by septa. The aperture is always in the new added chamber and the aperture of the previous chamber is converted in a foramen. The position and morphology of the aperture display a variety of types. The principal ones are: open end of tube, terminal radiate, terminal umbilical, loop-shaped, interiomarginal, single or multiple, orbate, with phialine lip, with bifid tooth or umbilical teeth (Haynes 1981; Hottinger 2000; Loeblich and Tappan 1964). Through these apertural openings, foraminifera extrude pseudopodia. These are networks of branched, fine anastomosed thread-like extrusions. They constitute the means by which foraminifera interact with the environment and many essential life functions are accomplished. They are responsible for building and structuring their test, as the available material from the surrounding environment can be attached or incorporated into the test (Bowser and Travis 2000; Goldstein 1999; Hottinger 2000; Haynes 1981; Makled and Langer 2009). Additionally, pseudopodia reflect the feeding mechanism as they facilitate the exploitation of trophic resources, gather food or catch prey (Bowser et al. 1992; Goldstein 1999; Haynes 1981; Jepps 1942; Langer and Bell 1995). Motility and attachment can be conducted as pseudopodia are dynamic. Finally, they are also involved in reproduction processes (Bowser and Travis 2000; Goldstein 1999; Hottinger 2000; Langer et al. 2009).

1.1.3 Diet

For their nutrition, foraminifera utilize several trophic mechanisms such as herbivory and bactivory, grazing, suspension feeding, parasitism, carnivory, direct uptake of DOC, and omnivory (Goldstein 1999; Lee et al. 1979; Lipps 1983). According to Hallock (1987), there are several ways that feeding mechanisms affect biodiversity. These are the diversity along the trophic resource continuum, the energetics and diversity, the trophic resources and the environmental stability and the zonation in the euphotic habitats. Different species are adapted to take advantage of the available food supplies, which made these foraminifera more abundant, and which allowed them to grow larger tests (Lipps 1983; Hallock 1987).

1.1.4 Habitat

Foraminifera are adapted to all aquatic habitats with the majority in marine environments, but some can exist in brackish and in freshwater or even on land (Holzmann et al. 2021). Adjustments are also observed in the full range of temperature and salinities (Murray 1973; Boltovskoy and Wright 1976; Haynes 1981; Lipps and Langer 1999). Moreover, different species are adapted to the full range of water depth. However, this term constitutes a complex gradient, as it evolves the factors of topography, illumination, water energy and hydrostatic pressure (Whittaker 1978; Hohenegger 1995). Topography affects the current system which controls the type of sedimentation and the formation of the sedimentary deposits (Murray 1973; Hohenegger 1995). Illumination is also a significant factor, especially for larger symbiont-bearing foraminifera (LBF), that house symbionts and they are therefore restricted to the euphotic zone (Hottinger 1977; Haynes 1981; Lee and Anderson 1991). The factor of water energy can be easily overtaken by constructing tests with the necessary and special mechanic features (Severin and Lipps 1989). Finally, the hydrostatic pressure parameter mainly exerts control on the availability of oxygen. Depending on the amount of available oxygen, environments are classified as anoxic, dysoxic and oxic and the microfauna is thus considered to be anaerobic, dysaerobic and aerobic, respectively (Allison et al. 1995). The distribution of foraminifera is not only influenced by the aforementioned factors but also by biotic ones such as competition, food supply and space (Lipps 1983; Hallock 1987; Goldstein 1999). According to their habitats and life strategy, foraminifera can be subdivided into planktonic foraminifera which float freely in the upper water column of the open ocean and into benthic foraminifera which live in or on the sea floor free or attached to a substrate. In general, there are two types of microhabitats for benthic foraminifera; epifaunal (on the surface of the substrate) and infaunal (in the sediment) (Haynes 1981; Murray 2006). Additionally, benthic foraminifera can be subdivided into two informal taxonomic groups, large and small benthic foraminifera. The classification of large benthic foraminifera (LBF) relies on the complex internal structures, the symbiont-bearing character, and their reproductive strategy (Haynes 1981; Goldstein 1999).

1.1.5 Life cycle and reproduction

Lister in 1895 was the first who outlined the “species-pair”. Through the following years, researchers (e.g., Jepps 1942; Lister 1903) introduced and explained the heterophasic alternation of asexual and sexual generation as the fundamental life cycle of foraminifera. Through the asexual reproduction, daughter cells are generated via meiosis and grow to give gamonts, which are also known as megalospheric forms (A-form). These are characterized by large proloculi and a small test size. In sexual reproduction, numerous gametes are generated via mitosis. When they meet and fuse, a zygote is produced which creates the agamont, also called microspheric form (B-form). There is also a third type of generation, where an agamont via multiple fission produces a megalospheric schizont (Haynes 1981; Goldstein 1999; Hottinger 2000).

1.1.6 Large Benthic Foraminifera (LBF)

The Large Benthic Foraminifera (LBF) are an informal group of benthic foraminifera that includes both fossil and living forms. They are distinguished due to their complex internal morphology and usually have a volume of more than 3 mm^2 (Ross 1974). Their living representatives belong to the orders of Miliolida and Rotaliida (Loeblich and Tappan 1984). Hallock (1998) identified seven families of living LBF: the Archaiadae, Peneroplidae, Soritidae and Alveolinidae, Amphisteginidae, Calcarinidae and Nummulitidae.

They are most commonly found in shallow, tropical and carbonate environments, with many species hosting symbiotic algae, a feature that also characterizes many extinct LBFs (Cowen 1983). Their presence is indicative of water depth of less than 130 m, and they live within the photic zone (Hottinger 1983; Hallock 1984).

Their distribution is often associated with periods of global warming, increases in relative humidity, expansion of tropical and subtropical environments, and reduced ocean circulation (Hallock and Glenn 1986). During such periods, nutrient cycling in surface waters declined dramatically as did organic productivity in the oceans (Bralower and Thierstein 1984). These oligotrophic conditions are particularly favorable for symbionts bearing LBF. The early Quaternary is one such typical period (Buxton and Pedley 1989).

Under favourable conditions, living foraminifera grow rapidly and reproduce in relatively small shell sizes (Hallock and Glenn 1986). However, in populations living in environments where environmental stress conditions prevail, due to temperature change/fall, food or light deficiency, etc., individuals grow more slowly and emerge with larger shell sizes (Bradshaw 1957). *Nummulites*, a characteristic genus of Eocene LBF group, has been shown to respond quickly to environmental changes and depositional conditions. Shell size is influenced by their mode of reproduction, water agitation and depth, temperature, and light intensity (Beavington-Penney and Racey 2004).

Lipps (1982) suggested that the asexual reproductive process is the dominant reason for the increase in population size when environmental conditions are associated with increased nutrient supply. Therefore, macrospheric forms dominate in these environments. In general, a pattern of unequal distribution of macro- versus microspheric forms is observed. Blondeau (1972), considers that a typical, normal population of *Nummulites*, has an A/B forms ratio of 10:1. This pattern suggests that the intrinsic reproductive process is restricted to certain ecological conditions, zones that are also related to depth (Hottinger 1977; Leutenegger 1977).

Based on numerous studies, systematic changes in shell morphology have been documented in relation to variations in depth, habitat, and the ability to bring symbionts into the shell (e.g., Haynes 1965; Hottinger and Drehner 1974; Larsen and Drooger 1977; Hallock 1979; Hallock and Hansen 1979). These researchers correlated morphological with the decrease in photosynthetic activity of symbionts and with increasing water depth. Morphological trends can be reflected both in different species of the same genus and in the same species (Hallock 1979; Hallock and Hansen 1979). More flattened forms were reported in species inhabiting depper waters, thus suggesting that light availability controls shell morphology through interaction with symbionts (Hallock 1979). This interaction and morphological adaptations provide a powerful tool for the interpretation of paleoenvironments (Hallock 1980; Leutenegger 1984). For example, Trevisani and Papazzoni (1996) observed changes in the distribution and shape of *N. fabianii* in the Italian Alps. Two subspecies were identified, one of which represents flattened forms, while the second belongs to the robust ones. The changes were attributed to the influence of water energy and light intensity. Hallock (1979), suggested that water movement is also a factor that can affect the shape of the shell. Their small mass responds extremely rapidly to small changes in water, although these are partially dependent on changes that may occur simultaneously with other environmental variables such as salinity and temperature (Kinne 1970). Temperature is generally considered the most important physical factor affecting the distribution of larger foraminifera (Lee 1974; Langer and Hottinger 2000). Also, the total size of microspheric forms increases over geological time. A similar increase in size of macrospheric forms occurs to a lesser extent, with a parallel increase in proloculus size (Blondeau 1972). The first *Nummulites* occurs in the late Paleocene, and they were represented by small-sized species. During the middle Eocene, they develop extremely large forms and they reach a maximum size (≥ 10 cm).

1.2 OBJECTIVES

The purpose of this study is to investigate the benthic foraminiferal assemblages along the Paleogene rimmed shelf of the Greek part of Thrace Basin in order to provide a paleoenvironmental reconstruction model. The aims of this thesis are:

- a revised and completed systematic description of the LBF
- the detailed microfacies analyses of the carbonated deposits
- a revised and comprehensive taxonomy of the small benthic foraminifera
- the establishment of the benthic foraminiferal biofacies
- record the assemblage distribution, facies and biostratigraphy and compare them with Turkish part of the Thrace basin
- the development of a paleoenvironmental model based on benthic foraminiferal biofacies
- give an overview of the LBF distribution, facies and biostratigraphy.

CHAPTER 2. REGIONAL GEOLOGY

The Thrace basin is a large Tertiary molassic basin located in the North Aegean region expanding from Greece to Bulgaria and finally terminates/ends in NW Turkey. The basin is formed upon the metamorphic rocks of the Rhodope massif in northern Greece and in Bulgaria and on the Strandja and Sankarya massifs in Turkey (Kopp 1965; Burchfiel et al. 2003; Bonev et al. 2006; Okay et al. 2010; Kilias et al. 2011; 2013). The western (greek) part of the basin at NE Greece, is bordered by the Pangaion Mts. in the west, Evros River in the east, the Rhodope Mountain chain massif in the north while in the south it is sporadically exposed as small remnants mainly at Lemnos, Agios Efstratios and Samothraki Islands. The evolution of the Thrace basin is also related to volcanic activity, which seems to have started in middle-late Eocene (Innocenti et al. 1982; Fytikas et al. 1984). Pyroclastic and subordinate lavas are exposed at Ferres-Soufli-Petrota and Maronia-Kirki-Esimi and their age ranges between 33-23.6 Ma (Innocenti et al. 1982) or 33.4-19.5 Ma (Christofides et al. 2004). However, the volcanic activity seems to have started in middle-late Eocene as its products are intercalated with clastic sediments of the same age (Kopp 1965; Zagorchev 1998; Burchfiel et al. 2003). According to Kilias et al. (2011, 2013) and Tranos (2009), the wider region underwent intense tectonic events which attributed to the architecture of the basin. A NE-SW extension that initiated during the middle-late Eocene dominates the area and is associated with strike-slip faults. As a result, a supra-detachment basin was formed (Kilias et al. 2011, 2013, 2015), divided into three sub-basins (Alexandroupolis, Orestias and Petrota, respectively - Papanikolaou and Triantaphyllou 2010). After this extensional event, Tertiary deposition took place. Paleogene mollasetype deposits, 3-5 km in thickness are present and overlie Rhodope basement. The stratigraphy of the Tertiary sequence can be divided into two general sequences followed by Neogene and Quaternary deposits (Kopp 1965; Papanikolaou and Triantaphyllou 2010).

The lower sequence deposition, which is exposed only in the Alexandoupolis sub-basin, started around middle-upper Lutetian (Kirki Formation), with red conglomerates. They considered as basal conglomerates and their maximum thickness is more than 1000 m, with type locality north of Avas (Papanikolaou and Triantaphyllou 2010). The deposition continues with sandstones, alternating with sand, marl and shales. The type locality of these shales is Kirki, where *N. perforatus* and *A. exponens* were recovered among other macrofauna, indicating a late Lutetian to early Bartonian age (Karageorgiou and Christodoulou 1957; SBZ 16/17 - Dimou et al. 2021), most possibly redeposited within. The Kirki Formation, which is assigned to calcareous nannofossil biozone NP17 (late Bartonian) and is overlain by alternations of sandstones and pelites of the Chorafaki Formation (Papanikolaou and Triantaphyllou 2010).

The upper sequence, exposing in all three sub-basins, refers to nummulitic limestones (Avas/Metaxades Formation), followed by marls, sandstones and limestone interbeds (Pylaea/Pythion Formation; Papanikolaou and Triantaphyllou, 2010). The middle-upper Eocene nummulitic limestone can be divided into two layers, the first layer is light yellowish and full of *Nummulites* and the second one that is gray-reddish, massive and is characterized by the presence of corals (Kopp 1965). The type locality of this limestone is Avas. An equivalent limestone is reported from Didymotichon (Orestias sub-basin). The upper Eocene to lower Oligocene deposits are the most widespread and differentiated. They can be expressed as fine, gray sandy marls alternating with dark gray fine sandstones, nummulitic limestones, conglomerates, shales and marls or andesitic lava flows and tuffites that in places are intercalated with thin limestone beds (Kopp 1965; nannofossil biozones NP19/20-NP23 - Papanikolaou and Triantaphyllou 2010).

The Oligocene deposits consist of grey sandstones alternating with marls and overlain by Neogene sedimentary deposits composed by conglomerates, siltstones sandstones and limestones. The following Quaternary deposits consist of gravels, and sandstones (Kopp 1965; Caracciolo et al. 2012).

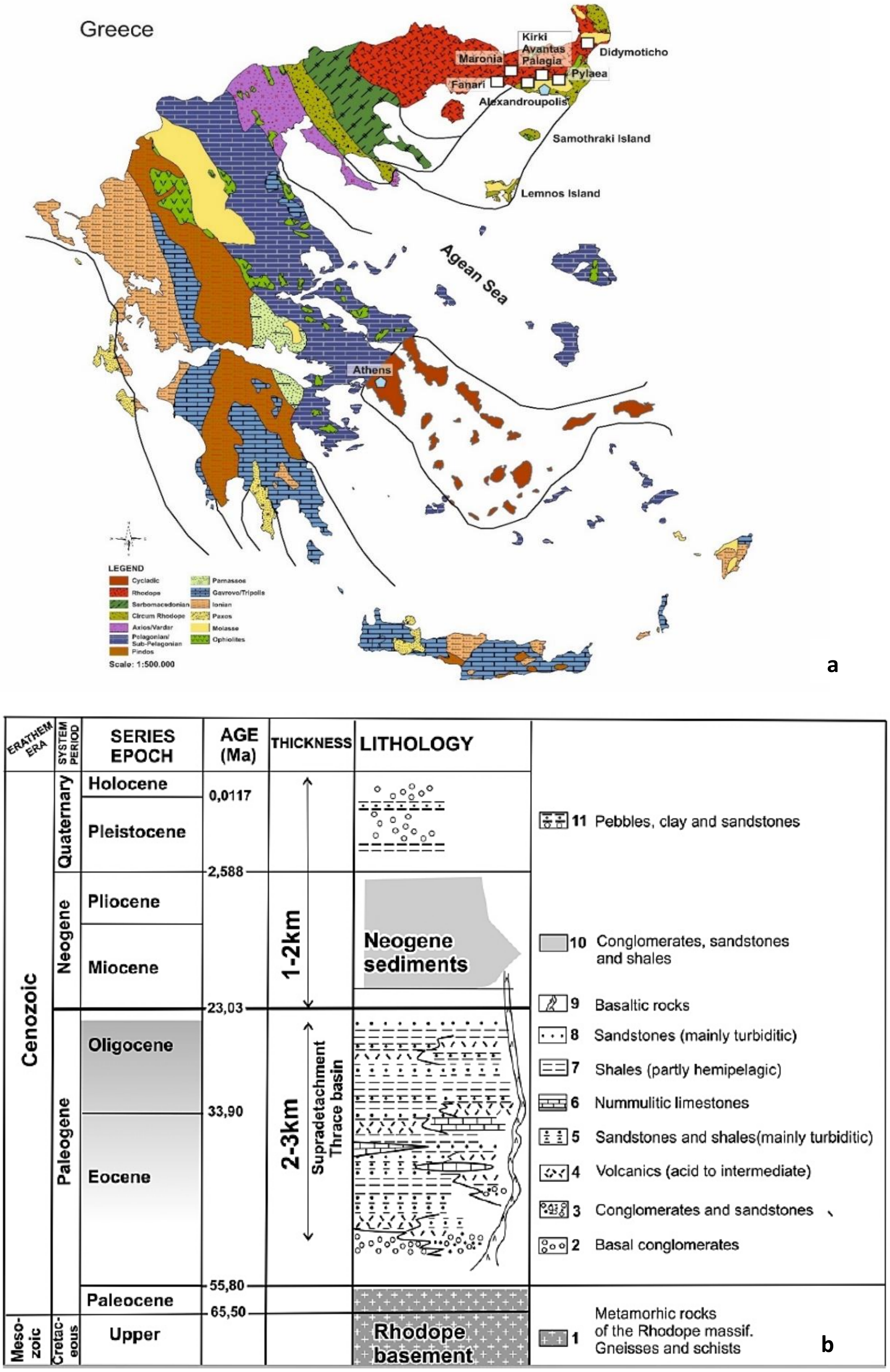


Figure 1. a) Generalized geological map of Greece and the location of the studied areas (modified by I.G.M.E. 1983). b) Stratigraphic column of Thrace basin from Kilias et al. 2013 (compiled after data in Christodoulou (1957), Kopp (1965), Lescuyer et al. (2003) and Burchfieald et al. (2003)).

CHAPTER 3. MATERIAL AND METHODS

3.1 INTRODUCTION

Foraminifera provide a great amount of information about biostratigraphy, paleoecology and taxonomic research, due to their abundance in the marine sediments. They occupy different habitats; therefore, they yield lots of information about environmental parameters such as ecological, climate and geochemical aspects. Consequently, methodical and systematic field work along with varying preparation, laboratory techniques are required. Protocols that were used for field sampling and laboratory techniques were introduced by Cummings (1950), Hagn (1953), Kremp (1953), MacVicar (1951; 1952), Todd et al. (1965) and are summarized by Green (2001) in his book with the title “A manual of practical laboratory and field techniques in palaeobiolgy”. The methods described within this chapter are those that have been used throughout this thesis. Moreover, all the samples and the studied material in this work are deposited at the Museum of Geology-Palaeontology-Palaeoanthropology of Aristotle University of Thessaloniki.

3.2 FIELD WORK

The field work was conducted in the Greek part of the Thrace basin and referred to a total of eight localities, Didymoticho, Pylaea, Avantas, Palagia, Kirki, Maronia, Fanari and Lemnos Island from east to west respectively. The stratigraphic sections, outcrops of these localities were measured and sampled. Additionally, observations about the stratigraphy, lithology and other macroscopic features were noted during the field work. Almost all samples derived from hard, compact carbonate sediments;

therefore, they were collected almost at a regular interval of 5 m where possible. Sampling also occurred where alternations in the lithology or any other kind of changes, were visible. Except for these hard rock samples, sampling was conducted from loose sediments that contained foraminiferal fauna from Fanari, Kirki, Pylaea (Fig. 2) and Lemnos Island. Few samples were provided from Kipos Cape located at the eastern end of Samothraki Island. Samples were collected from a non-stratified horizon; however, they were used in order to come up with some preliminary results that can be compared in terms of age assessment, microfossil content, microfacies analysis and finally paleoenvironmental conditions to the other studied sections. A total number of 58 rock samples and loose sediments were collected from all localities.

More detailed information on the stratigraphy of particular localities is provided to the chapters below.

Figure 2. Field work- sampling from Pylaea section (Thrace).

3.3 LABORATORY WORK

The laboratory work included four different techniques and preparations, based on the nature of the material. These are the sedimentary thin sections, subsampling and sieving, heat and cool technique and the orientated thin sectioning of individual microfossils.

3.3.1 Sediment thin sections

Rock samples from carbonate formations of Didymoticho, Pylaea, Palagia, Avantas, Maronia, Lemnos and Samothraki Islands studied in thin sections. Thin sectioning took place in the specialized laboratory of Department of Minerology-Petrology-Economic Geology, School of Geology, Faculty of Earth Science of Aristotle University of Thessaloniki. Rock samples were cut into thin parallel slices with a diamond cutting wheel and both surfaces were grinded flat and smooth with silicon carbid (SiC) #400 grade and water on an iron plate (Fig. 3), in order to be examined under the stereoscope and to select the appropriate area for further thin-sectioning. Meanwhile, microscope glass slides (5.0×5.0 cm and 2.5×6.0 cm) are grinded in order to make their surface rough so the rock sample can be fixed using epoxy resins. Afterwards, the mounted on the flass rock chip is slowly trimmed in thickness with a thin diamond cutting wheel. Then, follows grinding and polishing with successive grades of silicon carbid (#600, #800 and #1200) and water to achieve a flat, smooth polished surface of approximately 30 μm thickness (Fig. 3) where the microfauna can be visible under the microscope. The sedimentary thin sections were studied and photographed under microscope Zeiss Axioskop 40 with Canon Power Shot A640 camera. A total number of 64 thin sections were prepared in order to study the foraminiferal assemblages and to manage a microfacies analysis. The classification and identification of foraminifera followed that of Loeblich and Tappan (1988), Less (1987, 1998), Serra-Kiel et al. (1998), Less et al. (2011), Less and Özcan (2012), Özcan et al. (2010, 2022) and many others.

For the microfacies analysis the methods of Dunham (1962), Embry and Klovan (1972) and Flügel (1982, 2004) were followed (analysis of lithology, grain types, textures and foraminiferal assemblages).

Figure 3. Sedimentary thin section stages: griding surfaces with silicon carbid (SiC) #400 grade and water on an iron plate (left), polishing with successive grades of silicon carbid and water on a glass plate (right), in Lab. of Mineralogy and Petrology, AUTH.

3.3.2 Subsampling and extraction techniques

The loose sediments from Fanari, Kirki, Pylaea and Lemnos Island contained abundant micro- and macrofauna that can be studied and analyzed using a binocular microscope or stereoscope. These samples preparation relying on washing and sieving the sediment. This technique took place in the specialized laboratory of Structural, Historical and Applied Geology Department, School of Geology, Faculty of Earth Science of Aristotle University of Thessaloniki. 250 gr of dry sediment was sievd from each sample. They were placed into a suitable container and after they were soaked in a solution of water and H_2O_2 (70%). The samples were left to soak over the night and subsequently were washed under tap water using a column of 3 sieves (125, 250, 500 μm) (Fig. 4), thus the washed residue was separated in 3 fractionsthet after drying were stored for further analysis. The faunal richness of the sediments was variable. Observation and counting were performed on the whole fractions. The rest fractions were splitted into smaller parts. Later on, the representative fractions were studied under the microscope and the microfauna were separated from the sediments. The taxa obtained as far as they concerned the small benthic and planktonic foraminifera, were identified and counted. Nevertheless, for the LBF, the procedure of identification required the internal morphology to be examined and biometrics had to be applied upon the equatorial plane. For these reasons, two different techniques were used, depending on the characteristics of the taxa and the type of preservation.

Figure 4. Sieving of samples using different sieve fractions (left), in Lab. of Geology and Palaeontology, AUTH. Stage of the first LBF sectioning technique, where the microfossil is heated (right) in Lab. of Institute of Exploration Geosciences, University of Miskolc.

The first technique referred to high temperature heating and quenching method and was used upon LBF taxa that were characterized by a planispiral test that are bilaterally symmetrical about the equatorial plane, such as *Nummulites*, *Spiroclypeus* and *Heterostegina*. According to this, a number of microfossils were heated on a burner (Bunsen burner or butane gas burner) until they reached the highest temperature and after they were imershed in a container full of cold water (Fig. 4). At that time, in some cases specimens were splitted across the equatorial plane, the rest of them that did not open directly, were opened with the help of pliers. This procedure took place for only one specimen each time. A total number of 685 individuals were bisected.

3.3.3 Microfossils thin sectioning

The following method is not commonly fully described in papers and so was demonstrated to the author by Prof. Ercan Özcan from Istanbul Technical University.

The orientated thin sectioning of individual LBF (Fig. 5) took place when it was not possible to section the specimens with the previous described technique due to their poor preservation or their characteristics (orthophragminids whose tests can de truncated or their equatorial plane was not flat). This technique required microscope glass slides, waterproof abrasive papers and thermoplastic cement (Lexite). Firstly, the glass slides were grinded with silicon carbid (#400) and water in order to achieve a rough surface, where the microfossil can be attached/ mounted using the thermoplastic cement. The glass with a small amount of Lexite were placed on a hot plate (temprerate of 120 °C) so the thermoplastic cement could be melted and LBF was attached on. Before the cement sets, using a mounted needle, the LBF was manipulated under the microscope until its equatorial plane orientated parallel to the glass slide. Afterwards, when the cement sets, the specimen was grinded upon abrasive paper (#800, #1200) until the equatorial plane can be visible under the binocular microscope. Later on, the glass slide with the specimen were reheated on the hot plate (temperature of 120 °C) to remelt the thermoplastic cement. Then the specimen was turned over, re-attached to the glass slide using a needle in order to make sure that it is attached flat, firmly and without bubbles. Thereupon, the LBF was grinded until the equatorial plane and the proloculus could be visible under the microscope. At the end of the procedure, the equatorial plane was cleaned and then labeled. A total number of 246 orientated thin sections of individual LBFs were prepared.

The last two techniques took place in the Laboratory of Structural, Historical and Applied Geology Department, School of Geology, Faculty of Earth Science of Aristotle University of Thessaloniki and the Laboratory of Faculty of Earth Science and Engineering, University of Miskolc.

Figure 5. Oriented thin sectioning process of individual LBF (left) and close up view of oriented thin section (right), Lab. of Institute of Exploration Geosciences, University of Miskolc.

3.3.4 Morphometric measurements of LBF specimens

The small benthic and planktonic microfauna were determined only from the external features of the tests and imaging by Scanning Electron Micrography (SEM), used for taxonomical purposes, using the Jeol JSM-840A microscope of the scanning microscope laboratory of the Aristotle University of Thessaloniki. All the LBF prepared samples are imaged using a digital camera (MOTICAMS6) attached on Zeiss Stemi

305 trinocular microscope and Zeiss Discovery V.8 stereoscope (Aristotle University of Thessaloniki). Digital photographs were also derived from Zeiss Imager.A2m microscope and Zeiss Discovery.V20 stereoscope (University of Miskolc). Images were calibrated and measurements taken using the Motic image manager software. Different protocols of measurements were used upon the LBF according to the genus. Although, for many genera, such as *Discocyclina, Asterigerina* and *Operculina*, only the measurements of the embryo were taken so that the identification could take place. For the genera of *Nummulites*, *Heterostegina, Spiroclypeus* and *Pellatispira* a protocol for biometrics, proposed by Less (1987) and Less et al. (2011), was used. In the following image (Fig. 6), every measurement that took place is shown for each genus respectively.

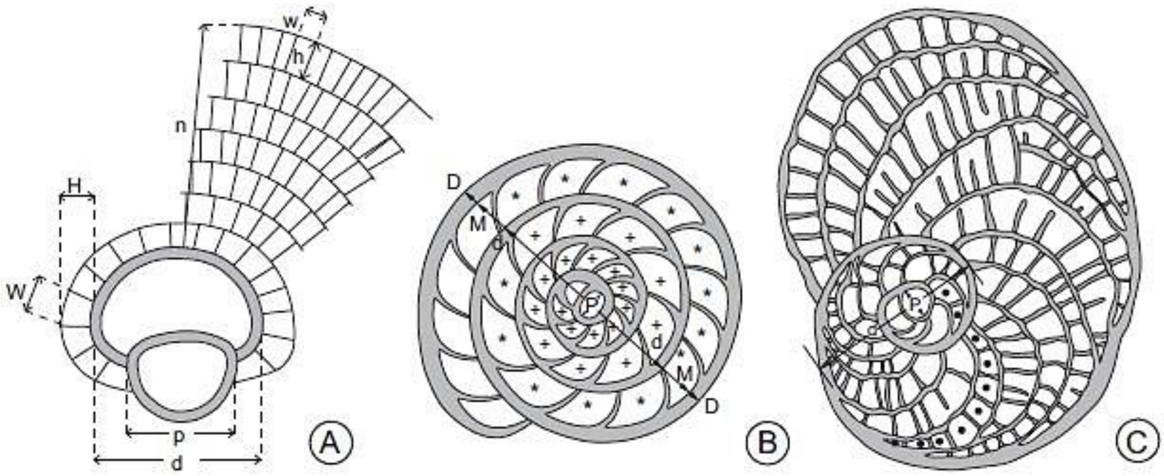


Figure 6. Measurement system for megalospheric larger benthic foraminifera with parameters for the definition of megalospheric orthophragmines (A, 7 parameters), *Nummulites* (B, 6 parameters), *Heterostegina* and *Spiroclypeus* (C, 4 parameters) (by Less et al. 2011).

CHAPTER 4. SYSTEMATIC PALEONTOLOGY AND BIOSTRATIGRAPHY OF THE UPPER EOCENE LARGE BENTHIC FORAMINIFERA OF FANARI (THRACE BASIN, GREECE)

4.1 INTRODUCTION

The Eocene deposits of the Thrace basin have been the subject of study for plethora of researchers (e.g., Kopp 1965; Christodoulou 1957) over the decades. Regardless, the Greek part of the basin remains poorly documented concerning detailed systematic and biostratigraphical description of Larger Benthic Foraminifera (LBF). Hochstetter (1870), noted for the first time, nummulite-bearing limestones in the Greek Thrace basin (Alexandroupolis and Ferres; East Rhodope), mentioning the taxon *Nummulites planulata*. Kopp (1965) also undertook studies on the Eocene foraminifera of this area, and recognized several genera and species, which were assigned to late Eocene. According to Kopp (1965), Mountrakis et al. (2006) and Papanikolaou and Triantaphyllou (2010), thick nummulitic limestones (Avas limestones) are displayed in the Avantas region (western Thrace basin). In the broader Thrace basin (Samothraki Island) Christodoulou (1957) reported a Priabonian assemblage characterized by *Nummulites* sp., *N. fabianii*, *Discocyclina sella*, *D. varians*, *Asterocyclina* sp., *Actinocyclina* sp., *Operculina* sp., *Heterostegina helvetica*, *Gypsina globulus*, *Fabiania* sp., *Asterigerina rotula*, *Eorupertia cristata*, *Schlosserina* sp., *Textularia* sp., *Pyrgo* sp., *Triloculina* sp., *Nodosaria* sp., *Robulus* sp., *Epistomina* sp., and *Globigerina*. Meinhold and BouDagher-Fadel (2009), referred to a nummulitic limestone formation also from Samothraki Island close to North Aegean coastline, suggesting a late Eocene-early

Oligocene age based on the presence of *N. fabianii*, *N. striatus*, *Pellatispira* sp. and *Operculina* sp. In accordance, Zagorchev et al. (2010), also noted the occurrence of *Nummulites incrassatus, N.* cf. *fabianii, Spiroclypeus granulosus, Asterigerina* cf. *lancicula*, *Haddonia heissigi*, *Fabiania cassis, Heterostegina* sp., *Glomalveolina*?, *Orbitolites* sp., *Sphaerogypsina* sp., *Gypsina* sp., in the limestones of Samothraki Island. Karageorgiou and Christodoulou (1957) and later Dimou et al. (2021) reported isolated specimens *Nummulites perforatus* and *Assilina exponens* in Kirki shales (Greek Thrace basin), while Papanikolaou and Triantaphyllou (2019) referred to nummulitic limestones in the southeastern part of Lemnos Island (North Aegean Sea).

The aim of the present study is to provide a revised and completed systematic description of the LBF from the shallow-marine succession of Fanari (western Thrace Basin, Greece), mostly based on biometric measurements. In addition, our intention was to (1) to assess the biostratigraphic age according to the most updated biostratigraphical scheme of Shallow Benthic Zones (SBZ) (Serra-Kiel et al. 1998; Less et al. 2008, 2011; Özcan et al. 2022), for the Paleogene of the Neotethys. (2) to describe the biofacies and the response of the micro- and macrofauna to environmental changes during the functioning of a carbonate platform upper foreslope and reconstruct its paleoenvironmental evolution.

4.2 MATERIAL

Despite that several, restricted or not, Paleogene outcrops are exposed in several localities within the Greek Thrace basin, the present study is focused on two of them, located 30 km southwest of Komotini city, at the coastline of Fanari village (Fig. 7). The two selected neighboring outcrops (FAN A, FAN B) that are described here for the first time, are separated by a normal fault, comprising in general fossiliferous sandstones and siltstones, (Figs. 8A, 9A). The foot wall of the fault exposes eastwards the lower FAN A outcrop, while the upper FAN B outcrop is exposed westwards on the hanging wall.

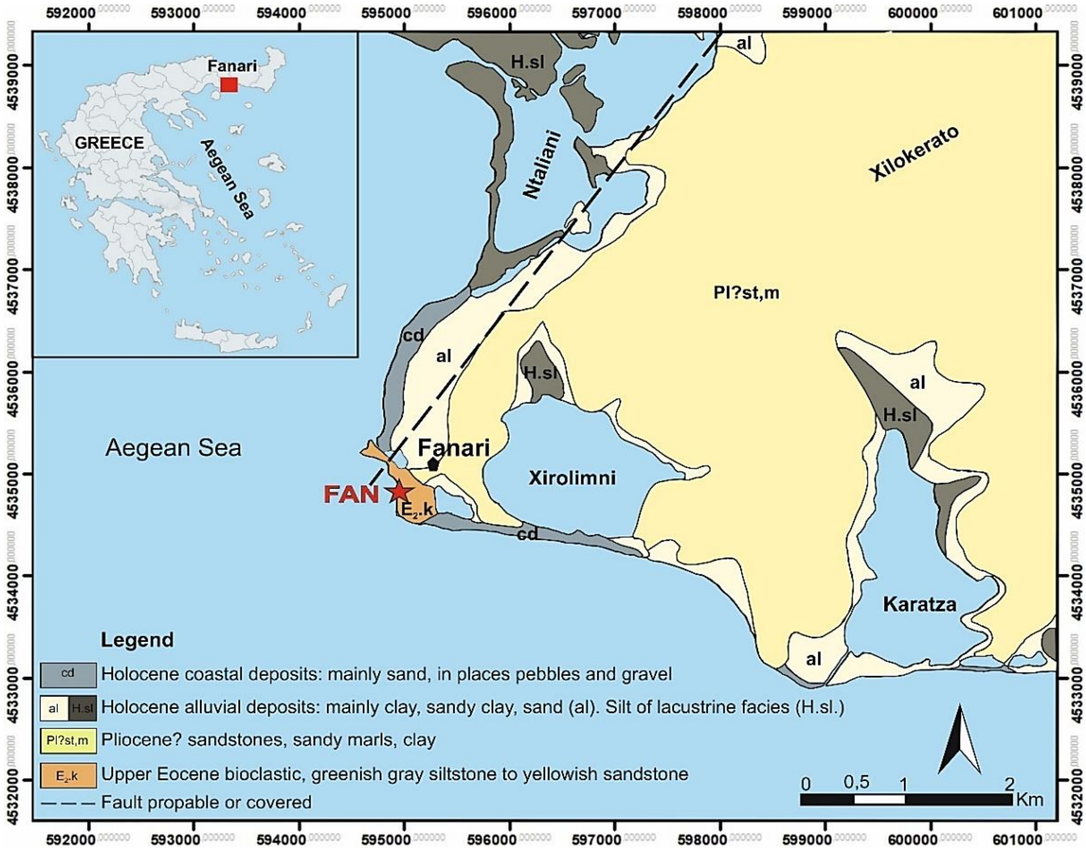


Figure 7. Geological map of Fanari (Thrace), modified after I.G.M.E. (1980a).

In total 16 samples were collected from two measured outcrops along the coastline of Fanari village. The outcrops are rather continuous, although the actual thickness of the section could not be estimated due to the occurrence of a normal fault (Fig. 8A). Thus, the two outcrops allowed us to obtain a composite section, with the lower part being FAN A section, followed by the FAN B section (Fig. 9A).

The lower part of the investigated sedimentary succession is exposed in the section FAN A (latitude 40° 57' 48.40" and longitude 25° 07' 74.10") (Fig. 8A). It is estimated to be around 8 m thick, although due to the difficulty in access, only the first 4 m were sampled with an interval of 20-40 cm. Up to 3 m, the section consists of a dark gray in colour siltstone that finally in the last meter becomes a yellowish to brown marly sandstone (Figs. 8C, 10). Eight samples were collected, both from the siltstone and sandstone. All of them contained free isolated specimens of LBF, characterized mainly of abundant nummulitids (Fig. 10).

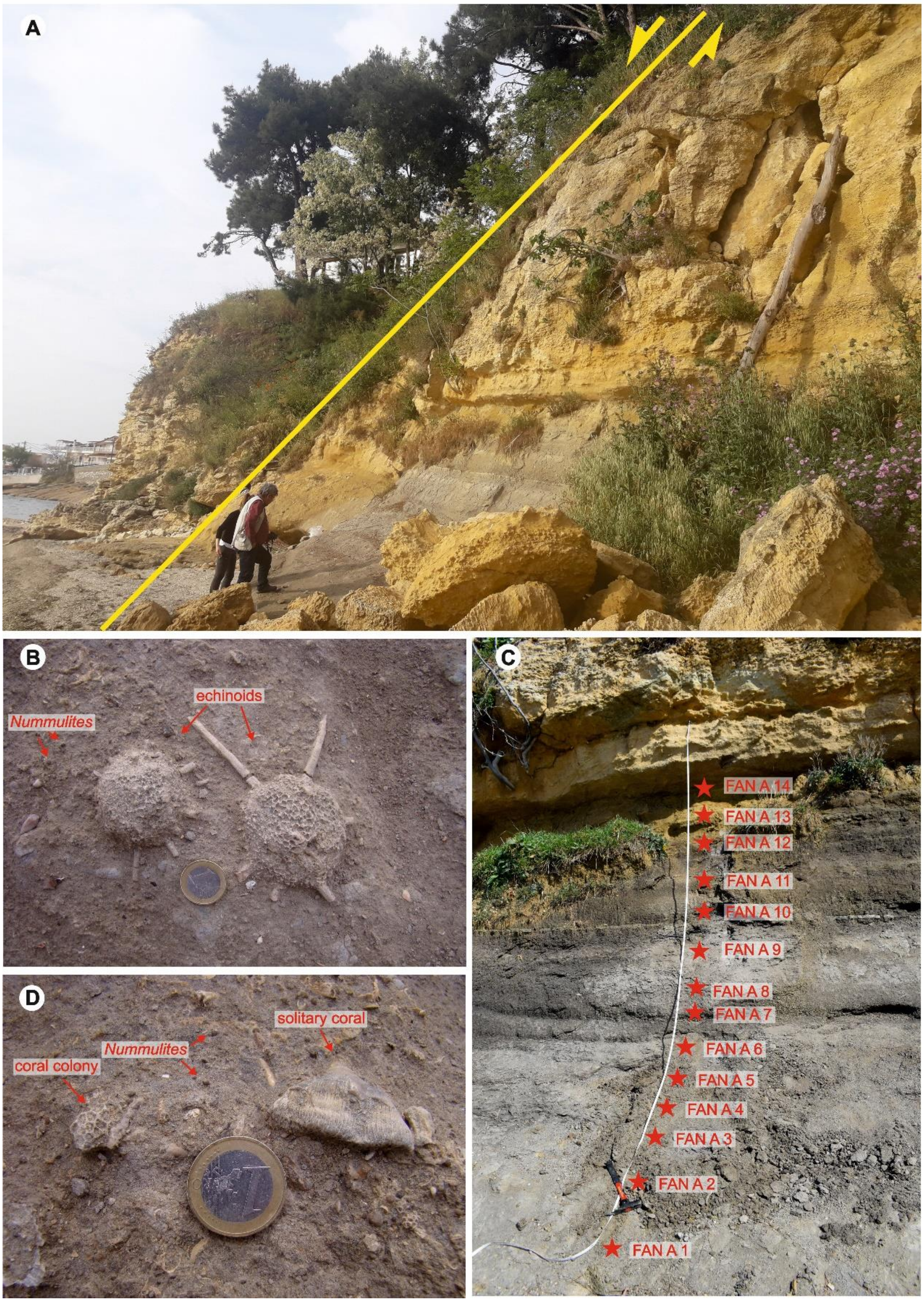


Figure 8. (A) Field photos of FAN A section (Fanari, Thrace) with the normal fault separating FAN B section (located at the right side) from section FAN A (located at the left side of the fault), (B) close up view of echinoids, (C) distribution of samples, (D) close up view of corals.

The upper part of the sampled section FAN B (Fig. 9A) is located at latitude 40° 57' 52.90" and longitude 25° 07' 74.60" and is 6 m thick. Nevertheless, due to dense vegetation, only the first 4 m were sampled with an interval of 30-80 cm (Fig. 9B). It comprises a bioclastic sandstone that becomes more compact going upwards, with intercalations of loose siltstone. In total 8 samples were collected, all of them containing free, isolated tests of abundant and diverse assemblage of LBF, including orthophragmines, nummulitids and other benthic taxa.

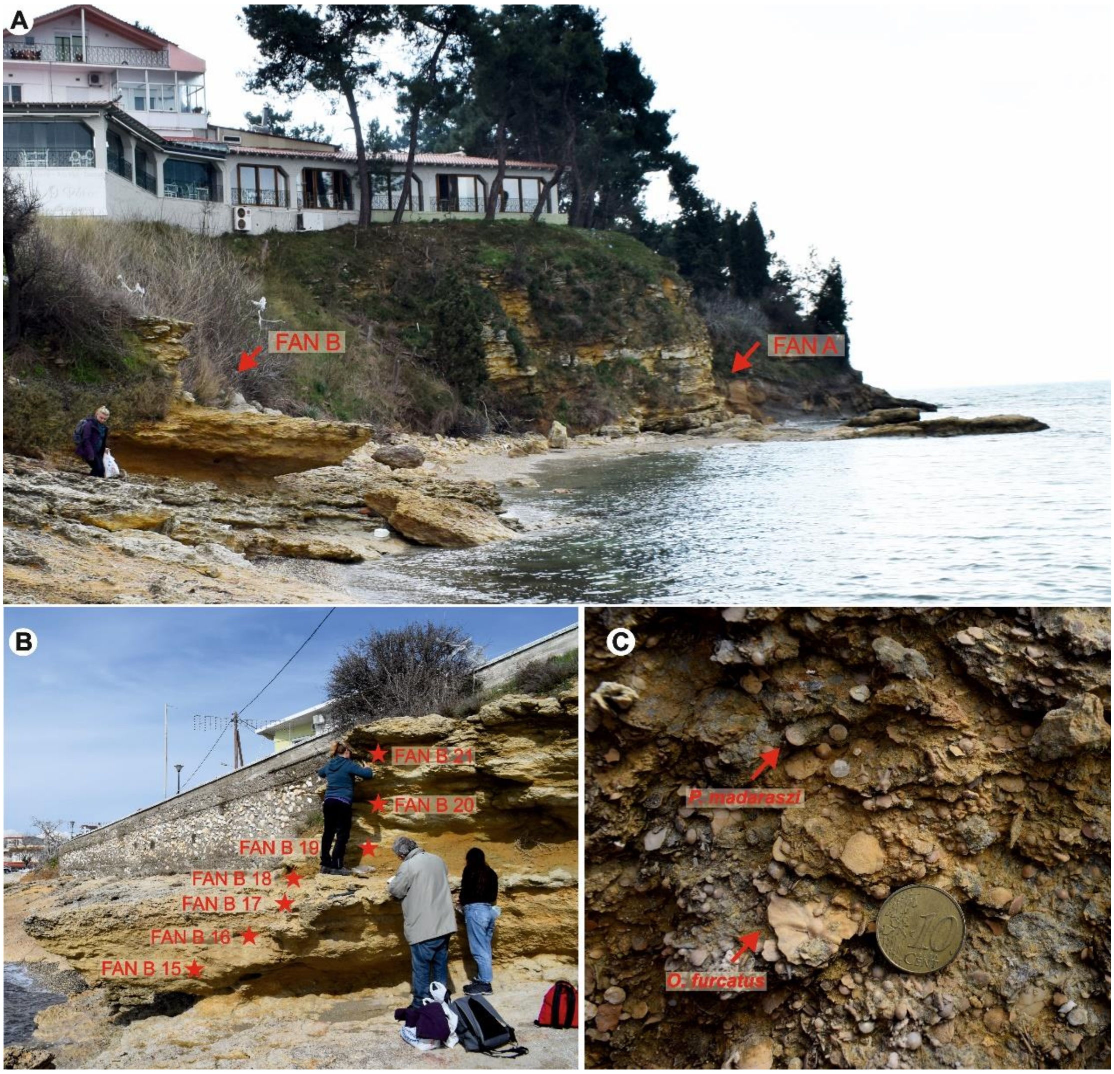


Figure 9. (A) overview of the studied sections of Fanari (Thrace), (B) distribution of samples of FAN B section, (C) close up view of FAN B section.

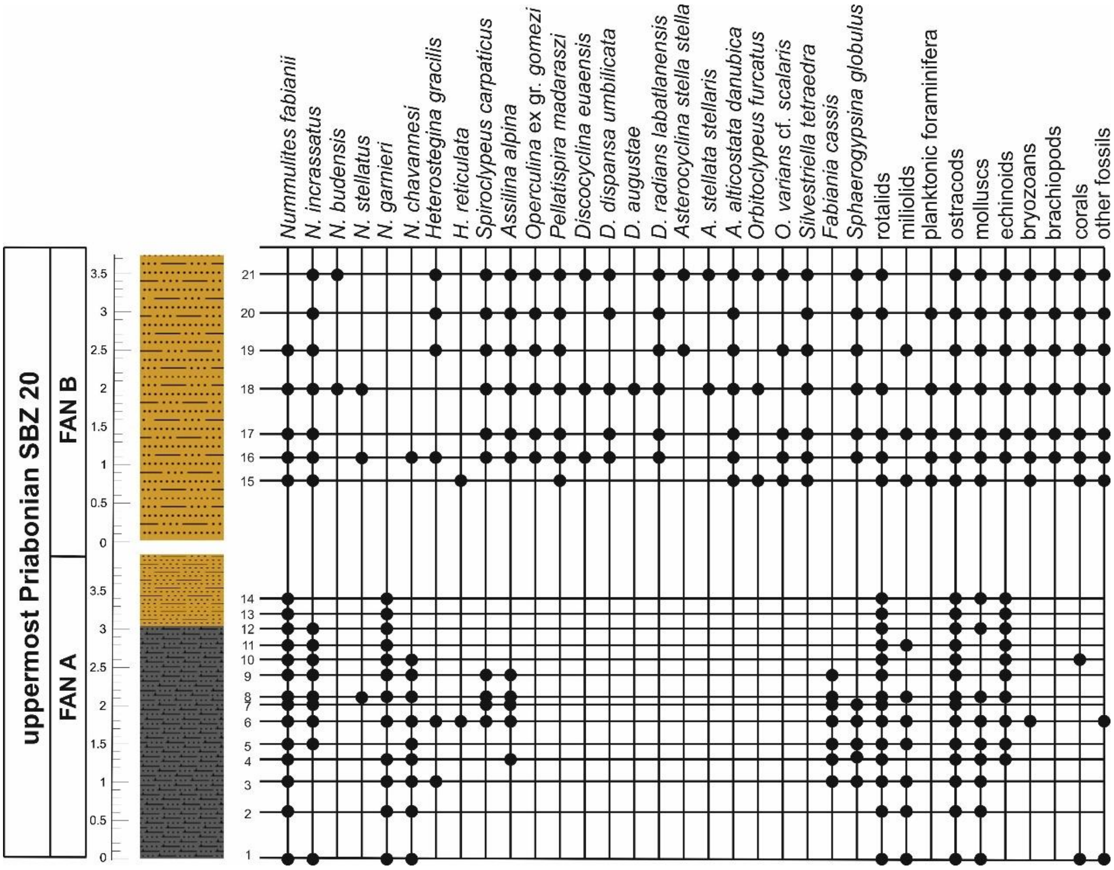


Figure 10. Lithostratigraphic column and distribution of LBF and other fossil groups of Fanari sections.

4.3 METHODS

The investigated specimens were extracted from the sandstone and siltstone samples after soaking in water and H_2O_2 (70%) and wet sieving. Even if the specimens are well-preserved externally, internally they were infilled and calcified. When possible, specimens were heated in a Bunsen flame and then quickly dropped in a glass beaker full of cool water, thus they became equatorially split. Otherwise, thin sections have been prepared. More than 1000 specimens were elaborated: 246 specimens were prepared in oriented thin sections, whereas 685 specimens were bisected. The internal morphological features were examined under a Zeiss Stemi 305 trinocular microscope, while specimens were digitally photographed under Zeiss Imager.A2m and Zeiss Discovery.V20. Morphometry was based on the biometric measurements and counts that were carried out on equatorial sections of the megalospheric specimens and the LBF were determined at the specific or subspecific level based on the detailed biometrical analysis (e.g., Less 1987; Less et al. 2008; Özcan et al. 2022). Standard biometric data for nummulitids and pellatispirids are summarized in Tables 1, 2, 3 and 4.

The identification and description of small benthic foraminifera will be the subject of further investigation. All studied material is stored at the Museum of Geology - Palaeontology - Palaeoanthropology of Aristotle University of Thessaloniki.

4.4 FORAMINIFERAL DISTRIBUTION

A total number of 37.300 fossils were recovered from the whole sequence, almost 9.000 are small benthic and planktonic foraminifera, around 500 ostracods, fragments and whole tests of brachiopods, gastropods, bivalves, echinoids, corals and bryozoans and the rest 27.800 are LBF (Fig. 11).

The FAN A section is characterized by the high abundance of *Nummulites* (dominated by *N. fabianii*), few *Assilina*, and rare *Heterostegina* and *Spiroclypeus* (Figs. 10, 11). The assemblages are exclusively composed by A-forms of typical nummulitid species of low energy hydrodynamic regime (Hallock and Glenn 1986). Bioerosion traces, such as borings and incrustations, are frequent on LBF tests. Apart from the LBF, this outcrop is also characterized by the presence of abundant small benthic foraminifera (SBF) belonging to Bolivinidae, Vaginulinidae, Cibicididae, Textulariidae, Nodosariidae and Miliolidae. The LBF assemblage is rich but compared to the section FAN B, appears less diversified and with lower abundances (Fig. 11). In the uppermost samples, a distinct change in foraminiferal assemblages is observed as the abundance decreases abruptly, with fewer LBF but still plenty SBF, suggesting transitional environmental conditions. The almost monospecific assemblage of mainly reticulate *Nummulites* is replaced by the highly diversified assemblage of the following FAN B section.

The FAN B section presents a diversified assemblage including orthophragmines, nummulitids (mainly *Spiroclypeus carpaticus*) and other benthic taxa such as *Pellatispira madaraszi* and *Silvestriella tetraedra* (Fig. 11). It is worth mentioning that *S. carpaticus* shows a slightly opposite trend to *P. madaraszi*, although both species present elevated abundances. The assemblage is dominated by A-form, however a few B-forms of *Heterostegina* and *Pellatispira* were recovered. SBF and planktonic foraminifera are also present (Figs. 9C, 10). The LBF tests are all well-preserved apart from the larger orthophragmines. This event can be characterized as in situ breakage caused most probably by mechanical compaction.

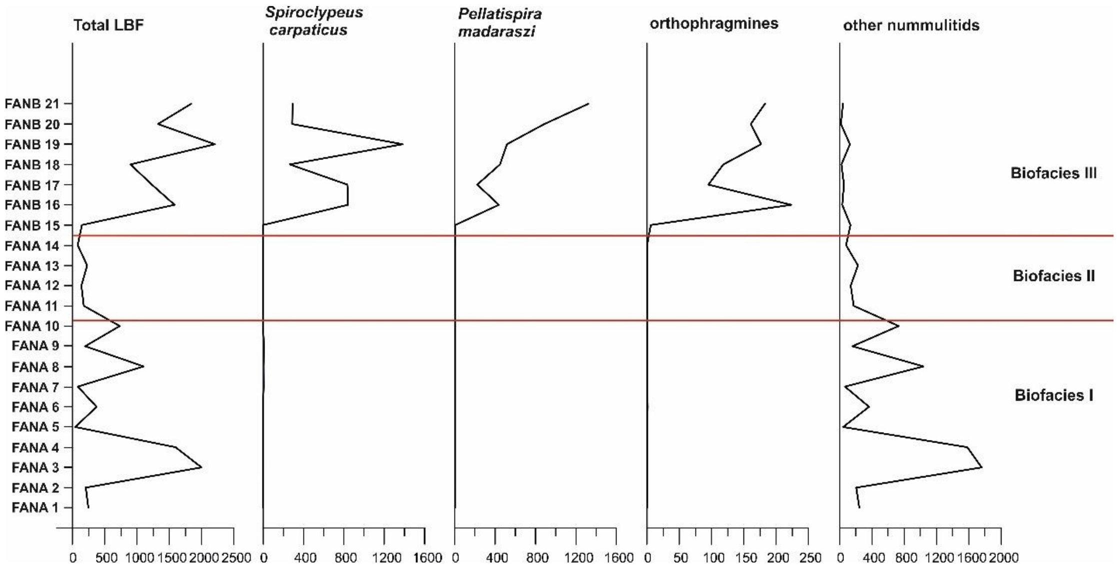


Figure 11. Contents of total LBF and the absolute abundance of the most common taxa. Nummulitids include the genera of *Nummulites*, *Operculina*, *Assilina* and *Heterostegina*.

Furthermore, a slight imbrication of the dominating flatten forms has been observed. These conditions reflect autochthonous to para-autochthonous accumulations of foraminifera (Beavington-Penney 2004; Beavington-Penney et al. 2006). A clear increase in water depth is registered in section FAN B according to the increase in flattened orthophragmines and increase in lenticular *Nummulites*.

The most abundant species are *Pellatispira madaraszi* with 3.809 specimens, reaching its mass abundance in sample FAN B 21 (Fig. 11), and *Spiroclypeus carpaticus* with 3.903 specimens. They were both recovered from FAN B samples outcrop plus only a few specimens of *S. carpaticus* from FAN A. Its highest accumulation is found in FAN B 19 sample, showing a slightly opposite trend to *P. madaraszi*. Another worth mentioning fact is that *S. carpaticus'* population in FAN B outcrop showed an increase (about 20 µm) in the inner cross-section diameter of the proloculus simultaneously with its massive abundance in sample FANB 19 (Fig. 12).

In both sections macrofauna is also present (Figs. 8B and D, 13). It is represented by both regular and irregular echinoids (whole tests, spicules and fragments), corals (solitary and fragments of colonies), bryozoans, bivalves and gastropods (whole tests, fragments and casts), serpuloid bioconstructions, ostracods and fish bones.

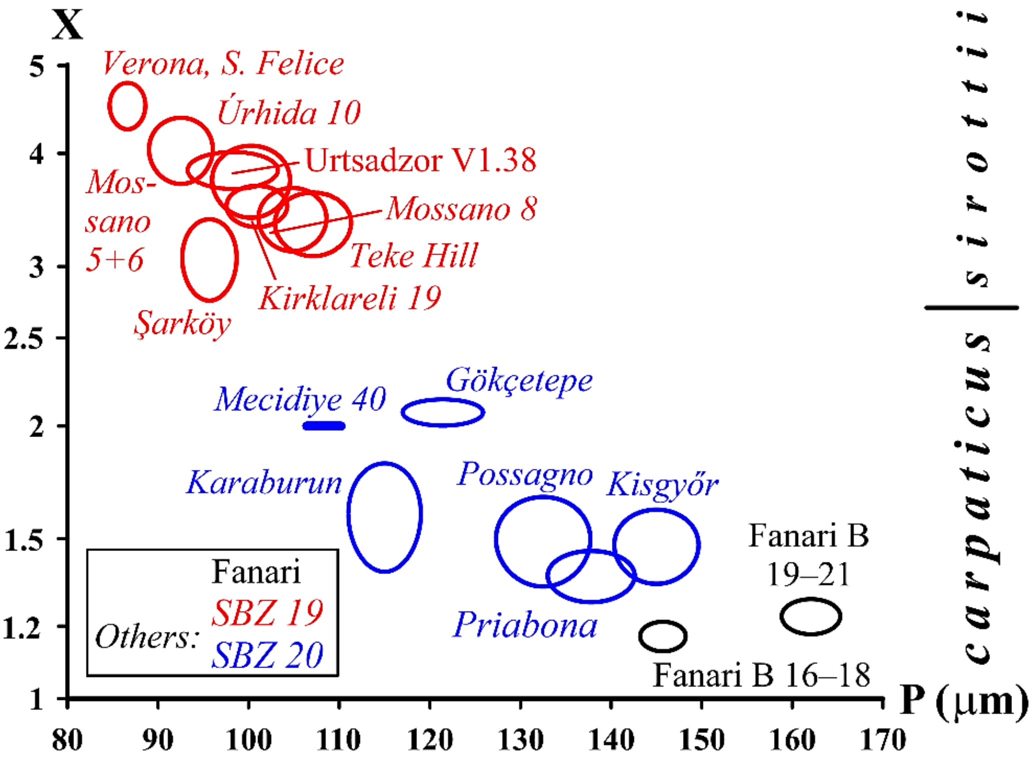


Figure 12. Distribution of *Spiroclypeus* population from Fanari area (mean values at the 68% confidence level corresponding to 1 s.e.) on the P-X (proloculus diameter versus the number of undivided postembryonic chambers) bivariate plot (X is on a logarithmic scale) with the specific subdivision of Eocene *Spiroclypeus*. Information on localities in Turkey and Europe was given by Less and Özcan (2008), Özcan et al. (2010), Less et al. (2011), and Yücel et al. (2020).

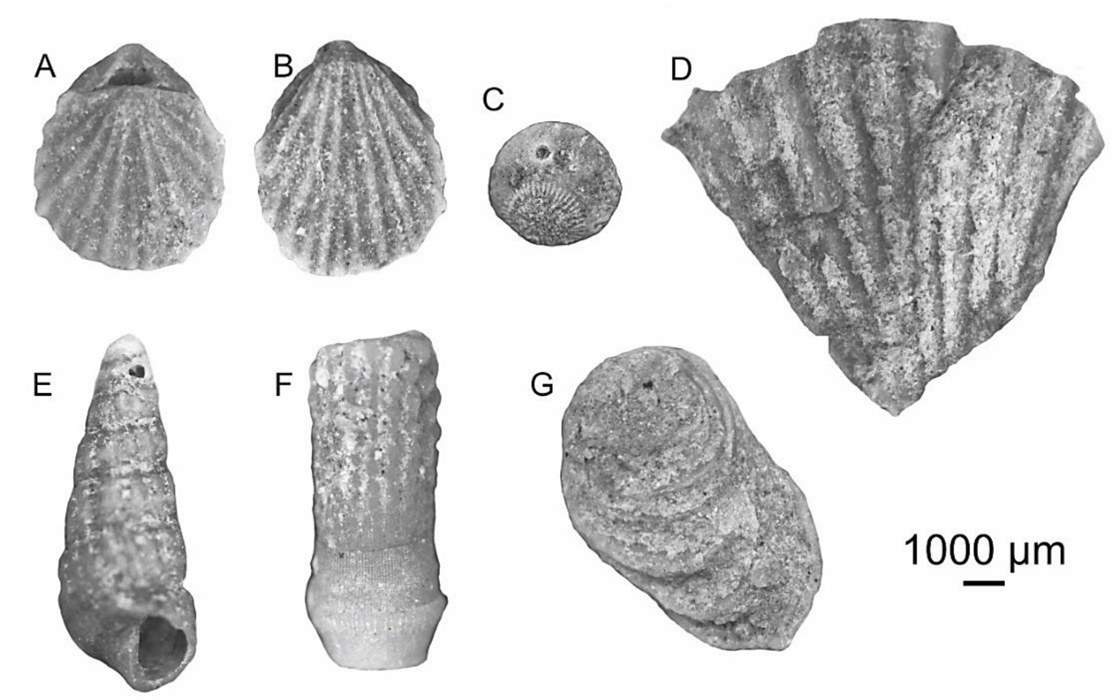


Figure 13. A-B: Brachiopod, C: Bioerosion on a *Nummulites* test, D: fragment of Pectinidae valve, E: gastropod, F: fragment of an echinoid's spicule, G: *Ostrea* valve.

4.5 SYSTEMATIC PALEONTOLOGY

The systematic description of stratigraphically important groups such as orthophragmines and nummulitids (e. g., *Heterostegina*, *Spiroclypeus* and *Nummulites*) and other benthic foraminifera such as *Pellatispira madaraszi*, *Silvestriella tetraedra*, *Sphaerogypsina globulus* and *Fabiania cassis* are given below. In this study, comprehensive data carried out of the biometric analyses of these taxa is also presented.

The identifications (description and conducted measurements) are based on Cole (1970), Hottinger (1977), Schaub (1981), Ferràndez-Cañadell and Serra-Kiel (1992), Papazzoni and Sirotti (1995), Ferràndez-Cañadell (1998), Less et al. (2008, 2011), Less and Özcan (2008, 2012), Özcan et al. (2010, 2016, 2018, 2019, 2022), Ali et al. (2018), Zakrevskaya et al. (2020) and Yücel et al. (2020). Specifically, the determination of *Nummulites* and *Pellatispira* is based on the morphometric method described by Drooger (1993), whereas for *Heterostegina* and *Spiroclypeus,* it is based on the method described by Drooger and Roelofsen (1982), modified by Less et al. (2008) and Less and Özcan (2008). As concerns orthophragmines, the principles used by Less (1987, 1993, 1998) and Özcan et al. (2022) are adopted. For the genera of *Assilina* and *Operculina* only the internal cross-diameter of the proloculus (P) was measured. All the parameters and the biometric data are explained and summarized in Tables 1, 2, 3 and 4.

Phyllum FORAMINIFERIDA Eichwald, 1830

Family NUMMULITIDAE de Blainville, 1827

Genus *Nummulites* Lamarck, 1801

This genus (the only one, found in the whole section except for the uppermost samples of the section - FAN B 20, 21) is represented by reticulate (*Nummulites fabianii*), radiate (*N. budensis*, *N. incrassatus*, *N. chavannesi*, *N. stellatus*) and granulated (*N. garnieri*) forms. Among them *N. budensis* and *N. stellatus* are described for the first time from the Greek peninsula. All the species were morphometrically analyzed (Table 1). Since except of *N. garnieri*, the other species were recently described by Less (1999), Özcan et al. (2010), Less et al. (2011), Zakrevskaya et al. (2020) and Yücel et al. (2020), a more detailed description of these five taxa is not given below.

Nummulites budensis Hantken 1875

Plate 1, figure J

1875 *Nummulites budensis* Hantken, p. 74, pl. 12, fig. 4.

2020 *Nummulites budensis* Hantken; Zakrevskaya et al., p. 290, fig. 15n (with synonymy).

Material: In the study area, only three specimens were recovered, one of them belonging to FAN B 18 and the other two to FAN B 21 sample respectively, although only in one specimen morphometric measurements were possible. B-forms of *N. budensis* have not yet found in the Fanari material.

Description: The A-forms of this small, flat, radiate taxon are characterized by very small proloculus and very narrow and high equatorial chambers, straight in the lower part, however strongly arched in the upper part. The single species that its preservation allowed measurements reaches 1.6 mm in diameter and its proloculus measures 89.7 μm (Table 1).

Stratigraphic range: According to Less et al. (2011), the biostratigraphic range of this species refers to SBZ 19-20 (Fig. 14).

Nummulites chavannesi de la Harpe 1878

Plate1, figure G, I

1878 *Nummulites chavannesi* de la Harpe, p. 232 (nomen nudum).

2011 *Nummulites chavannesi* de la Harpe; Less et al., p. 830, fig. 39 v, x-z, A, B (with synonymy).

2020 *Nummulites chavannesi* de la Harpe; Zakrevskaya et al., p. 919, fig. 14g-q.

Material: This species is recovered mainly from FAN A section and one specimen from FAN B 16 sample. B-forms have not been found yet in Fanari.

Description: The A-forms of this radiate taxon with a distinct umbo are characterized by moderately small embryon, moderately loose spiral and moderately arched, relatively high chambers. In our material, the diameter of the test ranges from 2.8 to 3.1 mm and the mean inner proloculus diameter ($P_{mean \pm s.e.}$) is 176.5±9.1 μm (Table 1).

Remarks: From the Greek territory, Christodoulou (1965) documented *N.* cf. *chavannesi* from Thessaloniki-Jannitza area (photos of equatorial and axial sections), and later, in 1967 he also reported *Nummulites* aff. *chavannesi* (external photo) from

Karpathos Island. Barattolo et al. (2007), signaled *N. chavannesi* from Mount. Klokova, but without providing any illustrations.

Stratigraphic range: Serra-Kiel et al. (1998), suggested a late Bartonian to Priabonian age (SBZ 18-20) for the stratigraphic range of *N. chavannesi* (Fig. 14).

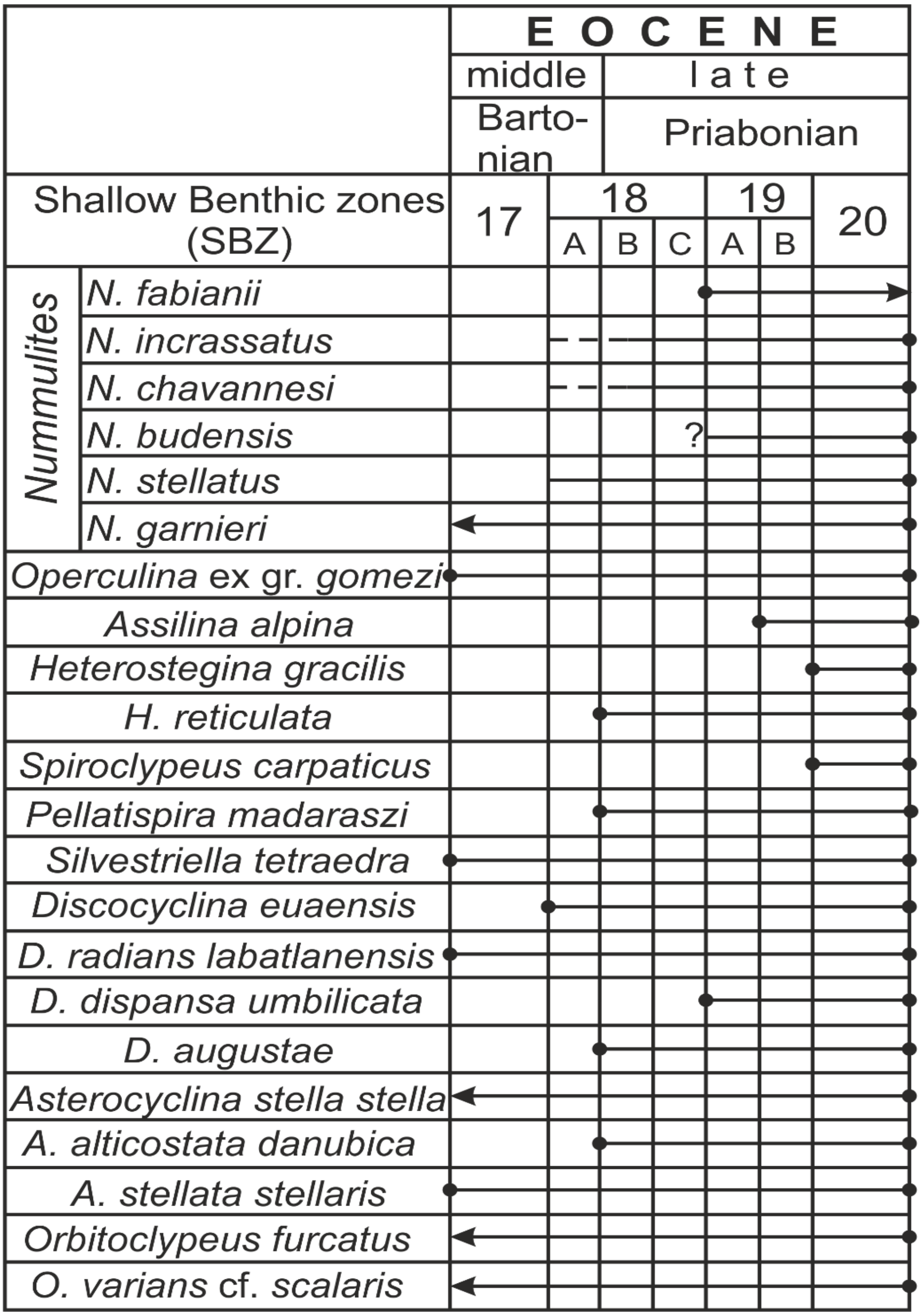


Figure 14. Range chart of biostratigraphically significant LBF species, based on Serra-Kiel et al. (1998), Less (1998) and Less et al. (2011).

Nummulites fabianii (Prever in Fabiani 1905)

Plate 1, figures K-P

1905 *Bruguieria fabianii* n. sp. Prever in Fabiani, p.1805, 1811.

1998 *Nummulites fabianii* (Prever in Fabiani); Papazzoni, p. 165, 168, pl. 1, figs. 1-15, pl. 2, figs 1-15 (with synonymy).

2010 *Nummulites fabianii* (Prever in Fabiani); Özcan et al., p. 65, figs. 31k-l.

2011 *Nummulites fabianii* (Prever in Fabiani); Less et al., figs. 37z-M.

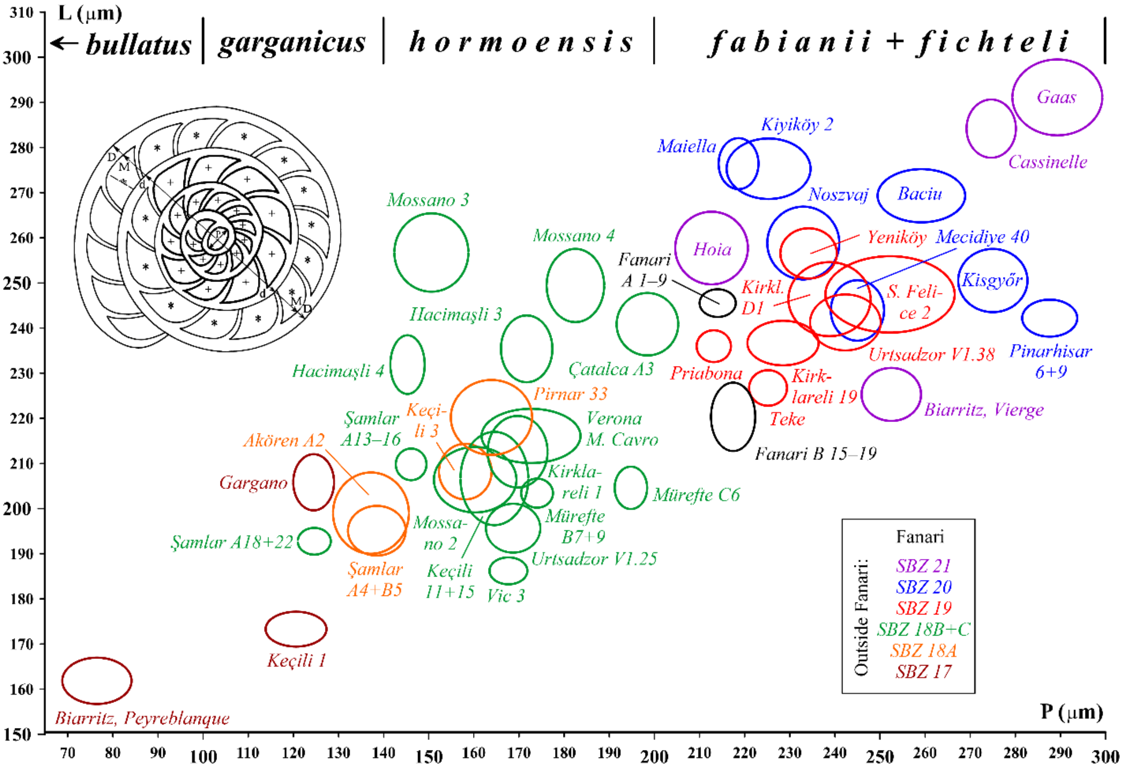
2020 *Nummulites fabianii* (Prever in Fabiani); Zakrevskaya et al., p. 922, 924, figs. 16w-D, 17, 18b, 18c.

Material: *N. fabianii* occurs in the whole Fanari sequence except samples FAN B 20-21.

Description: The A-forms of this taxon with heavy reticulation have medium-sized embryon, regular spire and almost isometric chambers. The mean inner diameter ($P_{mean \pm s.e.}$) is 214.6±3.9 μm and 215.8± 4.7 for FANB and FANA respectively (text-fig. 8, Table 1). B-forms of this species are very seldom in our material. According to Less et al. (2006), Özcan et al. (2009, 2010), Less et al. (2011) and Zakrevskaya et al. (2020), the mean inner cross diameter of the proloculus (P_{mean}=200-300 μm) distinguishes *Nummulites fabianii* from its ancestor, *N. hormoensis* with P_{mean}<200 μm (see also Fig. 15), within the *fabianii* lineage (sensu Schaub, 1981).

Remarks: In the study area, *N. fabianii* is the most abundant nummulite species, detected from the whole sequence of Fanari and presented in almost all samples. On the other hand, it is the most abundant species found in the material from FAN A. In these samples, some individuals present granules on the test surface and, also a distinct umbo. *Nummulites fabianii* was previously reported from the Greek Thrace basin (Christodoulou 1957; Kopp 1965; Zagorchev et al. 2010; Meinhold and BouDagher-Fadel 2009), from Thessaloniki-Jannitza area (Christodoulou 1965; Mercier 1960) and representatives of the group were reported from other Greek localities, such as Gavrovo unit (Barattolo et al. 2007), Tripolis unit (Florida 1932; Thiebault 1982), Pindos unit (Dalloni 1923; Dimou et al. 2021) and Ionian unit (Dimou et al. 2021). These previous works, however, except for Christodoulou (1965), not accompanied by figures in most cases.

Stratigraphic range: According to Less et al. (2011), *N. fabianii* ranges in the SBZ 19-21 interval (Fig. 14).



Figur 15. Distribution of populations of the *Nummulites fabianii* lineage (with their proposed specific subdivision by Özcan et al. 2010) from Fanari and other localities from the Western Tethys (mean values at the 68% confidence level corresponding to 1 s.e.) on the P-L (inner cross diameter of the proloculus versus average length of chambers in the third whorl) bivariate plot. For localities other than Fanari see Less and Özcan (2012).

Nummulites garnieri de la Harpe in Boussac 1911

Plate 1, figure Q-S, X

1911 *Nummulites garnieri* de la Harpe in Boussac, p. 56, pl. 1, figs. 12, 14, 16, 18-20, pl. 2, figs. 10, 11, pl. 3, figs. 8-11, pl. 4, fig. 5, pl. 5, figs. 1, 11-13.

1973 *Nummulites garnieri garnieri* de la Harpe in Boussac; Herbel & Hekel, p. 440, figs. 27-29.

1975 *Nummulites garnieri garnieri* de la Harpe in Boussac; Herbel & Hekel, pl. 3, figs. 8-12.

1981 *Nummulites garnieri* de la Harpe in Boussac; Schaub, p. 153, pl. 52, figs. 9-27, table 15o (with synonymy).

Material: *N. garnieri* is reported only from samples of section FAN A where only A-forms were found.

Description: Externally, the test is small, lenticular with rounded periphery. The test surface shows heavy ornamentation, such as granules and filaments. The granules are distributed over the filaments and around the umbo. Internally, in equatorial section, the proloculus is spherical and small and is followed by a deuteroconch of almost the same size and shape. The mean inner diameter of the proloculus ($P_{mean±s.e.}$) is 82.5±3.0 μm (Table 1). The septa are almost straight to slightly inclined, forming subrectangular chambers. The thick spiral lamina is growing progressively.

Remarks: The most detailed description of this species can be found in Herb and Hekel (1973, 1975). They distinguished two subspecies of *N. garnieri* (*N. g. garnieri* and *N. g. inaequalis*), among which the Fanari specimens correspond to the first one. This species has been previously reported by Mercier (1960) and Christodoulou (1965) from the Thessaloniki-Jannitza area but only with external illustrations.

Stratigraphic range: According to Less et al. (2011), the *Nummulites garnieri*-group distribution refers to SBZ 17-20 (Fig. 14).

Nummulites incrassatus de la Harpe 1883

Plate 1, figures A-F

1883 *Nummulites Boucheri* var. *incrassata* de la Harpe, p. 179, pl. 7, fig 53a.

2011 *Nummulites incrassatus* de la Harpe; Less et al., p. 823, figs. 39a-r (with synonymy).

2020 *Nummulites incrassatus* de la Harpe; Zakrevskaya et al., p. 917, figs. 14r-z.

Material: *Nummulites incrassatus* from Fanari was found abundantly in the FAN B section, whereas rarely from FAN A.

Description: The A-forms of this medium-sized radiate taxon (usually with umbo) is characterized by small to medium-sized proloculus, evenly coiled spiral and slightly arched, more or less isometric chambers. The diameter of the A-form test shows variation ranging from 1.5 to 3.8 mm whereas the diameter of very rare B-forms can reach 13 mm. The mean inner cross-diameter of the proloculus ($P_{mean±s.e.}$) is 213±4.8 μm (Table 1).

Remarks: *N. incrassatus* was reported from many localities in Greece (Barattolo et al. 2007; Zagorchev et al. 2010; Brunn 1956; Aubouin et al. 1958; Mercier 1960), however lacking in most cases any illustration.

Stratigraphic range: Serra-Kiel et al. (1998), indicated a late Bartonian to Priabonian age (SBZ 18-20) for this species (Fig. 14).

Table 1. Statistical data of *Nummulites* populations. №: number of specimens, s.e.- standard error.

Parameters		Inner cross-diameter of the proloculus			Outer diameter of the first two whorls			Number of post-embryonic chambers in the first two whorls			Index of spiral opening 3. whorl vs. 3 whorls		
		P(μm)			d(μm)			E			K=100*(D-d)/(D-P)		
Taxon	Sample	№	range	mean±s.e.	№	range	mean±s.e.	№	range	mean±s.e.	№	range	mean±s.e.
Nummulites budensis	FANB 18	1		89.7	1		1615	1		39	1		36.76
N. chavannesi	FANA 3+6+ FANB 16	11	119-240	176.5±9.1	11	825-1117	958±27	11	22-33	30.18±0.95	11	36-50	43.73±1.14
	FANB 16	1		118.9	1		895	1		22	1		42.11
	FANA 3	6	169-240	186.7±9.9	6	825-1040	948±35	6	29-33	31.00±0.62	6	36.1-50.2	43.48±1.90
	FANA 6	4	141-205	175.8±12.9	4	859-1117	987±47	4	27-33	31.00±1.17	4	41.5-48.5	44.52±1.49
N. fabianii	FANA1+3+4 +5+6+8+9	97	134-295	214.6±3.9	97	962-1736	1251±14	95	14-28	19.81±0.22	92	29.5-37.7	34.34±0.29
	FANA 1	15	134-276	202.6±9.9	15	992-1395	1238±28	15	17-24	19.33±0.47	13	31-40.1	34.44±0.69
	FANA 3	19	152-264	218.7±8.6	19	962-1540	1237±34	18	14-25	19.78±0.54	17	29.4-39.8	33.66±0.67
	FANA 4	13	168-269	220.3±8.4	13	1106-1462	1279±31	13	18-23	20.69±0.51	13	30.4-36.7	33.96±0.48
	FANA 5	1		273.6	1		1439	1		20	1		30.71
	FANA 6	36	143-295	206.9±6.8	36	967-1460	1236±21	35	14-23	19.20±0.34	36	29.7-42.3	34.61±0.51
	FANA 8	5	172-264	229.0±14.7	5	1068-1736	1284±104	5	19-28	22.40±1.40	5	30.9-38	34.87±1.02
	FANA 9	8	203-282	245.5±9.1	8	1039-1449	1291±41	8	18-23	20.38±0.61	8	31.9-41.4	35.87±1.05
	FANB15-19	35	162-274	215.8±4.7	35	1002-1635	1262±24	35	13-30	21.86±0.58	35	22.4-42.0	33.42±0.59
	FANB15	6	174-256	210.2±10.2	6	1019-1404	1237±47	6	22-26	23.17±0.60	6	30.6-39.3	34.17±1.07
	FANB16	8	162-254	227.0±1.8	8	1087-1420	1276±3	8	13-21	17.63±0.58	8	26.2-42	34.49±0.73
	FANB17	7	166-274	207.5±12.7	7	1050-1254	1176±24	7	18-25	21.60±1.00	7	31-37.1	34.12±0.67
	FANB18	11	170-244	220.8±6.6	11	1002-1635	1352±49	11	21-30	24.45±0.80	11	22.4-35.5	31.01±1.01
	FANB19	3	174-226	197.7±12.3	3	1108-1174	1142±16	3	21-22	21.67±0.27	3	35.4-37.2	36.31±0.44
N. garnieri	FANA 1+3+4	13	62-102	82.5±3.0	13	530-700	585±14	12	19-26	23.00±0.55	13	32.1-44.8	38.38±0.96
	FANA 1	6	67-96	83.8±3.7	6	530-700	605±26	6	19-25	22.33±0.87	6	32.2-43.8	36.76±1.48
	FANA 3	2	69-102	85.6±11.5	2	552-588	570±13	2	25-26	25.50±0.35	2	35.6-40	37.83±1.56
	FANA 4	5	62-92	79.8±4.5	5	534-621	569±14.9	4	22-23	22.75±0.22	5	38.2-44.9	40.54±1.05
N. incrassatus	FANB15-21	79	125-312	213.0±4.8	79	872-1797	1291±23	74	15-33	23.85±0.47	79	30.4-46.6	37.86±0.32
	FANB 15	5	137-187	153.6±7.7	5	1024-1221	1075±33	5	18-30	23.20±1.73	5	38.5-41.2	39.96±0.48
	FANB 16	8	137-274	209.5±14.4	8	1031-1582	1283±56	7	20-31	23.86±1.33	8	36.5-40.6	37.85±0.47
	FANB 17	8	190-312	238.0±14.2	8	1064-1312	1166±33	8	18-27	22.25±1.03	8	34.7-40.6	37.98±0.65
	FANB 18	12	175-276	223.4±9.2	12	994-1684	1345±53	11	20-33	26.91±1.02	12	33.5-46.6	38.46±0.98
	FANB 19	28	123-291	204.7±7.7	28	873-1541	1219±30	27	15-30	21.56±0.60	28	30.4-43.6	38.27±0.58
	FANB 20	9	159-277	232.8±12.4	9	1209-1764	1536±5	8	22-32	28.25±1.01	9	33.5-38.7	35.63±0.48
	FANB 21	9	149-276	218.7±13.5	9	1066-1797	1437±66	8	19-29	25.00±1.21	9	31.6-40.9	36.71±0.93
N. stellatus	FANB 16+18	2	43-45	44.2±0.7	2	487-636	562±53	2		21	2	42.3-46.7	44.47±1.54
	FANB 16	1		45.2	1		636	1		21	1		42.28
	FANB 18	1		43.3	1		487	1		21	1		46.65

Parameters		Third whorl								
		average length of chambers			Average shape of chambers			Relative width of the spiral cord		
		$L=d*\pi/N$ (μm)			$F=100*(D-d)/(D-d+2d*\pi/N)$			$m=100*(D-M)/(D-d)$		
Taxon	Sample	№	range	mean±s.e.	№	range	mean±s.e.	№	range	mean±s.e.
Nummulites budensis	FAN B 18	1		203.7	1		68.51	1		21.53
N. chavannesi	FANA 3+6+ FANB 16	11	105-162	129.8±4.9	11	64.1-76	69.96±1.05	11	17.9-36.4	24.61±1.51
	FANB 16	1		149.5	1		65.37	1		27.28
	FANA 3	6	105-162	126.9±7.9	6	64.1-74.8	69.74±1.39	6	17.9-36.5	24.27±2.37
	FANA 6	4	116-136	129.2±4.1	4	68.7-76	71.44±1.47	4	19.9-30.8	24.44±2.04
N. fabianii	FANA 1+3+4+ 5+6+8+9	91	179-306	244.56±2.9	90	44.2-61.2	52.59±0.38	92	18.9-50.7	33.98±0.66
	FANA 1	13	200-288	247.9±7.5	13	48-59.3	52.36±0.83	13	29.4-50.7	40.30±1.94
	FANA 3	17	179-295	243.3±7.2	17	44.2-59.2	51.90±0.86	17	23.1-38.6	31.59±1.13
	FANA 4	13	218-305	250.9±7.6	13	46.5-59.7	52.03±0.96	13	18.9-46.7	34.10±2.18
	FANA 5	1		249.7	1		50.83	1		37.61
	FANA 6	34	205-306	243.2±4.4	34	46.6-60.8	52.51±0.61	36	22.9-46	33.12±0.82
	FANA 8	5	202-265	225.2±9.5	5	53.9-56.9	55.06±0.47	5	26.9-37.1	32.00±1.87
	FANA 9	8	187-285	248.45±12.21	8	45.6-61.2	54.10±1.68	8	22.01-40.9	33.70±1.82
	FANB15-19	35	146-340	216.07±7.3	35	43-66.8	54.98±1.01	35	21.5-60.8	35.73±1.28
	FANB 15	6	184-252	214.3±9.5	6	50.1-62.4	55.36±1.60	6	21.5-43.7	36.89±3.08
	FANB 16	8	197-340	240.8±2.7	8	46.1-62.9	53.48±0.71	8	29.3-60.8	38.33±1.57
	FANB 17	7	162-276	204.2±13.1	7	44.8-60.8	55.35±1.89	7	25.4-42.4	33.22±2.23
	FANB 18	11	146-302	219±15.1	11	43-66.8	53.95±2.23	11	27.2-52.7	34.39±2.02
	FANB 19	3	164-175	170.7±2.7	3	59.1-62.9	61.17±0.91	3	33.7-42.8	37.23±2.30
N. garnieri	FANA 1+3+4	12	90-130	107.1±3.3	12	51.1-66	59.32±1.37	13	27.6-48.2	37.81±1.60
	FANA 1	6	90-130	112.7±4.9	6	51.1-66	57.14±2.07	6	27.7-46.5	36.02±2.69
	FANA 3	2	91-101	95.9±3.5	2	55.2-65.5	60.41±3.63	2	33.2-40.9	37.07±2.72
	FANA 4	4	95-112	104.3±3.4	4	61.4-63.1	62.03±0.33	5	36.3-48.3	40.26±1.91
N. incrassatus	FANB 15-21	74	123-326	195.3±3.2	73	53.7-73.2	62.58±0.49	79	18.9-50.1	33.16±0.80
	FANB 15	5	174-226	196.9±7.6	5	58.9-65.3	60.92±1.00	5	18.9-45.4	35.33±4.27
	FANB 16	8	123-228	194.9±13.1	7	53.7-73.2	63.23±2.07	8	32.2-50.1	39.13±2.18
	FANB 17	8	184-242	204±7.2	7	55-63.8	58.27±1.12	8	23.5-42.4	29.94±2.03
	FANB 18	11	170-210	186.9±4.3	11	59.2-68.8	64.94±0.98	12	20.3-40.8	31.96±2.00
	FANB 19	27	149-246	191.5±4.8	27	55.2-71.5	62.08±0.73	28	18.9-47.4	33.36±1.18
	FANB 20	8	163-209	189.2±5.8	8	63.4-67.9	65.76±0.46	9	21.1-36.2	29.17±1.87
	FANB 21	8	175-326	216.2±16.2	8	54.8-70	62.08±1.58	9	22.2-45.9	34.47±2.37
N. stellatus	FAN B 16+18	2	102-123	112.7±7.5	2	63.7-65.6	64.62±0.66	2	17.03-21.14	19.08±1.54
	FANB 16	1		123.30	1		63.70	1		17.03
	FANB 18	1		102.07	11		65.55	1		21.14

Nummulites stellatus Roveda 1961

Plate 1, figure H

1961 *Nummulites stellatus* Roveda, p. 181, pl. 15: 1-14, pl. 17: 7, 11, pl. 19: 3, text-figs. 12-13.

2011 *Nummulites stellatus* Roveda; Less et al., p. 829, fig.39U-X (with synonymy).

2020 *Nummulites stellatus* Roveda; Yücel et al., p. 102, figs 15D-E.

2020 *Nummulites stellatus* Roveda; Zakrevskaya et al., p. 921, fig. 15m.

Material: Only two A-forms of *Nummulites stellatus* are recovered from samples FAN B 16 and 18 respectively.

Description: This small radiate form is characterized by very small proloculus, regular spire, and nearly isometric chambers bordered by strongly arched, sickle-shaped septa. The diameter of the test ranges from 2.2 mm to 3.2 mm and mean inner cross-diameter of the proloculus ($P_{mean \pm s.e.}$) is 44.2±0.7 μm (Table 1).

Remarks: This taxon is described for the first time from Greece.

Stratigraphic range: According to Less et al. (2011) and considering the shift of the Bartonian/Priabonian boundary by Agnini et al. (2011), its distribution range fills the entire Priabonian, SBZ 18B-20 (Fig. 14).

PLATE 1. A-F *Nummulites incrassatus* de la Harpe 1883, A, FAN B 20.4; B, FAN B 21.6; C, FAN B 16 (micropaleontological slide,2/3,4); D, FAN B 20.8; E, FAN B 15.20; F, FAN B 17.9. G, I *Nummulites chavannesi* de la Harpe 1878, G, FAN A 6.1; I, FAN A 3.3. H *Nummulites stellatus* Roveda 1961, FAN B 16.20. J *Nummulites budensis* Hantken 1875, FAN B 18.4. K-P *Nummulites fabianii* (Prever in Fabiani 1905), K, FAN B 16 (micropaleontological slide,2/3,3); L, FAN A 9.3; M, FAN B 18.1; N, FAN A 6.1; O, FAN A 6.4; P, FAN A 6,12. Q-S, X *Nummulites garnieri* de la Harpe in Boussac 1911, Q, W, FAN A 1.4; T, U, FAN A 1.5; R-S, V, FAN A 9 (micropaleontological slide,2/2,5); X, FAN A 6 (micropaleontological slide,1/3,1). All A-forms. A, B, C, K, L, R, S, V, X-external views, D, E, F, G, H, I, J, M, N, O, P, Q, T, U, W-equatorial sections.

Genus *Heterostegina* d'Orbigny 1826

The Eocene representatives of this genus from the Neotethys have recently been revised by Less et al. (2008), therefore below is not presented their detailed description. *Heterostegina* has been previously reported from the Eocene of Greece (e.g., Christodoulou 1965; Mercier 1960). Two species were determined from the material of the whole section, however only a few specimens were recovered.

Heterostegina gracilis Herb 1978

Plate 2, figure C-F

1978 *Heterostegina gracilis* Herb, p. 761-762, figs. 31-34, 37.

2008 *Heterostegina gracilis* Herb; Less et al., p. 338, 341, figs. 1A, 15L-V (with synonymy).

2020 *Heterostegina gracilis* Herb; Yücel et al., p. 11, 12, figs 9A, B, 11A-K.

Material: A few specimens of *H. gracilis* were recovered from samples of the FAN B section, and only three from samples FAN A 3 and 6.

Description: This taxon is easily recognizable due to (i) the presence of granules on the test surface, (ii) large embryon, (iii) very loosely coiled spiral with densely spaced and strongly arched chambers subdivided into small chamberlets is described here for the first time from Greece. The mean inner diameter of the proloculus ($P_{mean \pm s.e.}$) is 221.5± 10.5 μm. The number of postembryonic undivided chambers (parameter X) is 2 and the number of chamberlets in chamber 14 (parameter S) is up to 24.

Stratigraphic range: *H. gracilis* has a narrow stratigraphic range in the SBZ 20 Zone (Herb 1978; Less et al. 2008) (Fig. 14) pointing to the latest Priabonian.

Heterostegina reticulata Rütimeyer 1850

Plate 2, figure A-B

1850 *Heterostegina reticulata* Rütimeyer, p. 109, pl. 4, 61.

Material: *Heterostegina reticulata* appears with only a few specimens in the samples FAN A 6 and FAN B 15.

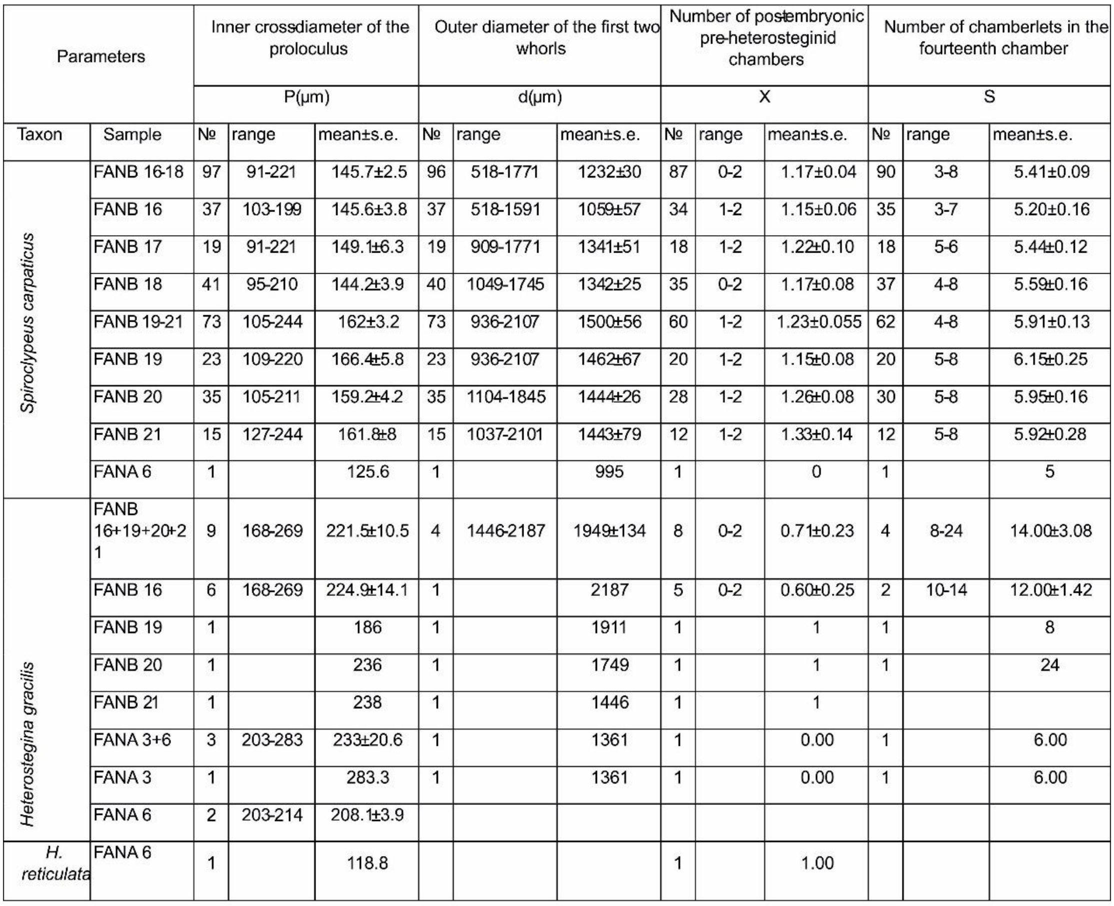
Description: The biometric data derive from one thin section; the diameter of the proloculus is 118.8 μm and the number of postembryonic undivided chambers (parameter X) is 1 (Table 2). Because of the lack of sufficient number of specimens for statistical evaluation, the very few specimens cannot be attributed to any subspecies of *H. reticulata* defined by Less et al. (2008). The very low value of operculinid chambers

(X=1) in the Fanari material suggests, however, an advanced subspecies, *H. r. mossanenesis* or *H. r. italica*, both characteristic for the SBZ 19-20 Zones.

Remarks: This species has been previously reported from the Greek territory by Accordi et al. (1998) from Cephalonia Island and from Zakynthos Island by Barattolo et al. (2007), although not illustrated.

Stratigraphic range: According to Less et al. (2008), *H. reticulata* ranges from SBZ 18B to SBZ 20 (Fig. 14), which in the interpretation of Agnini et al. (2011) corresponds to the entire Priabonian.

Table 2. Statistical data of *Spiroclypeus carpaticus, Heterostegina gracilis* and *H. reticulata* populations. №: number of specimens, s.e.- standard error.



Parameters		Inner crossdiameter of the proloculus			Outer diameter of the first two whorls			Number of postembryonic pre-heterosteginid chambers			Number of chamberlets in the fourteenth chamber		
		P(μm)			d(μm)			X			S		
Taxon	Sample	№	range	mean±s.e.	№	range	mean±s.e.	№	range	mean±s.e.	№	range	mean±s.e.
Spiroclypeus carpaticus	FANB 16-18	97	91-221	145.7±2.5	96	518-1771	1232±30	87	0-2	1.17±0.04	90	3-8	5.41±0.09
	FANB 16	37	103-199	145.6±3.8	37	518-1591	1059±57	34	1-2	1.15±0.06	35	3-7	5.20±0.16
	FANB 17	19	91-221	149.1±6.3	19	909-1771	1341±51	18	1-2	1.22±0.10	18	5-6	5.44±0.12
	FANB 18	41	95-210	144.2±3.9	40	1049-1745	1342±25	35	0-2	1.17±0.08	37	4-8	5.59±0.16
	FANB 19-21	73	105-244	162±3.2	73	936-2107	1500±56	60	1-2	1.23±0.055	62	4-8	5.91±0.13
	FANB 19	23	109-220	166.4±5.8	23	936-2107	1462±67	20	1-2	1.15±0.08	20	5-8	6.15±0.25
	FANB 20	35	105-211	159.2±4.2	35	1104-1845	1444±26	28	1-2	1.26±0.08	30	5-8	5.95±0.16
	FANB 21	15	127-244	161.8±8	15	1037-2101	1443±79	12	1-2	1.33±0.14	12	5-8	5.92±0.28
	FANA 6	1		125.6	1		995	1		0	1		5
Heterostegina gracilis	FANB 16+19+20+21	9	168-269	221.5±10.5	4	1446-2187	1949±134	8	0-2	0.71±0.23	4	8-24	14.00±3.08
	FANB 16	6	168-269	224.9±14.1	1		2187	5	0-2	0.60±0.25	2	10-14	12.00±1.42
	FANB 19	1		186	1		1911	1		1	1		8
	FANB 20	1		236	1		1749	1		1	1		24
	FANB 21	1		238	1		1446	1		1			
	FANA 3+6	3	203-283	233±20.6	1		1361	1		0.00	1		6.00
	FANA 3	1		283.3	1		1361	1		0.00	1		6.00
	FANA 6	2	203-214	208.1±3.9									
H. reticulata	FANA 6	1		118.8				1		1.00			

Genus *Spiroclypeus* Douvillé 1905

The Eocene representatives of this genus have recently been revised by Less and Özcan (2008), therefore here is not presented their detailed description. All specimens from Fanari belong to *S. carpaticus* (the more advanced species of the genus), described and measured for the first time from Greece (Table 2). Abundant number of specimens were recovered mainly from the upper part of the section, however only very few specimens were collected from the lower part, too. This genus from Greece was earlier reported (with no internal illustration and morphometric data) from the Gavrovo-Tripolis unit by Fleury (1980), from Thessaloniki-Jannitza area by Mercier (1960), Cephalonia by Hagn (1958) and from Zakynthos Island by Mirkou-Peripopolou (1975).

Spiroclypeus carpaticus (Uhlig 1886)

Plate 2, figures G-L

1886 *Heterostegina carpatica* Uhlig, p. 201-202, pl. 2: 14, 15, fig. 10.

2008 *Spiroclypeus carpaticus* (Uhlig); Less & Özcan, p. 312-313, figs. 7R, S, U, Z, 7AA-AD (with synonymy).

2020 *Spiroclypeus carpaticus* (Uhlig); Yücel et al., p. 18, figs 9C-E, 13A-M.

Material: *S. carpaticus* was retrieved from almost the whole section FAN B, and samples FAN A 6 to 9. However, only one specimen was measured from FAN A.

Description: Based on the morphometry, an increase in the proloculus size was detected leading to the subdivision of the population of FAN B outcrop into two groups. Fanari 1 (samples FAN B 16-18) where the mean inner cross diameter ($P_{mean±s.e.}$) is 145.7±2.5 μm and Fanari 2 (samples 19-21) where it is 162±3.2 μm (Fig. 12). The mean number of postembryonic chambers (parameter X) is X_{mean}=1.17 and X_{mean}=1.23 respectively (Table 2).

Remarks: This species is the second most abundant one in the material of FAN B and a total number of more than 3.000 specimens were collected. On the other hand, only few specimens were recovered from FAN A, which preservation did not allow morphometrical measurements. It occurs in large numbers in samples FAN B 16-17, and then in FAN B 18 it decreases. Upsection, in sample FAN B 19 it shows abrupt increase, reaching its mass abundance with 1659 specimens and then decreases again dramatically.

Stratigraphic range: These values unequivocally separate *S. carpaticus* defining the late Priabonian SBZ 20 Zone (Less and Özcan 2008) from the less advanced *S. sirottii*, characteristic for the middle Priabonian SBZ 19 Zone (Fig. 14).

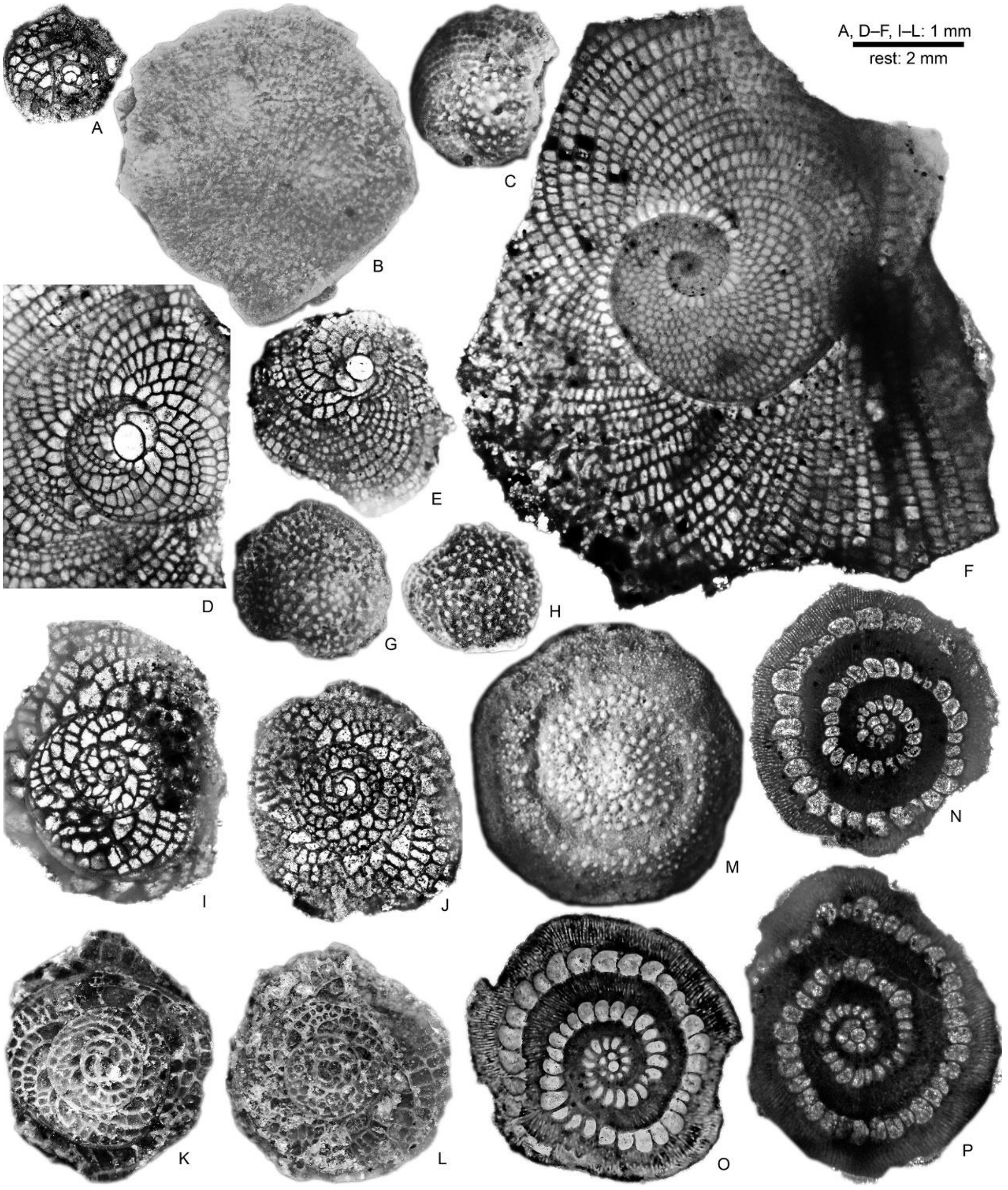


PLATE 2. A-B *Heterostegina reticulata* Rütimeyer 1850, A, FAN A 6.1; B, FAN B 16 (micropaleontological slide,1/3, 10); C-F *Heterostegina gracilis* Herb 1978, C, FAN B 16 (micropaleontological slide,2/3,9); D, FAN B 19.7; E, FAN A 6.19; F, FAN B 16.20; G-L *Spiroclypeus carpaticus* (Uhlig 1886), G, FAN B 16 (micropaleontological slide,2/3,9); H, FAN B 18.28; I, FAN A 6.2; J, FAN B 16.20; K, FAN B 16.21; L, FAN B 18.24; M-P *Pellatispira madaraszi* (Hantken 1875), M, FAN B 16 (micropaleontological slide,2/3,8); N, FAN B 16.7; O, FAN B 18.4; P, FAN B 21.10. Aparto from F which is -B-form, athe rest are A-forms. B, C, G, H, M-external views and A, D, E, F, I, J, N, K, L, O, P-equatorial sections.

Genus *Operculina* d'Orbigny 1826

Although this genus (with folded septa intersected by stolons as a diagnostic feature distinguishing it from genus *Assilina*) has been previously reported from the Eocene of Greece (Mercier 1960; Kopp 1965; Christodoulou 1965; Mirkou-Peripopolou 1975; Dimou et al. 2021), it is described and biometrically analyzed for the first time in this study. It occurs only in the upper part of the sequence, in section FAN B. The Eocene forms of the Neotethys are subdivided typologically by Hottinger (1977) into the most primitive *O. bericensis*, the more advanced *O. roselli* and the most advanced *O. gomezi*, however these taxa are not yet defined morphometrically. Therefore, here is used the joint name of *O.* ex. gr. *gomezi* for them. Since modern description of this taxon is not available, below there is a short characterization.

Operculina* ex gr. *gomezi Colom and Bauzá 1950

Plate 3, figures E-G

1950 *Operculina canalifera gomezi* Colom & Bauzá, p. 219, fig 1, 2, pl. 17, fig a. 1-3.

1977 *Operculina gomezi* Colom & Bauzá; Hottinger, p. 98, 100, figs. 38A-F (with synonymy).

Material: In Fanari, this taxon occurs in samples from FAN B outcrop.

Description: The test is flat, involute, medium-large sized with a distinct umbo. Although, the surface of the test is not heavily ornamented, the folded septal filaments can be distinguishable, with granules along the septa. Internally, the proloculus is moderately small. It is followed by a quite bigger in size, reniform deuteroconch. The spire is loose from the first whorl, and it rapidly opens in the outer whorl. The septa are very dense and folded. Consequently, very dense, high, sickle-shaped chambers are formed. The proloculus size varies from 83 μm to 125 μm.

Remarks: *O. gomezi* was previously reported from the middle-upper Eocene of several localities from Greece such as Vasiliki Trikala (Mesohellenic Trough), Perivoli Grevena (Pindos unit), and Dervenakia and Tripolis (Tripolis unit), but only from random thin sections (Dimou et al. 2021).

Stratigraphic range: According to Less and Özcan (2012), *O.* ex gr. *gomezi* ranges from the base of the Bartonian to the top of the Priabonian (SBZ 17-20, Fig. 14).

Genus *Assilina* d'Orbigny 1839

Following Romero et al. (1999), *Assilina* is considered as the nummulitids with simple short sutural canals and nonfolded septa without apertures. Medium-sized, semi-involute forms belonging to *A. exponens* were previously reported from the Middle Eocene of Kirki (Dimou et al. 2021). In Fanari, from the younger part of the Eocene evolute forms were found, which belong to the *A. alpina* lineage. Although the morphometric limits between the more primitive, mostly Bartonian *A. schwageri* and the more advanced Priabonian *A. alpina* are not yet exactly defined, the inner cross-diameter of the first species is usually below 120 μm, while for the second it is above this value. Consequently, *A. alpina* was measured and shortly characterized from the material of the whole Fanari section.

Assilina alpina (Douvillé 1916)

Plate 3, figures A-D

1916 *Operculina alpina* Douvillé, p. 329, fig. i.

1977 *Operculina alpina* Douvillé; Hottinger, p. 85-87, pl. 38, figs. 4-6, text-figs. 33, 34.

1999 *Assilina alpina* (Douvillé); Less, p. 356, pl. 2, fig. 8.

2020 *Assilina alpina* (Douvillé); Zakrevskaya et al., p. 925, figs. 18 g-i, 19 a-c.

2011 *Assilina* ex. gr. *alpina* (Douvillé); Less et al., p. 831, fig. 40a-i.

Material: This taxon is found in almost all samples in Fanari.

Description: *A. alpina* presents an evolute, rounded, very thin, flat, and medium to large sized test. Its surface is ornamented as sutures are elevated, radial slightly curved backwards. In the last whorl, they terminate in a thick marginal cord. The spire is relatively loose. In the equatorial section, the proloculus is small, the septa in the inner whorl are curved but in the outer one they are straight and slightly bended in their upper part. Therefore, in the inner whorl the chambers are sickle-shaped and then become narrow, high and subrectangular. The diameter of the proloculus ranges from 86 μm to 202 μm but usually exceeds 120 μm.

Remarks: The genus of *Assilina* has been reported from Gavrovo-Tripolis unit by Fleury (1980) and specifically, this species has been reported from Klokova Mt. by Barattolo et al. (2007). Kopp (1965) refers to *Operculina alpina* from the Greek part of Thrace basin.

Stratigraphic range: According to Serra-Kiel et al. (1998), Less and Özcan (2012) and Yücel et al. (2020), the range of *Assilina alpina* is SBZ 19-20 (Fig. 14).

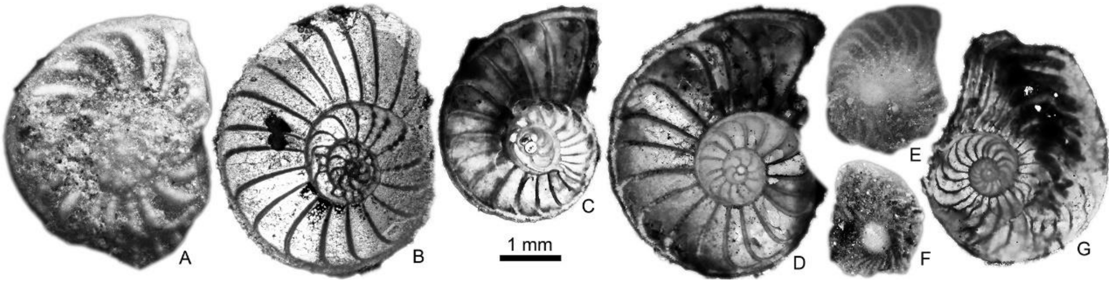


PLATE 3. A-D *Assilina alpina* (Douvillé 1916), A, FAN B 16 (micropaleontological slide,2/3,1); B, FAN B 16.2; C, FAN A 3.5; D, FAN A 6.1. E-G *Operculina* ex. gr. *gomezi* Colom and Bauzá 1950, E, FAN B 16 (micropaleontological slide,2/3,2); F, FAN B 19.12; G, FAN B 18.6. All A-forms. A, E and F-external views, B, C, D, G- equatorial sections.

Family PELLATISPIRIDAE Hanzawa 1937

Genus *Pellatispira* Boussac 1906

This genus and the exclusive Neotethyan species, *Pellatispira madaraszi* (determined from Fanari as well) was previously revised in detail by Hottinger et al. (2001), therefore below is not presented a detailed description of this easily recognizable taxon.

Pellatispira madaraszi (Hantken 1875)

Plate 2, figures M-P

1875 *Nummulites* aff. *madaraszi* Hantken, p. 86, pl. 16, figs. a-c.

1970 *Pellatispira madaraszi* (Hantken); Cole, p. B6-B9, pl. 1, figs 1-13, pl. 2, figs. 19-23.

2001 *Pellatispira madaraszi* (Hantken); Hottinger et al., p. 44, 46, text-figs 3, 4, 5A, 6A-C; pl. 7: 1-4; pl. 8: 1-5 (with synonymy).

2020 *Pellatispira madaraszi* (Hantken); Zakrevskaya et al., p. 931, figs. 21 h-j, o.

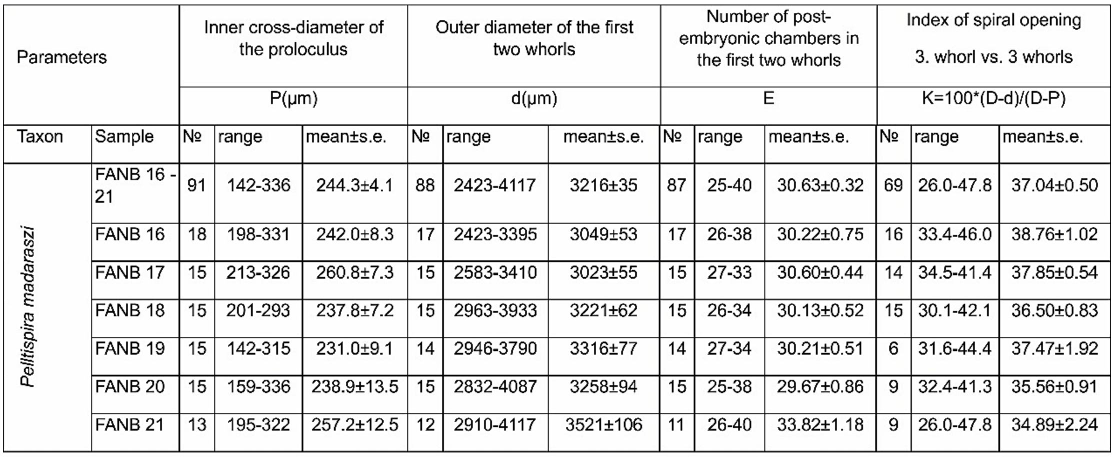
Material: *P. madaraszi* was recovered exclusively from the upper part of the section (FAN B).

Description: Although this taxon has been reported from many localities from the Greek territory, a morphometric analysis is conducted here for the first time (Table 3). The diameter of B forms reaches up to 9 mm. Meanwhile, the diameter of the test of the A-forms varies between 4-6 mm, thus sexual dimorphism is distinctive. The mean inner cross-diameter of the A-form proloculus ($P_{mean±s.e.}$) is 244.3±4.1 μm, for other parameters (measured and counted exactly in the same way as it is introduced by Less 1999 for *Nummulites*) see Table 3.

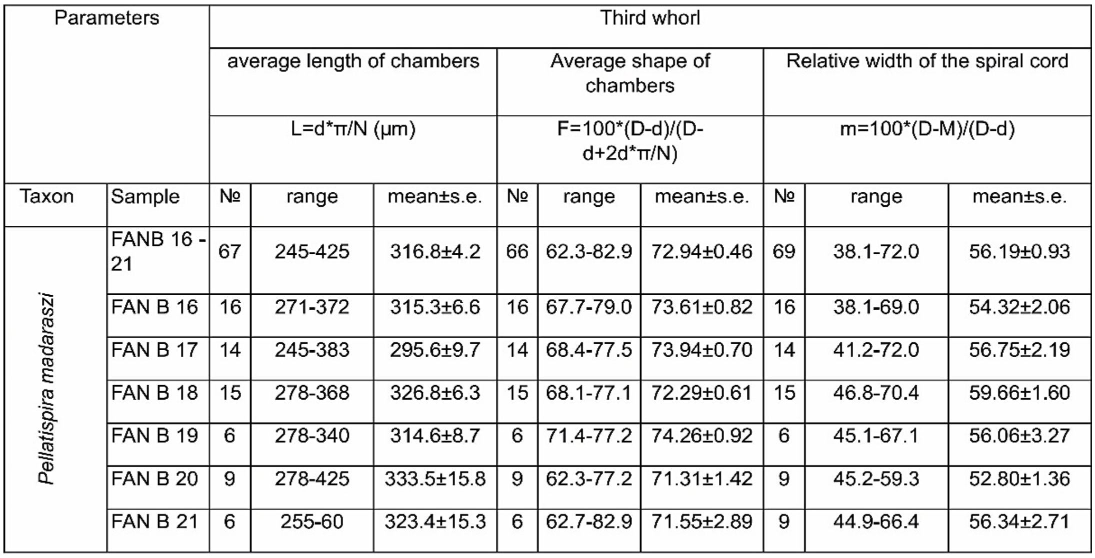
Remarks: A total number of 3.809 specimens were collected, making it one of the most abundant species. Specifically, it increases progressively and reaches its pick of 1226 specimens in the highest sample of the section FAN B 21. On the other hand, it is almost absent from the first sample (FAN B 15) of the outcrop. Both generations of the taxon were found, although B-forms are very rare (altogether 6 specimens were recovered). *Pellatispira madaraszi* is reported from the Greek territory from Zakynthos Island (Mirkou-Peripopolou 1975), Cephalonia Island (Accordi et al. 1998), Klokova Mt. by Fleury (1980) and by Barattolo et al. (2007) and from Perivoli (Grevena) by Dimou et al. (2021).

Stratigraphic range: *P. madaraszi* corresponds to SBZ 18B-20 Zones, thus it spans through the whole Priabonian (Serra-Kiel et al. 1998; Less et al. 2011) (Fig. 14).

Table 3. Statistical data of *Pellatispira madaraszi* populations. №: number of specimens, s.e.-standard error.



Parameters		Inner cross-diameter of the proloculus			Outer diameter of the first two whorls			Number of post-embryonic chambers in the first two whorls			Index of spiral opening 3. whorl vs. 3 whorls		
		P(µm)			d(µm)			E			K=100*(D-d)/(D-P)		
Taxon	Sample	№	range	mean±s.e.	№	range	mean±s.e.	№	range	mean±s.e.	№	range	mean±s.e.
Pelltispira madaraszi	FANB 16 - 21	91	142-336	244.3±4.1	88	2423-4117	3216±35	87	25-40	30.63±0.32	69	26.0-47.8	37.04±0.50
	FANB 16	18	198-331	242.0±8.3	17	2423-3395	3049±53	17	26-38	30.22±0.75	16	33.4-46.0	38.76±1.02
	FANB 17	15	213-326	260.8±7.3	15	2583-3410	3023±55	15	27-33	30.60±0.44	14	34.5-41.4	37.85±0.54
	FANB 18	15	201-293	237.8±7.2	15	2963-3933	3221±62	15	26-34	30.13±0.52	15	30.1-42.1	36.50±0.83
	FANB 19	15	142-315	231.0±9.1	14	2946-3790	3316±77	14	27-34	30.21±0.51	6	31.6-44.4	37.47±1.92
	FANB 20	15	159-336	238.9±13.5	15	2832-4087	3258±94	15	25-38	29.67±0.86	9	32.4-41.3	35.56±0.91
	FANB 21	13	195-322	257.2±12.5	12	2910-4117	3521±106	11	26-40	33.82±1.18	9	26.0-47.8	34.89±2.24



Parameters		Third whorl								
		average length of chambers			Average shape of chambers			Relative width of the spiral cord		
		L=d*π/N (µm)			F=100*(D-d)/(D-d+2d*π/N)			m=100*(D-M)/(D-d)		
Taxon	Sample	№	range	mean±s.e.	№	range	mean±s.e.	№	range	mean±s.e.
Pellatispira madaraszi	FANB 16 - 21	67	245-425	316.8±4.2	66	62.3-82.9	72.94±0.46	69	38.1-72.0	56.19±0.93
	FAN B 16	16	271-372	315.3±6.6	16	67.7-79.0	73.61±0.82	16	38.1-69.0	54.32±2.06
	FAN B 17	14	245-383	295.6±9.7	14	68.4-77.5	73.94±0.70	14	41.2-72.0	56.75±2.19
	FAN B 18	15	278-368	326.8±6.3	15	68.1-77.1	72.29±0.61	15	46.8-70.4	59.66±1.60
	FAN B 19	6	278-340	314.6±8.7	6	71.4-77.2	74.26±0.92	6	45.1-67.1	56.06±3.27
	FAN B 20	9	278-425	333.5±15.8	9	62.3-77.2	71.31±1.42	9	45.2-59.3	52.80±1.36
	FAN B 21	6	255-60	323.4±15.3	6	62.7-82.9	71.55±2.89	9	44.9-66.4	56.34±2.71

Orthophragmines

Orbitoidal forms of the late Paleocene and Eocene are united under the informal name of orthophragmines, which include two co-occurring but independent families, Discocyclinidae and Orbitoclypeidae. Their distinction and generic subdivision were described by Less (1987), Ferràndez-Cañadell (1998) and recently by Özcan et al. (2022). Based on the development of numerous lineages, reflected first of all in the gradual increase of the megalospheric embryo, Less (1987, 1998) established an orthophragminid (OZ) zonation integrated into the larger benthic foraminiferal (SBZ) zonation of Serra-Kiel et al. (1998). Most of these lineages are interpreted as species and arbitrarily subdivided into chronosubspecies in Less (1987, 1998), and then in subsequent papers summarized by Özcan et al. (2022), which also contains the most updated stratigraphic range of the particular taxa (species and subspecies).

Since the preservation of orthophragmines is rather poor in the Fanari section, they are not studied in a large quantity, and therefore a reliable determination at the subspecific level was not always possible. As up-to-date descriptions of orthophragminid taxa are available in Özcan et al. (2022), below they are not presented. Among the morphometric parameters, the outer cross diameter of the megalospheric deuteroconch (d), essential for subspecific determination was systematically measured (Table 4).

Different orthophragminid taxa were mentioned from Greece by Kopp (1965), Christodoulou (1967), Accordi et al (1998), Dimou et al. (2021), however they were assigned to different species based on their external features contrary to the concept introduced by Less (1987)), who determine taxa mainly on the basis of internal characteristics. Since these earlier reports on orthophragmines from Greece (see above) are not accompanied by illustrations of the internal features, there is no meaning to correlate these determinations with the recently used names, with the exception of the ribbed *Discocyclina radians* (see there).

Family DISCOCYCLINIDAE Galloway 1928

Genus *Discocyclina* Gümbel 1870

Discocyclina occurs abundantly in the upper part of the section, unlike in the lower part that none was recovered. Four species and two subspecies were determined, while *D. euaensis* and the subspecies are described and measured for the first time from the Eocene deposits of Greece.

Discocyclina augustae van der Weijden 1940

1940 *Discocyclina augustae* van der Weijden, p. 23-26, pl. 1, figs. 4, 5, 7, 8; pl. 2, figs. 1, 2, 11.

1987 *Discocyclina augustae* van der Weijden; Less, p. 151-156, pl. 9, figs. 7, 9-12, pl. 10, figs. 1-6, 8-12, pl. 11, figs. 1-4, pl. 17, fig. 4 (with four subspecies and synonymies).

2022 *Discocyclina augustae* van der Weijden; Özcan et al., p. 38, figs. 22.6, 26.2, 29.5, 6, 52.1-13, 53.

Material: Only one specimen of this unribbed species was recovered only from sample FAN B 18. Therefore, it cannot be attributed to any subspecies.

Description: The outer cross-diameter of the deuteroconch (d) is 271 μm, which is most characteristic for *D. augustae augustae* (Table 4).

Stratigraphic range: According to Özcan et al. (2022) the stratigraphic range of the above taxon corresponds to the SBZ 18B-20 Zone, thus to the Priabonian (Fig. 14).

Discocyclina dispansa (Sowerby 1840)

Plate 4, figures A-C

1840 *Lycophris dispansus* Sowerby, p. 327, pl. 24, figs. 16, 16a-b.

1987 *Discocyclina dispansa* (Sowerby); Less, p. 157-165, pl. 11, figs. 10-13, pl. 12, figs. 1-12, pl. 13, figs. 1-12, pl. 14, figs. 1-8 (with seven subspecies and synonymies).

2022 *Discocyclina dispansa* (Sowerby); Özcan et al., p. 40, 44, figs. 23.3-5, 30.1-3, 56.1-8, 57.1-11, 58, 59, 60.

Material: This unribbed taxon occurs only in the material of FAN B outcrop (except of sample FAN B 15).

Description: The outer cross-diameter of the deuteroconch (d) ranges between 479 and 782 μm, while $d_{mean \pm s.e}$ is 573.9±16.1 μm based on 24 specimens, which determines *D. dispansa umbilicata* (Table 4).

Stratigraphic range: According to Özcan et al. (2022) the stratigraphic range of this taxon corresponds to SBZ 19-20 (Fig. 14).

Discocyclina euaensis Whipple 1932

Plate 4, figures G-H

1932 *Discocyclina euaensis* Whipple, p. 84, pl. 22, figs. 3-7, text fig. 6.

1987 *Discocyclina euaensis* Whipple; Less, p. 175-176, pl. 19, figs. 4-6 (with synonymy).

2022 *Discocyclina euaensis* Whipple; Özcan et al., p. 44, figs 61.1-6, 62.

Material: A few specimens were recovered from FAN B 16,18 and 21.

Description: Internally this species resembles *D. radians* however lacks ribbing. The outer cross-diameter of the deuteroconch (d) ranges between 375 and 441 μm, while $d_{mean±s.e}$ is 408.2±7.6 μm based on 8 specimens (Table 4), which fits very well to the data from Hungary (Less 1987) and Turkey (Özcan et al. 2007).

Stratigraphic range: According to Özcan et al. (2022), *D. euaensis* indicates the SBZ 18-20 Zones (latest Bartonian to Priabonian, Fig. 14).

Discocyclina radians (d'Archiac 1850)

Plate 4, figures D-F

1850 *Orbitolites radians* d'Archiac, p. 405, 406, pl. 8, figs. 15, a-b.

1987 *Discocyclina radians* (d'Archiac); Less, p. 166-169, pl. 15, figs. 1-15, pl. 16, figs. 1-7 (with three subspecies and synonymies).

2022 *Discocyclina radians* (d'Archiac); Özcan et al., p. 52, 54, figs. 4E, 27.1, 88.1-10, 89, 90 (with four subspecies).

Material: This species is the only ribbed discocyclinid form found in the study area. It is present in the material of FAN B and absent from the whole outcrop of FAN A and sample FAN B 15.

Description: The outer cross-diameter of the deuteroconch (d) ranges from 342 to 470 μm, while $d_{mean±s.e}$ is 393.8±23.7 μm based on 4 specimens, which indicate *D. radians labatlanensis* (Table 4).

Remarks: Based on their well recognizable external features Fleury (1980) and later Barattolo et al. (2007) from Klokova Mt., Christodoulou (1968) from Pserimos Island and Kopp (1965) from Melia (Greek part of Thrace basin) reported these ribbed forms from the Bartonian-Priabonian deposits of Greece, under the generic name of *Actinocyclina* (or *Aktinocyclina*), an abandoned genus according to Ferràndez-Cañadell (1997; 1998).

Stratigraphic range: According to Özcan et al. (2022) this suggests a latest Bartonian-Priabonian (SBZ 17-20 Zones; Fig. 14) age.

Family ORBITOCLYPEIDAE Brönnimann 1946

Genus *Orbitoclypeus* Silvestri 1907

The genus *Orbitoclypeus* has only been reported and illustrated from the late Paleocene deposits (SBZ 3) of Cephalonia Island by Accordi et al. (1998), however without any description. In Fanari, two species are found and shortly described for the first time from the Eocene of Greece.

Orbitoclypeus furcatus (Rütimeyer 1850)

Plate 4, figure I

1850 *Orbitulites furcata* Rütimeyer, p. 118, pl. 5, fig. 75.

1987 *Orbitoclypeus furcata* (Rütimeyer); Less, p. 214-217, pl. 32, figs. 5-11, pl. 34, figs. 1-7, text-figs. 30 r-t (with two subspecies and synonymies).

2022 *Orbitoclypeus furcatus* (Rütimeyer); Özcan et al., p. 80, 85, figs 27.4, 34.3, 134.1-5, 135.1-5, 136.1-3, 137 (with four subspecies).

Material: *Orbitoclypeus furcatus* with characteristic bifurcating ribs is very rare and only a few specimens were recovered from samples FAN B 15, 18and 21.

Remarks: Because of their low frequency, none of them has been under any preparation techniques. Nevertheless, the specimens found can be identified due to their characteristic bifurcation.

Stratigraphic ranges: According to Özcan et al. (2022), the stratigraphic range of *O. furcatus* corresponds to the SBZ 10-20 Zones (Fig. 14).

Orbitoclypeus varians (Kaufmann 1867)

Plate 4, figure J

1867 *Orbitoides varians* Kaufmann, p. 158-160, pl. 10, figs. 1-10.

1987 *Orbitoclypeus varians* (Kaufmann); Less, p. 207-214, pl. 28, figs. 9-12, pl. 29, figs. 1-12, pl. 30, figs. 1-12, pl. 31, figs. 1-12, pl. 32, figs. 1-4 (with five subspecies and synonymies).

2022 *Orbitoclypeus varians* (Kaufmann); Özcan et al., p. 114, figs 28.3-4, 37.9-10, 152.1-9, 153.1-9, 154, 155, 156 (with six subspecies).

Material: The unribbed *O. varians* is very rare in Fanari material. A few specimens were recovered from FAN B, whereas only two of them could be measured.

Description: The outer cross-diameter of the deuteroconch ranges from 317 μm to 370 μm (Table 4). Based on these two measurements, the subspecific attribution cannot be attempted although it probably belongs to the *O. v.* cf. *scalaris* according to the deuteroconch size and morphological features.

Stratigraphic range: According to Özcan et al. (2022), the stratigraphic range of *O. v.* cf. *scalaris* corresponds to the SBZ 16-20 Zones (Fig. 14).

Genus *Asterocyclina* Gümbel 1870

The genus of *Asterocyclina* has been previously reported from the Greek deposits from several localities (e.g., Kopp 1965; Christodoulou 1967; Accordi et al. 1998) but neither further determination nor morphometric measurements were conducted. In this research, representatives of three species were found, described, and measured for the first time from the Eocene of Greece. They occur abundantly in samples of FAN B section. On the other hand, they were absent from samples of FAN A section.

Asterocyclina alticostata (Nuttall 1926)

Plate 4, figures N-P

1926 *Actinocyclina alticostata* Nuttall, p. 151, pl. 8, figs. 6-8.

1987 *Asterocyclina alticostata* (Nuttall); Less, p. 240-244, pl. 43, figs. 9-12, pl. 44, figs. 1-11, pl. 45, figs. 1-11 (with four subspecies and synonymies).

2022 *Asterocyclina alticostata* (Nuttall); Özcan et al., p. 120, figs. 6B, 27.5, 36.9-10, 159.1-10, 160.

Material: This easily recognizable taxon is common in samples of FAN B outcrop.

Description: The outer cross-diameter of the deuteroconch (d) ranges between 360 and 636 µm, while $d_{mean±s.e}$ is 496.2±19 µm based on 18 specimens (Table 4).

Stratigraphic range: This calls for *A. a. danubica*, the most advanced chronospecies of *A. alticostata* with a stratigraphic range of SBZ 18B-20 Zones (comprising the entire Priabonian) according to Özcan et al. (2022) (Fig. 14).

Asterocyclina stellata (d’Archiac 1846)

Plate 4, figures K-L

1846 *Calcarina stellata* d’Archiac, p. 199, pl. 7, figs. 1, 1a.

1987 *Asterocyclina stellata* (d’Archiac); Less, p. 233-237, pl. 37, figs. 1-12, 38, figs. 1-11, pl. 39, figs. 1-4, 7-12, pl. 40, figs. 1-11, pl. 41, figs. 1-6 (with three subspecies and synonymies).

2022 *Asterocyclina stellata* (d'Archiac); Özcan et al., p. 174, 178, figs. 4D, 11.6-7, 27.6, 172.1-10, 173 (with four subspecies).

Material: This taxon was recovered from FAN B samples.

Description: The outer cross-diameter of the deuteroconch (d) ranges between 174 and 230 µm, while $d_{mean\pm s.e}$ is 207.8±9.5 µm based on 5 specimens (Table 4).

Stratigraphic range: This indicates *A. s. stellaris* with a stratigraphic range of SBZ 17 to 19 Zones according to Özcan et al. (2022). The present study suggests that this range should be extended till the end of the Priabonian (SBZ 20) (Fig. 14).

Asterocyclina stella (Gümbel 1861)

Plate 4, figure M

1861 *Hymenocyclus stella* Gümbel, p. 653.

1987 *Asterocyclina stella* (Gümbel); Less, p. 226-227, 230-233, pl. 42, figs. 7-12 (with three subspecies and synonymies).

2007 *Asterocyclina stella* (Gümbel); Özcan et al., p. 507-508, pl. 4, figs. 4-7 (with emended subdivision into two subspecies).

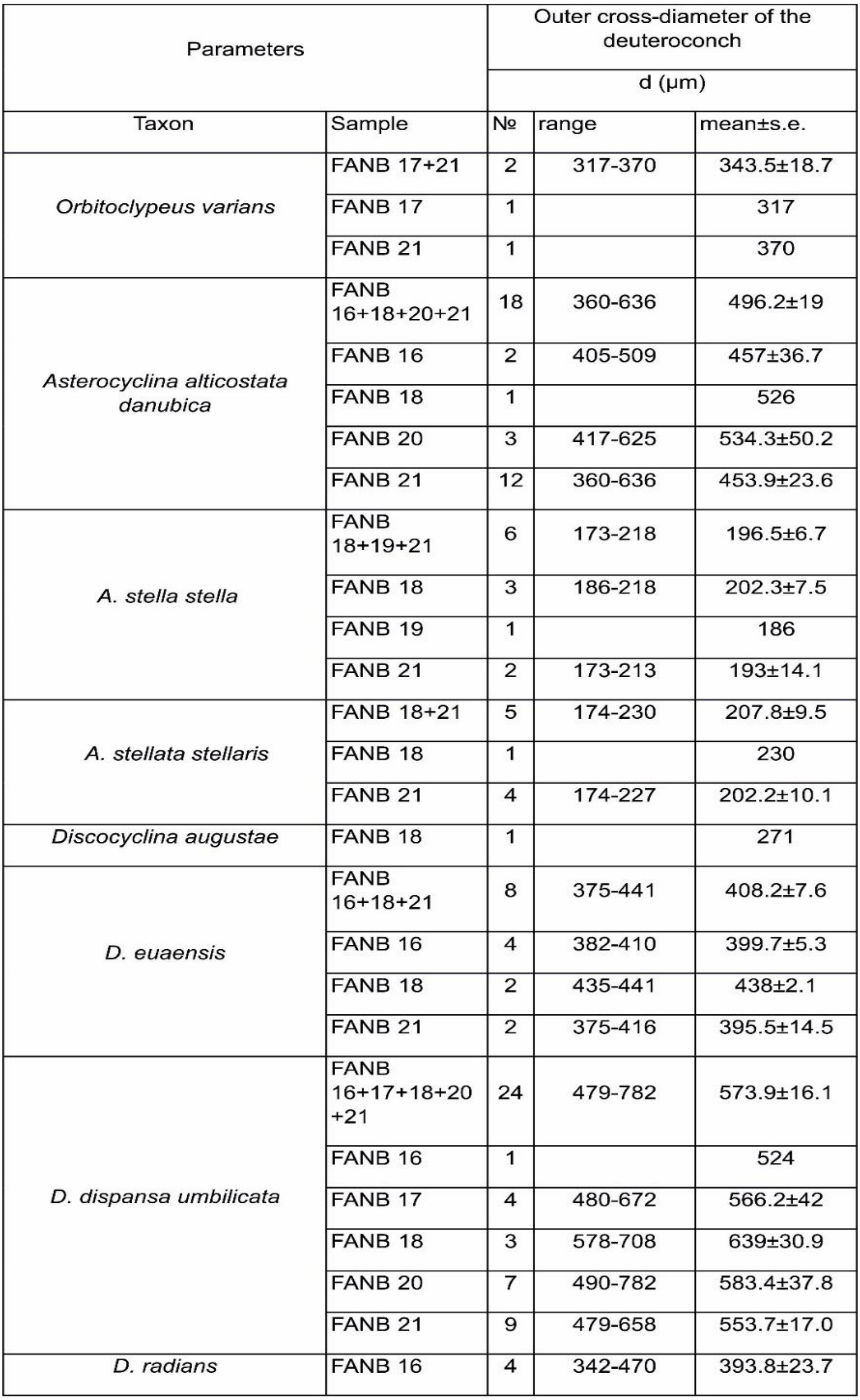
2022 *Asterocyclina stella* (Gümbel); Özcan et al., p. 174, figs. 170.4-9, 171.

Material: This taxon was recovered from samples of FAN B section.

Description: The outer cross-diameter of the deuteroconch (d) ranges between 173 and 218 µm, while $d_{mean\pm s.e}$ is 196.5±6.6 µm based on 6 specimens (Table 4).

Stratigraphic range: This could suggest the chronosubspecies *A. s. stella* with a stratigraphic range of SBZ 13 to 20 Zones according to Özcan et al. (2022) (Fig. 14).

Table 4. Statistical data of orthophragmines populations. №: number of specimens, s.e.- standard error.



Parameters		Outer cross-diameter of the deuteroconch		
		d (µm)		
Taxon	Sample	№	range	mean±s.e.
Orbitoclypeus varians	FANB 17+21	2	317-370	343.5±18.7
	FANB 17	1		317
	FANB 21	1		370
Asterocyclina alticostata danubica	FANB 16+18+20+21	18	360-636	496.2±19
	FANB 16	2	405-509	457±36.7
	FANB 18	1		526
	FANB 20	3	417-625	534.3±50.2
	FANB 21	12	360-636	453.9±23.6
A. stella stella	FANB 18+19+21	6	173-218	196.5±6.7
	FANB 18	3	186-218	202.3±7.5
	FANB 19	1		186
	FANB 21	2	173-213	193±14.1
A. stellata stellaris	FANB 18+21	5	174-230	207.8±9.5
	FANB 18	1		230
	FANB 21	4	174-227	202.2±10.1
Discocyclina augustae	FANB 18	1		271
D. euaensis	FANB 16+18+21	8	375-441	408.2±7.6
	FANB 16	4	382-410	399.7±5.3
	FANB 18	2	435-441	438±2.1
	FANB 21	2	375-416	395.5±14.5
D. dispansa umbilicata	FANB 16+17+18+20+21	24	479-782	573.9±16.1
	FANB 16	1		524
	FANB 17	4	480-672	566.2±42
	FANB 18	3	578-708	639±30.9
	FANB 20	7	490-782	583.4±37.8
	FANB 21	9	479-658	553.7±17.0
D. radians	FANB 16	4	342-470	393.8±23.7

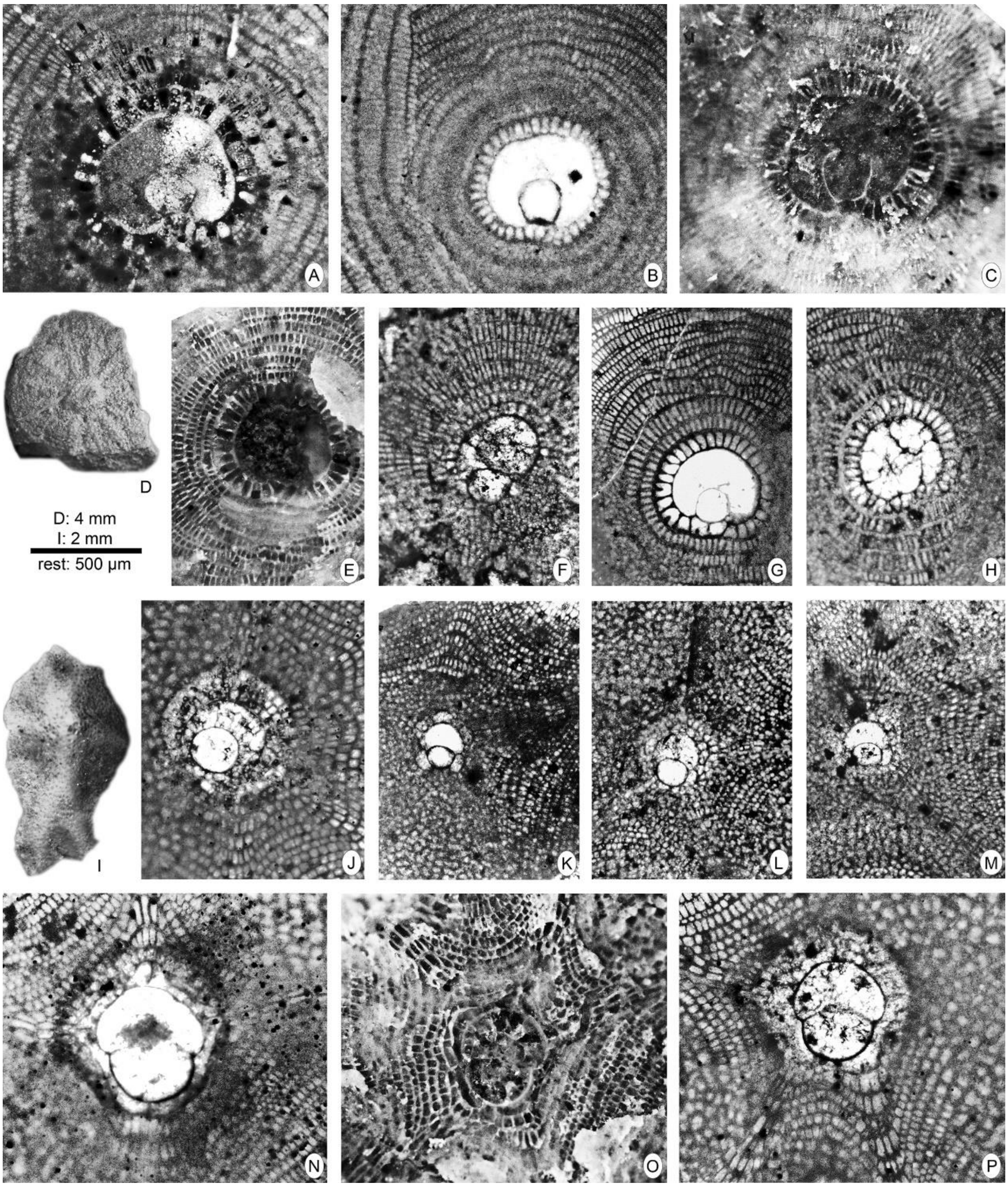


PLATE 4. A-C *Discocyclina dispansa umbilicata* (Deprat 1905), A, FAN B 21.1; B, FAN B 21.3; C, FAN B 19.7. D-F *Discocyclina radians labatlanensis* Less 1987, D, FAN B 19.1; E, FAN B 17.1; F FAN B 16.8. G-H *Discocyclina euaensis* Whipple 1932, G, FAN B 16.3; H, FAN B 16.6. I *Orbitoclypeus furcatus* (Rütimeyer 1850) FAN B 21. J *Orbitoclypeus varians* cf. *scalaris* (Schlumberger 1903) FAN B 21.2. K-L *Asterocyclina stellata stellaris* (Brünner in Rütimeyer 1850), K, FAN B 21.12; L FAN B 21.16. M *Asterocyclina stella stella* (Gümbel 1861), FAN B 18.5. N-P *Asterocyclina alticostata danubica* Less 1987, N, FAN B 16.1; O, FAN B 16.8; P, FAN B 21.10. All A-forms and equatorial sections apart from D, I- external views.

Family CALCARINIDAE d'Orbigny 1826

Genus *Silvestriella* Hanzawa 1952

Silvestriella tetraedra (Gümbel 1870)

Plate 5, figure D-H

1870 *Calcarina tetraedra* Gümbel, p. 656, taf. II, fig. 97a, b.

2012 *Silvestriella tetraedra* (Gümbel); Less & Özcan, fig. 5h.

2019 *Silvestriella tetraedra* (Gümbel); Özcan et al., fig. 6 A-G.

2020 *Silvestriella tetraedra* (Gümbel); Zakrevskaya et al., fig. 21 l-n.

Material: This species is recovered from samples of FAN B outcrop.

Description: The external features of this species are specific and unique since the test consists of three to four spines that are joined in a central base. The test is large, almost triangular in outline and the spines are long, cylindrical near the base and cuspidal at the ending. The surface of the test is generally smooth but sometimes with ornamentation. In the equatorial section, the proloculus is spherical. The following second and third chambers present almost the same features. The rest of the chambers are subrectangular. The septa are thin, slightly curved to nearly straight. The spines are canaliculate throughout and characterized by concentric rings.

Remarks: *S. tetraedra* has been previously reported from the Hellenic peninsula from the Bartonian of Vasiliki Trikala, Mesohellenic Trough (Dimou et al. 2021). However, its systematic description from the Greek material is presented here for the first time.

Stratigraphic range: Stratigraphic distribution of *S. tetraedra* refers to SBZ 18-20 (Serra-Kiel et al. 1998; Less et al. 2011; Yücel et al. 2020).

Family CYMBALOPORIDAE Cushman 1927

Genus *Fabiania* Silvestri 1924

Fabiania cassis (Oppenheim) 1896

Plate 5, figures I-L

1896 *Patella (Cymbiola) cassis* Oppenheim, p. 55-56, pl. 2, figs. 2-3.

1982 *Fabiania cassis* (Oppenheim); Samanta, p. 262, pl. 1, figs. a-d, pl. 2, figs. a-e.

2018 *Fabiania cassis* (Oppenheim); Özcan et al., fig. 16 M.

Material: *Fabiania cassis* occurs only in the lower part of the sequence, in samples FAN A 3 to 9.

Description: Externally, the test is medium to large, low to high conical and laterally compressed. Dorsal side convex with a bluntly rounded apex and thick calcareous perforate outer wall. The umbilical side is empty. Internally, the two embryonic chambers are characterized by a medium protoconch of subspherical shape and a second larger, unequal, elliptical deuteroconch. Later chambers were added in a cyclic series. They are subdivided into chamberlets of different sizes and shape (subrectangular to subspherical). The basal outline is irregular and wavy.

Remarks: The genus has been previously reported from the Hellenic peninsula from the Thessaloniki-Jannitza area (Mercier 1960) and Samothraki Island (Christodoulou 1957). However, Mirkou-Peripopolou (1974) and Accordi et al. (1998) noted the species *F. cassis* of Zakynthos and Cephalonia Island respectively.

Family ACERVULINIDAE Schultze 1854

Genus *Sphaerogypsina* Galloway 1933

Sphaerogypsina globulus (Reuss) 1848

1848 *Ceriopora globulus* Reuss, p. 33, pl. 5, fig. 7.

2018 *Sphaerogypsina globulus* (Reuss); Özcan et al., fig. 16 H-I.

2020 *Sphaerogypsina globulus* (Reuss); Zakrevskaya et al., fig. 21 k.

Plate 5, figures A-C

Material: The first occurrence of *Sphaerogypsina globublus* is at FAN A 3 sample and is present in almost all samples.

Description: Externally, the test is medium to large and spherical in shape. Sometimes it is almost irregular. The outer surface is characterized by very strong and raised septal filaments that run over the test surface, creating polygonal, angular to circular, large pores. Internally, the protoconch is surrounded by chambers arranged in a regular pattern of radial columns.

Remarks: This species has been previously reported from the Hellenic peninsula from Klokova Mt. (Barattolo et al. 2007), Pserimos Island (Christodoulou 1968) and from the Bartonian of Vasiliki Trikala, Mesohellenic Trough (Soliman and Zygojiannis 1977; Dimou et al. 2021), where has been studied from random thin sections. However, its systematic description from the Greek material is presented here for the first time.

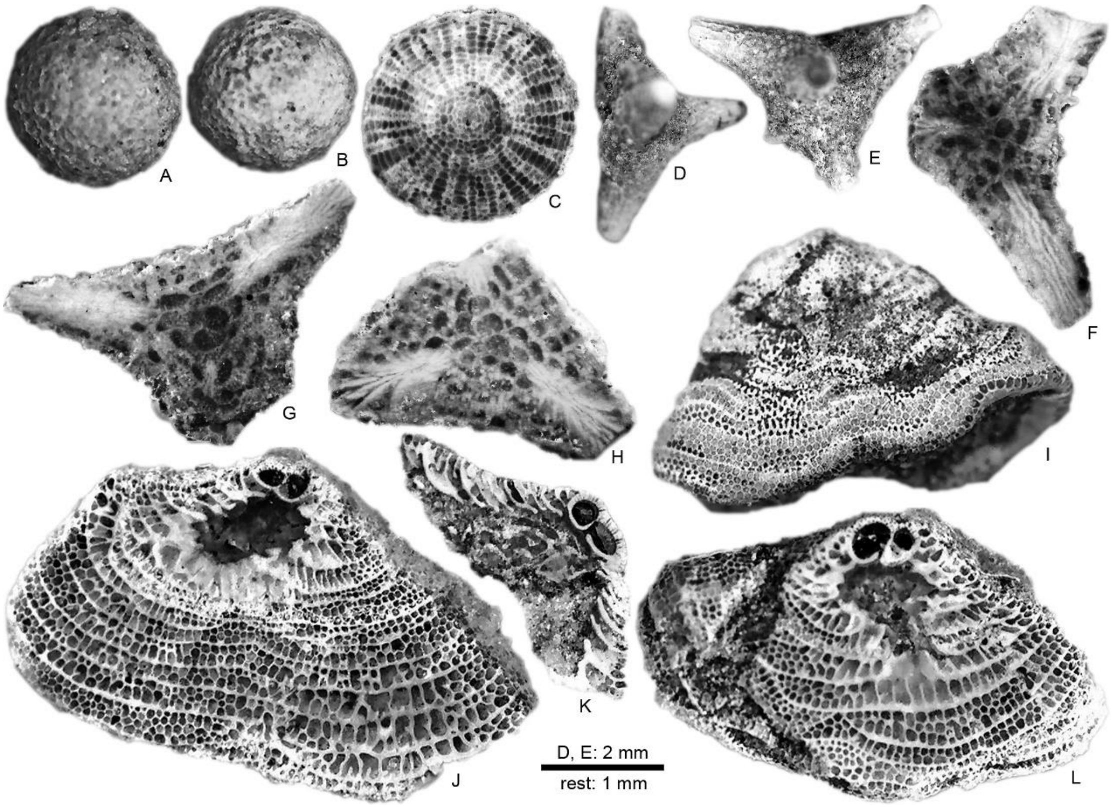


PLATE 5. A-C *Sphaerogyspina globulus*, A-B, FAN B 19 (micropaleontological slide,2/3,2); C, FAN B 18.1. D-H *Silvestriella tetraedra* (Gümbel 1870), D-E, FAN B 16 (micropaleontological slide,2/3,5); F, FAN B 18.5; G, FAN B 18. 4; H, FAN B 18. 2. I-L *Fabiania cassis*, I, FAN A 6; J, FAN A 6.1; K, FAN A 6.4; L, FAN A 6.2. All A-forms. A, B, D, E, I- external views, C, F, G, H, J, K, L-equatorial sections.

4.6 PALEOENVIRONMENTAL INTERPRETATION

The faunal composition allowed us to make approximate paleodepth range estimations and paleoenvironmental observations, thus reconstructing the depositional evolution of Fanari region. Three main biofacies and their implementation to depositional marine shelf facies that operated at the shallow upper foreslope of the carbonate platform of the Thrace basin, have been recognized (Fig. 11).

Biofacies I: (FAN A 1-10) Dark-colored, fine-grained sediments with nummmulitids. The foraminiferal fauna is dominated by the reticulate *Nummulites fabianii*, common *N. garnieri*, *Assilina alpina*, almost absent *Heterostegina gracilis*, *H. reticulata and Spiroclypeus carpaticus*. Quite a large number of the LBF’s tests, characterized by encrustation and borings are common. Small benthic foraminifera are represented by abundant rotaliids, rare bolivinids, buliminids, texturariids, nodosariids, cast of miliolids and polymorphiniids. In addition, bivalves, echinoids, gastropods, and corals, as well as their fragments occur in minor amounts along with rare ostracods, *Fabiania cassis* and *Sphaerogypsina globulus*.

Biofacies II: (FAN A 11-14) Light yellowish brown, with equal gradients of silt and sand, sediment. The assemblage is characterized mainly by small rotaliids. Minor elements are *Nummulites garnieri, N. fabianii*, ostracods, other groups of SBF, planktonic foraminifera and fragments of echinoids, bivalves, and bryozoans. Encrustation is also present on the tests.

At this part of the sequence the total LBF content declines dramatically, as nummulitids display a gradual decrease in density and diversity, while at the same time *Fabiania* and *Sphaerogypsina* disappear. This is most possibly the result of unstable environmental conditions suggesting a transitional zone between the shallower Biofacies I to the following deeper Biofacies III.

Biofacies III: FAN B outcrop corresponds to a bioclastic sandstone. The predominant constituent of the sandstone is the fossil tests of *Pellatispira madaraszi*, *Spiroclypeus carpaticus*, *Nummulites fabianii, N. incrassatus*, *Operculina* ex gr. *gomezi*, *Assilina alpina*, *Discocyclina dispansa umbilicata*, *D. radians labatlanensis*, *D. euaensis*, *D. augustae*, *Orbitoclypeus varians* cf. *scalaris*, *Asterocyclina stellata stellaris*, *A. stella stella*, *A. alticostata danubica*, and abundant small rotaliids. Minor components are *Heterostegina gracilis*, *Nummulites budensis*, *N. stellatus, Orbitoclypeus furcatus, Silvestriella tetraedra, Sphaerogypsina globulus,* other SBF, globigerinids, ostracods, brachiopods, fragments of corals, echinoids, bivalves, and gastropods. The microfaunal tests seem to be oriented with a slight inclination. Minor elements are the quartz grains and pebbles of other non-carbonate grains. Between the grains, mud occurs.

4.7 DISCUSSION-CONCLUSIONS

The Fanari section can be considered as one of the most important sites of the Greek part of the Thrace basin in micropaleontological and paleoenvironmental terms. Primarily, for its accessibility and the good preservation mainly of foraminifera but also of the rest of the fauna. Secondly, it comprises comprehensive data of the uppermost Eocene assemblages and constitutes one of the most diverse in LBF sequences of the Tethys realm with 24 different taxa. This can be compared with other recently studied LBF assemblages from the SBZ 20 zone: the "Nodular limestone" and "*Asterocyclina* beds" from Priabona (N Italy) contain about 20 LBF taxa (Sirotti 1978; Setiawan 1983; redetermined by Less 1998); in Kisgyőr, Remete-kút (NE Hungary) 17 LBF taxa are listed in Less (1999) and Less et al. (2000); from the Turkish part of the Thrace Basin

Yücel et al. (2020) found 17 taxa in Gökçetepe and 16 taxa in Karaburun, while Özcan et al. (2010) mentions 16 taxa from Mecidiye. The presence of 15-20 different LBF taxa can be estimated also from the "Calcari di San Giustina" from Possagno (N Italy) based on the data by Herb and Hekel (1975) and Herb (1978). Other localities ranked into the SBZ 20 zone in Less and Özcan (2012) (Benidorm - SE Spain; Baciu - NW Romania; Biarritz, Lou Cachaou - SW France; Maiella - Central Italy; Pinarhisar and Kiyiköy - Turkish part of the Thrace Basin, with references therein) seem to contain less than 10 different LBF taxa.

Biostratigraphical and paleoenvironmental inferences of the investigated site are summarized in text-figs. 10 and 11 respectively. Most of the investigated species are reported and described in detail for the first time from this area and generally from the Greek peninsula. Moreover, biometric measurements are applied for the first time in this material (Tables 1, 2, 3 and 4). The foraminiferal assemblage is represented by a rich and diverse microfauna of twenty-four taxa, among which six (chrono)subspecies, belonging to twelve genera as described above. The only species constantly retrieved from almost the whole section is *Nummulites fabianii*. Another worth mentioning fact is the increase in the inner cross section of the proloculus of *S. carpaticus*. It was detected in the upper part of the outcrop; hence two groups were distinguished. However, this size variation associated with the population proliferation is not yet clear if it’s either environmentally controlled, evolutionary originated, or a combination of multiple parameters.

The Eocene deposits from the Fanari site of the Greek Thrace basin can be dated mainly with LBF of the families Nummulitidae and orthophragmines. Based on the co-occurrence and first appearance of *S. carpaticus* and *H. gracilis* already from the beginning of FAN A to the end of the section, the age of the whole sedimentary succession is defined as late Priabonian (SBZ 20 Zone). According to Özcan et al. (2022), the stratigraphic range of *A. s. stellaris* corresponds to SBZ 17-19, although its presence in the Fanari section if confirmed with the biometric analysis of statistically significant population, the stratigraphic range of the subspecies could be extended to the SBZ 20. The foraminiferal assemblage presented herein displays great similarity to those reported from several western parts of the Tethyan realm (NE Spain, Serra-Kiel et al. 2003; N. Italy, Papazzoni and Sirotti 1995; Hungary, Less et al. 2000; E. Turkey, Özcan et al. 2007) and has also been recorded in the Thrace Basin (for the southern part see Özcan et al. 2010). Thus, it can be stated that the Fanari section is a key area of the latest Priabonian.

According to the biofacies analysis, the nearly monospecific and highly abundant nummulitid assemblage of Biofacies I indicates a most probably shallow, quiet and restricted to the shelf edge environment (Beavington-Penney and Racey 2004 and references therein; Gebhardt et al. 2013; Torres-Silva et al. 2019). This hypothesis is supported by the faunal composition of relatively low species diversities, the absence of orthophragmines and the scarce presence of *Heterostegina*, suggesting a low-energy water, shelf environment limited to the shallowest parts of the upper slope (Setiawan 1983; Hallock and Glenn 1986).

A transitional facies is reported in Biofacies II. During the deposition of the Biofacies III the orthophragmines become more and more frequent and as suggested by Ćosović et al. (2004), their abundance and diversity increase showing a positive trend with depth of deposition, at the same time that the shallow water foraminifera of Biofacies I significantly decrease (Fig. 11). This diverse biota comprised mainly of flat tests and planktonic foraminifera, associated with a deepening of the depositional environment (Beavington-Penney and Racey 2004). Furthermore, according to Ghose (1977), the abundance of *Pellatispira,* that dominates the assemblages referred to the Biofacies III, suggests a fore-slope environment. In the same time frame '*Pellatispira* beds' are documented from the early Priabonian of Pakistan (Eames 1951; Özcan et al. 2019) and have been deposited in the outer shelf setting, associated with a diverse fauna (*N. hormoensis*, *Silvestriella tetraedra*, *Pellatispira madaraszi*, *Heterostegina indusen*, *Assilina* ex. gr. *alpina*, *Linderina* sp. and *Baculogypsina* n. sp.). Our findings present similarities but also differences in faunal composition, even if the depositional paleoenvironments are similar. However, this mass abundance could be characterized as a *Pellatispira*-bed or a *Pellatispira-Spiroclypeus*-bed.

The specimens test, without severe abrasion except for the fragmentation of the thin flanges of large orthophragmines, indicate autochthonous to para-autochthonous accumulations, a sudden deepening-upwards and thus a shift to a deeper environment of the upper foreslope during a general transgressive phase, with open marine influences and possible sporadic terrigenous influx (Setiawan 1983; Hallock and Glenn 1986; Beavington-Penney and Racey 2004; Ćosović et al. 2004).

Generally, a mixture of autochthonous and allochthonous specimens is always expected in such deposits (Hohenegger and Yordanova 2001; Beavington-Penney and

Racey 2004; Briguglio and Hohenegger 2011). In the Fanari composite section evidence of a degree of transportation is implied. However, the LBF preservation and the absence of specimens from different depths or environments points to a minor allochthony or displacement, possibly due to a smooth slope inclination and a short distance transportation.

The Fanari sedimentary succession constitutes the upper foreslope environment of a carbonate platform, most probably of the Avas Formation belonging to Alexandroupolis sub-basin. The Eocene of Greece is the missing piece of the Tethyan jigsaw puzzle and therefore further investigation concerning the micropaleontology of small and large benthic foraminifera, their biostratigraphic distribution and paleoecological interpretation is already carried out and is going to be published separately. The Fanari site can serve as a key area of latest Priabonian and a well-exposed analogue for paleoenvironmental interpretations.

CHAPTER 5. THE PALEOENVIRONMENTAL EVOLUTION OF A LATE BARTONIAN TO PRIABONIAN RIMMED TETHYAN CARBONATE SHELF: A CASE STUDY OF THE GREEK PART OF THE THRACE BASIN

5.1 INTRODUCTION

During the middle-late Eocene, three main shallow water carbonate platforms thrived in the Greek peninsula, from north to south, the Thrace Basin, the Mesohellenic Trough and the Gavrovo-Tripolitza zone. The last one is the oldest as the deposition initiated in the Late Triassic and continued through the late Eocene (Aubouin 1958; Aubouin et al. 1958; Decourt 1964; Fleury 1980). The most recent study by Baratollo et al. (2007) focused on the middle-upper Eocene of the Klokova Mountain (Gavrovo-Tripolitza area), located in the south-west Greece. Based on the microfacies analysis, they concluded that the area operated at that time as a middle platform, characterized by rather stable conditions.

Both the Mesohellenic Trough and the Thrace Basin consist of post-Alpine, molasse-type sedimentation that initiated roughly simultaneously (e.g., Kopp 1965; Soliman and Zygojannis 1977). Concerning the Mesohellenic Trough, Vasiliki (central Greece) is still the only known exposure of Eocene shallow water sediments. During Bartonian, shallow marine conditions prevailed in the basin (upper Lutetian by Soliman and Zygojannis, 1977, which corresponds to Bartonian according to the recent Eocene subdivision; SBZ 17-18A, Dimou et al. 2021). A paleoenvironmental shift towards an open marine environment occurred in the latest part of the Eocene. According to Soliman and Zygojannis (1979) and Zygojannis and Müller (1982) the upper Eocene deposits of the Mesohellenic Trough contain calcareous nannoplankton of the NP19-20 biozone and planktonic foraminifera indicating open marine environment.

On the contrary, a great number of middle-upper Eocene exposures occur in both the western (Greek) and eastern (Turkish) parts of the Thrace basin. The eastern part has been studied in detail over the decades, hence many paleoenvironmental evolutionary models have been proposed (e.g., Turgut and Eseller 2000; Okay et al. 2010; Less et al. 2011; Özcan et al. 2010, 2018). Regarding the western part, comprehensive studies were carried out during the 50-s and 60-s (e.g., Christodoulou 1957; Karageorgiou and Christodoulou 1957; Kopp 1965). During the intervening years, only a few studies were published, focusing mainly on Samothraki Island (Meinhold and BouDagher-Fadel 2009; Zagorchev et al. 2010) as well as in other areas (Chatalov et al. 2015; Dimou et al. 2023).

The development of the Thrace basin begins in the middle Eocene times and is strongly associated with an intensive tectonic activity affecting the Paleogene deposits (Kopp 1965; Rondoyanni et al. 2004; Tranos 2009; Papanikolaou and Triantaphyllou 2010; Kilias et al. 2013). Therefore, according to Papanikolaou and Triantaphyllou (2010) the basin is divided into three sub-basins (Alexandroupolis, Orestias and Petrota) filled with Paleogene molasse-type deposits overly the Rhodope basement.

The present study deals with the analysis of several outcrops comprising shallow water carbonate deposits in the wider region of the Greek part of the Thrace Basin (Fig. 16). Particularly, it highlights the synthesis of the micropaleontological data derived from the micro- and macrofauna assemblages, their distribution and their ecological classification. The main objective is to provide a detailed and updated microfacies analysis in order to propose a complete model for the Greek part of the Thrace Basin.

5.2 MATERIAL AND METHODS

For the present study representative samples were collected from each investigated outcrop. In total 64 thin sections were prepared (5.0×5.0 cm and 2.5×6.0 cm) to accomplish the microfacies analysis. Their classification follows the schemes proposed by Dunham (1962), Embry and Klovan (1972), Wilson (1975) and Flügel (1982, 2004). For this purpose, the determination of lithology and matrix as well as the systematic designation of the fossil content took place. Based on the combination of both sedimentological and paleontological data, 16 microfacies types were distinguished.

The foraminiferal content was taxonomically identified in randomly oriented equatorial planes occurring in thin sections, as well as on thin sections of isolated specimens (derived from spot samples); consequently, their age assessment derived according to plethora of studies (e.g., Less 1987, 1998; Serra-Kiel et al. 1998; Less et al. 2011; Less and Özcan 2012; Özcan et al. 2010, 2022). Moreover, coralline red algae and bryozoans are described at a generic level in order to avoid taxonomic uncertainties. The description of coralline growth forms' terminology follows Nebelsick and Bassi (2000).

Quantitative evaluation of the fossil content in each thin section was held in randomly selected areas of 1 cm^2 per thin section (Ćosović et al. 2004). Measurements of the test diameter (D) and thickness (T) as well as counts of abundances (including counts of megalospheric A- and microspheric B-forms) were performed on nummulitids and orthophragmines. Counts of both whole and broken specimens of planktonic and benthic foraminifera were also performed. Abundances were calculated as abundant (species > 50%), common (species > 20%) and rare when few specimens were present. Based on the conducted measurements and counts, the diameter/ thickness ratio in orthophragmines and nummulitids (D/T), the planktonic ratio in foraminiferal associations (P/B), and the A-form/ B-form ratio were calculated. In addition, a qualitative estimation of the test degradation on benthic foraminifera has been accomplished following the scheme proposed by Beavington-Penney (2004).

All studied material is stored at the Museum of Geology-Palaeontology-Palaeoanthropology of Aristotle University of Thessaloniki.

5.3 SITE SETTING, MICROFACIES ANALYSIS AND THEIR INTERPRETATION

The stratigraphy of the Paleogene sequence was described in detail by Kopp (1965) and many other researchers afterwards, whereas recently summarized by Dimou et al. (2023), thus will not be further discussed. More detailed information on the stratigraphy of particular localities is provided below.

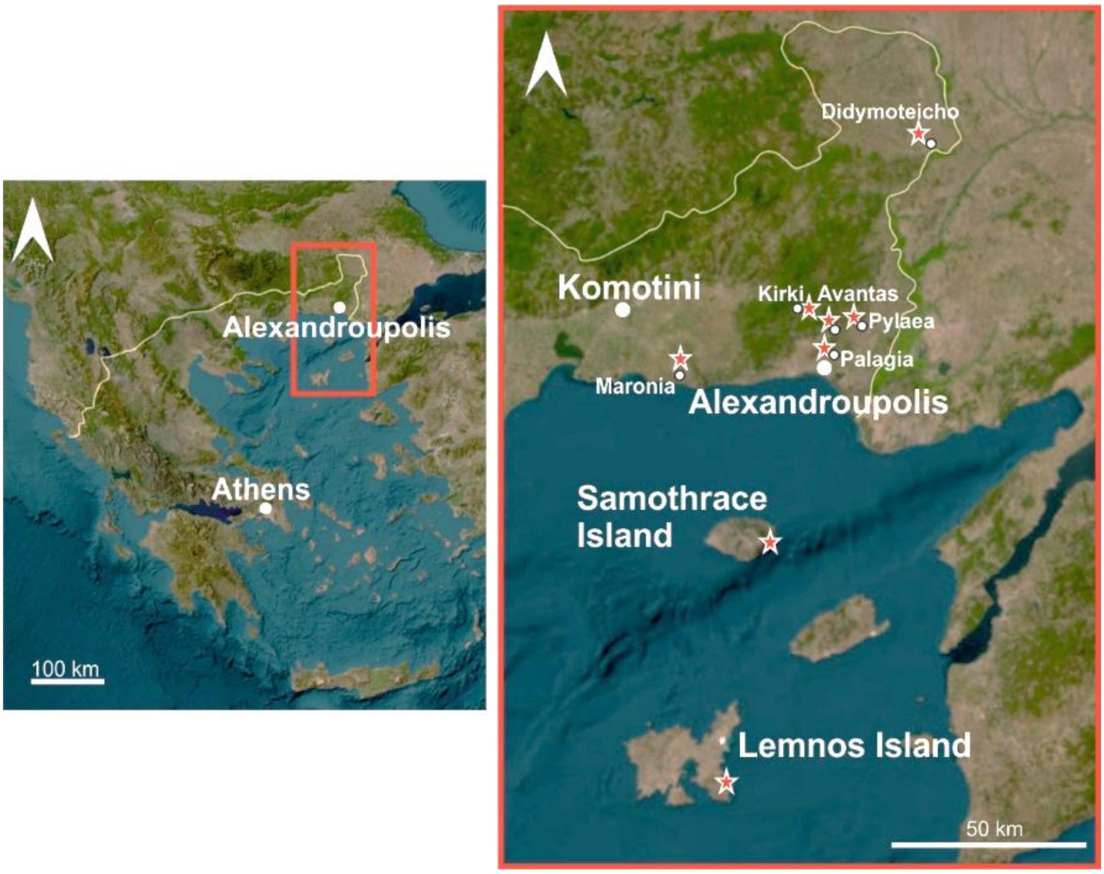


Figure 16. Overview map of Greece with the location of sampled sites depicted with red star (modified from Google Earth).

We focus on five localities in the mainland (Pylaea, Maronia, Didymoticho, Avantas and Palagia) whereas two sites (Lemnos and Samothraki Islands) are located in the Aegean Archipelago (Fig. 16). Based on the lithological features (e.g., texture, fabric) and the biogenic components, 16 microfacies types were identified, that refer to the three main environments corresponding to the inner, middle and outer platform. They are described in detail below and summarized in Table 5 (Appendix I). The taxonomic study yielded the identification of several taxa; representatives are illustrated in Figure 17.

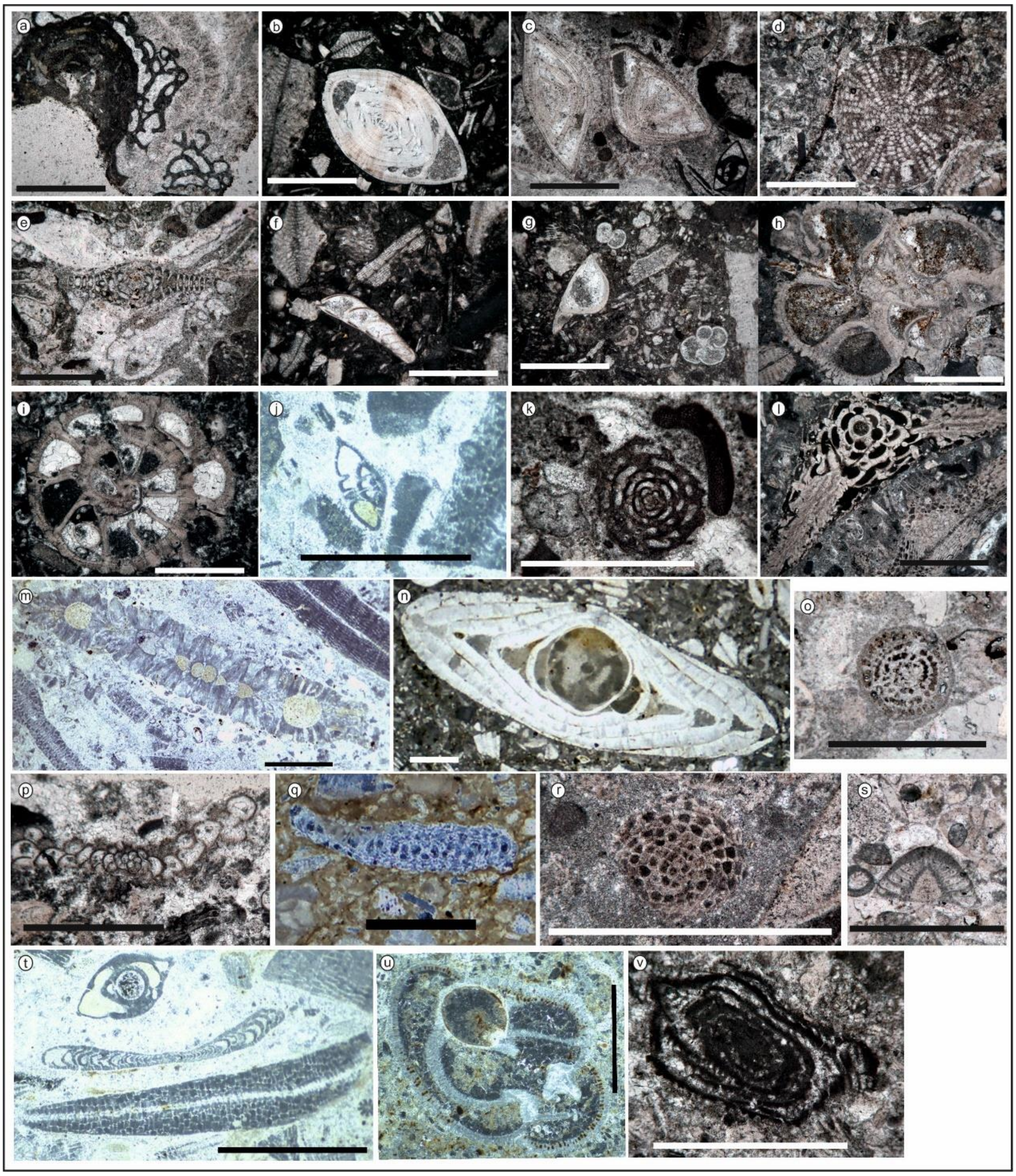


Figure 17. Representative foraminifera. a) encrusting foraminifera upon CRA, DDM1 (Didymoticho section), b) *Lenticulina* sp., LM1.1 (Lemnos Island), c) *Amphistegina* sp. (left) and *Asterigerina* sp. (right), DDM2 (Didymoticho section), d) *Sphaerogypsina* cf. *globula*, AVT9 (Avantas section), e) *Peneroplis* cf. *flabeliformis*, MAR1.1 (Maronia), f) *Nodosaria* sp., LM1 (Lemnos Island), g) planktonic foraminifera, LM1 (Lemnos Island), h) *Carpenteria* sp., S1 (Palagia section), i) *Gyroidinella* cf. *magna*, AVT10.1 (Avantas section), j) *Pararotalia* sp., PYL1 (Pylaea section), k) *Penarchaias* cf. *glynnjonesi*, MAR1.1 (Maronia), l) *Silvestriella tetraedra*, PYL9 (Pylaea section), m) *Pellatispira madaraszi*, PYL1 (Pylaea section), n) representative of *Nummulites millecaput-maximus* group, LM1.1 (Lemnos Island), o) *Praebullalveolina* cf. *afyoni*, PYL3 (Pylaea section), p) *Planorbulina* cf. *bronnimanni*, AVT10 (Avantas section), q-r) *Linderina* sp. q) PYL3 (Pylaea section), r) LM2.1 (Lemnos Island), s) *Halkyardia* cf. *minima*, S3.1.1 (Palagia section), t) *Lenticulina* sp. (up), *Eoannularia* cf. *eocenica* (middle) and orpthophragminind (down), PYL1 (Pylaea section), u) *Eorupertia* sp., PYL10 (Pylaea), v) *Praebullalveolina* cf. *afyoni*, AVT8 (Avantas section). Scale bar 1000μm.

5.3.1 Pylaea

Pylaea village is situated 26 km east-northeast of Alexandroupolis city (Figs. 16). Two sections were sampled (Figs. 18-19, 20). The first one is situated west of the village, on the hilly terrain. Along the north margin of the hill, thick conglomerates expose overlain by thin sparsely calcareous sandstones. The strata dip gently to SE. Sampling took place from two locations where nummulitic calcareous sandstones were exposed. Three samples were collected, the first one from the top (40° 55' 49.40" N/ 26° 6' 51.70" E) and the rest near the base of the hill at the roadside (40° 55' 49.80" N/ 26° 6' 76.40" E; 40° 55' 48.50" N/ 26° 6' 73.00" E, Fig. 18). The samples refer to a fossiliferous, dense sandstone containing LBF, echinoids and corals.

Figure 18. Sampling site at the hill at the roadside in first section from Pylaea area (Thrace).

The second section is exposed along the roadside from Pylaea to Melia village (40° 55' 82.70" N/ 26° 7' 08.20" E, Fig. 19) and covers a total sediment thickness of about 50 m. The strata dip gently to NE revealing a lens-shaped body rather than continuous strata. The lithostratigraphic section comprises carbonate deposits overlain the marls and siltstones of Pylaea Fm (Papanikolaou and Triantaphyllou, 2010), shown in Figure 21. They consist of a sandy limestone containing a rich association of Large Benthic Foraminifera (LBF) (*Nummulites* and orthophragmines) and other fossil groups (corals, bivalves and gastropods). Nine surface rock samples were collected at 5 m to 10 m intervals and also one spot sample from the loose sediments. Three different microfacies were identified.

Figure 19. Sampling site from the second section, exposed along the roadside from Pylaea to Melia village.

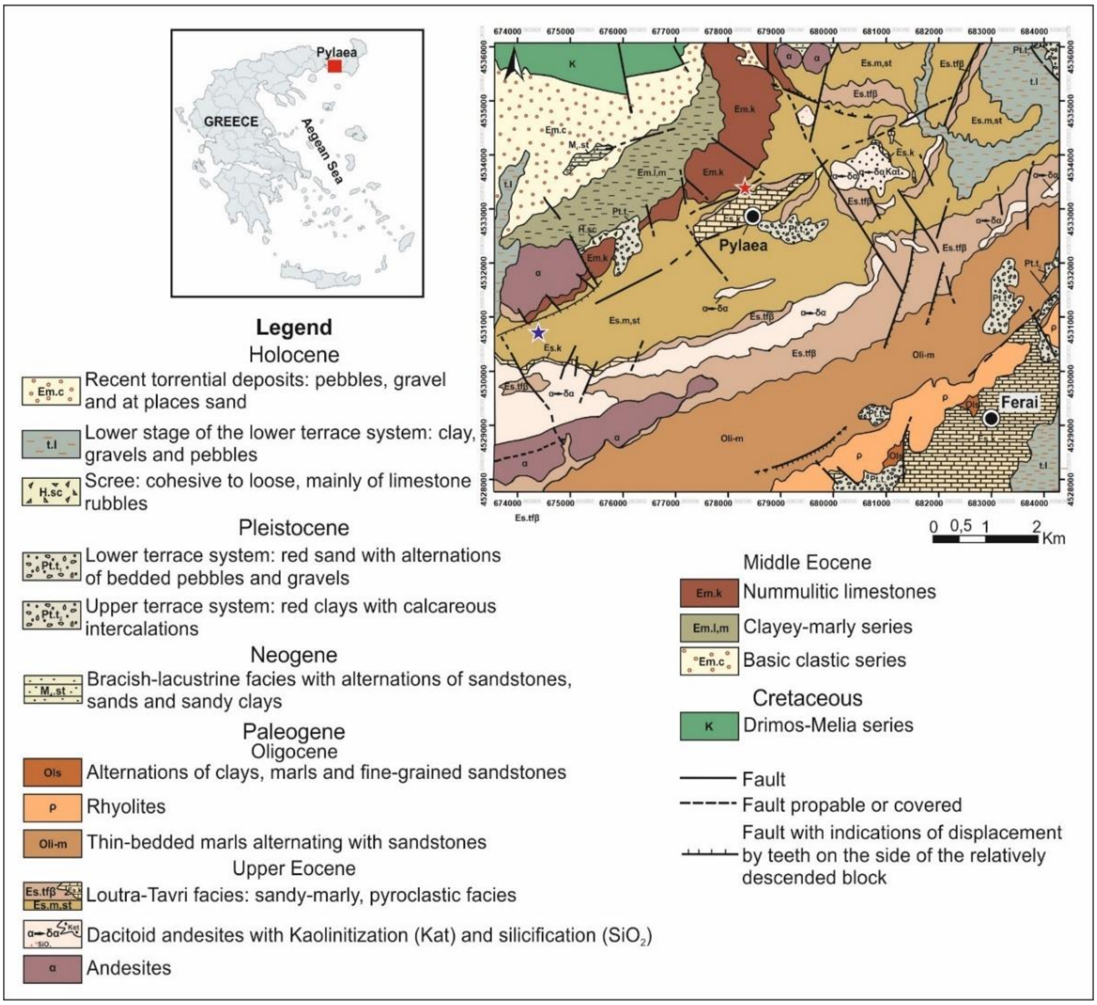


Figure 20. Geological map of Pylaea area, with red star marking the location of Pylaea sampling site and with blue one marking the location where the conglomerate with *Assilina exponens* were found (modified from I.G.M.E. 1980b).

5.3.1.1 MF 1: PYL 1-4, 9, LBF packstone

Description: The microfacies is represented mainly by orthophragminids (65%) and nummulitids (23%) (Fig. 22a, b). It is characterized by a heterogenous assemblage of *Orbitoclypeus varians, O. zitteli*?, *Asterocyclina, Discocyclina radians*?, *Nummulites incrassatus*, *Operculina* ex. gr. *gomezi*, *Heterostegina reticulata*, *Pellatispira madaraszi*, *Sphaerogypsina* cf. *globula*, *Eoannularia eocenica*, *Victoriella* sp., amphisteginids, other small rotaliids, miliolids, and planktonic foraminifera. Based on the assemblage, the late Eocene (Priabonian) age can be attributed. The macrofauna is represented by bryozoans, echinoid spicules, bivalves and debris of corralinaceans (faunal distribution and qualitative abundances are summarized in Figure 21). The foraminiferal tests are generally nearly intact, although large sized specimens show moderate abrasion. Bioerosion structures are relatively common, represented by serpulid tubes in tests mainly of orthophragmines (Fig. 22b) and less of *Operculina*'s. Tubes are of triangular to rectangular shape with circular lumen. In most cases, they are covered by lateral chamberlets. Furthermore, borings of *Trypanites*-like inside the test of the orthophragmines are observed. Upon them, encrusting foraminifera are also noted. Coralline red algae are found either as encrustations around the tests or as fragments. Additionally, sporadic small clasts of quartz, few muscovite and rare clasts of glauconite (Fig. 22a) are documented.

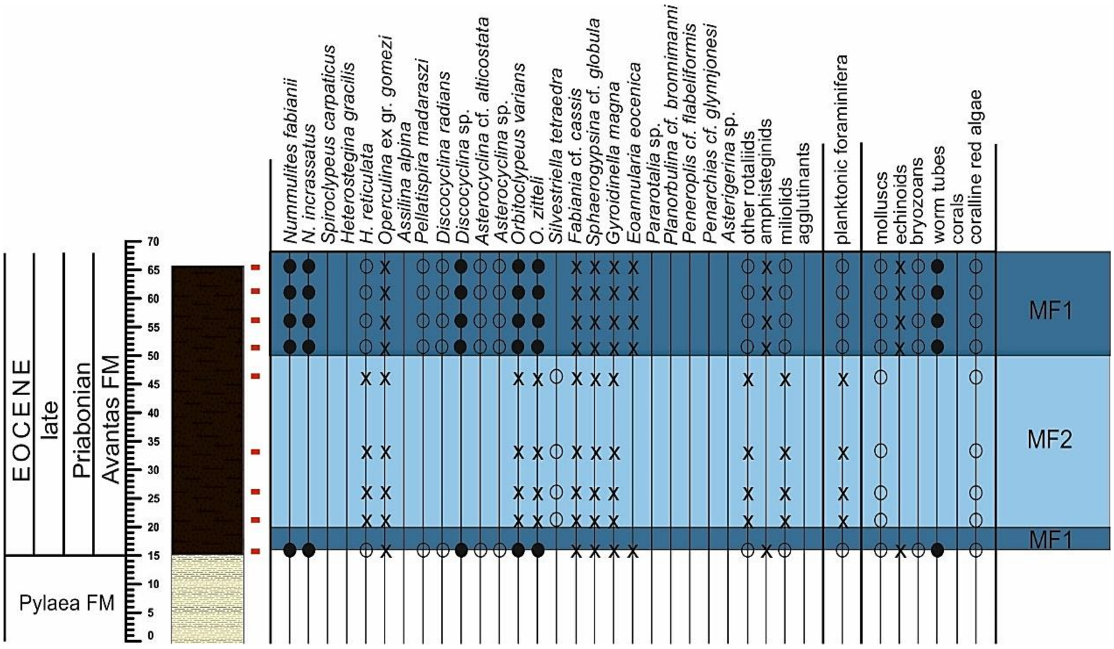


Fig. 21. Stratigraphic log showing the qualitative abundances of components of Pylaea samples. Symbol legend: ● abundant, ○ common, x rare.

Interpretation: The diverse benthic microfauna is indicative of fore reef settings with open marine influence as suggested by the presence of planktonic foraminifera (P/B ratio 0.14) (e.g., Ghose 1977; Setiawan 1983; Hallock and Glenn 1986; Hottinger 1997; Geel 2000; Bassi et al. 2000; Ćosović et al. 2004; Bassi 2005; Less et al. 2011). The tests of orthophragmines are lenticular to flat lenticular, while nummulitid tests are inflated lenticular based on the D/T ratio and the characterization proposed by Renema (2002). Foraminiferal tests do not display orientation or abrasion, except for the low-rate abrasion on larger forms caused by mechanical compaction. The aforementioned evidence supports foraminiferal autochthonous nature and, low energy conditions, most probably under the prevailed Fair Weather Wave Base (FWWB) (Setiawan 1983; Beavington-Penney 2004; Beavington-Penney et al. 2006; Ferràndez- Cañadell 2018). Foraminiferal tests could constitute the only solid substrate in a muddy environment, while at the time of infesting the foraminifer was alive (Ferràndez- Cañadell 2018). A similar transitional facies between the distal middle platform and the proximal outer platform has been described from the Colli Berici (Italy) by Bassi (2005). Moreover, the presence of some glauconite clasts and some glauconite-filled bioclasts suggests deeper waters with a low sedimentation rate (Odin and Matter 1981 and references therein). According to the small size of the quartz and muscovite clasts, their not so close landward origin can be assumed. Summarizing, a middle-outer platform of about 40-60 m depth can be attributed (Setiawan 1983; Hottinger 1997; Geel 2000; Renema 2005). This facies is interpreted as Standard Facies 4 (Wilson 1975; Flügel 1982, 2004).

5.3.1.2 MF 2: PYL 5-8, coralline bindstone

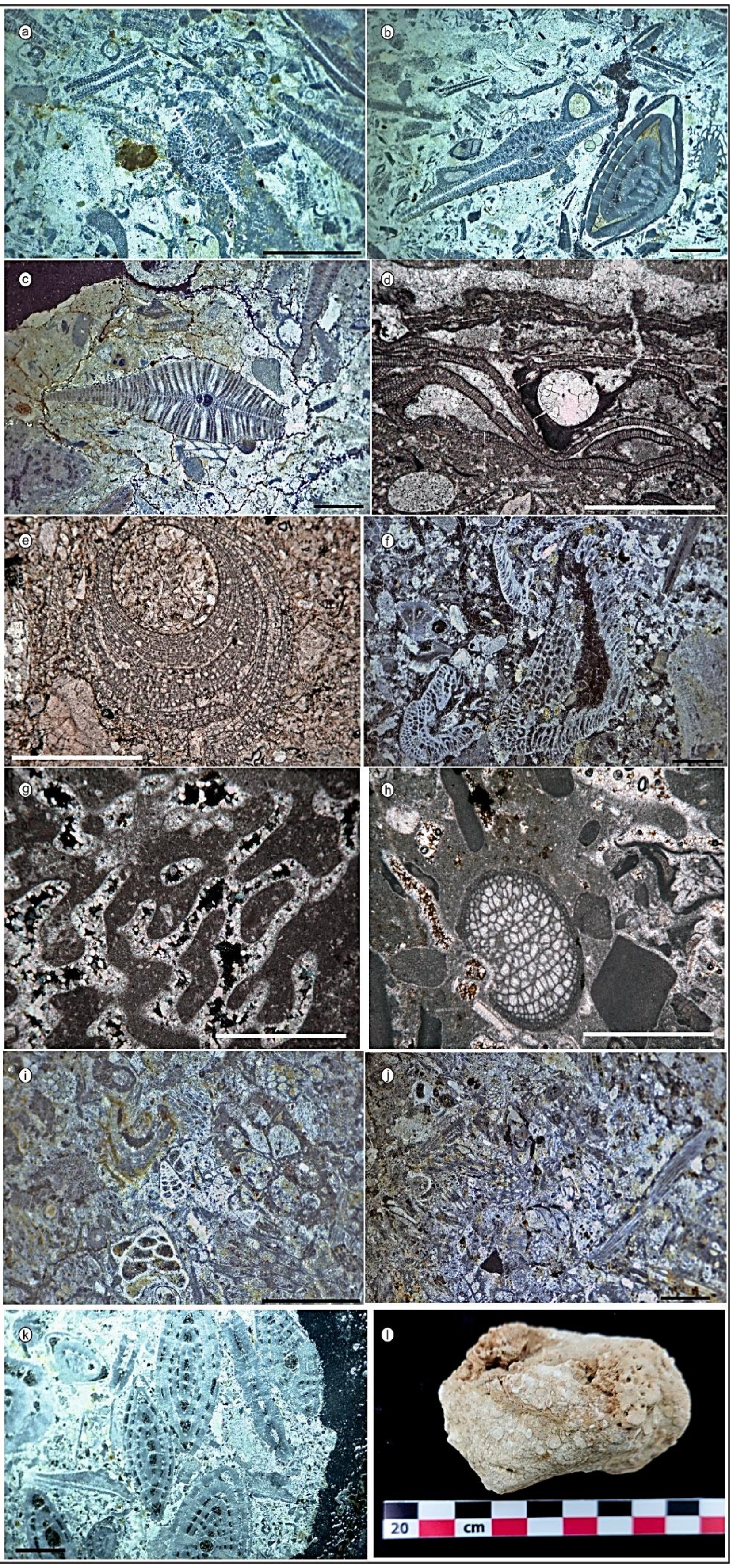
Description: This microfacies is dominated by coralline algae (Fig. 22d) represented by encrusting thalli or/and branches of phaceloid forms of corals. They are embedded in a wackestone packestone matrix. Benthic foraminifera of late Eocene age such as *Silvestriella tetraedra*, orthophragmines (Fig. 22c) (*Orbitoclypeus*, *Asterocyclina*, *Discocyclina*), *Heterostegina reticulata*, *Operculina* ex. gr. *gomezi*, miliolids, few planktonic foraminifera, *Sphaerogypsina* cf. *globula*, *Fabiania* cf. *cassis*, *Gyroidinella* cf. *magna*, amphisteginids, and few other small rotaliids are reported. However, benthic foraminifera are less abundant than the MF 1 (orthophragmines 36.5% and nummulitids 14,8%) (distribution and qualitative abundances are summarized in Figure 21). The foraminiferal tests are generally undamaged, whereas the flat forms show an inclination. Worm tubes (Fig. 22d) are noted on the encrustations, as well as encrusting foraminifera. Quartz clasts of similar size but more in number compared to MF1 are noticed along with few muscovite clasts.

Interpretation: The Facies MF 1 alternates with Facies MF 2 in the middle part of the studied section. The alternation is marked by the abrupt decrease of the orthophragmines and the total absence of *Nummulites*. This evidence along with the increase of *Silvestriella tetraedra* and especially their co-occurrence with corals implies very shallow waters with hard substrates but still a fore reef sub-environment (Hottinger 1997; Geel 2000). This setting is supported by the presence of planktonic foraminifera. Going upwards the section, epiphytic foraminifera such as *Fabiania* and *Gyroidinella* also increase, indicating vegetation cover. Additionally, the average D/T ratio refers to the same value. The observed "isolated to isolated chaotic imbrication" of the tests depicts current-dominated conditions (Beavington-Penney et al. 2006). The presence of marine vegetation is evident throughout the whole section due to the abundant coralline red algae that also bind the clasts. The lithoclasts indicate the continuity of the terrigenous input. This facies is interpreted as Standard Facies 4 (Wilson 1975; Flügel 1982, 2004).

5.3.1.3 MF 3: PYL 10, grainstone with encrusting and other rotaliids and miliolids

Description: The microfacies is dominated by encrusting foraminifera (some of them include matrix as nuclei) (Fig. 22e) and other small rotaliids, that are embedded in a grainstone matrix. The foraminiferal assemblage is represented by *Fabiania* cf. *cassis* (Fig. 22f), *Planorbulina* cf. *bronnimanni*, *Gyroidinella* cf. *magna*, *Pararotalia* sp., amphisteginids, other small rotaliids, miliolids, texturariids. Nevertheless, LBF are rare, represented by *Nummulites* ex gr. *fabianii*, while planktonic foraminifera are absent. Thin encrustations of coralline red algae and their debris are relatively common.

Fig. 22. Description of microfacies types. MF1 (a) orthophragmines and glauconite, PYL9 (Pylaea section) (b) orthophragmines with worm tubes and nummulitids, PYL9 (Pylaea section), MF2 (c) orthophragmines and *Silvestriella tetraedra*, PYL5 (Pylaea section) (d) encrusting coralline red algae with triangular worm tube, PYL8 (Pylaea section), MF3 (e) encrusting foraminifer, PYL10 (Pylaea section) (f) *Fabiania cassis* and small rotaliid, S.3.1.1 (Palagia section), MF4 (g) coral with calcitic infilling, MAR1.1 (Maronia) (h) *Subterraniphyllum thommasi*, MAR1.1 (Maronia), MF5 (i) bryozoans and textulariids, MAR (Maronia) (j) bryozoans fragments, MAR (Maronia), MF6 (k) *Nummulites fabianii*, S2F (Palagia section) (l) macroscopic view of *N. fabianii* limestone (Maronia).



MF1
Main components:
Orthophragminids/nummulitids
Subordinate components:
other LBF, small rotaliids, planktonic foraminifera, CRA, bryozoan,molluscs, echinoids, worm tubes
Texture: packstone

MF2
Main components:
CRA, corals, *S. tetraedra*
Subordinate components:
other LBF, small rotaliids, miliolids, planktonic foraminifera, molluscs
Texture:
wackestone/packstone

MF3
Main components:
encrusting foraminifera, rotaliids, textulariids, miliolids
Subordinate components:
Nummulites, CRA
Texture: grainstone

MF4
Min components:
CRA, corals, molluscs, bryozoans, small rotaliids
Subordinate components:
N. fabianii, milliolids, peneroplids, textulariids, planktonic foraminifera, worm tubes, ostracods
Texture: packstone (locally boundstone)

MF5
Main components:
bryozoans, small rotaliids, miliolids
Subordinate components:
Operculina ex. gr. *gomezi,* planktonic foraminifera, echinoids, worm tubes
Texture: packstone

MF6
Main components:
Nummulites fabianii
Subordinate components:
Operculina ex. gr. *gomezi*, *Discocyclina* sp., small rotaliids, CRA, molluscs
Texture:
packstone/grainstone

Fragments of bivalves and bryozoans are also reported. This facies is documented from samples S3.1.1 and S3.1.2 from Palagia section and Pyl 10 sample. In all samples abundant quartz grains (angular and rounded) and K-feldspars are noticed. Specifically, from Palagia samples, two generations of quartz can be distinguished.

Interpretation: The fair abundance of both miliolids and small rotaliids indicates very shallow marine conditions (e.g., Ghose 1977 and references therein; Hallock and Glenn 1986; Geel 2000; Beavington-Penney and Racey 2004). The occurrence of encrusting forms such as *Fabiania* and *Gyroidinella* implies vegetation cover. Moreover, the detritus of red coralline algae along with the fragments of bivalves and bryozoan suggest moderate energy conditions. Based on the identified lithoclasts, terrigenous input is assumed here as well and most possibly derived from the plutonic rocks of Elatia (N Rhodope Mountains) (Soldatos et al. 2001a, 2001b; Christofides et al. 2004). The two generations of quartz imply that some clasts (large) derived from the nearby plutonic source; the rest of them (small and attached to each other) form from silica solution that flows along with the calcite solution, either two sources occur. These evidence together with the occurrence of the winnowed fine sediments suggest a protected interior environment, most probably lagoonal of maximum depth of 40 m (Ghose 1977 and references therein; Hottinger 1997; Hallock and Glenn 1986; Geel 2000). This facies is interpreted as Standard Facies 7 or 8 (Wilson 1975; Flügel 1982, 2004).

5.3.2 Maronia

Maronia village is situated 29 km south of Komotini city, while the sampling area is located north-west of the village (Fig. 16, 23). Stratigraphically, the metamorphic basement underlies the Eocene carbonate sediments. However, the contact was not detected near the studied outcrops. Three samples were collected from two outcrops. The first two were derived from the bioclastic limestone, exposed at the roadside to Maronia Cave (40° 55' 71.10" N/ 25° 29' 68.00" E, Fig. 24). The gray limestone contains macrofauna of corals, bivalves, crinoids and microfauna of nummulitids. The third sample came from the nummulitic, massive, gray-colored limestone near the entrance of the cave (40° 55' 57.26" N/ 25° 30' 07.39" E). We observed three different microfacies as follows.

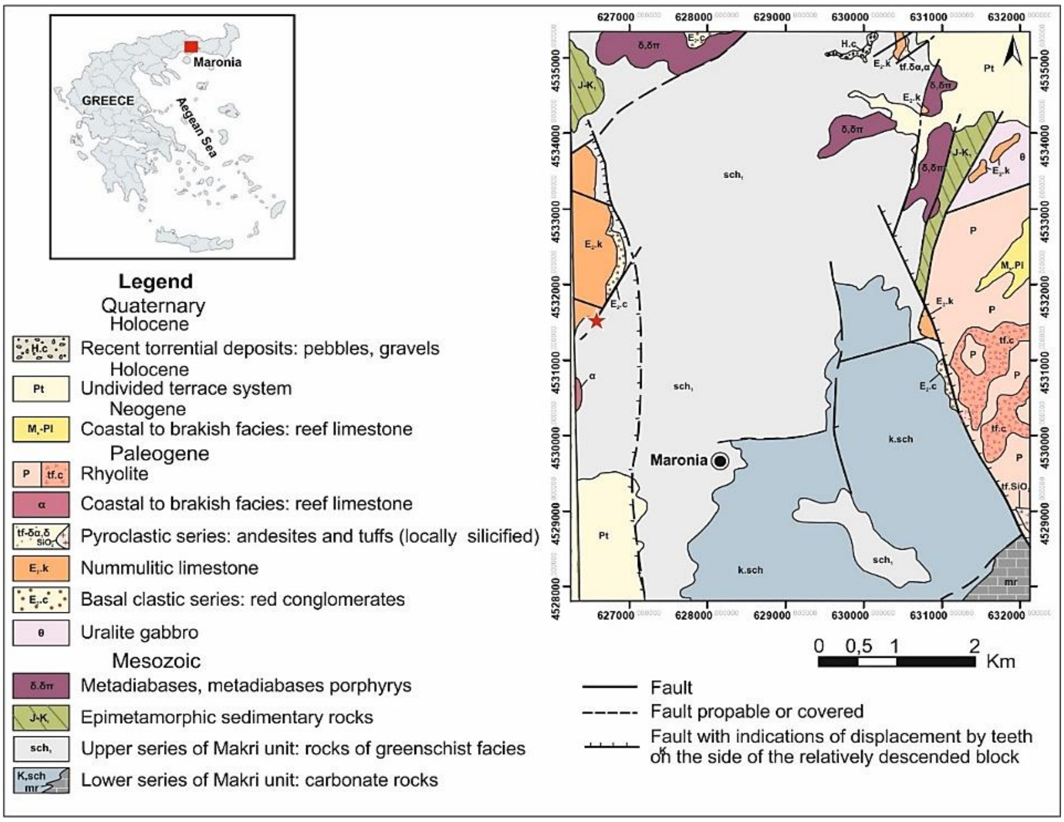


Figure 23. Geological map of Maronia area (Thrace), the red star depicts the sampling site (modified from I.G.M.E. 1982).

Figure 24. Sampling site exposed at the roadside to Maronia Cave (Thrace).

5.3.2.1 MF 4: MAR 1.1-1.2, Coralline algae bindstone

Description: This microfacies is dominated by coralline algae, mainly of *Subterraniphyllum thommasi* (Fig. 22h), forming rhodoliths and encrustations. Debris of all of them is documented. Moreover, they constitute the nuclei for encrusting foraminifera. Other significant biotic elements are corals (Fig. 22g), gastropods, bivalves, ostracods and fragments of bryozoans. All the allochems are embedded within packstone matrix to locally coral boundstones. The hyaline-perforated forms include late Eocene rare *Nummulites* ex. gr. *fabianii, N*. cf. *incrassatus*? and amphisteginids. Other abundant small rotaliids such as *Pararotalia* sp., *Praebullalveolina* cf. *afyonica*, *Peneroplis* cf. *flabeliformis* and *Penarchaias* cf. *glynnjonesi* also occur along with many miliolids and rare textulariids. Subordinate bioclasts consist of planktonic foraminifera. Foraminiferal tests exhibit low to moderate abrasion and no orientation. Serpulid worm tubes of circular external shape and lumen are noted. Moreover, peloids are also present. Additionally, algal voids are filled up by micrograined matrix. Moreover, small and rounded quartz grains are documented.

Interpretation: The abundant occurrence of coralline red algae and encrusting foraminifera indicate intensive vegetation cover. The smaller foraminifera association is indicative to very shallow marine conditions (e.g., Ghose 1977 and references therein; Hallock and Glenn 1986; Geel 2000; Beavington-Penney and Racey 2004). Nummulitid lenticular tests (D/T ratio 2,6) indicate shallow water conditions. The presence of *Peneroplis* cf. *flabeliformis* and *Penarchaias* cf. *glynnjonesi* suggests Arnis's (1965) facies as summarized by Kulka (1985), characterized by shoal deposits with Peneroplidae. According to Sirel and Acar (1982), the co-occurrence of *Peneroplis* cf. *flabeliformis* and *Praebullalveolina* cf. *afyoni* is indicative of restricted, back-reef areas although they can be found in reef shoals and fore-reef environments. The moderate abrasion as well as the coralline red algae detritus imply high energy regime. This facies is interpreted as Standard Facies 6 or 5 (Wilson 1975; Flügel 1982, 2004), Standard Microfacies Type (SMF) 11 representing winnowed platform edge sands, in areas at or above the wave action.

5.3.2.2 MF 5: MAR 1, bryozoan packstone

Description: This microfacies is strongly characterized by Cheilostomate bryozoans that occur as debris or colonies (Fig. 22i, j) within the micritic matrix. Small rotaliids, biserial foraminifera, textulariids (Fig. 22i) and miliolids are common biotic components. *Operculina* sp. is the only representative of the larger benthic foraminifera; its tests show moderate abrasion. Other bioclasts of subordinate importance are the planktonic foraminifera. Rounded worm tubes with circular lumen and echinoderms represented by spine cross sections and plates of echinoids are also recorded. All the bioclasts are densely and chaotically stacked. Small quartz grains are also noticed.

Interpretation: The abundant detritus and the chaotic stacking of the bioclasts suggest high energy, wave dominated environment (Beavington-Penney et al. 2006). The foraminiferal association indicates shallow water conditions to the upper fore slope with influences of the open sea (Ghose 1977 and references therein; Geel 2000).

5.3.2.3 MF 6: nummulitic packstone

Description: The dominant biotic constituent is *N. fabianii* (Fig. 22k, l), embedded within a packstone to grainstone matrix. This almost monospecific facies is characterized by the mass abundance of megalospheric A-forms that dominates over the rare microspheric B-forms (late Eocene). *Nummulites* are very densely packed and may show a low degree of imbrication. This facies is referred to samples from the Maronia area and the Palagia section. The Maronia sample was studied directly from the hard rock, while the sample from the other area was studied in thin section. *Operculina* ex. gr. *gomezi*, *Discocyclina* sp., *Asterigerina* sp. and other small rotaliids considered to be sparse faunal elements. *Planorbulina* cf. *bronnimanni, Gyroidinella* cf. *magna* and biserial foraminifera also occur in small amounts, along with rare thin encrustations of coralline red algae fragments of bivalves and serpulid worm tubes. Very small lithoclasts of quartz and K-feldspar are recorded.

Interpretation: The fact that this facies is composed almost entirely of *N. fabianii*, suggests an analogous of *Nummulites*-bank. However, the striking occurrence of A-forms conflicts with the original description of such bank settings by Arni (1965). The edgewise isolate imbrications to edgewise contact imbrications (Racey 2001) of *N. fabianii'*s tests and their lenticular shape (Renema 2002) (avg. D/T ratio 1.9) indicate shallow, wave-influenced middle shelf conditions. Yet, the currents were inefficient to cause any damage to the tests, but only to concentrate them mechanically (Aigner 1983a). Hence, the lack of abrasion indicates autochthonous accumulations, near the coral reef or interfingering with the corals (Aigner 1983a; Beavington-Penney 2004; Less et al. 2011). Subordinate to extremely rare occurrence of *Operculina* ex. gr. *gomezi* and *Discocyclina* sp. in this facies support this theory (Ghose 1977; Hottinger 1997). The occurrence of lithoclasts shows terrigenous plutonic input. This facies is interpreted to represent Standard Facies 6, SMF 12 (Wilson 1975; Flügel 1982, 2004).

5.3.3 Didymoticho

The city of Didymoticho is situated 85 km northeast of Alexandroupolis city (Fig. 16). Since no official geological map is available, therefore it is not given below. The stratigraphy of the area is characterized by the ophiolitic- basement of the Rhodope massif exposed close the limestone quarry of the Petroton hill (~100 m altitude) at the Koufovouno village (2,5 km west of Didymoticho), overlain uncomfortably by the Eocene carbonate succession (Fig. 25).

Figure 25. The ophiolitic- basement of the Rhodope massif exposed close the limestone quarry at the Koufovouno village (Thrace), overlain uncomfortably by the Eocene carbonate succession.

The studied section is located (41° 21' 10.50" N/ 26° 29' 17.00" E) at the west of Didymoticho city, where the unconformity contact is not observed. The exposed outcrop consists of a carbonate succession of about 50 m thickness, without bedding but with karstic caves, massive and light grey colored limestone (Fig. 26). It can be characterized as reefal limestone, due to the abundant corals, algae, bivalves and LBF fauna. Due to the very steep (almost vertical) surface of the outcrop, only the first meters of the sequence were sampled. Four samples (DDM1-4) at 0.50 to 1.20 m interval were collected. One more sample (DDM5) was collected from the slightly recrystallized limestone that overlies the ophiolites (near the quarry at the Koufovouno village). The limestone is light gray and characterized by the presence of corals (also reefal facies). A lithostratigraphical section is provided in Figure 27. The following two microfacies were recognized.

Figure 26. The exposed outcrop at Didymoticho (Thrace) consists of a carbonate succession of about 50 m thickness, without bedding but with karstic caves, massive and light grey colored limestone.

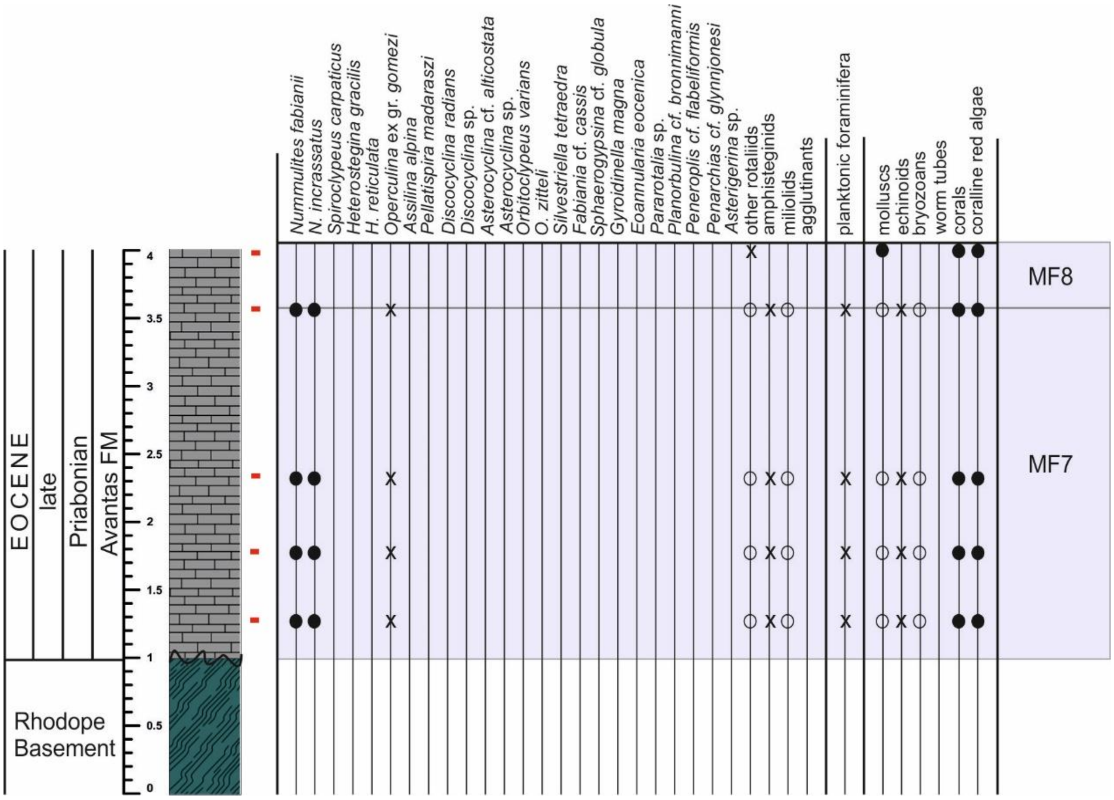


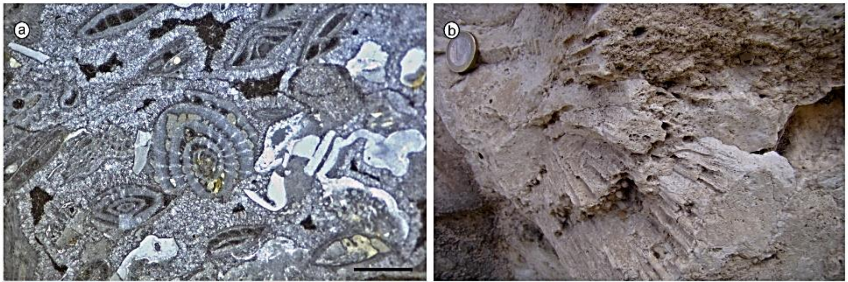
Figure 27. Stratigraphic log showing the qualitative abundances of components of Didymoticho samples. Symbol legend: ● abundant, ○ common, **x** rare.

5.3.3.1 MF 7: DDM 1-4, coralline algal- nummulitid bounstone to framestone

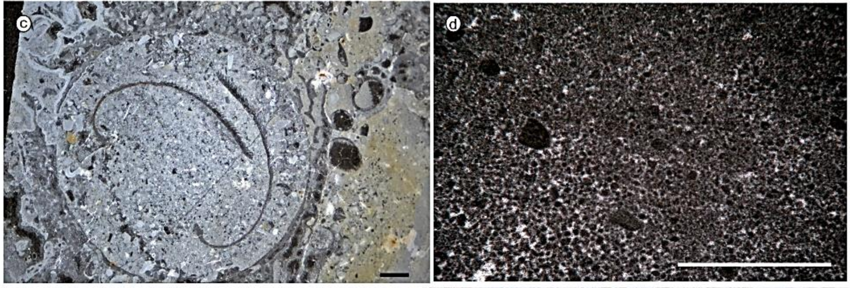
Description: At the sampled lower part of the outcrop, this facies is represented by massive light grey limestone with scattered coral patches (Fig. 28b). The dominant coralline red algae and the subordinate nummulitids of late Eocene age (Fig 28a) are embedded in a wackestone packstone matrix, forming a boundstone to framestone. The coralline algae are represented by encrusts, warty and fruticose growth forms as well as by their debris, with *Trypanites*-like borings.

Figure 28. Description of microfacies types., MF7 (a) nummulitids and fibrous cement, DDM2 (Didymoticho section) (b) outcrop view of coral patch (Didymoticho section) MF8 (c) endolithic bivalve, DDM2 (Didymoticho section) (d) peloids, DDM2 (Didymoticho section), MF9 (e) miliolid, worm tube, bryozoan, AVT2 (Avantas section) (f) bryozoans, orthophragmines, AVT2 (Avantas section), MF10 (g) fibrous aragonite cement, AVT3 (Avantas section) (h) outcrop view of coral (Avantas section), MF11 (i) heterosteginids, AVT5 (Avantas section) (j) orthophragmines, AVT3 (Avantas section), MF12 (k) coral, AVT14 (Avantas section) (l) encrusting coralline red algae, AVT15.1 (Avantas section).

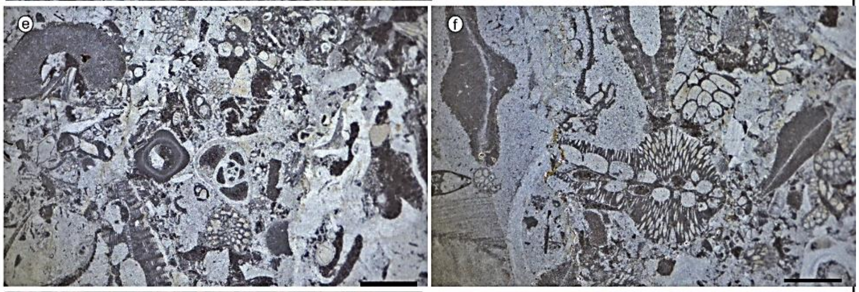
MF7
Main components:
corals, CRA, nummulitids
Subordinate components:
other LBF, small rotaliids, planktonic foraminifera, miliolids, bryozoans, echinoids
Texture:
wackestone/packstone



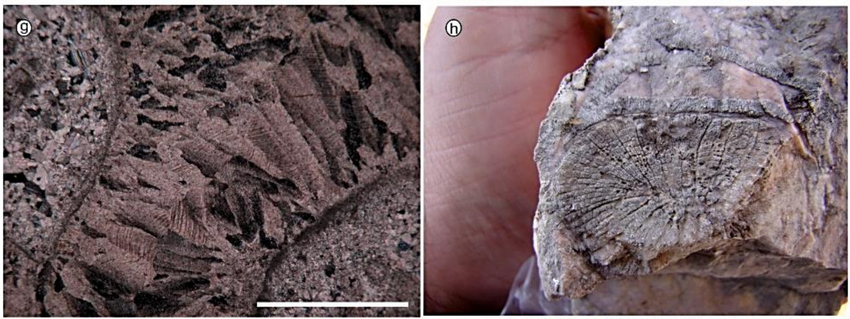
MF8
Main components:
Corals, endolithic bivalves CRA
Surbordinate components:
small rotaliids
Texture: wackestone/ packstone



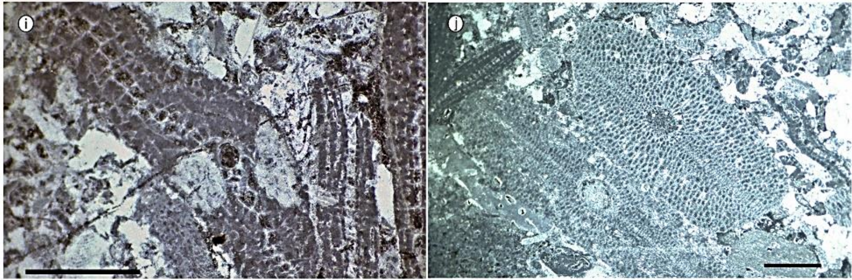
MF9
Main components:
Corals, CRA, bryozoans
Subordinate components:
orthophragminids, nummulitids, miliolids, small rotaliids, planktonic foraminifera, echinoids, molluscs, worm tubes
Texture:
wackestone/packstone



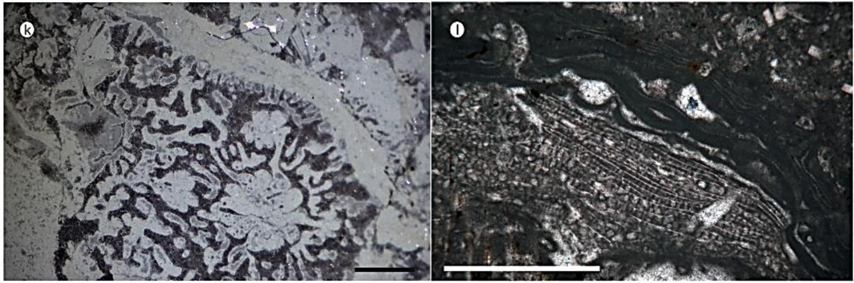
MF10
Main components:
radial fibrous aragonite cement,
CRA, corals
Subordinate components:
LBF, small rotaliids, miliolids, molluscs, ostracods
Texture:
wackestone/packstone



MF11
Main components:
orthophragminids, heterosteginids, CRA
Subordinate components:
other nummulitids, small rotaliids, miliolids, agglutinants, bryozoans, corals, molluscs, worm tubes
Texture: micritic matrix



MF12
Main components:
corals, CRA
Subordinate components:
small rotaliids, miliolids, bryozoans, molluscs
Texture: micritic matrix



Rhodoliths are rare in contrast to the relatively abundant fragments. Moreover, along with the crust forms they enclose corals, bryozoan and foraminifera as nuclei. Nummulitids are represented by flat to slightly robust *Nummulites* (*N.* ex. gr. *fabianii*, *N.* cf. *incrassatus*) and the rare *Operculina* ex. gr. *gomezi.* Amphisteginids, other small rotaliids, miliolids, uniserial and biserial foraminifera are common components. Encrusting foraminifera are also noted. The foraminiferal tests do not exhibit any abrasion. Planktonic foraminifera are also present but in low numbers. Other skeletal grains are bivalves, echinoderm fragments and bryozoan debris (distribution and qualitative abundances are summarized in Figure 27). Locally, fibrous calcitic thin rims are observed (Fig. 28c).

Interpretation: According to Aigner (1983a), the isolated patches of coral colonies that co-occur along with coralline red algae and microfauna of *Nummulites* indicate shoal reef facies where very shallow, high-energy conditions prevail (Racey 2001; Less et al. 2011). Additionally, the association of *Nummulites* and *Operculina* supports this assumption (Ghose 1977). Their intact tests are inflated lenticular (characterized by D/T ratio 2) implying that the assemblage is autochthonous and thrives in the shallowest depths (Hottinger 1997; Renema 2002; Beavington-Penney 2004). The presence of the rare occurrence of planktonic foraminifera places the microfacies on fore reef shoal areas with the influence of the open marine environment.

5.3.3.2 MF 8: DDM 5, coralline algal- bivalve wackestone-packstone

Description: This microfacies is characterized by corals, red coralline algae forming thin encrustations and rarely small rhodoliths in a wackestone packstone matrix. Borings and valves of endolithic bivalves (Fig. 28c) are observed along with ostracod valves. The foraminiferal assemblage consists of rare rotaliids. In this facies high open porosity is documented bordered by carbonate cement as thin rims of fibrous calcite crystals and filled up with calcitic cement. Peloids are also noted (Fig. 28d).

Interpretation: Endolithic bivalves penetrate the hard coral substrate. Their co-occurrence as well as the low diversified biota suggests very shallow water conditions up to 20 m depth (Kleemann 1980; Aigner 1983b; Bromley and Asgaard 1993; Jiménez and Braga 1993).

5.3.4 Avantas

Avantas village is located 10 km north of Alexandroupolis city. The sampled section is situated to the northwest of the homonymous village and is well exposed along the roadside from Avantas to Aisymi (40° 56' 16.10" N/ 25° 54' 74.20" E) (Figs. 16, 29). It consists of basal, thick, red conglomerates underlying the Eocene marine carbonate deposits of Avas Fm. This is followed by the Pylaea Formation (marls, sandstones and some limestone interbeds; Papanikolaou and Triantaphyllou, 2010) (Fig. 30). The Avas Formation consists of a compact, pink to grey massive nummulitic limestone with a total thickness of 166 m (sampled strata), dipping southwest (Fig. 31). Near the contact, the limestone is less compact, due to fracturing, pinkinsh in color and full of corals, coralline algae and calcitic veins. Northwestwards, it becomes more compact, grey colored and larger benthic foraminifera (LBF) become visible to the naked eye. A total number of 15 samples (AVT 1-15) were collected with an interval of 6 to 18 m, leading to four identified microfacies types.

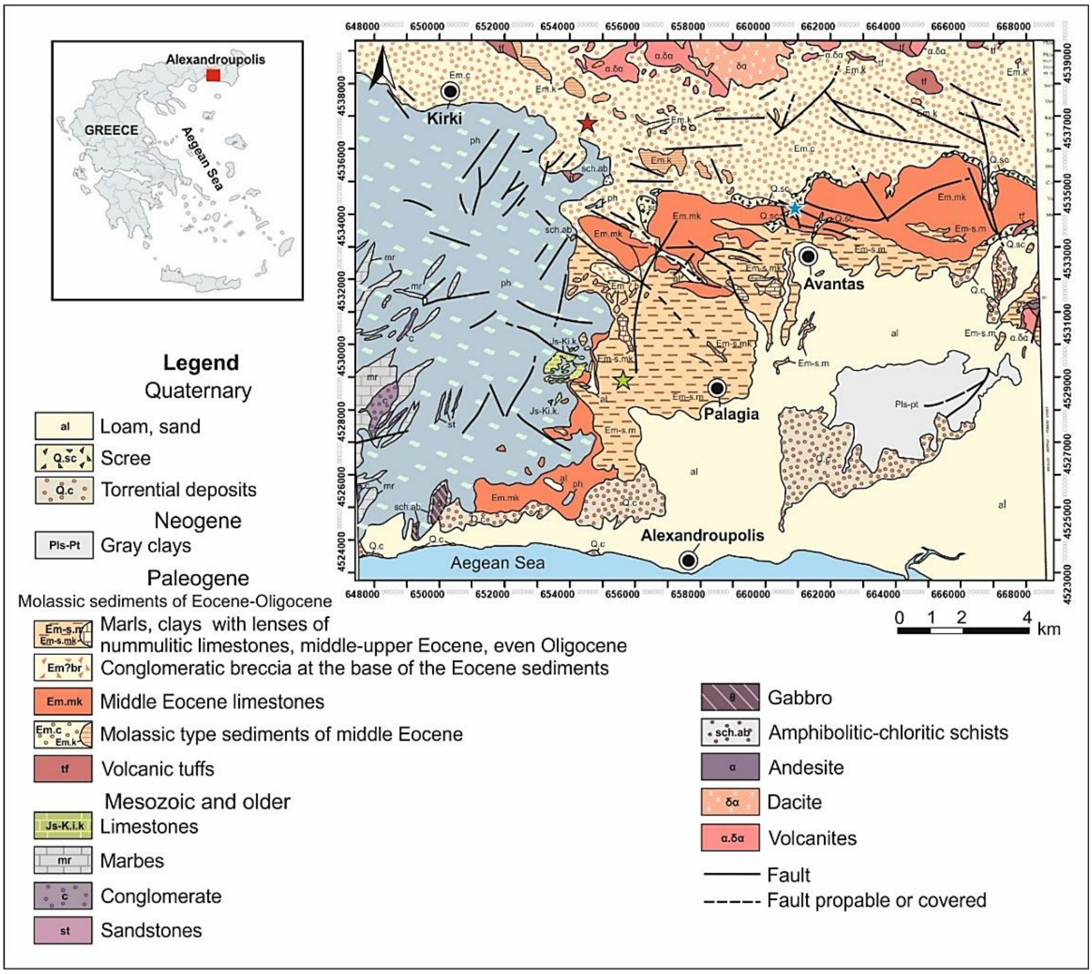


Figure 29. Geological map of Alexandroupolis area (Thrace), with red star marking Kirki sampling site, blue star marking Avantas sampling site and light green marking the Palagia sampling site (modified from I.G.M.R., 1977).

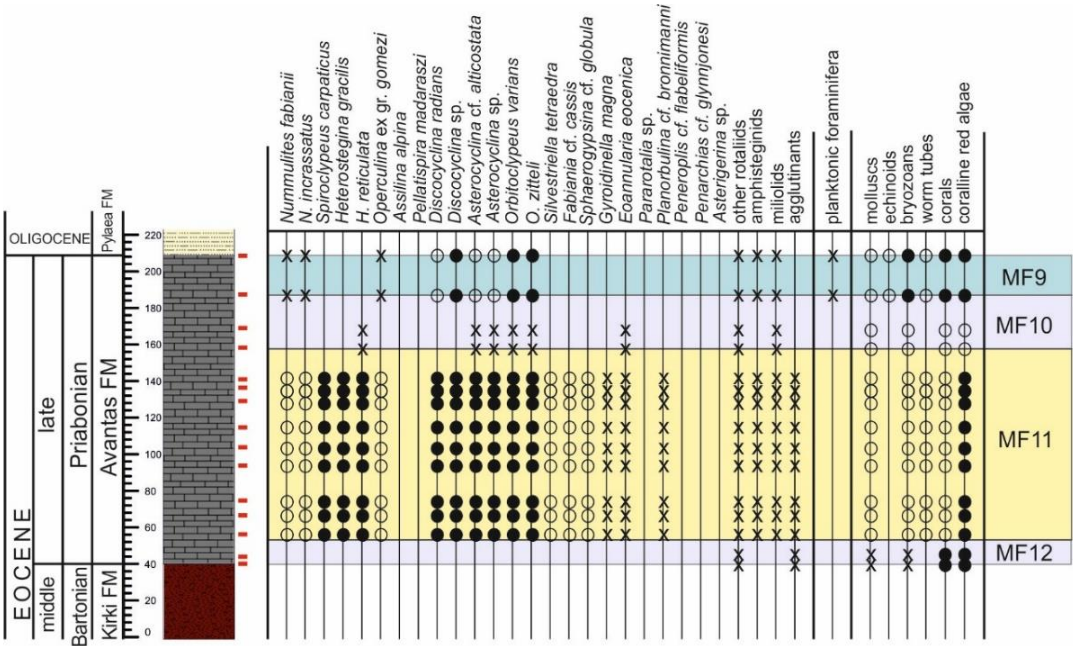


Figure 30. Stratigraphic log showing the qualitative abundances of components of Avantas samples. Symbol legend: ● abundant, ○ common, **x** rare.

Figure 31. Sampling site from Avantas area (Thrace) showing the compact, pink to grey massive nummulitic limestone of Avas Formation dipping southwestards.

5.3.4.1 MF 9: AVT 1-2, bryozoan - coralline algae wackestone packstone

Description: The biogenic components of this microfacies are represented by corals, Cheilostomate bryozoans as colonies and their debris (Fig. 28e, f) along with common coralline red algae of lumpy, crust and foliose growth form within a wackestone to packstone matrix. The LBF assemblage consists mainly of late Eocene flat to robust orthophragmines (such as *Asterocyclina*, *Orbitoclypeus*), rare lenticular nummulites and *Operculina* ex. gr. *gomezi*. Miliolids and other small benthic foraminifera are of subordinate components (Fig. 28e) (distribution and qualitative abundances are summarized in Figure 30). The LBF tests show low to moderate abrasion. Planktonic foraminifera are also present. Macrofossils represented by fragments of echinoid’s spine and plates, bivalves, rounded serpulid worm tubes and very small *Trypanites*-like borings, observed on red algae and foraminifera.

Interpretation: The dominance of abraded detritus and the texture of this facies indicate a high energy depositional environment, probably open circulation due to the presence of planktonic foraminifera. The D/T ratio values (range from 2.31-4) are indicative of shallower environments. The presence of abrasion of the foraminifera suggests either para-autochthonous accumulations, or moderate current transportation (Beavington-Penney 2004). Hence, this facies can be attributed to middle platform, near the fair weather wave base (Flügel 1982, 2004).

5.3.4.2 MF 10: AVT 3-4, coral aragonite/ magnesian calcite cemented-wackestone/packstone

Description: This microfacies is characterized by branching corals (Fig. 28h) and the local development of radial fibrous aragonite/ magnesian calcite cement (Fig. 11g) enclosing bioclasts, such as corals, bryozoans, coralline red algae and foraminifera. In this microfacies corals are also found. Accessory components are the late Eocene orthophragmines (*Orbitoclypeus*, *Discocyclina* and *Asterocyclina*), *Heterostegina* sp., *Eoannularia eocenica*, other small rotaliids and miliolids. Fragments of bivalves and ostracods are present (faunal distribution and qualitative abundances are summarized in Figure 30).

Interpretation: Radial fibrous crusts of rhombic calcite crystals indicate deposition on shelf margin where tides and waves cause constant water movement through the porous reef framework (Flügel 1982; Moore and Wade 2013). Abundant colonial corals, coralline red algae, and the encrusting foraminifera supported this hypothesis. This facies is interpreted as Standard Facies 5 (Wilson 1975; Flügel 1982, 2004), representing patch reef in a marine phreatic environment.

5.3.4.3 MF 11: AVT 5-13.1, heterosteginid-orthophragminid packstone

Description: This microfacies contains a highly diverse, shallow marine biota, composed mainly of foraminifera within a micritic matrix. The diverse assemblage is represented by (A- and B-forms) of predominant latest Eocene lenticular to flattened lenticular (Renema 2002) orthophragmines (Fig. 28j) and heterosteginids (Fig. 28i). Specifically, *Orbitoclypeus*, *Discocylina*, *Asterocyclina*, *Heterostegina* cf. *gracilis*, *H.* cf. *reticulata*, *Spiroclypeus* cf. *carpaticus*, common *Nummulites* ex. gr. *fabianii*, *N.* cf. *incrassatus*, *Operculina* ex. gr. *gomezi*, rather frequent *Silvestriella tetraedra*, *Sphaerogypsina* cf. *globulus*, *Fabiania* cf. *cassis*, rare *Eoannularia eocenica*, *Planorbulina* cf. *bronnimanni*, *Gyroidinella* cf. *magna* and amphisteginids. Minor elements are miliolids (such as *Triloculina* cf. *trigonula*, *T.* cf. *tricarinata*, *Pyrgo* sp.), agglutinants and other small rotaliids. The LBF tests are flat to robust, locally display slight inclination and moderate abrasion. Coralline red algae and their debris are relatively abundant and are represented by rhodoliths, thin encrustations and foliose growth forms. The encrustations occur around small foraminifera, bryozoans, or even sediment matrix. Occurrence of Cheilostomate bryozoans, fragments of corals and bivalves, serpulid worm tubes and *Trypanites*-like borings are noted (faunal distribution and qualitative abundances are summarized in Figure 30).

Interpretation: The absence of both *Pellatispira madaraszi* and planktonic foraminifera not in favor of a fore reef environment communicating with the open sea. On the other hand, the abundant heterosteginids are indicative of low energy regimes such as back reef lagoons and reef flats; orthophragmines are typical for deeper environments, but they can also live in these conditions (Ghose 1977 and references therein; Geel 2000). Moreover, orthophragmines that are characterized mainly by inflated lenticular to less flattened lenticular tests (D/T ratio 2.45-5.41) amplify this outcome. Additionally, the diverse microfauna of miliolids, rotaliids and textulariids collaborate with this hypothesis as well. The low degree of abrasion of foraminiferal tests, their inclination as well as the texture of the facies imply moderate action of currents (Beavington-Penney 2004; Beavington-Penney et al. 2006). Based on the synthesis of the above data, this microfacies can be interpreted as a back reef setting very close to the reef or as a reef flat (Ghose 1977 and references therein; Geel 2000). This facies is interpreted as Standard Facies 7 (Wilson 1975; Flügel 1982, 2004).

5.3.4.4 MF 12: AVT 14-15.1, coral/coralline algae framestone/boundstone

Description: Colonial corals (sheet-like and platy ones; Fig. 28k) and coralline red algae (Fig. 28l) are almost the exclusive constituents of this microfacies. Algae are represented by thin encrustations, fruticose growth forms and also by their debris. Cryptalgal laminar crusts are noted. Various encrusting organisms contribute to the stabilization of the sediment binding of the grains. Few bryozoans are present. In places, rare miliolids and small rotaliids occur. Fragments of bivalves and gastropods are accessory components (distribution and qualitative abundances are summarized in Figure 30).

Interpretation: This facies is interpreted as Standard Facies 5. SMF 7 (Wilson 1975; Flügel 1982, 2004), verified by coral colonies that create framestones to boundstones. This is also supported by the associated micro- and macrofauna.

5.3.5 Palagia

Several outcrops along the provincial road from Alexandroupolis to Sapes (Fig. 16, 29) were sampled and documented as they depict the transition from the Cretaceous to middle- late Eocene and finally the Oligocene deposits. The Cretaceous referred to a massive, gray limestone that is overlain tectonically by a conglomerate that passes into a pebbly limestone that upwards become sandy; where one sample was collected, S3 (40° 54' 00.00'' N/ 25° 50' 20.60'' E, Fig. 32).

Following, the middle-upper Eocene gray massive limestone is characterized by LBF fauna where two more samples were collected. The first (S2, 40° 53' 97.00'' N/ 25° 50' 17.00'' E) derived from a massive light gray limestone containing monomictic microfauna of nummulitids (Fig. 33). The second one (S1, 40° 53' 88.60'' N/ 25° 50' 23.30'' E) came from a sandy horizon of the limestone and comprises diverse microfauna of nummulitids and orthophragminids. Finally, above the limestones lies the Pylaea Fm, represented in this site by mudrocks and light beige-colored sandy layers with lamination. A lithostratigraphic column is given in Figure 34.

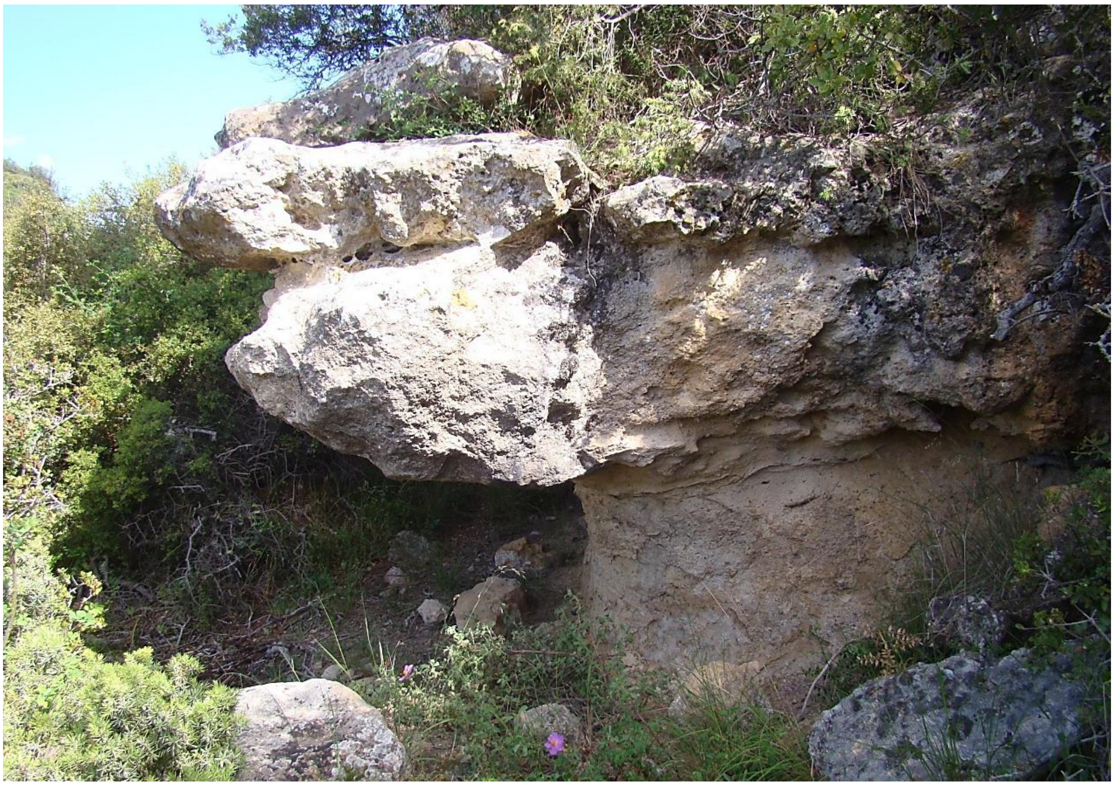


Figure 32. Sampling site from Palagia section (Thrace); pebbly to sandy limestone.

Figure 33. Massive light gray limestone containing monomictic microfauna of nummulitids from Palagia section (Thrace).

In this area, three microfacies (MF3, MF6 and MF13) were distinguished, two of them displaying similar features to MF3 of Pylaea (grainstone with encrusting and other rotaliids and miliolids) and MF6 of Maronia (nummulitic packstone) respectively. Hence, they are not described here.

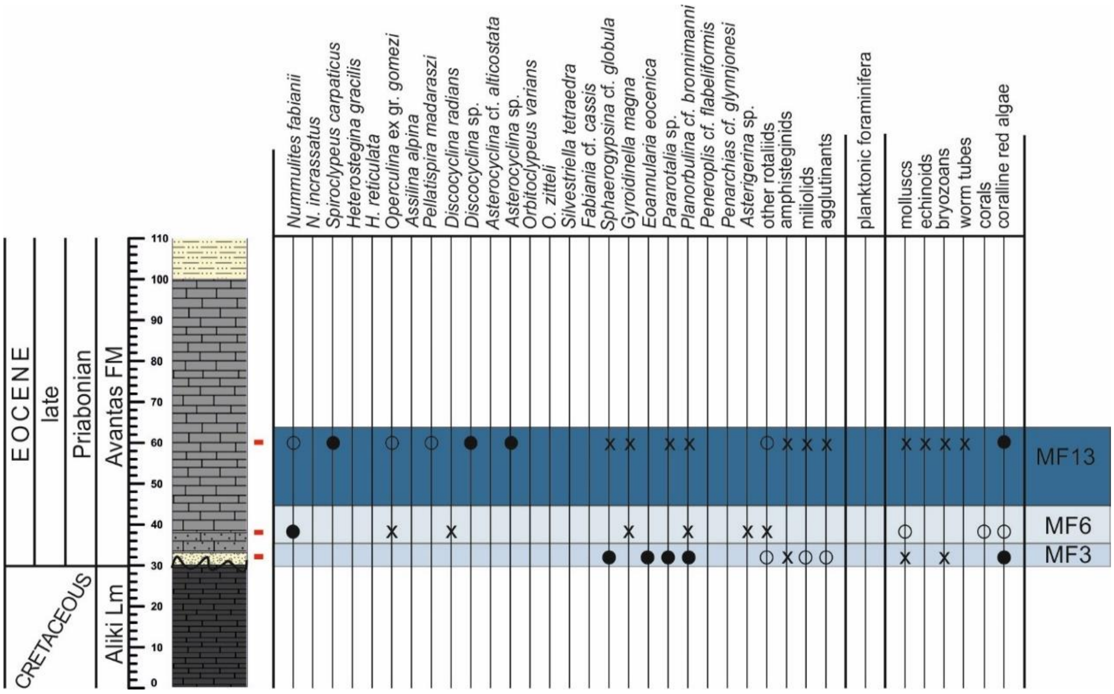
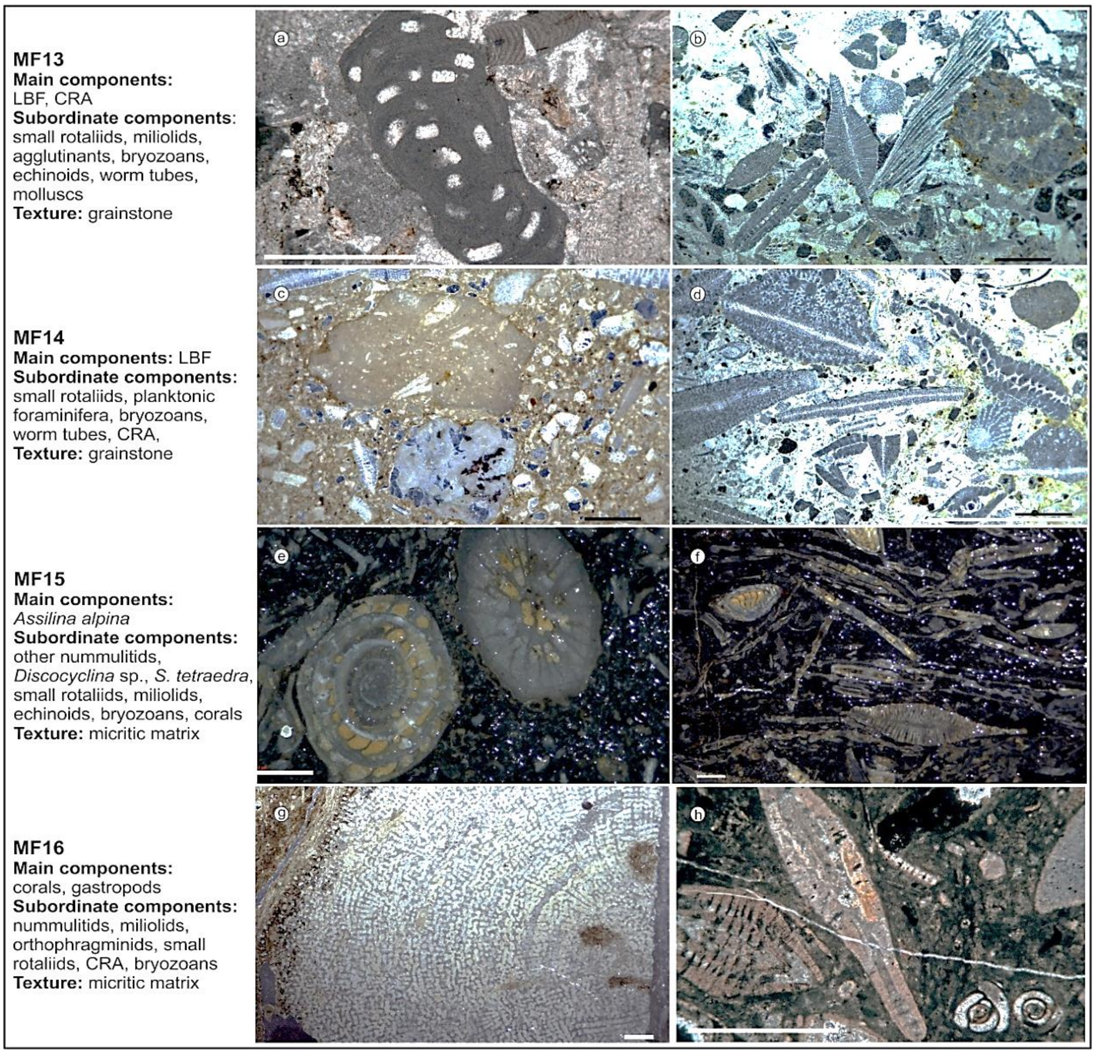


Fig. 34. Stratigraphic log showing the qualitative abundances of components of Palagia samples. Symbol legend: ● abundant, ○ common, **x** rare.

5.3.5.1 MF 13: LBF packstone/wackestone

Description: LBF comprise the predominant component that are embedded within a grainstone matrix of poor sorting (Fig.35b). Coralline red algae as fragments, rhodoliths and thin encrusts (including matrix as nuclei) are relatively abundant, while on some of them borings of *Trypanites*-like are noted (Fig. 35a). Fragments of bivalves, bryozoans, spines of echinoids and seprulid tubes are of subordinate importance. Small rotaliids, textulariids and miliolids are minor elements. The flat-shaped (avg. D/T ratio >7.33) LBF (latest Eocene) assemblage is represented by common *Spiroclypeus* sp. and orthophragmines (*Discocyclina* sp. and *Asterocyclina* sp.). *N. fabianii*, *Operculina* ex. gr. *gomezi*, *Pellatispira madaraszi*, *Sphaerogypsina* cf. *globula*, *Planorbulina* cf. *bronnimanni*, *Gyroidinella* cf. *magna, Pararotalia* sp. and amphisteginids also occur (distribution and qualitative abundances are summarized in Figure 34). LBFs' tests are generally abraded, displaying breakages and damages on the terminal chamber. Several rounded and angular pebbles of terrestrial origin are also documented along with small quartz grains. Some of these pebbles form the nuclei for encrusting foraminifera, most likely *Miniacina*.


MF13
Main components:
LBF, CRA
Subordinate components:
small rotaliids, miliolids, agglutinants, bryozoans, echinoids, worm tubes, molluscs
Texture: grainstone

MF14
Main components: LBF
Subordinate components:
small rotaliids, planktonic foraminifera, bryozoans, worm tubes, CRA,
Texture: grainstone

MF15
Main components:
Assilina alpina
Subordinate components:
other nummulitids, *Discocyclina* sp., *S. tetraedra*, small rotaliids, miliolids, echinoids, bryozoans, corals
Texture: micritic matrix

MF16
Main components:
corals, gastropods
Subordinate components:
nummulitids, miliolids, orthophragminids, small rotaliids, CRA, bryozoans
Texture: micritic matrix

Figure 35. Description of microfacies types. MF13 (a) rhodolith of coralline red algae with *Trypanites*-like borings, S1 (Palagia section) (b) orthophragmines, heterosteginids, *Sphaerogypsina globula*, S1 (Palagia section), MF14 (c) lithoclasts, LM2 (Lemnos Island) (d) orthophragmines and nummulitids, LM2 (Lemnos Island), MF15 (e) coral and *Nummullites* sp., SAM1.1 (Samothraki Island) (f) *Assilina alpina*, *Discocyclina* sp., *Nummulites* sp., SAM1 (Samothraki Island), MF16 (g) coral and encrusting coralline red algae, SAM2 (Samothraki Island) (h) nummulitids and miliolids, SAM2 (Samothraki Island).

Interpretation: The diverse benthic microfauna is indicative of fore reef settings (e.g. Ghose 1977; Hottinger 1997; Setiawan 1983; Hallock and Glenn 1986; Bassi et al. 2000; Geel 2000; Ćosović et al. 2004; Bassi 2005; Less et al. 2011). The texture as well as the highly abraded foraminiferal tests imply high energy conditions (Setiawan 1983; Beavington-Penney 2004; Beavington-Penney et al. 2006; Ferràndez- Cañadell 2018). Moreover, many bioclasts show infilling of glauconite leading to the assumption of deeper water conditions with low sedimentation rate (Odin and Matter 1981 and references therein). Similar characteristics have been identified by Bassi (2005) as channel structures generated by sporadic storms. All evidence suggest a middle platform near the FWWB and storm wave base (Hottinger 1997; Setiawan 1983; Geel 2000; Renema 2005). This facies is interpreted to represent Standard Facies 4 (Wilson 1975; Flügel 1982, 2004).

5.3.6 Lemnos Island

The sampled outcrop is situated (39° 48' 56.62'' N/ 25° 21' 59.59'' E) on the Agios Sozon hill north of Fissini village (Figs. 16, 36). The exposed Lutetian-Priabonian to Lower Miocene sedimentary succession is intruded and covered by volcanic deposits (Innocenti et al. 1994; Papanikolaou and Triantaphyllou 2019). The lower part of the succession (Fissini-Sardes Unit, middle-upper Eocene to middle Oligocene) consists of several meters thick deep-marine turbidite deposits including olistoliths of nummulitic pebbly limestone blocks. Samples derived from olistoliths, are characterized by blue to gray color and a diverse microfauna. Moreover, a spot surface sample was collected directly next to the olistolith, as scattered microfossils were found within. Despite they are a weathering product; they will contribute significantly to the systematic taxonomy.

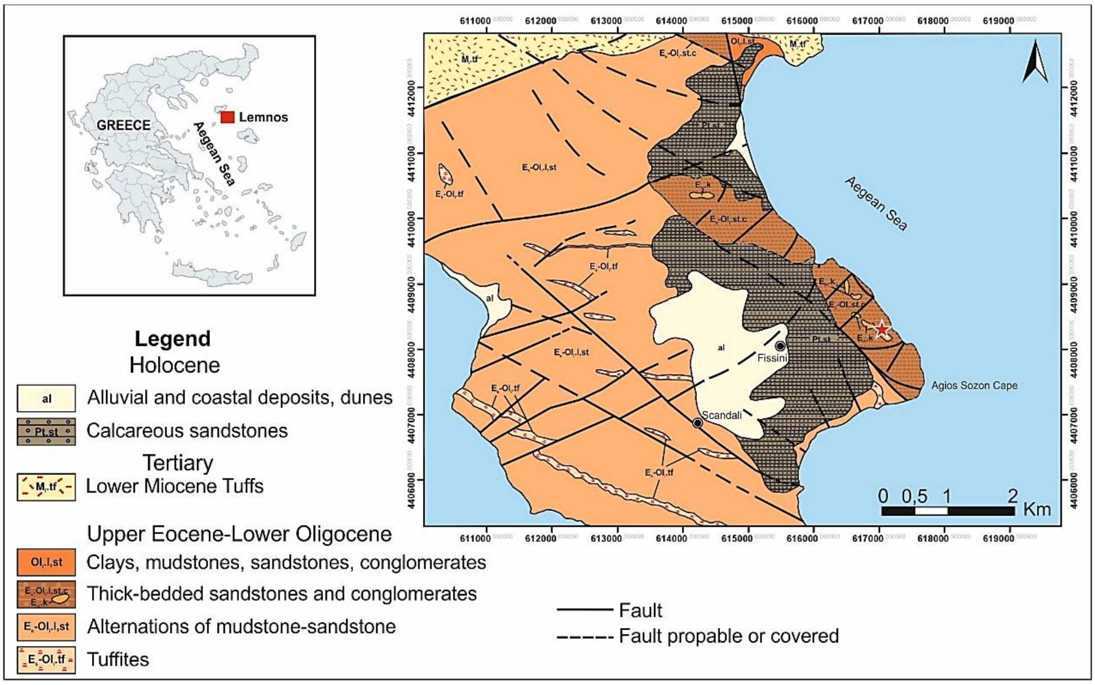


Figure 36. Geological map of Agion Sozon Cape in SE part of Lemnos Island, a red star depicts the sampling site (modified from I.G.M.E. 1993).

5.3.6.1 MF 14: orthphragminid-nummulitid packstone/wackestone

Description: This microfacies is characterized by abundant orthophragmines and nummulitids (Fig. 35d), embedded in a grainstone matrix. Orthophragmines are represented by abundant *Orbitoclypeus* (avg. D/T ratio 2.11), common *Asterocyclina* (avg. D/T ratio 3.17) and common *Discocyclina* (avg. D/T ratio 6.26). Nummulitids are only represented by A-forms of common *in situ Nummulites* (avg. D/T ratio 1.92), redeposited giant representatives of the *Nummulites millecaput-maximus* group as well as common to rare *Heterostegina reticulata*. Rare small rotaliids, *Sphaerogypsina* cf. *globula*, nodosariids and biserial foraminifera are also noted. Another common component is the planktonic foraminifera. LBF bioclasts abrasion ranges from undamaged to highly abraded and fragmented, while they exhibit chaotic stacking to linear accumulation. Debris of coralline red algae, fragments of bryozoans and rare worm tubes are also recorded. It is worth mentioning that the existing pebbles are distinguished into three categories according to their nature and content. Pebbles containing LBF assemblage, pebbles with pelagic association of planktonic foraminifera and finally the ones of terrestrial origin (Fig. 35c).

Interpretation: This facies is dominated by polymictic and diverse fauna of foraminifera characterizing different time spans. Bioclasts of Bartonian are documented. Thus, their redeposition is clearly concluded and most possibly can be attributed to the syn-rifting. This fact is also evidenced by the lithoclasts of different origins (pelagic to terrestrial). However, based on the undamaged foraminifera referring to the same time frame and their flat shape, outer shelf conditions can be assumed.

5.3.7 Samothraki Island

A few samples were provided from the Kipos Cape located at the eastern end of Samothraki Island (Figs. 1, 37). They were collected from the middle-upper Eocene carbonate succession (about 100 m thick) overlain the Cretaceous diabase. It comprises a compact, dark grey limestone containing a diverse micro- and macrofauna of LBF (e.g., *Nummulites*, *Assilina*, *Discocyclina*), corals, algae and molluscs respectively. Samples were collected from a non-stratified horizon; however, they were used in order to come up with some preliminary results that can be compared in terms of age assessment, microfossil content, microfacies analysis and finally paleoenvironmental conditions to the other studied sections. The following two microfacies types could be distinguished.

5.3.7.1 MF 15: Assilina alpina- coral packstone

Description: This microfacies is dominated by mass occurrence of large-sized *Assilina alpina* (avg. D/T ratio 12.1) and sheet-like, platy and branches corals distributed in dark grey micritic matrix (Fig. 35e, f). Other late Eocene bioclasts are the common *N. fabianii*, the rare *Heterostegina* sp., *Discocyclina* sp. (Fig. 35f), *Silvestriella tetraedra*, *Sphaerogypsina* cf. *globula*, *Gyroidinella magna*, biserial foraminifera and scarce miliolids and *Asterigerina* sp. Planktonic foraminifera are absent. Subordinate components are echinoid spicules and fragments of bryozoans. Nummulitids' tests are characterized by contact imbrication and linear accumulation. Bioclasts show low grade of abrasion.

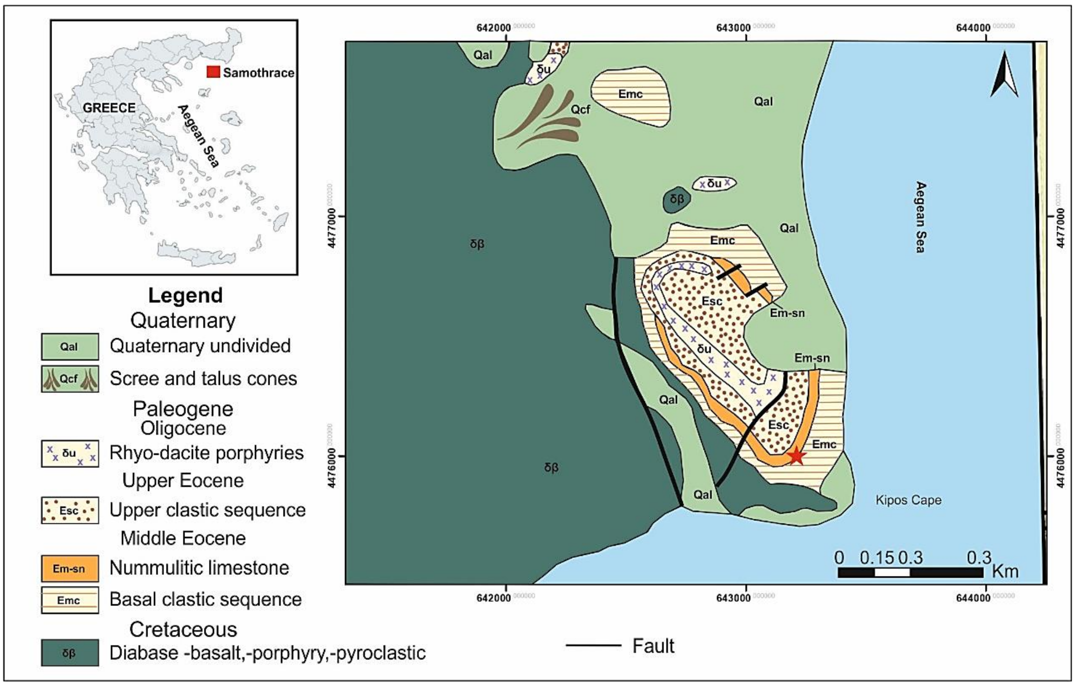


Figure 37. Geological map of Kipos Cape in east end of Samothraki Island, sampling site is depicted by a red star (modified from I.G.S.R. 1972).

Interpretation: Hottinger (1997) places *Assilina alpina*, when co-occurs with *Nummulites*, *Heterostegina* and *Discocyclina* in the upper photic zone (maximum depth of 40 m). This hypothesis is supported by the presence of *Discocyclina* and the flat shape of almost all foraminiferal tests. The occurrence of platy and sheet-like corals, suggests relatively deep settings of the middle platform. The linear accumulation of the tests as well as the micritic matrix indicates relatively shallow water conditions, influenced by current action. Most probably, this facies is interpreted as middle platform deposits.

5.3.7.2 MF16: coral-gastropod wackestone/framestone

Description: This facies is characterized by abundant corals (Fig. 35g) (sheet-like and branched forms) and gastropods embedded in the same dark gray micritic matrix. Bioclasts of corals are coated by encrusting foraminifera most likely belonging to *Miniacina*. Coralline red algae forming rhodoliths (borings of *Trypanites*-like are noted) and encrustations, show fair abundance. In contrast, foraminifera are represented by the common miliolids, the rare nummulitids of late Eocene (Fig. 35h) (*N. fabianii*, *A. alpina*), orthophragmines, the scarce *Asterigerina* sp. and *Sphaerogypsina* cf. *globula*. Minor elements are bryozoans and echinoid spicules. Almost no abrasion is observed on the foraminifera tests.

Interpretation: The synthesis of the assemblage and its low abundance suggest ashallow-water settings of the middle shelf. According to Bosellini and Papazzoni (2003), *Miniacina* occurs at both shallow and deeper depths. The nearly intact foraminiferal tests imply either moderate to low energy water conditions or a coral-protected environment.

5.4 DISCUSSION AND CONCLUSIONS

5.4.1 Depositional model

A depositional model resulting from the microfacies analysis is provided in Figure 38. The schematic aspect of the model displays the main features of the rimmed carbonate shelf developed in the western (Greek) part of the Thrace basin. These are the paleotopography associated with the paleodepth, as well as the distribution of the microfacies. Paleoenvironments, concerning their characteristics, are described in detail as follows.

The inner shelf is divided into two sub-environments, represented by grainstone and foraminiferal packstone, respectively. Both are characterized by the absence of planktonic foraminifera and the presence of miliolids, agglutinants and rotaliids (mainly encrusting foraminifera). All these suggest a restricted environment with vegetation cover with limited circulation or communication with the open sea. Their position regarding the reef is determined by the matrix and the differences in the faunal association. Thus, the striking occurrence of orthophragminids and heterosteginids (MF11) and the micritic matrix suggest low energy water conditions, in transitional facies from the backreef to the reef. However, their absence, the shift to grainstone and the terrigenous input in MF3 imply moderate water energy, positioned closer to land than to reef.

The middle shelf is characterized by wackestones/packstones (locally boundstones) dominated by corals, coralline red algae and large benthic foraminifera, occupying the first 40 m of the water column. Based on the microfacies analysis, it is divided into two parts: the fore-reef and the reef core associated with platform margins and shoals. The transition from the inner to the middle platform is marked by the presence of abundant corals, coralline red algae as well as radial fibrous cement, all evidenced by the MFs 7, 8, 10, 12 and 16. These facies represent the higher part of the reef core where the massive corals grow under low energy water regime, and the sedimentation is controlled by tides and currents. Adjacent and slightly deeper to the platform margins, nummulitic packstones (MF6) and interfingering shoals with the presence of peneroplids (MF4) create barriers. They protect the reef core as they absorb the high energy of the strong wave action. The absence of planktonic foraminifera and the good preservation of fossil tests of the reef core facies, along with the presence of bryozoans and the increase in biodiversity of the fore-reef facies, reflect the gradients between the two parts. From the fore-reef, three laterally developed sub-environments were distinguished. The upper fore-reef sub-environment (MFs 5, 9) is characterized by wackestones/packstones dominated by bryozoans' fragments and abraded tests of large benthic foraminifera (nummulitids and orthophragmines). This suggests high energy conditions and vegetated substrates. The change from the previous MFs to the adjacent MF15, is justified by the noteworthy reduction of bryozoans, orthophragmines and the striking increase of *Assilina alpina*. Based on the linear accumulation of their tests, a current/wave-dominated sub-environment is attributed that probably operated as a barrier. The same conditions but with an increase in vegetation cover (MF2) occur at the distal part of the middle platform, above the strong wave base. This change is associated with the increase in the *Silvestriella tetraedra* population.

The outer platform described in this study refers to its proximal part with a range depth of 40-60 m. The change of conditions from the middle to the outer platform (MF1, 13) is strongly correlated with the shift and high diversity in the fossil content. This shift is marked by the increase and dominance of flat orthophragmines, the increase of flat *Nummulites*, and finally the presence of heterosteginids and *Pellatispira madaraszi*. The foraminiferal tests of MF1 exhibit low degree of abrasion, in contrast to those of MF13. Additionally, the matrix ranges from grain-supported (MF13, 14) to micritic-supported (MF1). All these lead to the assumption either of a deepening trend and a decrease in the hydrodynamic regime, or that MF13 and 14 was a high-energy storm-induced episode of MF1. According to the worm tubes on the orthophragmine tests' and the fact that the tubes are covered by lateral orthophragmine chamberlets, a muddy bottom is attributed.

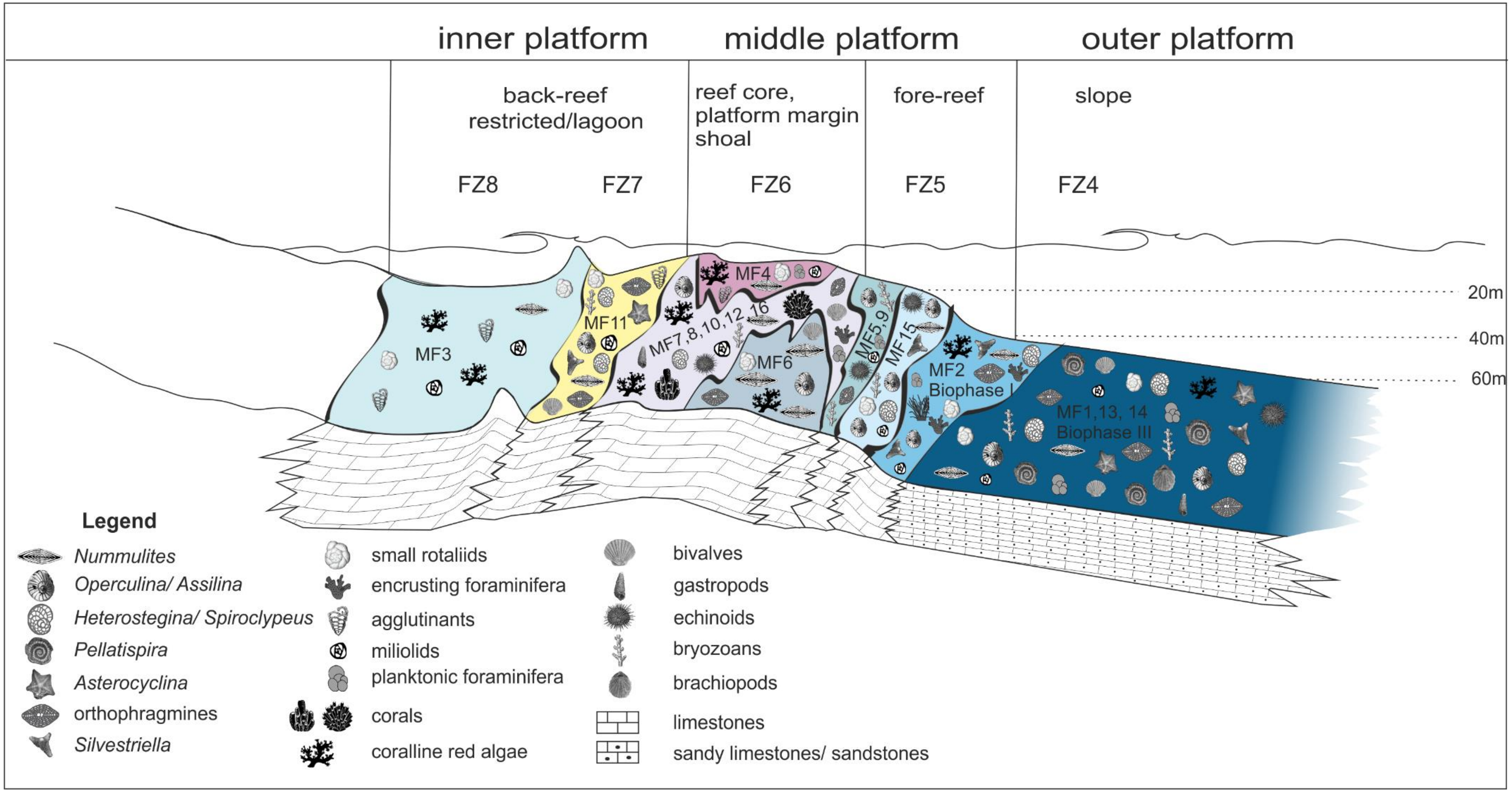


Figure 38. Schematic depositional model resulting from microfacies of the Thrace platform (NE Greece).

5.4.2 Remarks on the timeframe and comparison to the eastern part of the Thrace Basin

The region of the Thrace basin during Eocene represents in general a shallow carbonate platform. It is well known that the Greek part of the Thrace basin suffered from both severe tectonic and volcanic activity, affecting the paleotopography of the basin (Papanikolaou and Triantaphyllou 2010). According to the present study, it comprises two stages of development during the middle-late Eocene. In the first stage, an older platform seems to have been operated as evidenced by the occurrence of remains of late Lutetian to early Bartonian assemblages. According to Dimou et al. (2021), the redeposited fauna recovered from the Kirki area of the corresponding age, constitutes the remains of this platform. Nevertheless, the initial formation cannot be found as it is demolished due to tectonics or underlies a new transgression, hence for research purposes we consider this as a distinct Formation ("Phantomas" Formation). This transgressive episode (T1, conglomerate containing clasts of *Assilina exponens*) marks the closure of this platform and the launching of the rise/operation of a younger Bartonian-Priabonian one. Assemblages of similar age have only been described in the NW part of Gökçeada Island from Özcan et al. (2010), including them to Soğucak Fm. However, Kopp (1964, 1965) found a similar assemblage in the carbonate layers from the NE part of Gökçeada Island, including them in Avas Fm (e2n; Kopp 1964), and in the transgressive conglomerate near Kirki (e2b; Kopp 1965) considering it as a marine stage of the transgression.

The second stage of development refers to the operation of a late Bartonian to Priabonian platform. The Bartonian is reported only from MF 14 (Lemnos Island) represents middle to outer shelf settings with high energy water conditions, as opposed to Priabonian which is found widespread in the mainland. Calcareous nannofossil evidence (biozone NP 19-20) from the clastic sediments just below the Avas Fm limestones further supports the Priabonian age (Papanikolaou and Triantaphyllou 2010). It should be noted that redeposited mixed fauna has been recorded, as well as clasts of terrigenous origin, clasts of the deeper open marine environment and also clasts containing microfauna most likely from "Phantomas" Fm. In the Turkish part, the Bartonian is well exposed in several outcrops such as Akören, Hacimaşli, Şamlar, Çatalca, Tayfur, Beşyol and Mürefte sections that operated mainly as inner and outer platform (Özcan et al. 2010; Less et al. 2011). Özcan et al. (2010) concluded in four phases of deposition/drowning of the platform, with a WSW to ENE transgression.

Therefore, these could justify the demise of the “Phantomas” Fm as well as the Bartonian age of Avas Fm.

The Priabonian in the whole basin refers to three main environments (inner, middle and outer platform) with the distinction of several sub-environments. During this period, the development of coral reefs took place in the Avantas (MF12) and Didymoticho (MF7) regions, referring to the shallowest part of the reef. The development of patch reefs, suggests the establishment of a rimmed carbonate platform similar to that of the Turkish part. Basinwards, in the upper part of the middle shelf, the nummulitic-packstone (MF6) is formed in interfingering with shoal deposits (MF4). Both of them most likely operated as a barrier. The almost monospecific banks of *N. fabianii* recognized in the Maronia and Palagia sections, are equivalent to those reported by Less et al. (2011) in Kirklareli (samples KIRK 12, B15 and D1), Dolhan, Pinarhisar (samples PINAR 1, 6 and 9) and in Kiyiköy (samples KIY 1 and 2). Moving deeper to the middle shelf, to the distal outer platform an *Assilina* bank is formed in shallow wave dominated environment (MF15). Nevertheless, references for corresponding *Assilina* packstones noted from Samothraki Island (present study), are not found. In the upper fore-slope settings of the middle platform (MF5) high energy water regime and the strong action of waves are reported.

Later on, the microfacies analysis of the Pylaea section indicates that was operating mainly as an outer platform of low energy regime. However, in the middle part of the section, a regression episode (R1) is supposed based on the appearance of MF2. During this period, the water depth decreases, and the substrate consists of marine vegetation. This episode is also marked in the wider area towards the mainland, by the Biophase I of the Fanari area (Dimou et al. 2023) and the protected areas of the inner shelf. Behind the reef core, the back-bank deposits are occupied by the lower part of Avas Fm. Microfacies analysis of MF3 reported from the Pylaea area and Palagia section reveals a restricted/ lagoon type inner platform setting, also reported from the Turkish part by Turgut and Eseller (2000). Moreover, the back reef setting is very close to the reef or reef flat- type of MF11 where moderate water-conditions have been assigned. This facies is indicated by the Avantas section. According to Özcan et al. (2010), the samples from the Mecidiye region represent fauna equivalent to that of MF11.

Continuously, a second transgressional episode (T2) occurred. Traces of this event is initially documented by Biophase III of the Fanari area (Dimou et al. 2023) attributed to the upper part of the fore-slope, most likely between the FWWB and the storm wave base. T2 with similar settings to Biophase III, is also evident in the upper part of the Pylaea section where moderate energy conditions prevailed at a depth of approximately 40-60 m, with the foraminiferal tests being the only solid substrate in a muddy environment (MF1). Additionally, similar but slightly shallower deposits were described in MF13. At the time of the sea-level rise, Avantas (MF10) and Didymoticho (MF8) operated again as the highest parts of the coral reef and yet the deepening continued (MF9). According to Less et al. (2011), Çatalca (Çat B) and Kirklareli (Kirk 19) correspond to the outer shelf conditions.

Apart from the Bartonian transgression, localized changes in water depth are controlled by regressive/transgressive episodes. However, the cause that triggered the sea level fall/rise during these episodes could be related either to tectonic events or global fluctuation but is not studied in this research. These episodes are less intense compared to those of the Bartonian and they are evidenced by the deepening trends of the Pylaea's and Fanari's deposits. Finally, the platform submerges under the new Oligocene transgression.

CHAPTER 6. Eocene Benthic Foraminifera from Fanari: taxonomy and paleoenvironmental inferences

6.1 INTRODUCTION

Most of the information concerning the micropaleontological content of western Thrace basin, derived mainly from stratigraphers of 60's and 70's. Christodoulou (1957) was the first who reported, from Samothrace Island, a Priabonian assemblage of LBF and also *Asterigerina rotula*, *Eorupertia cristata*, *Schlosserina* sp., *Textularia* sp., *Pyrgo* sp., *Triloculina* sp., *Nodosaria* sp., *Robulus* sp., *Epistomina* sp., and *Globigerina*. A decade after, Kopp (1965) after personal communication with Dr. Ellermann, characterized the lower part of a section near Doriko as marine and listed the following: *Bathysiphon filiformis* Sars, *Cyclammina acutidorsata* (Hantken), *Haplophragmoides* cf. *obliquecarinatus* Marks, *Spiroplectammina carinata* (d' Orbigny), *Quinqueloculina* sp., *Dentalina soluta* (Reuss), *Guttulina problema* d' Orbigny, *Globulina gibba* d' Orbigny, *Virgulina schreibersiana* Czizek, *Bolivina punctata* d' Orbigny, *Bulimina truncata* Gümbel, *Nonion soldanii* (d 'Orbigny), *Nonion affine* (Reuss), *Nonion* cf. *boueanum* (d' Orbigny), *Gyroidina soldanii girardana* (Reuss), *Eponides haidingeri* (d' Orbigny), *Cancris turgidus* Cushman & Todd, *Almaena (Pseudoplanulinella)* sp., *Cibicides lobatulus* (Walker & Jacob). Later, Zagorchev et al. (2010) noted also from Samothrace Island, the occurrence of *Asterigerina* cf. *lancicula*, *Haddonia heissigi*, *Sphaerogypsina* sp., *Gypsina* sp. among LBF. However, all these previous publications do not perform fully quantitative analysis of benthic foraminifera and they do not include systematic descriptions or illustrations, as they mainly focus on the stratigraphy.

Fanari section was chosen because of the good preservation of the foraminiferal content and the thorough data of the uppermost Eocene. The age assignment was well-established based on the Large Benthic Foraminifera (LBF) recovered from the same material studied here (Dimou et al. 2023).

The aim of this research is to present a comprehensive (in cases revised) and complete systematic analysis of benthic foraminifera of Priabonian of the western Thrace basin, as well as to provide a paleoenvironmental interpretation.

6.2 MATERIAL AND METHODS

The studied material was collected from a stratigraphic section which is located at the coastline of Fanari village (30 km southwest of Komotini city). Additionally, three spot samples were collected from Pylaea, Kirki and Lemnos Island respectively, in order to compare the foraminiferal content and the paleoenvironmental conditions. The geological setting, the stratigraphy of the sections as well as the sampling procedure were described in detail in previous chapters (Dimou et al. 2023: chapter 4, 5), thus they will not be further discussed.

Foraminiferal analysis was carried out on twenty-four sediment samples. Firstly, all of them (250 gr dry weight) were soaked in water, to which diluted Hydrogen Peroxide (H_2O_2, 70%) was added to accelerate the process of disaggregation. Continuously, they were washed over a 125 μm sieve. The final sieved residues were air-dried at room temperature. Afterwards, due to the high-density samples were split into representative fractions using a micro-splitter. All the included specimens were collected.

All the material was studied, identified and photographed under Zeiss Stemi 305 trinocular microscope. The best preserved and representative specimens were selected and coated with Au for Scanning Electron Micrography (SEM), used for taxonomical purposes, using the Jeol JSM-840A microscope of the scanning microscope laboratory of the Aristotle University of Thessaloniki. However, several specimens were charging, therefore they were scanned with the low vacuum method. All illustrated material is deposited in the Museum of Geology, Palaeontology, Palaeoanthropology of Aristotle University of Thessaloniki.

6.3 DATA ANALYSIS

Absolute abundance of each species across the study interval was calculated. Absolute abundances were preferred as many species show very low number of specimens making relative abundances not an appropriate method for the purposes of this study. Additionally, the heterogeneity evaluation expressed by the Shannon Wiener diversity Index (H') was succeeded through the Past3.exe software package (Hammer et al. 2001). Foraminifera were distinguished as epifaunal and infaunal species. Moreover, epiphytic foraminifera were divided into four major categories (A, B, C, D) according to Langer (1993). This differentiation groups different species in morphotypes according to their life mode, their life span and the way they move.

Finally, Principal Component Analysis (PCA), Q-mode and R-mode Hierarchical Cluster analysis were performed to extract ecological information derived from the separated assemblages from single samples using IBM SPSS Statistics Package v 28.0 (2021) statistical software. These methods are often used in foraminiferal analysis in order to countify the community structure of the foraminifera fauna (Schmiedl et al. 1997; Schönfeld 2002; Mendes et al. 2004). Euclidean distances as a similarity index and Ward's Minimum Variance method were used for determining the species groups and also to extract the ecological information from them. The analysis performed on species that attain a frequency of 5% at least in one sample. Data were logarithmically transformed to reduce the score and the bias of other abundant species that may have otherwise masked the effect of less abundant species.

6.4 RESULTS

6.4.1 Systematic paleontology

Rich benthic foraminiferal fauna was recovered which is associated with planktonic foraminifera, ostracods, numerous molluscs (bivalves and gastropods), echinoid spines and test fragments, bryozoans, brachiopods, siliceous sponge spicules and several fishbones. The highly diversified assemblages comprise 76 pecies. Benthic foraminifera taxonomy follows the systematic classification of Loeblich and Tappan (1988). Identifications are mostly to species level except for planktonic foraminifera (genus level). Geographical range distribution is given in taxonomy descriptions.

Order Astrorhizida

Suborder Astrorhizina

Superfamily Astrorhizoidea Brady 1881

Family Rhabdamminidae Brady 1884

Genus *Psammosiphonella* Avnimelech 1952

***Psammosiphonella cylindrica* (Glaessner 1937)**

Plate 1, Fig. 1

1937 *Rhabdammina cylindrica* Glaessner, p. 354, pl. 1, figs. 1

2005 *Psammosiphonella cylindrica* (Glaessner); Kaminski & Gradstein, p. 145, pl. 6, figs. 1-5

2016 *Psammosiphonella cylindrica* (Glaessner); Moura de Mello, p. 47, pl. 1, fig. 5

Remarks: Test agglutinated, straight and cylindrical with thick wall. All recovered specimens show moderate preservation.

Occurrence: The species rarely occurs in all samples of the upper part of the sequence and in samples FANA 2, 5 and 8-10 with slightly lower numbers.

Genus *Rhizammina* Brady 1879

***Rhizammina* sp.**

Plate 1, Figs. 2-3

Description: Specimens are large with tubular tests that in cases are branched. Wall is finely agglutinated.

Remarks: All recovered specimens show moderate preservation.

Occurrence: This species occurs rarely in samples FANB 15, 16, 20, 21 of the upper part of the sequence and in samples FANA 1-2, 7-8 of the upper part.

Suborder Hippocrepinina

Superfamily Hippocrepinoidea Rhumbler 1895

Family Hyperamminidae Eimer & Fickert 1899

Genus *Hyperammina* Brady 1878

***Hyperammina* sp.**

Plate 1, Fig. 4

Description: Specimens are fragments with straight and tubular shape. Their wall is coarsely agglutinated.

Remarks: All recovered specimens present moderate preservation.

Occurrence: This species is rare in samples FANA 5, 7, 10 and in FANB 16, 19, 20-21.

Suborder Hosmosinina

Superfamily Hormosinelloidea Rauzer-Chernousova & Reitlinger 1986

Family Hormosinellidae Rauzer-Chernousova & Reitlinger 1986

Genus *Hormosinella* Shchedrina 1969

***Hormosinella* sp.**

Plate 1, Fig. 5

Description: Test elongated with oval chamber. Wall coarsely agglutinated.

Remarks: All recovered specimens present poor preservation.

Occurrence: This species is found only in samples FANB 19 and 20 but in very low numbers.

Order Spirillinida

Suborder Ammodiscina

Superfamily Ammodiscoidea Reuss 1862

Family Ammodiscidae Reuss 1862

Genus *Ammodiscus* Reuss 1862

***Ammodiscus* sp.**

Plate 1, Figs 10a-10b

Description: The test is discoidal in shape and thin. It is planispirally coiled with depressed coil sutures. Only the outermost whorl is noticeable. Wall is finely agglutinated.

Remarks: All recovered specimens present moderate preservation.

Occurrence: This species is found only in samples FANA 1-2, 8 and FANB 16, 20 with few specimens.

Order Lituolida

Suborder Lituolina

Superfamily Lituoloidea

Family Haplophragmoididae Maync 1952

Genus *Haplophragmoides* Cushman 1910

***Haplophragmoides* sp.**

Description: Test agglutinated, planispiral, wall test coarsely agglutinated.

Remarks: The specimens included here are poorly preserved and do not show any morphological features.

Occurrence: Only two specimens were recovered from the lower part of the section (FANA 6 and FANA 3).

Suborder Verneulinina
Superfamily Verneuilinoidea Cushman 1911
Genus *Gaudryina* d'Orbigny 1839
***Gaudryina pyramidata* Cushman 1926**
Plate 1, Fig. 6
1926 *Gaudryina laevigata* Franke var. *pyramidata* Cushman, p. 587, pl. 16, fig. 8
2001 *Gaudryina pyramidata* Cushman; Alegret & Thomas, p. 285, pl. 6 fig. 4
2016 *Gaudryina pyramidata* Cushman; Moura de Mello, p. 68, pl. 5, fig. 6
Description: Test agglutinated, pyramidal in shape with acute periphery.
Remarks: All recovered specimens present good preservation.
Occurrence: This species occurs in almost the whole sequence except samples FANA 8, 12-15.

Order Textulariida
Suborder Textulariina
Superfamily Textularioidea Ehrenberg 1838
Family Textulariidae Ehrenberg 1838
Subfamily Textularioidinae Loeblich & Tappan 1984
Genus *Textularia* Defrance 1824
***Textularia* sp. 1**
Plate 1, Fig. 9
Description: Enlongated, rounded and almost straight test with heavy ornamentation. The aperture is a slit at the base of the apertural face with a narrow lip.
Remarks: The recovered specimens were broken at the end of the test and therefore the aperture was not visible.
Occurrence: Very few specimens were recovered from samples FANA 3, 7-8 and FANB 17, 21.

***Textularia* sp. 2**

Plate 1, Fig. 7

Description: Test is biserial, compressed in the longitundinal axis, triangular in lateral view. Wall is finely to slight coarsely agglutinated. Chambers gradually increasing in size. Aperture is an arch at the base of the apertural face.

Remarks: The specimen show good preservation.

Occurrence: Only one specimen was recovered from the lower part of the sequence, FANA 6 sample.

***Textularia* sp. 3**

Plate 1, Fig. 8

Description: Test is large, biserial, triangular to circular in lateral view. Wall is coarsely agglutinated. Chambers gradually increasing in size.

Remarks: The specimen shows good preservation. It is distinguished from *Textularia* sp. 1 due to the circular shape and coarsely perforated wall.

Occurrence: Only one specimen was recovered from the lower part of the sequence, FANA 6 sample.

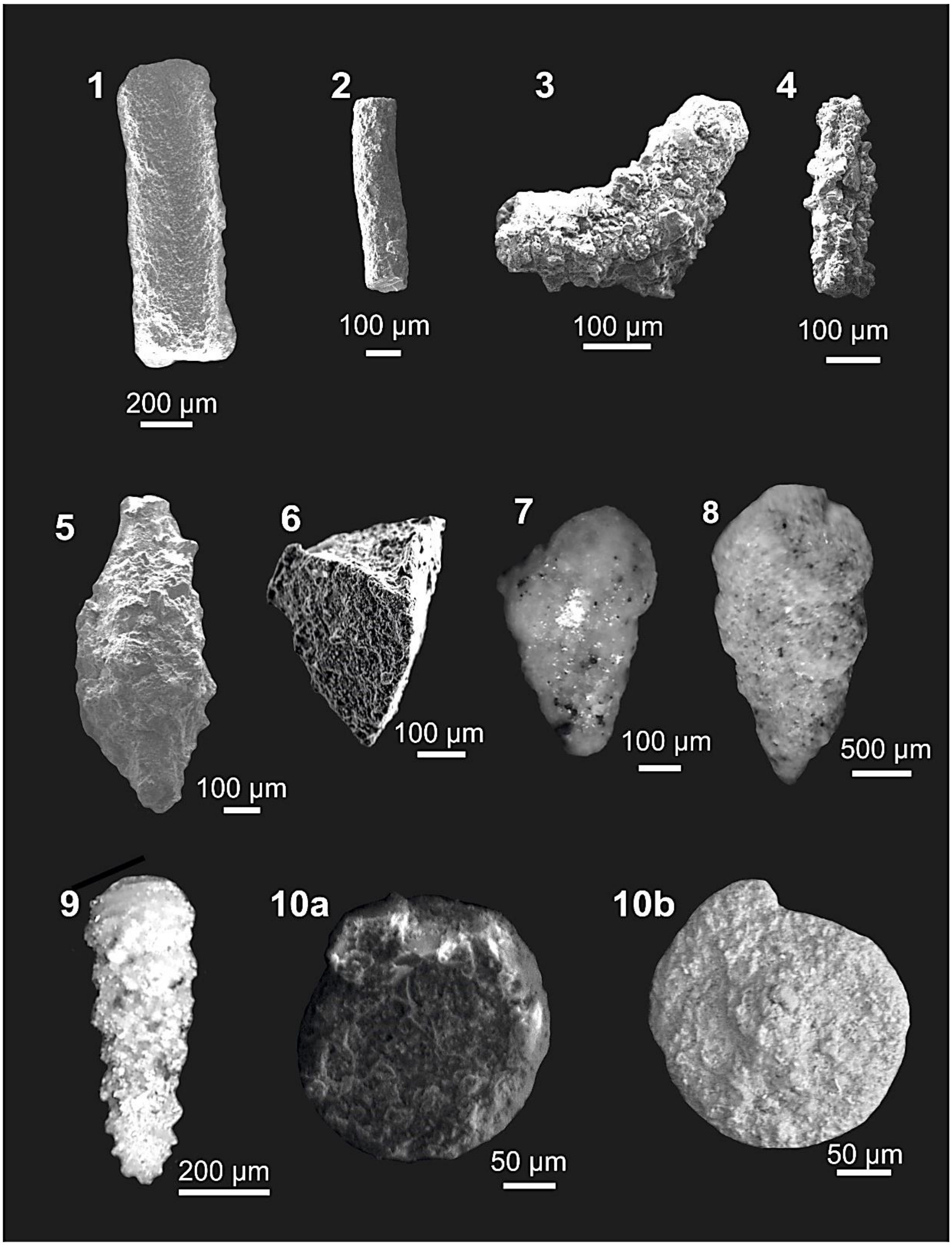


Plate 6. Foraminiferal species. **1.** *Psammosiphonella cylindrica* (Glaessner) FANA 8, **2-3.** *Rhizammina* sp.; **2.** FANB 16, **3.** FANA 7, **4.** *Hyperammina* sp. FANB 16, **5.** *Hormosinella* sp. FANB 20, **6.** *Gaudryina pyramidata* Cushman FANA 6, **7.** *Textularia* sp. 2 FANA 6, **8.** *Textularia* sp. 3 FANA 19, **9.** *Textularia* sp. 1 FANA 6, **10.** *Ammodiscus* sp. FANB 18.

Order Miliolida

Suborder Miliolina

Superfamily Miliolidea Ehrenberg 1839

Plate 7, Figs. 1, 2a-b

Remarks: Almost all recovered representatives of this superfamily are poorly preserved. Nearly all specimens show dissolution of their test. Based on the morphology of the remaining internal casts, it can be concluded that there are more than three genera.

Occurrence: They occur in all samples with the highest abundance in sample FANA 6.

Family Hauerinidae Scwager 1876

Genus *Quinqueloculina* d' Orbigny 1826

***Quinqueloculina* sp. 1**

Descpriction: Test ovate to round in outline, triangularly in cross section. The wall is calcareous, porcelaneous and with smooth surface. Chambers in quinqueloculine arrangement and acute creating ridges.

Remarks: Only one specimen was recovered with moderate to poor preservation.

Occurrence: *Quinqueloculina* sp. 1 is recovered only from FAN B 17 sample (upper part of the section) from the 250 μm sieve residual.

***Quinqueloculina* sp. 2**

Descpriction: Test elongated and ovate with chambers in quinqueloculine arrangement. The wall is calcareous, imperforate and moderately thick. At the end of the last chamber, a short neck is visible.

Remarks: Only one specimen was recovered. Its preservation is poor as it is broken along the perpendicular axis. Thus, the aperture is also destroyed.

Occurrence: *Quinqueloculina* sp. 2 is recovered only from FAN B 17 sample, from the 250 μm sieve residual.

Order Vaginulinida

Family Vaginulinidae Reuss 1860

Subfamily Marginulininae Wedekind 1973

Genus *Vaginulinopsis* Silvestri 1904

***Vaginulinopsis* sp.**

Plate 7, Fig. 3

Description: Test elongated. In early stages is planispirally coiled but the later chambers are uncoiled. They gradually increase in width. Aperture is terminal.

Remarks: The preservation of the tests are moderate.

Occurrence: Only three specimens were recovered from the upper part of the sequence (FANB 15, 18-19).

Subfamily Lenticulininae Chapman, Parr and Collins 1934

Genus *Lenticulina* Lamarck 1804

***Lenticulina inornata* (d' Orbigny 1846)**

Plate 7, Figs. 4a-c

1846 *Robulina inornata* d' Orbigny, p. 102, pl. 4, figs. 25, 26

1982 *Lenticulina inornata* (d' Orbigny); Foraminiferi Padani, pl. 10, figs. 4, a

1985 *Lenticulina* (*Robulina) inornata* d' Orbigny; Papp & Schmid, p. 43, pl. 31, figs. 6-8

1986 *Lenticulina inornata* (d' Orbigny); Rupp, p. 64, pl. 26, figs. 6, 7

Description: Test planispiral, involute and lenticular. Chambers gradually increasing. Sutures slightly oblique, bent backward. Aperture terminal and radiate.

Remarks: The preservation of the tests varies from sample to sample. They mainly present good preservation, however several specimens are broken.

Occurrence: This species is common throughout the sequence, except samples FANA 1 where none was recovered.

***Lenticulina calcar* (Linnaeus 1758)**

1758 *Nautilus calcar* Linnaeus, p. 704 (fide Ellis & Messina, 1940)

1982 *Lenticulina calcar* (Linnaeus); Foraminiferi Padani, pl. 9, figs. 3, a

1985 *Lenticulina (Robulina) calcar* (Linnaeus); Papp & Schmid, p. 42, pl. 30, figs. 1-3

1991 *Lenticulina calcar* (Linnaeus); Cimerman & Langer, p. 51, pl. 53, figs. 1-4

1993 *Lenticulina calcar* (Linnaeus); Sgarella & Moncharmont Zei, p. 194, pl. 12, fig. 11

2005 *Lenticulina calcar* (Linnaeus); Rasmussen et al., p. 69, pl. 6, fig. 5

Description: Test planispiral, involute and lenticular. It is characterized by the presence of spines at the periphery. Chambers gradually increasing. Sutures slightly oblique, bended backward. Aperture terminal and radiate.

Remarks: The recovered specimens present moderate preservation.

Occurrence: This species is only found in samples FANA 2, 4 and FANB 17.

***Lenticulina carinata* (d' Orbigny 1826)**

1826 *Soldania carinata* d' Orbigny, p. 281

1964 *Lenticulina carinata* (d' Orbigny); Loeblich & Tappan, p. C520

Plate 7, Fig. 6a-b

Description: Test planispiral, involute and lenticular. It is characterized by the presence of carina at the periphery. Chambers gradually increasing. Sutures slightly oblique, bended backward. Aperture terminal and radiate.

Remarks: The test of the specimen presents good preservation.

Occurrence: Only one specimen was retrieved from sample FANB 17.

Family Lagenidae Reuss 1862

Genus *Lagena* Walker & Jacob 1798

***Lagena striata* (d'Orbigny 1839)**

Plate 7, Fig. 5

1839 *Oolina striata* d'Orbigny, pl. 5, fig. 12 (fide Ellis & Messina, 1940)

1991 *Lagena striata* (d'Orbigny); Cimermam & Langer, p. 53, pl. 55, figs. 6-7.

1993 *Lagena striata* (d'Orbigny); Sgarella & Moncharmont Zei, p. 189-199, pl. 12, figs. 2-3.

Description: Test unilocular and flask-shaped. It is circular in section with a long, cylindrical neck. The outer surface is characterized by the presence of costae extended from the base up to the middle of the test.

Remarks: Tests show poor preservation. The outer wall is missing and therefore the recovered specimens are characterized as casts. Moreover, the aperture is destroyed in all samples.

Occurrence: This species occurs only in sample FANB 16.

***Lagena* sp.**

Plate 7, Fig. 7

Description: Test unilocular and flask-shaped. It is oval in section with a long, cylindrical and slightly truncated neck.

Remarks: Tests show poor preservation. The outer wall is missing and therefore the recovered specimens are characterized as casts. Moreover, the aperture is destroyed in all samples.

Occurrence: This species occurs only in sample FANB 16.

Genus *Hyalinonetrion* Patterson & Richardson 1988

***Hyalinonetrion* sp.**

Plate 7, Fig. 8

Description: Test in elongated and unilocular. It is characterized by a circular shape that in the middle part thickens.

Remarks: The tests present good preservation. However, in some cases, sand grains are attached.

Occurrence: This species occurs rarely in samples FANA 3, 6, 8 and FANB 19-20.

Order Polymorphinida
Suborder Polymorphinina
Superfamily Polymorphinoidea d'Orbigny 1839
Family Polymorphinidae d’Orbigny 1839
Subfamily Polymorphininae d'Orbigny 1839
Genus *Globulina* d’Orbigny 1839

***Globulina gibba* (d’Orbigny 1826)**

Plate 7, Fig. 9

1826 *Polymorphina gibba* d’Orbigny, p. 226, no 26
1935 *Globulina gibba* (d’Orbigny); Cushman, p. 26, pl. 9, figs. 19, 20
1982 *Globulina gibba* (d’Orbigny); Foraminiferi Padani, pl. 20, figs. 1, a, p
1985 *Globulina gibba* (d’Orbigny); Papp & Schmid, p. 79, pl. 71, figs. 9-12
1986 *Globulina gibba* (d’Orbigny); Rupp, p. 62, pl. 21, figs. 5-8
1993 *Globulina gibba* (d’Orbigny); Hottinger et al., p. 79, pl. 91, figs. 6-12
2005 *Globulina gibba* (d’Orbigny); Rasmussen et al., p. 74, pl. 7, fig. 11

Description: Ovoid test with quinqueloculine chamber arrangement. Aperture terminal and radiate.

Remarks: The preservation of the tests can be characterized as moderate.

Occurrence: This species is rare in samples of the lower part of the sequences and its number slightly increases to the upper part where is found in all samples.

Polymorhinid genus 1 sp. A

Plate 7, Figs. 10a-b

Description: Ovoid test with quinqueloculine chamber arrangement. Aperture terminal upon a short neck.

Remarks: The preservation of the test is moderate as the outer wall is missing.

Occurrence: This species is only recovered from sample FANA 15.

Family Ellipsolagenidae Silvestri 1923

Genus *Favulina* Patterson & Richardson 1987

***Favulina hexagona* (Williamson 1848)**

Plate 7, Fig. 11

1848 *Entesolenia squamosa* (Montagu) var. hexagona Williamson, p. 20, pl. 2, fig. 23.

1993 *Favulina hexagona* (Williamson); Hottinger et al., p. 80, pl. 92, fig. 9-13.

Description: Unilocular test, circular in outline. Wall is ornamented with a raised rids of an hexagonical pattern. Aperture at the end of a short neck.

Remarks: Specimens present good preservation.

Occurrence: Only three specimens recovered from samples FANB 16, 18.

***Favulina* sp.**

Plate 7, Fig. 12

Description: Test unilocular, smooth, flask-shaped and compressed in outline. Aperture probably upon the tubular, long neck. Ornamentation of two costae extending from the lower half to the neck. Slightly sharp edges are formed at the base of the test.

Remarks: The preservation of the test is moderate to poor as the outer wall in cases is completely missing. Aperture was not visible.

Occurrence: This species is retrieved almost exclusively from the lower part of the sequence but common to rare. From the upper part, only one specimen was found in sample FANB 17.

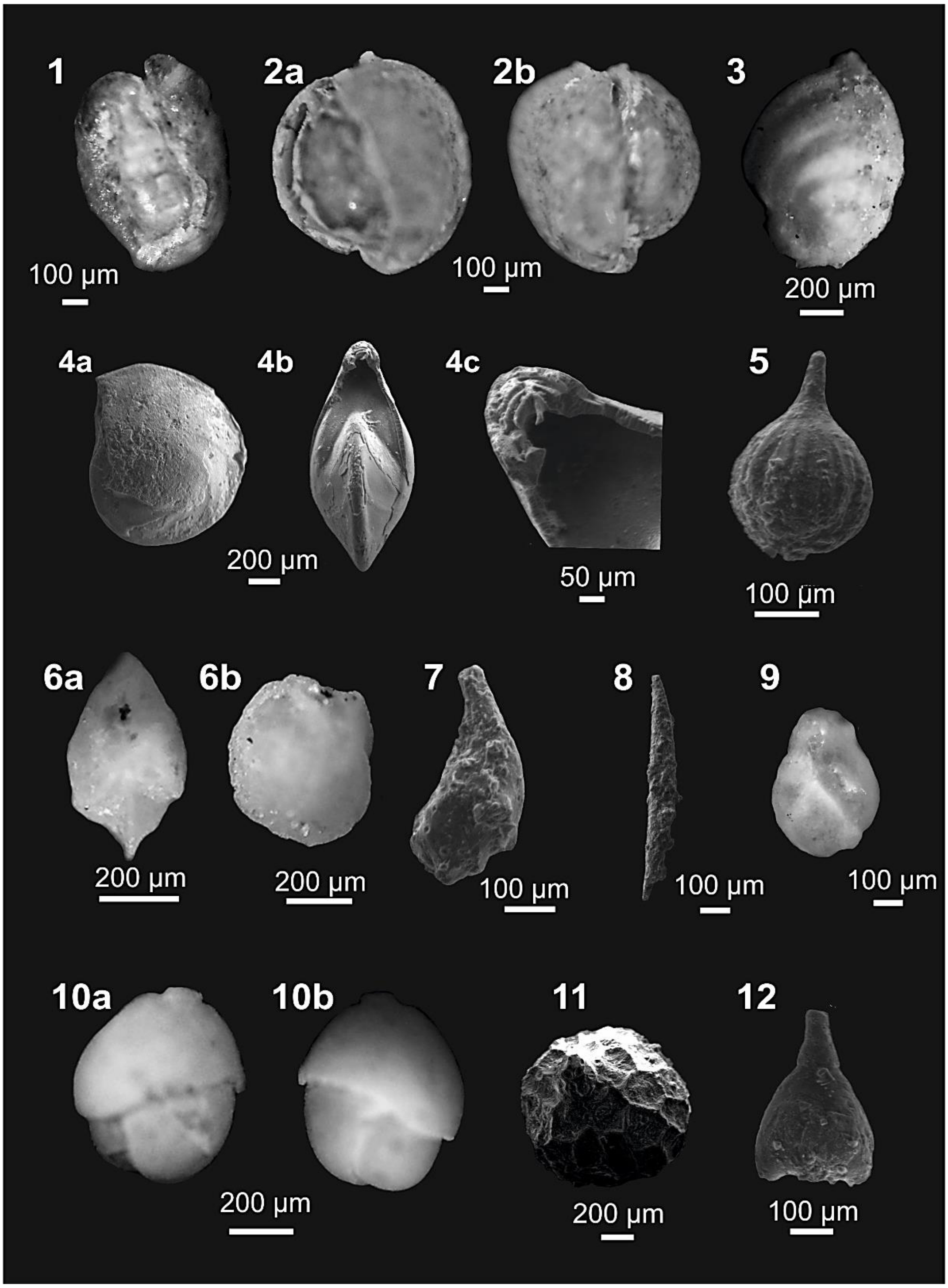


Plate 7. Foraminiferal species. **1-2.** Miliolid casts FANA 5, **3.** *Vaginulinopsis* sp. FANB 18, side view, **4.** *Lenticulina inornata* (d' Orbigny) FANA 8, **4a.** side view, **4b.** peripheral view, **4c.** apertural view, **5.** *Lagena striata* FANB 16, side view, **6.** *Lenticulina carinata* FANB 17, **6a**. peripheral view, **6b.** side view, **7.** *Lagena* sp. FANB 16 side view, **8.** *Hyalinonetrion* sp. FANB 19, **9.** *Globulina gibba* FANB 17, side view, **10a-b.** Polymorphinid genus FANB 15, side view, **11.** *Favulina hexagona* (Williamson) FANB 16, apertural view, **12.** *Favulina* sp. FANB 17, side view.

Order Nodosariida

Suborder Nodisariina

Superfamily Nodosarioidea Ehrenberg 1838

Family Nodosariidae Ehrenberg 1838

Genus *Laevidentalina* Loeblich & Tappan 1986

***Laevidentalina* sp.**

Plate 8, Figs. 1-2

Description: Test uniserial and elongated. Chambers are arranged almost horizontally. Wall do not show any ornamentation. Below the initial chambers, a spine is visible.

Remarks: The recovered specimens present moderate to poor preservation. All of them are broken and the aperture was not visible. In many cases, also the first chambers were broken.

Occurrence: This species occurs with only a few representatives in several samples throughout the sequence.

Genus *Nodosaria* Lamarc 1816

***Nodosaria latejugata* Gümbel 1868**

Plate 8, Figs. 3

1868 *Nodosaria latejugata* Gümbel, p. 41, pl. 1, fig. 32

2006 *Nodosaria latejugata* Gümbel; Cimerman et al., p. 22, pl. 4, fig. 11

Description: Elongated, calcareous test. First chamber is globular, bigger than the rest and at its base there is a short spine. The followings are circular in section, of equal size. Sutures are straight. Surface is ornamented with costae.

Remarks: The specimens recovered are broken. The aperture is missing in both cases, unlike the first chambers with the ending spine.

Occurrence: Only two specimens were recovered from samples FANB 19 and 20.

***Nodosaria* sp. 1**

Plate 8, Fig. 4

Description: Test is elongated with smooth surface. Sutures are slightly depressed.

Remarks: All the recovered specimens of *Nodosaria* sp. 1 are fragments. Hence, there is no documentation about the aperture.

Occurrence: This species occurs rarely in samples FANA 1, 4-7, 11 and in FANB 17, 19-20.

***Nodosaria* sp. 2**

Plate 8, Fig. 5

Description: Test is elongated with smooth surface and a short neck. Chambers are globular and abruptly increase in size.

Remarks: All the recovered specimens of *Nodosaria* sp. 2 are well preserved. It differs from *Nodosaria* sp. 1 due to the shape of the chambers.

Occurrence: This species occurs rarely in sample FANB 19.

***Nodosaria* sp. 3**

Plate 8, Fig. 6

Description: Test is elongated. Chambers increase gradually in size. Surface is ornamented with costae.

Remarks: The recovered specimen of *Nodosaria* sp. 3 presents good preservation. This species differs from *N. latejuata* because of the chamber arrangement and size and from the rest species due to the ornamentation.

Occurrence: Only one specimen was recovered from sample FANB 16.

Superfamily Stilostomelloidea Finlay 1947

Genus *Siphonodosaria* Silvestri 1924

***Siphonodosaria jacksonensis* (Cushman & Applin 1926)**

Plate 8, Fig. 7

1926 *Nodosaria jacksonensis* Cushman & Applin, p. 170, pl. 7, figs. 14-16.

2016 *Siphonodosaria jacksonensis* (Cushman & Applin); Moura de Mello, p.77, pl.6, fig. 12.

Description: Test calcareous, uniserial, rectilinear to slightly arched. Chambers subglobular, increasing gradually in size, sutures distinct and constricted. Terminal aperture on a neck at the last chamber.

Remarks: All recovered specimens show good preservation.

Occurrence: This species is common in the upper part of the sequence. However, in the lower part occurs rarely in samples FANA 1-2, 4, 9-10.

***Siphonodosaria* sp. 1**

Plate 8, Fig. 8

Descpriction: Test calcareous and uniserial. Chambers globular, with rectilinear arrangement.

Remarks: All the recovered specimens of *Siphonodosaria* sp. present moderate to good preservation. It differs from *S. jacksonensis* because of the rectilinear arrangement of the chambers and the lack of the neck.

Occurrence: This species occurs in several samples through the sequence.

***Siphonodosaria* sp. 2**

Plate 8, Fig. 9

Descpriction: Test calcareous and uniserial with neck. Chambers subglobular, with rectilinear to slightly curved arrangement. Sutures are strongly depressed.

Remarks: All the recovered specimens of *Siphonodosaria* sp. 2 show moderate preservation as the embryonic chambers are missing. It differs from the rest species of this genus due to the shape of the chambers and sutures.

Occurrence: This species is only retrieved from sample FANB 19.

Suborder Pleurostomellina

Superfamily Pleurostomellacea Reuss 1860

Family Pleurostellidae Reuss 1860

Genus *Pleurostomella* Reuss 1860

***Pleurostomella acuta* Hantken 1875**

1875 *Pleurostomella acuta* Hantken, p. 37, pl. 13, fig. 18.

2013 *Pleurostomella acuta* Hantken; Alegret & Thomas, p. 44, pl. 1, fig. 13.

Description: Test loosely biserial early stage, oval in outline and circular in cross-section, Chambers increasing gradually in size. Sutures barely visible, slightly depressed and oblique. Wall calcareous hyaline smooth and finely perforated, aperture terminal with large oval opening of final chamber.

Remarks: Only few specimens were found, and their preservation was moderate.

Occurrence: This species rarely occurs in samples FANA 1, 14 and FANB 16 and 19.

***Pleurostomella incrassata* Hantken 1883**

Plate 8, Fig. 10

1883 *Pleurostomella incrassata* Hantken, p. 146, pl. 1, figs. 4, 7

Description: Test loosely biserial, lobulate in outline and circular in cross-section. Chamber gradually increase in size and the last chamber it inflated globular and large. Sutures distinct and strongly depressed. Wall calcareous hyaline smooth and finely perforated. Aperture small oval opening of final chamber.

Remarks: Only few specimens were found, and their preservation was moderate.

Occurrence: This species rarely occurs in samples FANB 16 and 21.

Family Glandulonodosariidae Silvestri 1901

Genus *Neugeborina* Popescu in Cicha et al. 1998

***Neugeborina longiscata* (d'Orbigny 1846)**

Plate 8, Fig. 11

1846 *Nodosaria longiscata* d'Orbigny, p. 32, pl. 1, figs. 10-12

1985 *Nodosaria longiscata* d'Orbigny; Papp & Schmid, p. 23, pl. 3, figs. 1-5

Description: Test elongated and smooth. The embryonic chamber is very inflated.

Remarks: The specimen found is broken, hence the aperture is not visible.

Occurrence: Only one specimen was recovered from sample FANB 16.

Order Rotaliida

Superfamily Cassidulinoidea d'Ordigny 1839

Family Bolivinitidae Cushman 1927

Subfamily Bolivinitinae Cushman 1927

Genus *Bolivina* d'Orbigny 1839

***Bolivina* sp. 1**

Plate 8, Fig. 12

Description: Calcareous, biserial, finely perforated and very short test. Lenticular in section with triangular shape. Chambers increase abruptly in size.

Remarks: All recovered specimens are well preserved.

Occurrence: This species commonly occurs in samples FANA 8-10. However, it is rarely found in samples FANA 2, 4, 6 and FANB 16, 18.

***Bolivina* sp. 2**

Plate 8, Fig. 13

Description: Calcareous, biserial, finely perforated and long test. Lenticular in section. Chambers increase gradually in size.

Remarks: Tests present good preservation. It differs from *Bolivina* sp. 1 because of its long test and the normally increasing chambers.

Occurrence: This species rarely occurs in samples FANA 3, 5-6, 9-10 and FANB 16, 19-20.

***Bolivina* sp. 3**

Plate 8, Fig. 14

Description: Calcareous, biserial and finely perforated test. Oval in section. Chambers are almost of same size.

Remarks: This species is the most distributed of the genus. It differs from the previous species due to the more inflated and circular chambers. Specimens' tests show moderate to good preservation. The last chambre is broken in some of them.

Occurrence: The recovered specimens rarely occur in samples FANA 1-6, 10-11 and FANB 15-16, 19-20.

***Bolivina* sp. 4**

Plate 8, Fig. 15

Description: Calcareous, biserial and finely perforated test. It is characterized by the appearance and structure of the costae. Oval in section. Chambers are gradually increasing in size.

Remarks: *Bolivina* sp. 4 differs from the rest species as it is the only ornamented. All recovered specimens present good preservation.

Occurrence: This species rarely occurs in samples FANA 3, 7 and FANB 16, 19-21.

Genus *Sigmavirgulina*

***Sigmavirgulina tortuosa* (Brady 1881)**

Plate 8, Fig. 16

1881 *Bolivina tortuosa* Brady, p. 57 (Fide Ellis & Messina 1940)

1982 *Sigmavirgulina tortuosa* (Brady); Foraminiferi Padani, pl. 32, fig. 7-7p

2006 *Sigmavirgulina tortuosa* (Brady); Cimerman et al., p. 32, pl. 8, figs. 9-10

Description: Test is calcareous, biserial and coarsely perforated. Chambers are gradually increasing in size. Its diagnostic feature is the twisted test.

Remarks: All the recovered specimens show good preservation.

Occurrence: This species rarely occurs in samples FANA 1, 3-4, 6-8, 10 and FANB 16, 21.

Subfamily Fursenkoininae Loeblich & Tappan 1961

Genus *Fursenkoina* Loeblich & Tappan 1961

***Fursenkoina* sp.**

Plate 8, Fig. 17

Description: Calcareous, biserial, finely perforated, triangular, long and twisted test. Oval in section. Sutures are oblique and slightly depressed.

Remarks: All recovered specimens show good preservation.

Occurrence: This species rarely occurs in samples FANA 2, 4, 6 and FANB 16.

Family Cassidulinidae d'Ordigny 1839

Genus *Globocassidulina* Voloshinova 1960

***Globocassidulina globosa* (Hantken 1875)**

1875 *Cassidulina globosa* Hantken, p. 64, pl. 16, figs. 2a-b

1983 *Globocassidulina globosa* (Hantken); Setiawan, p. 128, pl., 12, fig. 8

2006 *Globocassidulina globosa* (Hantken); Cimerman et al., p. 28, pl., 6, figs. 12-13

Description: Test calcareous with globular to subglobular shape. Oblique aperture in the terminal chamber.

Remarks: All recovered specimens present good preservation.

Occurrence: This species rarely occurs in the lower section (samples FANA 1-2, 6, 11, 14) and commonly occurs in almost all samples of FANB section apart from samples FANB 15 and 21.

Family Uvigerinidae Haeckel 1894

Genus *Uvigerina* d'Orbigny 1826

***Uvigerina* sp.**

Plate 8, Fig. 18

Description: Test triserial and short with a short neck. Chambers are circular.

Remarks: All recovered specimens are well preserved.

Occurrence: This species rarely occurs in samples FANA 4, 6-9, 11 and FANB 16-17.

Superfamily Buliminoidea Jones 1875

Family Buliminidae Jones 1875

Genus *Bulimina* d'Orbigny 1826

***Bulimina bradyi* Sellier de Civrieux 1981**

Plate 8, Fig. 19

1981 *Bulimina bradyi* Sellier de Civrieux, p. pl. fig.

Description: Triserial, calcareous, finely perforated test with circular outline. Chambers continuously increase in size.

Remarks: The specimen recovered show moderate preservation.

Occurrence: This species is only retrieved from sample FANA 2.

***Bulimina gibba* Fornasini 1902**

1902 *Bulimina gibba* Fornasini, p. 378, pl. O, figs. 32, 34.

1980 *Bulimina gibba* Fornasini; Boltovskoy et al., p. 20, pl. 5, figs. 7-9.

2013 *Bulimina gibba* Fornasini; Holbourn et al., p. 96, figs. 1-3.

Description: Triserial, calcareous, finely perforated test with circular outline. Chambers are convex and continuously increase in size. Sutures oblique and slightly compressed.

Remarks: The recovered specimen is well preserved.

Occurrence: This species is only found with very few specimens in sample FANA 5.

Bulimina elongata d 'Orbigny 1846

1864 *Bulimina elongata* d' Orbigny, p. 187, pl. 11, figs. 19-20.

1980 *Bulimina elongata* d' Orbigny; Boltovskoy et al., p. 20, pl. 5, figs. 4-6.

2013 *Bulimina elongata* d' Orbigny; Holbourn et al., p. 94, figs. 1-2.

Description: Triserial, elongated test. Chambers increase continuously in size.

Remarks: The recovered specimens show good preservation.

Occurrence: Only a few specimens were retrieved from samples FANA 6 and FANB 17.

Bulimina sp. 1

Plate 8, Fig. 20

Description: Triserial, calcareous, test with circular outline and conical shape. Wall smooth and finely perforated. Chambers are convex and abrupt increase in size.

Remarks: Specimens recovered present moderate preservation, as the upper part is missing in most cases.

Occurrence: This species occurs rarely in the lower part of the sequence (FANA 4-12).

Bulimina sp. 2

Plate 8, Fig. 21

Description: Triserial, calcareous, test with oval outline. Wall finely perforated. Chambers compressed, gradually increasing in size. Sutures slightly depressed.

Remarks: Specimens show moderate preservation. This species is easily distinguished because the test is compressed.

Occurrence: This species occurs rarely in the lower part of the sequence (FANA 1, 3, 6, 8-9, 11).

Bulimina sp. 3

Plate 8, Fig. 22

Description: Calcareous and elongated test. Test ornamented with costate. Chambers globular, continuously increasing in size.

Remarks: The preservation of the specimen is moderate. This species resembles *Bulimina* sp. 2 but it differs due to its ornamentation.

Occurrence: Only one specimen was retrieved from sample FANB 17.

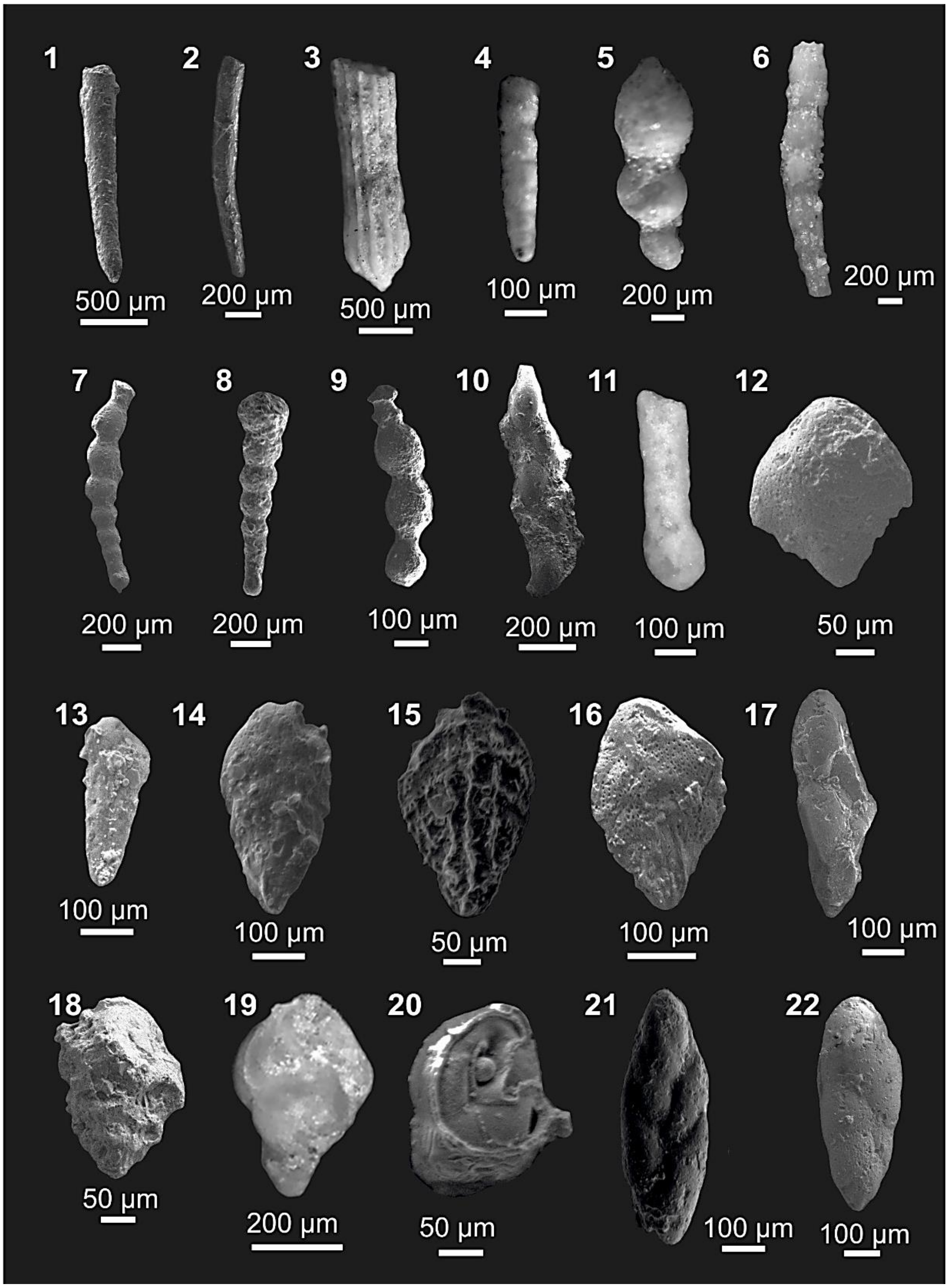


Plate 8. Foraminiferal species. **1-2.** *Laevidentalina* sp, **1.** FANB 19, **2.** FANA 4, **3**. *Nodosaria latejugata* Gümbel FANA 20**,** **4.** *Nodosaria* sp. 1 FANA 19, **5.** *Nodosaria* sp. 2 FANA 19, **6.** *Nodosaria* sp. 3 FANA 16, **7.** *Siphonodosaria jacksonensis* (Cushman & Applin) FANB 16, **8.** *Siphonodosaria* sp. 1 FANB 19, **9.** *Siphonodosaria* sp. 2 FAN B 16, **10.** *Pleurostomella incrassata* Hantken FANB 16, **11.** *Neugeborina longiscata* (d'Orbigny) FANA 16, **12.** *Bolivina* sp. 1 FANA 6, **13.** *Bolivina* sp. 2 FANA 6, **14.** *Bolivina* sp. 3 FANA 6, **15.** *Bolivina* sp. 4 FANB 16, **16.** *Sigmavirgulina tortouosa* (Brady) FANB 16, **17.** *Fursenkoina* sp FANA 2, **18.** *Uvigerina* sp. FANA 4, **19.** *Bulimina bradyi* FANA 2, **20.** *Bulimina* sp. 1 FANA 4, **21.** *Bulimina* sp. 2 FANA 1, **22.** *Bulimina* sp. 3 FANA 17.

Superfamily Discorboidea Ehrenberg 1838

Family Cancrisidae Chapman, Parr & Collins 1934

Genus *Cancris* Montfort 1808

***Cancris* sp.**

Plate 9, Fig. 1

Description: Test is asymmetrically coiled. Chambers gradually increase. They normally increase dorsally and ventrally they overlap the earlier ones.

Remarks: The tests show moderate preservation.

Occurrence: Only a few specimens were recovered from samples FANA 6-7, 9 FANB 15, 19.

Genus *Gyroidinoides* Brotzen 1942

***Gyroidinoides* sp.**

Plate 9, Figs. 2a-c

Description: Test calcareous, trochospiral coiling, biconvex with subcircular outline periphery. Dorsal side nearly flat and spiral convex. Umbilicus is narrow and open. Aperture a slit at the base of the last chamber.

Remarks: The recovered specimens present good preservation of their tests.

Occurrence: This species rarely occurs in samples FANA 3-4, 6-11, and FANB 16-17.

Family Pegidiidae

Genus Kuremsia Özdikmen 2009

***Kuremsia papillata* (Heron-Allen & Earland 1928)**

Plate 9, Fig. 3

1928 *Sphaeridia papillata* Heron-Allen & Earland, p. 294, pl. 2, figs. 27-33, pl. 3, figs. 34-37.

1993 *Sphaeridia papillata* Heron-Allen & Earland; Hottinger et al., p. 108, pl. 140, figs. 6-10.

Description: Spherical, nearly globular in shape with heavy ornamentation of rounded pustules.

Remarks: The specimen recovered present good preservation.

Occurrence: This species is only found from sample FANB 19.

Family Rosalinidae Reiss 1963

Genus *Neoconorbina* Hofker 1951

***Neoconorbina* sp.**

Plate 9, Figs. 4a-c

Description: Conical, calcareous, finely perforated test with circular periphery. Ventral side flattened, sutures straight ending in a closed umbilicus. Dorsal side much elevated and conical.

Remarks: Specimens’ tests display moderate to good preservation.

Occurrence: This species is present in the whole sequence except for samples FANA 13-14. It abundantly to commonly occurs in FANA, unlike FANB where it occurs rarely.

Genus Rosalina d’Orbigny 1826

***Rosalina* sp.**

Plate 9, Figs. 5a-b

Description: Test small, trochospiral, circular in outline. Dorsal side elevated with sutures slightly curved. Ventral side concave with umbilicus.

Remarks: Specimens’ tests show good preservation.

Occurrence: Few specimens were documented from samples FANA 4 and FANB 19.

Family Mississippinidae Saidova 1981

Subfamily Stomatorbininae Saidova 1981

Genus *Stomatorbina* Dorreen 1948

***Stomatorbina torrei* (Cushman & Bermoudéz 1937)**

Plate 9, Fig. 3

1937 *Lamarckina torrei* Cushman & Bermoudéz, p. 21, pl. 2, figs. 24-26

1993 *Stomatorbina torrei* (Cushman & Bermoudéz); Hottinger et al., p. 107, pl. 138, figs. 10-14, pl. 139, figs. 1-6

Description: Test is flat, very low trochospiral. Chambers gradually increase their size. Sutures on the dorsal side are curved backward and raised, on the ventral side they are slightly curved and depressed. Aperture is interiomarginal with a lip, extended from the periphery to the umbilical side.

Remarks: The preservation of the tests is good. However, specimens’ tests of the lower section are slightly abraded.

Occurrence: This species occurs abundantly to common in almost the whole sequence, except for samples FANB 20-21.

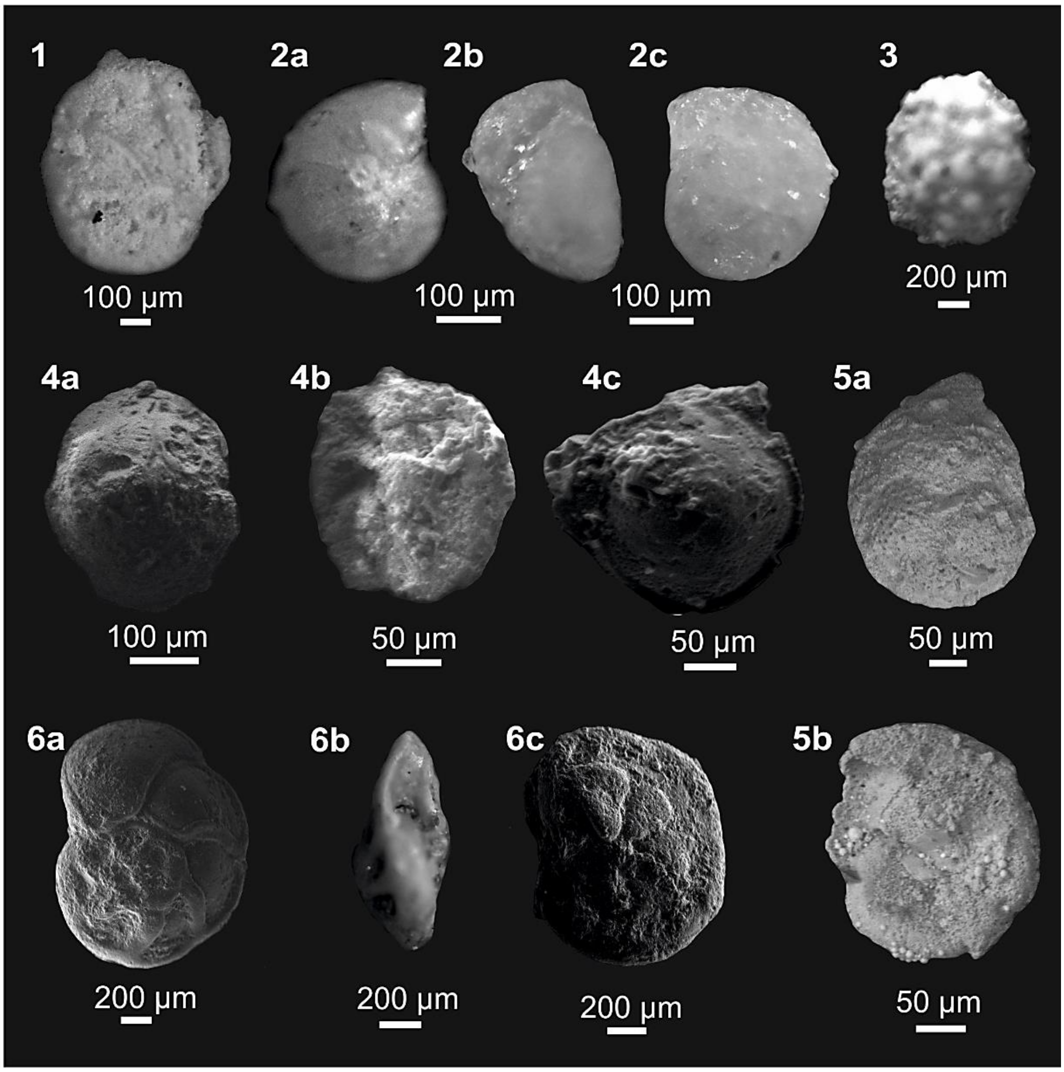


Plate 9. Foraminiferal species. **1.** *Cancris* sp. dorsal side, FANB 19, **2.** *Gyroidinoides* sp. FANB 16, **2a.** ventral side, **2b.** apertural view, **2c.** ventral side, **3.** *Kuremsia papillata* (Heron-Allen & Earland) FANB 19, **4.** *Neoconorbina* sp. FANA 6, **4a.** dorsal side, **4b.** ventral side, **4c.** dorsal side, **5.** *Rosalina* sp. FANA 10, 5a. dorsal side, 5b. ventl side, **6.** *Stomatorbina torrei* (Cushman & Bermoudéz) FANB 17, **6a**. dorsal side, **6b.** apertural view, **6c.** ventral side.

Superfamily Planorbulinoidea Schwager 1877

Family Cibicididae Cushman 1927

***Cibicidoides grimsdalei* (Nuttall 1930)**

Plate 10, Figs. 1a-c

1930 *Cibicides grimsdalei* Nuttall, p. 291, pl. 25, figs. 7-8, 11.

1986 *Cibicidoides grimsdalei* (Nuttall, 1930); Van Morkhoven et al., p. 247, pl. 83A, figs. 1-3, pl. 83B, figs. 1-7.

2006 *Cibicidoides grimsdalei* (Nuttall, 1930); Ortiz & Thomas, p. 116, pl. 5, fig. 3.

2013 *Cibicidoides grimsdalei* (Nuttall, 1930); Houlborn et al., p. 174, figs. 1-3.

Description: Test trochospiral, plano-convex to biconvex, ventrally almost flat with closed umbilicus, dorsally much elevated. Wall is coarsely perforated. Sutures are stronlgy curved backwards. Circular periphery. Aperture a low interiomarginal and equatorial arch at the base of the apertural face.

Remarks: This species presents different stages of preservation even between the side of the same specimen. However, mainly they display moderate to good preservation.

Occurrence: This species is abundant is FANA except for the two upper samples of this section. From the upper section on the sequence, a few specimens retrieved only form sample FANB 18.

Cibicidoides praemundulus **(Berggren & Miller 1986)**

Plate 10, Figs. 2a-b

1986 *Cibicidoides praemundulus* Berggren & Miller, p. 264, pl. 87, figs. 1-3.

2013 *Cibicidoides praemundulus* Berggren & Miller; Holbourn et al., p. 200, figs. 1-3.

2016 *Cibicidoides praemundulus* Berggren & Miller; Moura de Mello, p. 85, pl. 8, figs. 7a-c.

Description: Test trochospiral, biconvex to planoconvex with circular and acute periphery with an imperforate band. Spiral side evolute, coarsely perforate. Sutures curved on both sides. Umbilical side with glossy umbilical plug.

Remarks: Specimens show moderate to good preservation. The moderate preservation is evident in the large specimens where the last chamber or the periphery are missing.

Occurrence: This species is abundant to common in the whole sequence.

Cibicidoides variabillis **(d'Orbigny 1826)**

Plate 10, Fig. 3

1826 *Truncatulina variabilis* d'Orbigny, p. 279, pl. 2, fig. 29

1980 *Cibicidoides variabillis* (d'Orbigny); Boltovskoy et al., p. 25, pl. 9, figs, 13-17.

Description: Biconvex test with coarsely perforated wall. Dorsal side is convex but the ventral one is either plane or curved depending on the substrate. Chambers are gradually increase. Aperture extended in the spiral side.

Remarks: Specimens recovered show moderate preservation.

Occurrence: This species rarely occurs in samples FANA 3-6, 8, 11, 14 & FANB 15-16, 21.

Cibicidoides **sp. 1**

Plate 10, Figs. 4a-b

Description: Test calcareous, coarsely perforated, trochospiral and biconvex. Dorsal side nearly flat to convex, ventral broadly convex. Periphery is circular to lobulated. Chambers increase gradually. Sutures almost straight and in the last two chambers they are strongly depressed. Aperture a low interiomarginal and equatorial arch at the base of the apertural face.

Remarks: All recovered specimens are well preserved.

Occurrence: This species occurs abundantly in only one sample of lower section (FANA 7) and commonly occurs in the whole upper section FANB.

***Cibicidoides* sp. 2**

Plate 10, Figs. 5a-c

Description: Test calcareous, coarsely perforated and thick. Circular in outline. Sutures on the ventral side are strongly depressed, whereas on the dorsal is less depressed. The aperture is a marginal slit bordered by a lip, extending from the ventral to the dorsal side.

Remarks: All recovered specimens show good preservation. It is distinguished from the other species because of its very large tests and the lobate periphery.

Occurrence: It occurs abundantly to commonly only in the upper part of the sequence.

Genus *Lobatula* Fleming 1828

***Lobatula lobatula* (Walker & Jacob 1798)**

Plate 10, Figs. 6a-c

1798 *Nautilus lobatulus* Walker & Jacob, p. 642, pl. 14, fig. 36 (fide Ellis & Messina, 1940)

1935 *Cibicides lobatulus* (Walker & Jacob); Cushman, p. 52, pl. 22, figs. 7a-c

1980 *Cibicides lobatulus* (Walker & Jacob); Boltovskoy et al., p. 24, pl. 9, figs. 1-4

1982 *Cibicides lobatulus* (Walker & Jacob); Foraminiferi Padani, pl. 101, figs. 6d, p, v

1983 *Cibicides lobatulus* (Walker & Jacob); Setiawan, p. 126, pl. 11, fig. 2

1985 *Cibicides (Truncatulina) lobatulus* (Walker & Jacob); Papp & Schmid, p. 64, pl. 56, figs. 1-5

1988 *Lobatula lobatula* (Walker & Jacob); Loeblich & Tappan, p. 168, pl. 637, figs. 10-13

1991 *Cibicides lobatulus* (Walker & Jacob); Cimerman & Langer, p. 71, pl. 75, figs. 1-4

1993 *Cibicides lobatulus* (Walker & Jacob); Sgarella & Moncharmont Zei, p. 234, pl. 22, figs. 10-11

2005 *Cibicides lobatulus* (Walker & Jacob); Rasmussen et al., p. 99, pl. 15, figs. 4-6

2006 *Lobatula lobatula* (Walker & Jacob); Cimerman et al., p. 34, pl. 9, figs. 7-8

2006 *Lobatula lobatula* (Walker & Jacob); Ortiz &Thomas, p. 121, pl. 9, figs. 1-2

Description: Dorsal side is convex but the ventral one is either plane or curved depending on the substrate. Chambers are gradually increase. Aperture extended in the spiral side.

Remarks: All recovered specimens show good preservation.

Occurrence: This species occurs abundant to common in the whole sequence.

Genus *Planulina* d'Orbigny 1826

***Planulina* sp.**

Plate 10, Figs. 7a-c

Description: Planispiral, calcareous test with rounded periphery. Septa are thick, in the dorsal side are slightly curved unlike ventral side where they are strongly curved. Moreover, they are strongly elevated, thus chambers are depressed.

Remarks: All recovered specimens present moderate to goo stage of preservation.

Occurrence: This species rarely occurs in both sections except for samples FANA 2, 8 11 and FANB 15, 20 21.

Genus *Planorbulina* d' Orbigny 1826

***Planorbulina mediterranensis* d' Orbigny 1826**

Plate 10, Fig. 8a-b

1826 *Planorbulina mediterranensis* d' Orbigny, p. 280, no 2, pl. 14, figs. 4-6 (fide Ellis & Messina, 1940)

1980 *Planorbulina mediterranensis* d' Orbigny; Boltovskoy et al., p. 43, pl. 25, figs. 1-3

1982 *Planorbulina mediterranensis* d' Orbigny; Foraminifero Padani, pl. 102, figs. 8d, p., v

1985 *Planorbulina mediterranensis* d' Orbigny; Papp & Schmid, p. 64, pl. 55, figs. 5-7

1988 *Planorbulina mediterranensis* d' Orbigny; Loeblich & Tappan, p. 588, pl. 645, figs. 1-6; pl. 646, figs. 1-2

1991 *Planorbulina mediterranensis* d' Orbigny; Cimerman & Langer, p. 71, pl. 78, figs. 1-8

1993 *Planorbulina mediterranensis* d' Orbigny; Sgarella & Moncharmont Zei, p. 235, pl. 23, fig. 4

2005 *Planorbulina mediterranensis* d' Orbigny; Rasmussen et al., p. 100, pl. 15, fig. 14

Description: Test is flat or curved depending on the substrate. Lobate in outline. Chambers are arched in the dorsal side and flattened on the ventral side.

Remarks: All recovered specimens present good preservation.

Occurrence: This species is common to rare. It occurs in both upper and lower parts of the sequence, except for samples FANA 1 and FANB 17-19.

Genus *Heterolepa* Franzenau 1884

***Heterolepa eocaena* (Gümbel 1868)**

Plate 10, Figs. 9a-b

1868 *Rotalia eocaenus* Gümbel, p. 650, pl. 2, figs. 87a-b.

1986 *Cibicidoides eocaenus* Gümbel; Van Morkhoven et al., p. 256, pl. 86A, figs. 1-4, pl. 86B, figs. 1-2.

2006 *Cibicidoides eocaenus* Gümbel; Ortiz & Thomas, p. 115, pl. 5, fig.2.

2013 *Cibicidoides eocaenus* Gümbel; Holbourn et al., p. 172, figs. 1-3.

2016 *Cibicidoides eocaenus* Gümbel; Moura de Mello, p. 82, pl. 8, figs. 3a-c, 4a-c.

1994 *Cibicidoides tuxpamensis tuxpamensis* Cole; Bolli et al., p. 148, figs. 40.1-3.

1994 *Cibicidoides perlucidus* Nuttall; Bolli et al., p. 366, figs. 79.21a-b, 88.3a-c.

Description: Test trochospiral, plano-convex to biconvex, circular in outline. Umbilical side evolute and commonly more flattened than spiral side. Curved sutures on both sides, slightly depressed on umbilical side. Dorsal wall coarsely perforate. Very distinct umbo in the central part of the test. Periphery acute with imperforate keel. Aperture is a narrow equatorial slit bordered by a thin lip, extending onto the spiral side.

Remarks: Based on the opinion of Van Morkhoven et al. (1986) the species of *Cibicidoides eocaenus* Gümbel, *Cibicidoides tuxpamensis* Cole, and *Cibicidoides perlucidus* Nuttall are synonymous. Comparing the studied specimens, it is difficult to differentiate them, therefore the opinion of Van Morkhoven et al. (1986) is followed. Hence, specimens with rounded peripherally, evolute umbilical side and very pronounced umbilical boss are assigned to *tuxpamensis-eocaenus* type. Specimens with more angular periphery and flat umbilicus side are assigned to *perlucidus* type. Morphotype of *tuxpamensis-eocaenus* present higher numbers. All specimens show moderate to good preservation. The moderate preservation is evident in the large specimens where the last chamber or the periphery are missing.

Occurrence: *Tuxpamensis-eocaenus* type is highly abundant in the whole sequence and presents mass abundances in samples FANA 6, 8 and 10. *Perlucidus* type rarely to commonly occurs only in samples FANA 3, 6, 9, 11 and FANB 16, 19 and 21.

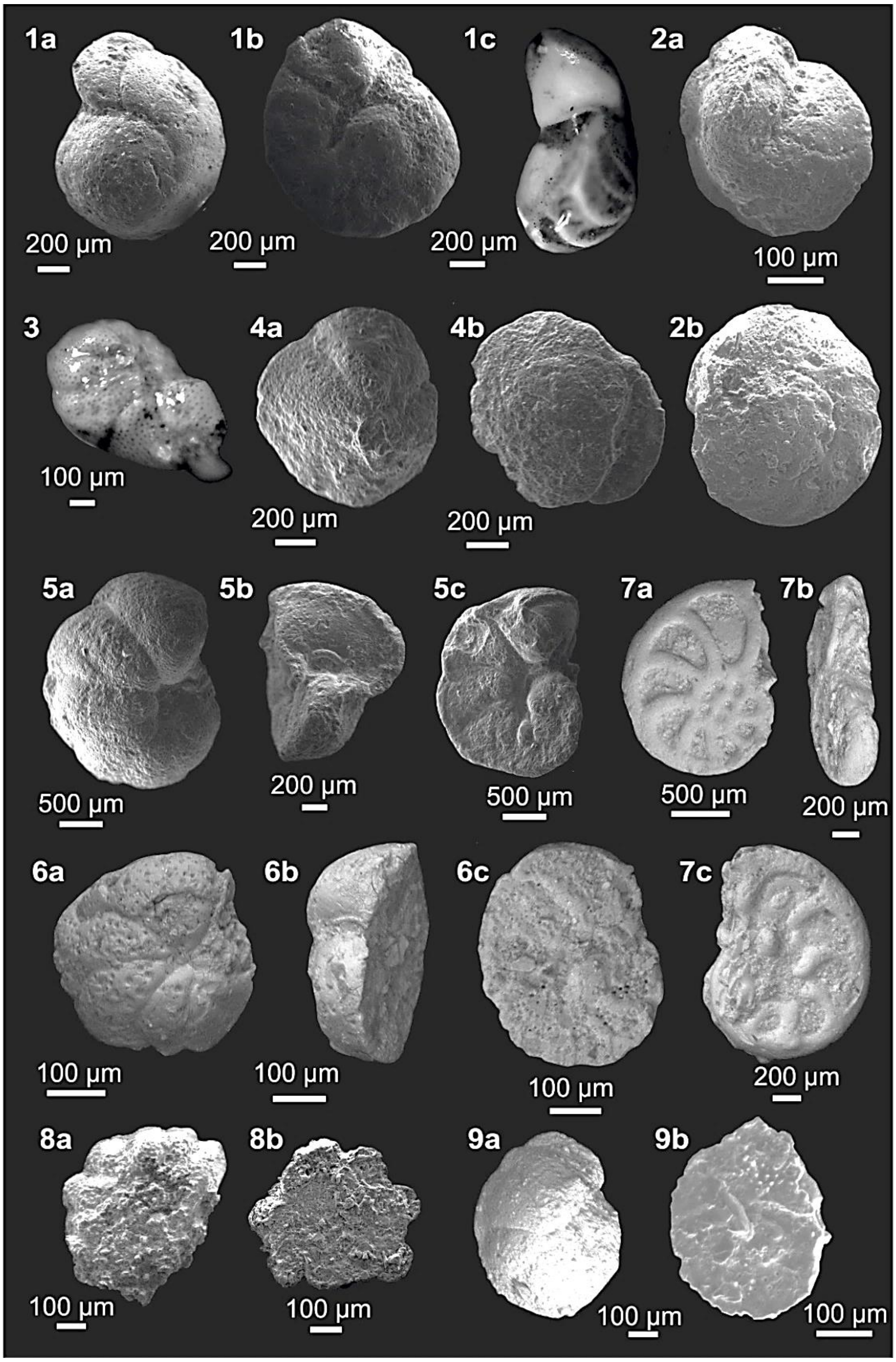


Plate 10. Foraminiferal species. **1.** *Cibicidoides grimsdalei* (Nuttall) FANA 6, **1a.** ventral side, **1b.** dorsal side, **1c.** apertural view, **2.** *Cibicidoides praemundulus* Berggren & Miller FANB 19, **2a.** ventral side, **2b.** dorsal side, **3.** *Cibicidoides variabilis* (d'Orbigny) FANA 6 ventral side, **4.** *Cibicidoides* sp. 1 FANB 18 , **4a.** ventral side, **4b.** dorsal side, **5.** *Cibicidoides* sp. 2 FANB 16, **5a.** dorsal side, **5b.** apertural view**,** **5c.** ventral side, **6.** *Lobatula lobatula* (Walker & Jacob) FANA 11, 6**a.** dorsal side, **6b.** apertural view, **6c**. ventral side, **7.** *Planulina* sp. FANA 5, **7a.** dorsal side, **7b.** apertural view**,** **7c.** ventral side, **8.** *Planorbulina meditteranensis* d' Orbigny FANA 6, **8a.** dorsal side, **8b.** ventral side, **9.** *Heterolepa eocaena* (Gümbel) FANA 18, **9a.** ventral side, **9b.** dorsal side.

Superfamily Nonionoidea Schultze 1854

Family Nonionidae Schultze 1854

Subfamily Nonioninae Schultze 1854

Genus *Nonion* Montfort 1808

***Nonion commune* (d'Orbigny 1846)**

Plate 11, Figs. 1a-b

1846 *Nonionina communis* d'Orbigny, 1846, p. 106, pl. 5, figs. 7-8.

1985 *Nonion commune* (d'Orbigny, 1846); Papp & Schmid, p. 45, pl. 34, figs. 1-6.

Description: Test calcareous, planispiral and involute with rounded periphery. Chambers in the last whorl increasing abruptly in size as added, sutures distinct, slightly curved, aperture low.

Remarks: The retrieved specimens present good to moderate preservation.

Occurrence: This species commonly to rarely occurs only in the lower section, except for samples FANA 13-14. In the upper section is present only in sample FANB 17.

Subfamily Pulleniinae Schwager 1877

Genus *Melonis* de Montfort 1808

***Melonis pompilioides* (Fichtel and Moll 1798)**

Plate 11, Figs. 2a-b

1798 *Nautilus pompiloides* Fichtel & Moll, 1798, p. 31, pl., 2, figs. a-c.

1982 *Melonis* cf. *M. pompilioides* (Fichtel & Moll); Foraminiferi Padani, pl. 21, figs. 5, 5a, 5p.

1985 *Melonis pompilioides* (Fichtel & Moll); Papp & Schmid, p. 46, pl. 36, figs. 1-5.

Description: Test calcareous, planispiral, involute, circular in outline and coarsely perforated. Chambers are gradually increase in size and sutures are almost straight. Umbilicus evident and open in both sides. Aperture at the base of the last chamber.

Remarks: Specimens present good to moderate preservation.

Occurrence: This species is recovered only from the upper part of the sequence (except sample FANB 15) where it occurs rarely.

Family Almaenidae Myatlyuk 1959

Subfamily Almaeninae Myatlyuk 1959

Genus *Queraltina* Marie 1950

Queraltina epistominoides **Marie 1950**

Plate 11, Figs. 3a-b

1950 *Queraltina epistominoides* Marie, p. 74, figs. 1-3, 8-9.

1982 *Queraltina epistominoides* Marie; Foraminiferi Padani, pl. LII, figs. 7d, p, v.

1983 *Queraltina epistominoides* Marie; Setiawan, p. 133, pl. 15, figs. 2, 3.

1988 *Queraltina epistominoides* Marie; Loeblich & Tappan, p. 623, pl. 697, figs. 8-12.

2006 *Queraltina epistominoides* Marie; Cimerman et al., p. 38, pl. 10, figs. 11-12.

Description: Calcareous test and trochospiral to planoconvex. Test is coarsely perforate with a double flange. Chambers are gradually increase in size, limbate on the ventral side. Sutures depressed on ventral side. Umbilicus small and open in both sides. Aperture an arch at the base of the last chamber, bordered by a lip.

Remarks: All recovered specimens present good preservation.

Occurrence: This species occurs abundant to common to almost the whole sequence apart from the uppermost samples of FANB.

Superfamily Chilostomelloidea Brady 1881

Family Alabaminidae Hofker 1951

Genus *Osangularia* Brotzen 1940

Osangularia **sp.**

Plate 11, Figs. 4a-b

Description: Test calcareous, trochospiral, biconvex and lenticular in shape. It is characterized by subcircular outline with acute periphery formed by flange. The aperture was not visible.

Remarks: The specimens found present good rate of preservation.

Occurrence: This species occurs rare to common in samples FANA 2-7 and FANB 16-17, 20-21.

Family Anomalinidae Cushman 1927

Genus *Anomalinoides* Brotzen 1942

Anomalinoides capitatus **(Gümbel 1868)**

Plate 11, Figs. 5a-b

1868 *Rotalia capitata* Gümbel, p. 653, pl. 2, fig. 92.

2013 *Anomalinoides capitatus* (Gümbel); Holbourn et al., p. 50, figs. 1-6.

2016 *Anomalinoides capitatus* (Gümbel); Moura de Mello, p. 96, pl. 11, figs. 1a-b.

Description: Test is calcareous, planoconvex and coarsely perforated with circular outline. Sutures curved and slightly depressed on the umbilical side with small open umbilicus. The aperture is an interiormarginal arch in the umbilical side.

Remarks: The recovered specimens present good to moderate preservation.

Occurrence: This species commonly occurs in the whole sequence.

Superfamily Discorbinelloidea Sigal 1952

Family Discorbinellidae Sigal 1952

Genus *Hanzawaia* Asano 1944

***Hanzawaia mantaensis* (Galloway & Morrey 1929)**

Plate 11, Figs. 6a-b

1929 *Anomalina mantaensis* Galloway and Morrey, p. 28, pl. 4, figs. 5a-c.

2016 *Hanzawaia mantaensis* (Galloway & Morrey); de Mello, p. 104, pl. 10, figs 8a-c.

Description: Test is trochospiral, asymmetrical biconvex with dorsal side flat and ventral side convex. It is characterized by a thick and limbate periphery and clear umbilical boss.

Remarks: The recovered specimens show good preservation.

Occurrence: This species is mainly retrieved from the upper part of the sequence and some specimens from samples FANA 3-4, 8 and 12. However it occurs rarely.

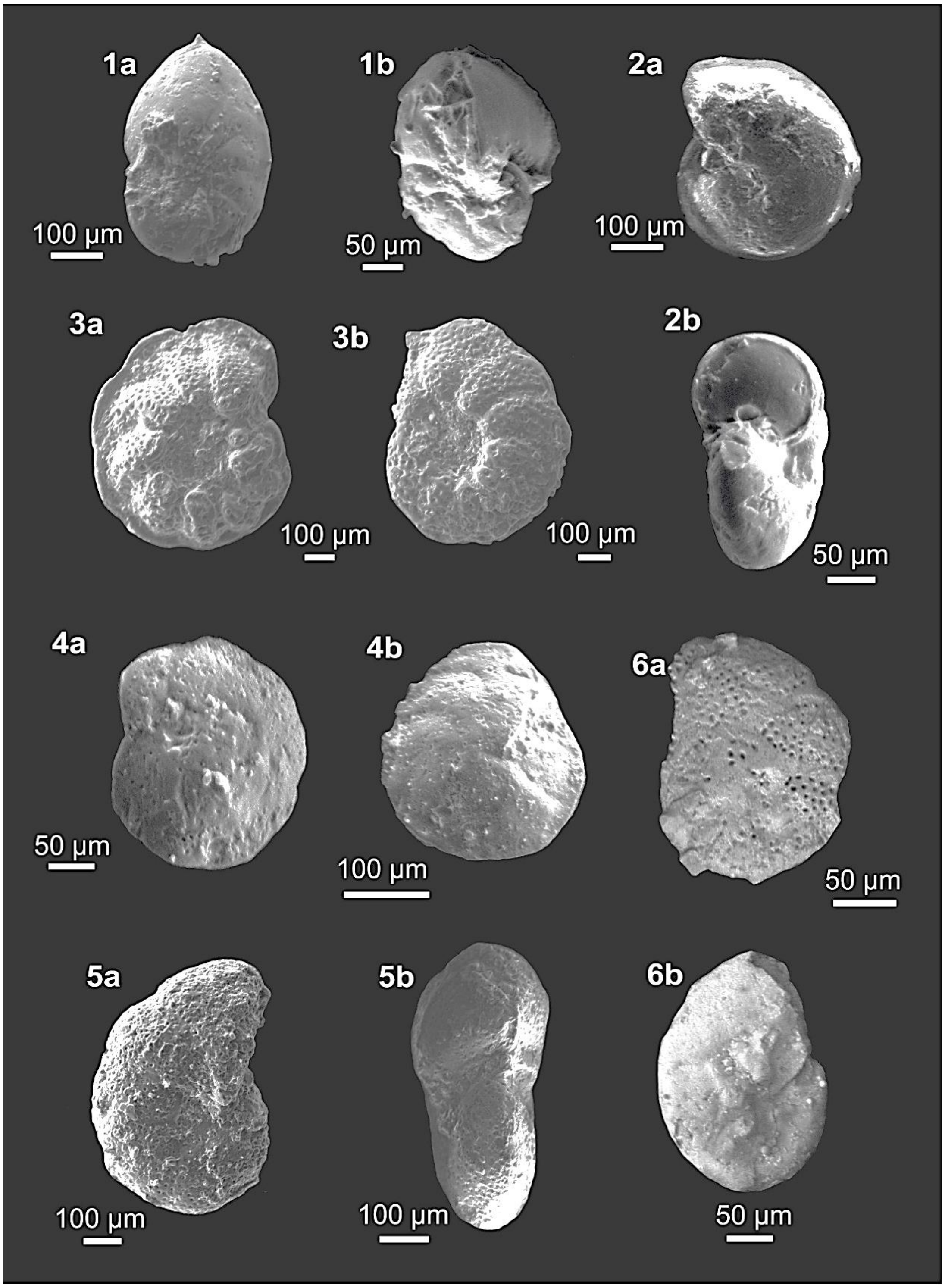


Plate 11. Foraminiferal species. **1.** *Nonion commune* (d' Orbigny) FANA 5, **1a.** side view, **1b.** apertural view, **2.** *Melonis pompiloides* (Fichtel & Moll) FANA 5, **2a.** side view, **2b.** apertural view, **3.** *Queraltina epistominoides* Marie FANA 8, **3a.** dorsal side, **3b.** ventral side, **4.** *Osangularia* sp. FANA 1, **4a.** dorsal side, **4b.** ventral side, **5.** *Anomalinoides capitatus* (Gümbel) FANA6, **5a.** side view, **5b.** apertural view, **6.** *Hanzawaia mantaensis* (Galloway & Morrey) FANA 5, **6a.** dorsal side, **6b.** ventral side.

Superfamily Calcarinoidea Schwager 1876

Family Calcarinidae d'Orbigny 1826

Genus *Paratotalia* Le Calves 1949

***Pararotalia audouini* (d'Orbigny 1850)**

Plate 12, Figs. 1a-c, 2a-b, 4a-b

1850 *Rotalia audouini* d'Orbigny, p. 407, pl. 2, figs. 9-10

1983 *Pararotalia audouini* (d'Orbigny); Setiawan, p. 120 (no illustration)

2006 *Pararotalia audouini* (d'Orbigny); Cimerman et al., p. 40, pl. 11, figs. 10-11

2006 *Pararotalia audouini* (d'Orbigny); Ortiz & Thomas, p. 126, pl. 10, fig. 5

Description: Calcareous test with heavy ornamentation. Ventral side convex with strongly depressed sutures. Umbilicus with tubercle. Chambers are triangular to trapezoid. Periphery acute with spines.

Remarks: Recovered specimens show moderate to good preservation. Usually, their spines are broken.

Occurrence: This species commonly occurs in samples FANA 3-4, 6-11. On the contrary, only a few specimens were retrieved from the upper part of the sequence (samples FANB 16, 19).

***Pararotalia inermis* (Terquem 1882)**

Plate 12, Figs. 3a-b

1882 *Rotalina inermis* Terquem, p. 68, pl. 6, fig. 1.

1991 *Pararotalia inermis* (Terquem); Hottinger et al., p. 19, figs. 1.1, 1.3, 1.4.

Description: Calcareous tests without ornamentation. Ventral side convex with strongly depressed sutures and closed umbilicus. Chambers are triangular to polygonal in shape.

Remarks: The recovered specimens display moderate to good preservation.

Occurrence: This species abundantly to commonly occurs in FANA section and commonly to rarely in FANB section.

Superfamily Asterigerinoidea d' Orbigny 1839

Family Asterigerinidae d' Orbigny 1839

Genus *Asterigerina* d' Orbigny 1839

***Asterigerina brencei* Haque 1960**

Plate 12, Figs. 5a-b

1960 *Asterigerina brencei* Haque, p. 33-34, pl. 2, fig. 3a-c.

1983 *Asterigerina brencei* Haque; Setiawan, p. 118, pl. 9, fig. 3.

2006 *Asterigerina brencei* Haque; Cimerman et al., p. 36, pl. 10, figs. 1-2.

Description: Test calcareous, planoconvex with slightly limbate periphery with spines.

Remarks: It is easily distinguished from *Asterigerina* sp. because of the spines attached at the last whorl. Tests show good to moderate preservation. The moderate preservation is documented only by the large specimens, that the last chamber is broken.

Occurrence: This species occurs commonly in the whole FANA section and rarely in samples FANB 16-17.

***Asterigerina* sp.**

Plate 12, Figs. 6a-c

Description: Test calcareous, finely perforated, low-trochospiral to conical in shape. Dorsal side convex with curved sutures. Ventral side with sigmoidal sutures. Distinct umbo. Peripheral margin smooth and imperforated. Aperture is a long slit bordered by a lip at the base of the last chamber. In front of the aperture, the first chambers of the last whorl are covered by pustules.

Remarks: Test preservation stage ranges from good to moderate. The moderate stage is mainly noted from the large specimens.

Occurrence: This species occurs commonly to abundantly in the whole sequence.

Family Epistomariidae Hofker 1954

Subfamily Nuttallidinae Saidova 1981

Genus *Nuttallinella* Belford 1959

***Nuttallinella florealis* (White 1928)**

1928 *Gyroidina florealis* White, p. 293, pl. 40, figs. 3a-c.

2016 *Nuttallinella florealis* (White); de Mello, p. 88, pl. 9, figs. 5a-c.

Description: Test is calcareous, with limbate periphery ending in a thin flange. Evolute side is flat, and the involute is strongly convex. Sutures are slightly curved and depressed in the involute side. Very small open umbilicus on the involute side.

Remarks: All the recovered specimens present good preservation.

Occurrence: This species is found common to rare in samples FANA 1, 7-8, 10-12 and FANB 16-17.

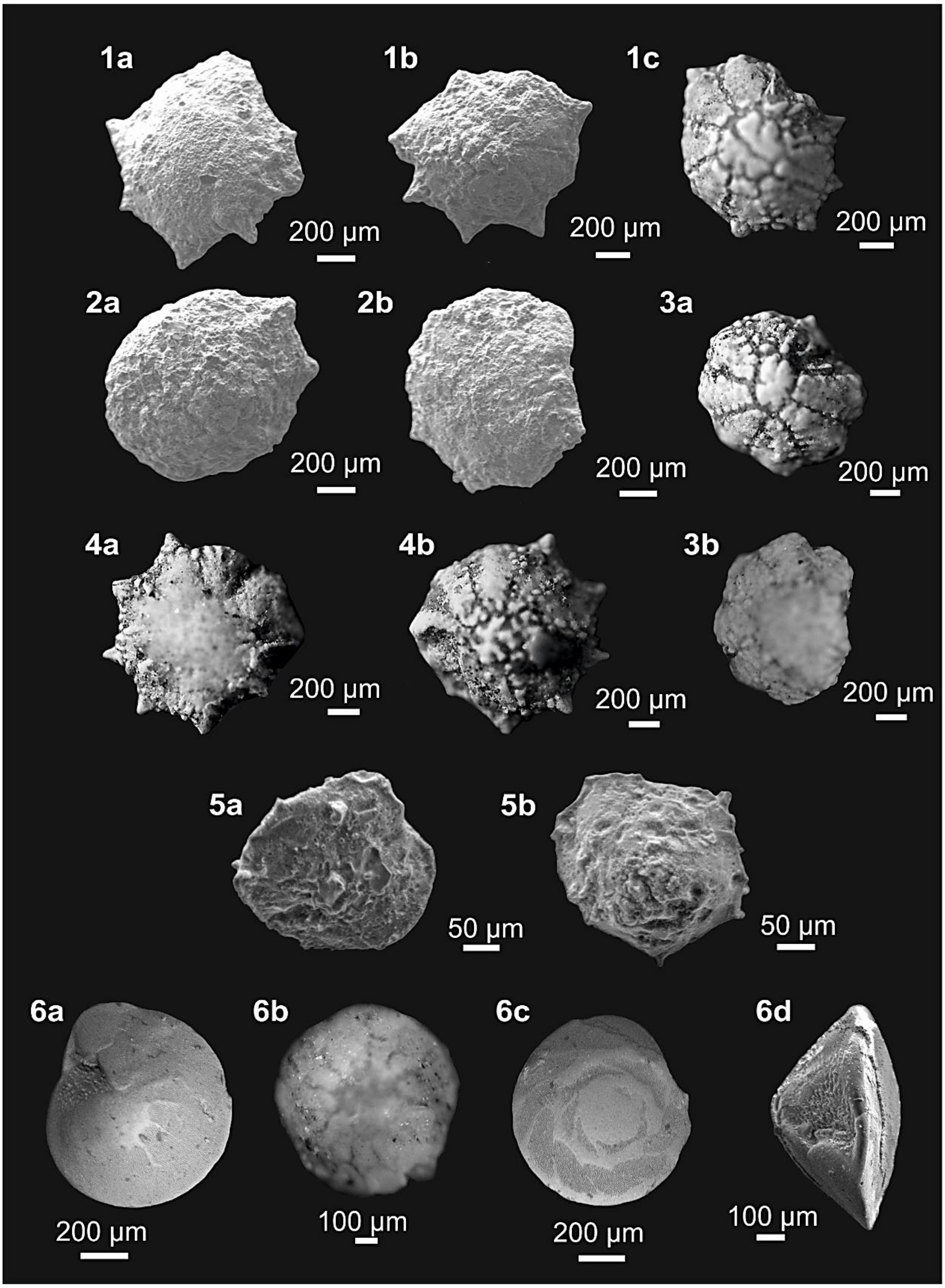


Plate 12. Foraminiferal species. **1-2, 4.** *Pararotalia audouini* (d'Orbigny), **1a.** dorsal side, **1b-1c** ventral side FANA 6, **2a.** ventral side, **2b** dorsal side FANA 8, **4a.** dorsal side, **4b** ventral side FANA6, **3.** *Pararotalia inermis* (Terquem) FANA 6, **3a.** ventral side, **3b** dorsal side, **5.** *Asterigerina brencei* Haque FANA 6, **65a.** ventral side, **5b** dorsal side, **6.** *Asterigerina* sp. FANB 18, **6a.** ventral side, **6b** dorsal side, **6c.** apertural view.

6.4.2 Foraminiferal distribution

The diversity of the microfauna is high and a total of 100 foraminiferal species were identified. From them, 72 are presented here and the rest (LBF) were comprehensively analyzed in previous chapter (chapter 4), therefore is not discussed in detail here. Yet, the analysis of the rest LBF taxa and the small ones will be provided here. The number of specimens of each species in the investigated samples is provided in Appendix II. The observed foraminiferal taxa are characterized mainly by benthic foraminifera, while a few planktonic ones were obtained. The assemblage is strongly dominated by calcareous-perforate forms throughout the sequence and less porcelaneous and agglutinated. The calcareous forms are represented by the perforate (62 species in total) orders of Rotaliidae (40 species), Vaginulinida (7 species), Polymorphinida (4 species) and Nodosariida (11 species), while porcelaneous forms are represented by *Quinqueloculina* and miliolid casts, that probably belong to more than three genera. Finally, the agglutinated (10 species in total) forms are represented by the orders of Astrorhizida (4 species), Spirillinida (1 species), Lituolida (2 species) and Textulariida (3 species).

The foraminiferal assemblages are very rich and in general present a good state of preservation. They are also characterized by the dominance of epifaunal over infaunal forms. Groups were differentiated based on the similar morphotypes, test material and comparable habitats of either frequent or less numerous species. Groups can be distinguished into the following.

Group of LBF consisting of nummulitids (represented by *Nummulites*, *Operculina*, *Assilina*, *Heterostegina* and *Spiroclypeus*), orthophragmines (represented by *Discocyclina*, *Asterocyclina* and *Orbitoclypeus*), *Rupertia* sp., *Fabiania cassis*, *Sphaerogypsina globulus*, *Praebullaelveolina* sp., *Silvestriella tetraedra*, *Pararotalia* spp. and *Asterigerina* sp.

Group of Cibicidae comprising all representatives of the genus *Cibicidoides*, *Heterolepa eoceana*, and *Lobatula lobatula.*

Group of the rest small rotaliids represented by *Gyroidinoides* sp., *Sphaeridina papillata*, *Nuttalides* sp., *Cancris* sp., *Rosalina* sp., *Planulina* sp., *Planorbulina meditteranensis*, S*tomatorbina torrei*, *Hanzawaia manatensis* and *Osangularia* sp., conical *Asterigerina* sp. and *Neoconorbina* sp.

Group of elongated forms represented by *Laevidentalina* spp., *Pleurostomella* sp., *Siphonodosaria* spp., *Nodosaria* spp., *Lagena* spp., *Hyalinonetrion* sp., *Favulina* spp. and *Vaginulinopsis* sp.

Group of biserial and triserial forms of *Bulimina* spp., *Bolivina* spp., *Sigmavirgulina tortuosa, Fursenkoina* sp. and *Uvigerina* sp.

Group of Nonionidae represented by *Nonion commune*, *Melonis pompiloides* and *Queraltina epistominoides*.

Group of miliolids containing the porcelaneous *Quinqueloculina* spp. and the miliolid casts.

Group of agglutinants represented by *Textularia* spp., *Gaudryina pyramidata*, *Psammosiphonella cylindrica*, *Nothia* sp. or *Rhizammina* sp., *Hyperammina rugosa*, *Hormosinella* sp., *Ammodiscus* sp. and *Haplophragmoides* sp.

Group of globular forms of *Globulina gibba* and *Globocassidulina subglobosa*. Group of *Lenticulina* spp. Finally, *Anomalinoides capitatus* is described alone.

The groups, described above, are not uniformly distributed in the studied area. Based on previous chapter, the investigated area is divided into three Biofacies (I, II, III). Biofacies I and II refer to the lower part of the sequence, samples FANA 1-10 and FANA 11-14 respectively, while Biofacies III refer to the upper part. Hence, they will be analyzed and discussed using these sample groups.

The lower part of the sequence (Biofacies I; samples FANA 1-10) is dominated by the group of LBF (abundant *Nummulites* spp., *Asterigerina* sp., and rare *Fabiania cassis*), and the groups of Cibicidae and other small rotaliids (Fig. 39). *Nummulites* spp., and mainly *N. garnieri*, show two peacks in samples FANA 3 (max= 1952 specimens) and 6 (max= 1092 specimens) respectively, while co-occuring with *Fabiania cassis* (max= 7 specimens). Going upwards, nummulitids decrease while *Asterigerina* sp. seems to increase abruptly with its peak in sample FANA 6 and maximum number of specimens exceeding 4450. Cidicidae and other small rotaliids display similar pattern of distribution (Fig. 40).

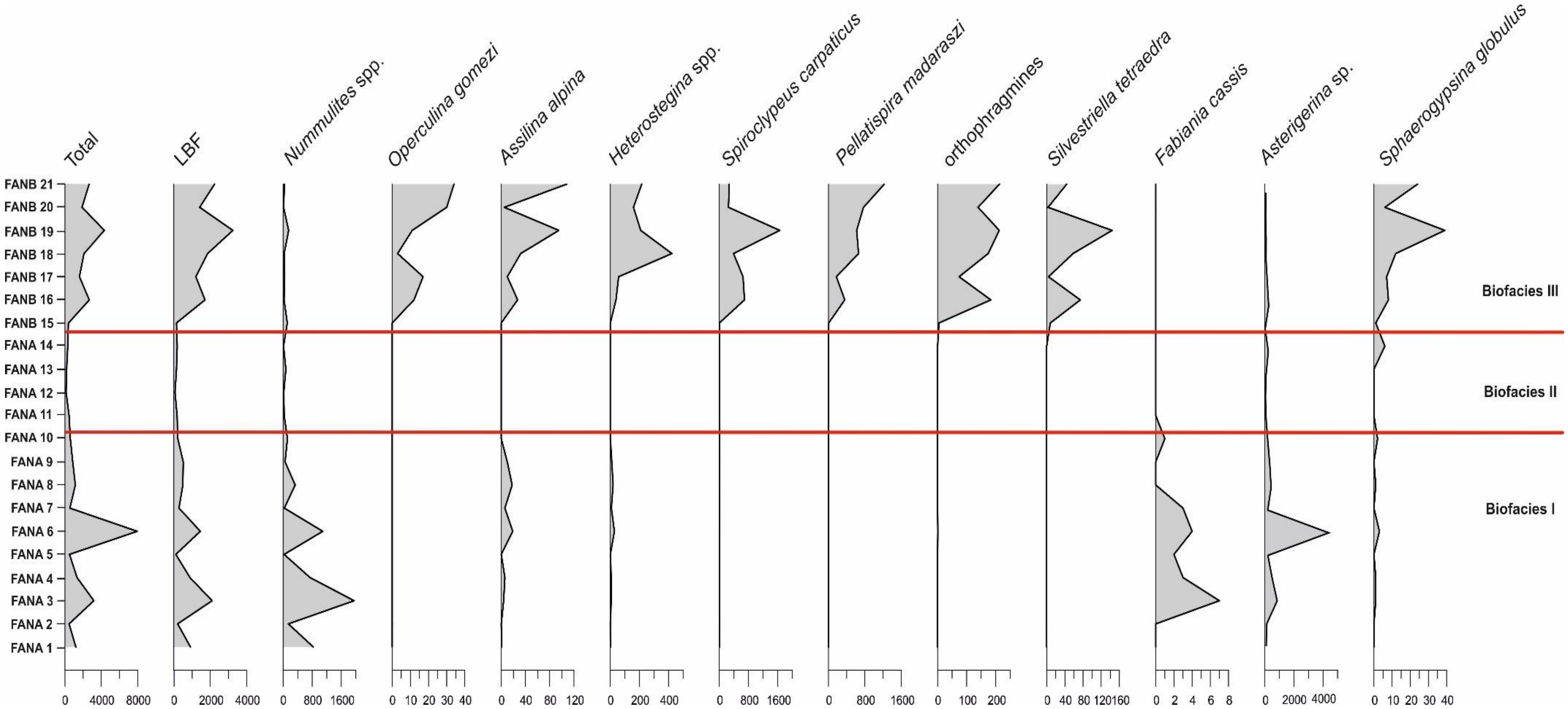


Figure 39. Foraminiferal absolute abundances of the LBF species in Fanari, Thrace.

The latter present lower abundances in all samples except for FANA 6 where exceed their maximum (cibicidae max= 533 specimens and rotaliids max= 1294 specimens). Cibicidae are extremely abundant in this sample with *Cibicidoides grimdalei* being the dominant species of the group (max= 333 specimens). However, *Stomatorbina torrei* is the dominant species of the small rotaliids, comprising 1030 specimens. Biserial and triserial forms show almost the same abundance pattern, but they occur in lower numbers (max= 59 specimens). *Bulimina* sp. 2 is the dominant species of the group with maximum number of specimens reaching 24. Miliolids display very low numbers until FANA 6 and then increase abruptly (max= 86 specimens). Nonionidae occur rarely to commonly (max= 38 specimens) with *Queraltina epistominoides* being the dominant species (max= 30 specimens). Nodosariata (max= 26 specimens), *Lenticulina* spp. (max= 21 specimens), *Anomalinoides capitatus* (max= 18 specimens) along with the agglutinated forms (max= 21 specimens) occur rarely throughout these samples. The group of Nodosariata is represented by dominant *Favulina* sp. 1, the group of *Lenticulina* spp. mainly by *L. inornata* and finally the group of the agglutinants are mostly represented by *Gaudryina pyramidata*. Planktonic foraminifera are almost absent (max= 2 specimens). Foraminiferal tests depict all the stages of preservation; however, they mainly display moderate preservation. Epifaunal species (max= 32 specimens) dominate this part of the sequence over infaunal ones (max= 17 specimens) (Fig. 41). Species richness (S) is high and ranges from 33 to 53, with sample FANA 6 displaying the higher values. On the contrary, Evenness (J) values are low and ranges from 0.11 to 0.39. Diversity indices are relatively low with Fischer-a values ranging from 6.36 to 10.33 and Shannon Wiener-H’ index values ranging from 1.77 to 2.59.

Samples 11-14 (Biofacies II) already from the previous chapter were characterized by the abrupt decrease of LBF. This fact is also evident from the abrupt decrease of all benthic foraminifera (Fig. 39), not only in abundance but also in species richness with S values ranging from 17-33 species (Fig. 41). This part of the sequence is characterized by the dominance of the groups of cibicidae (max= 145 specimens) and LBF (max= 175 specimens), presenting an opposite trend. Cibicidae present higher number of specimens in samples FANA 11 and 19 (max= 145 specimens) while in samples FANA 12-14 decrease to 17-38 specimens. The dominant species of the group is *Lobatula*

lobatula with maximum number of specimens reaching 74. LBF group is represented by the dominant *Asterigerina* sp. with maximum number of 151 specimens in sample FANA 14. Small rotaliids show a gradual decrease moving upwards. Their peak is in sample FANA 11, with maximum number of specimens 39. The group is dominated by *Stomatorbina torrei* (max= 11 specimens), *Neoconorbina* sp. (max= 10 specimens) and *Planorbulina meditteranensis* (max= 8 specimens). Nonionidae are rare with their maximum values in sample FANA 11, with 10 specimens, and comprise almost exclusively *Queraltina epistominoides* (max= 9 specimens). *Anomalinoides capitatus* shows the same distridution pattern. Agglutinants, polymorphinidae, Nodosariata, biserial and triserial forms and planktonic foraminifera are almost missing. Additionally, foraminiferal tests present mainly moderate to poor preservation. Epifaunal species decrease significantly (max= 21) but still dominate over the infaunal that decrease even more (max= 9) (Fig. 41). Samples FANA 13-14 comprise the least diversified samples (17 species) not only for this part but for the whole sequence. However, Shannon H' index values ranges remain almost the same (1.54-2.62). Fischer-a values show a decreasing trend, ranging from 3.69-7.63 while the evenness (J) values show a slight increase, varying from 0.27-0.65.

The upper part of the sequence (Biofacies III; samples FANB15-21) is characterized by the abrupt appearence of the LBF group, represented by exceptionally abundant *Spiroclypeus carpaticus* (max= 1659 specimens) and *Pellatispira madaraszi* (max= 1226 specimens). Abundant *Heterostegina* spp. (max= 423 specimens), orthophragmines (max= 213 specimens), *Silvestriella tetraedra* (max= 144 specimens), *Assilina alpina* (max= 108 specimens) and *Asterigerina* sp. (max= 245 specimens) (Fig. 39). *Heterostegina* spp. is mainly represented by *H. gracilis* (max= 388 specimens), whereas the group of orthophragmines by asterocyclinids (max= 150 specimens). *Nummulites* spp. decrease dramatically compared to the lower part of the sequence (max= 152 specimens) with *N. incrassatus* being the dominant species depicting its highest number of specimens in sample FANB 19 (max= 152 specimens).

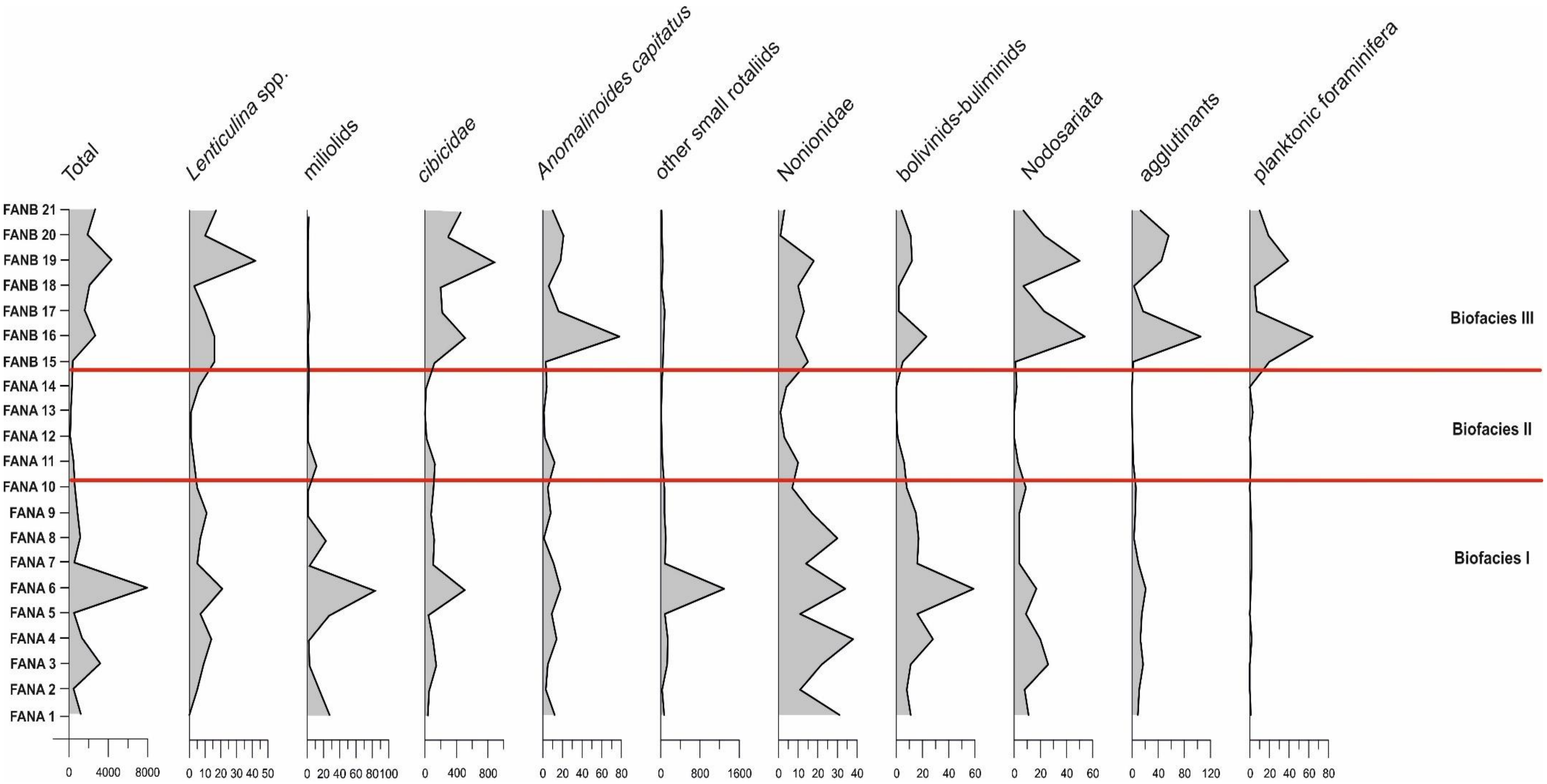


Figure 40. Foraminiferal absolute abundances in Fanari, Thrace.

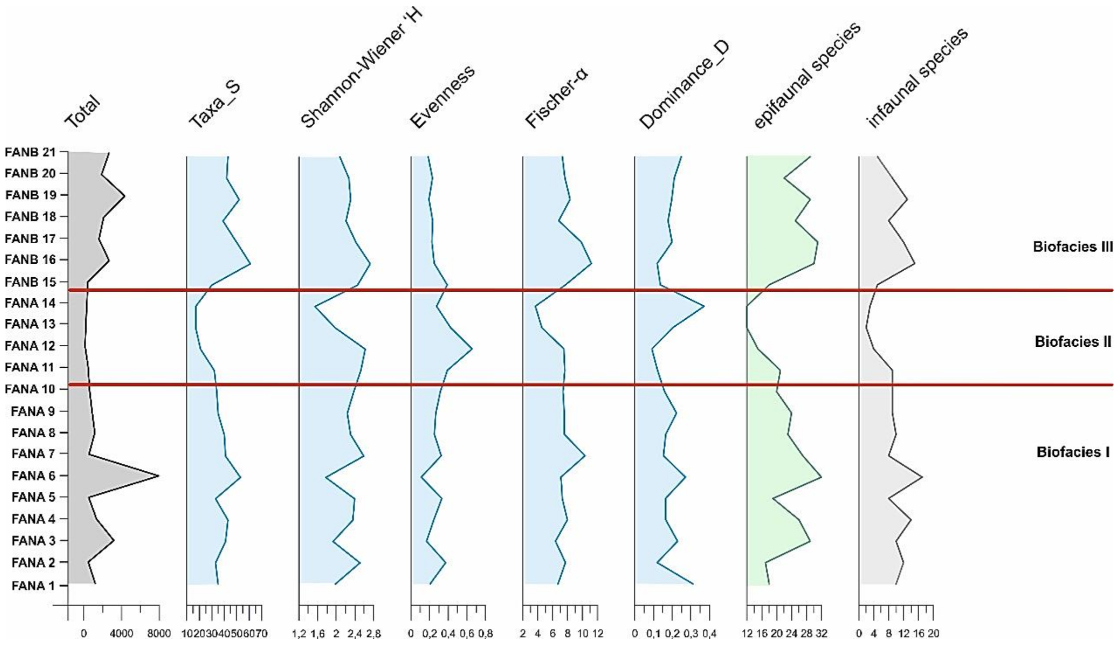


Figure 41. Absolute abundance of total benthic foraminifera, species richness (Taxa_S), Shannon-Wiever H’, Evenness, Fisher-α, Dominance D indices, number of species of epifaunal and infaunal foraminifera.

Operculina gomezi (max= 34 specimens) and *Sphaerogypsina globulus* (max= 39 specimens) commonly present only in this part of the sequence, and seem to increase upwards. On the other hand, *Fabiania cassis* is totally absent from this part of the sequence. *Asterigerina* sp. displays its highest numbers in sample FANB 16 (max= 245 specimens) and then decreases. An increase of the abundance of all groups is evident (Fig. 40), except for small rotaliids which values are stable. Cibicidae are also abundant and present two peaks; the first in sample FANB 16 (max= 528 specimens) and the second in sample FANB 19 (max= 899 specimens). The dominant species of this group is *Heterolepa eocaenus* (*tuxpamenis-eoceanus* type), which reaches its peak in sample FANB 19 with maximum values (max= 673 specimens). *Lenticulina* spp. are common but present higher numbers (max= 42 specimens) than in the other parts of the sequence (samples FANA 1-10, max= 21 specimens and FANA 11-14, max= 6 specimens), with *L. inornata* being the dominant species of the group. Nonionidae (max= 18 specimens), biserial and triserial forms (max= 23 specimens) display the same abundance pattern, mainly represented by *Queraltina epistominoides* and *Boliniva* sp. 3 respectively. *Anomalinoides capitatus* increases abruptly compared to the other samples and present its highest numbers in sample FANB 16 (max= 78 specimens). Nodosariata also increase abruptly (max= 54 specimens) along with the agglutinated forms (max= 105 specimens), represented by the dominant *Siphonodosaria jacksonensis* (max= 25 specimens) and *Gaudryina pyramidata* (max= 48 specimens) respectively. The abrupt increase of planktonic foraminifera is also evident, whereas miliolids are almost absent. The preservation of the tests varies from moderate to good. Nummulitids, othrophragmines, *P. madaraszi* and other large sized benthic taxa, were infilled with calcified mud. Epifaunal species continue to prevail over the infaunal ones with maximum values of 31 species. Species richness (S) is high and ranges from 30 to 61. The most diversified sample is FANB 16, while sample FANB 15 displays the less diversified one. Evenness (J) values decrease and present the same values as in Biofacies I, ranging from 0.18 to 0.38. Fischer-a values ranges from 6.80 to 11.18 presenting similar values to Biofacies I. Shannon H' index values show a sudden increase, reaching the higher values throughout the whole sequence, varying between 2.07 to 2.72 (Fig. 41).

6.4.3 Epipthytic Morphotypes

All four morphotypes of epiphytic foraminifera were recognized in the studied samples as distinguished by Langer and Hottinger (1988) and Langer (1993) (Fig. 42a). Morphotype A is represented only by *P. mediterranensis*. In Morphotype B, 15 species belonging to 9 genera were assigned (*Asterigerina*, *Cibicidoides*, *Hanzawaia*, *Heterolepa*, *Lobatula*, *Neoconorbina*, *Planulina*, *Rosalina* and *Sphaerogypsina*). Morphotype C includes 16 species belonging to 9 genera (*Assilina*, *Asterocyclina*, *Discocyclina*, *Heterostegina*, *Nummulites*, *Operculina*, *Pararotalia*, *Pellatispira and Spiroclypeus*). Finally, morphotype D comprises 7 species belonging to 6 genera of *Stomatorbina*, miliolid casts, *Quinqueloculina*, *Textularia*, *Queraltina* and *Gaudryina*.

The lower part of the sequence (FANA) mainly consists of morphotype B and C (44% and 31% respectively), followed by morphotype D (22%) and morphotype A with only 3%. Morphotype B exceeds C while in some samples are almost equal (FANA 7). Morphotype D is absent in sample FANA 1 (Fig. 42b).

In the upper part of the sequence (FANB) a decrease of morphotype B and D is evident, whereas an increase of morphotype C is noted. The percentage of morphotype A is stable. The proportions of morphotypes B and C are either almost equal or morphotype C exceeds B. The percentages of morphotype D through the samples of the upper part, present almost the same distribution pattern as in the lower part of the sequence. Morphotype A is absent from samples FANB 17-19 (Fig. 42b).

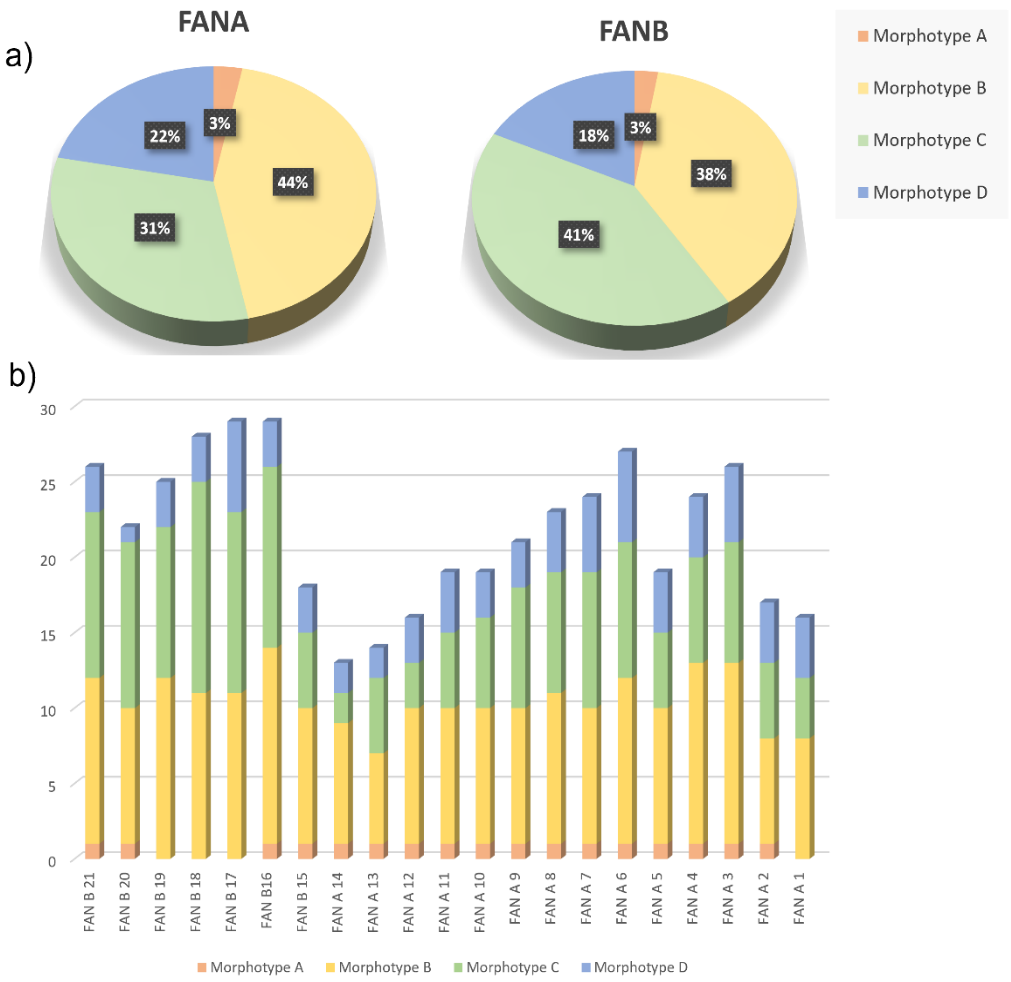


Figure 42. a) Epiphytic morphotype percent abundances, b) morphotype species distridution pattern.

6.4.4 Multivariate analysis

The Q-mode Cluster analysis and the Principal Component Analysis (PCA) distinguished two clusters (Figs. 43, 44). For their determination, the lithology of both parts of the section was taken into account. Group I coincided with the fine-grained, grey siltstones to yellowish sandstones of the lower part of the sequence and also the sample FANB 15, which consists of fossiliferous, calcareous, yellowish sandstone. Group II comprises the homogenous samples of the upper part of the section. The aforementioned analysis could not separate the transitional zone including samples FANA 11-14 as the main factors affecting the cluster do not show significant changes. Sample FANB 15 is grouped with the lower part of the sequence as the assemblage was not yet restored/ recovered.

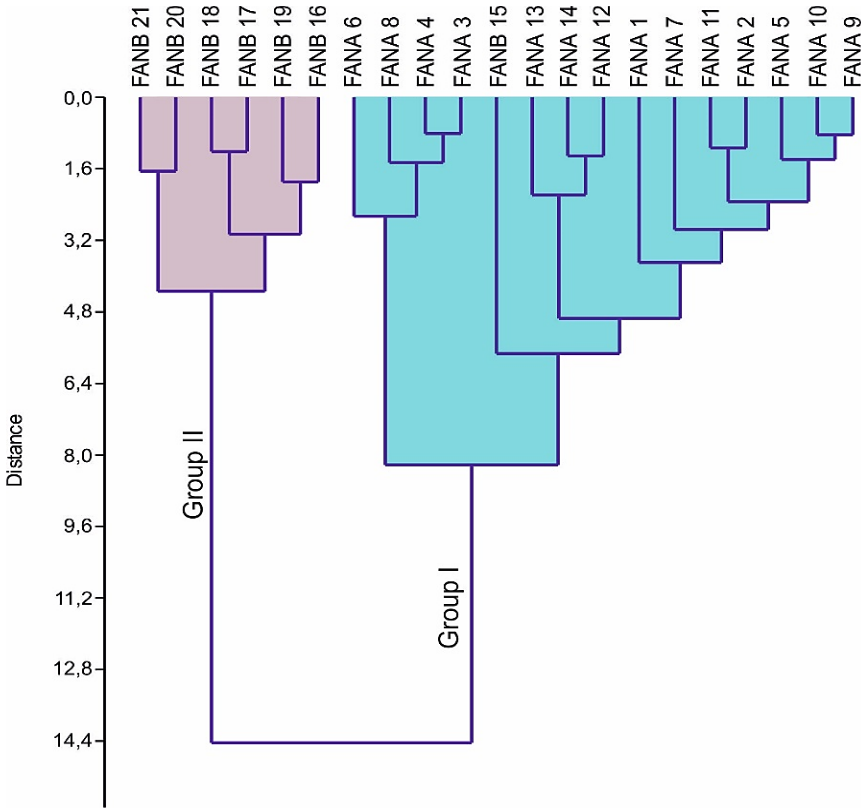


Figure 43. Dendrogramm classification is produced by Q-mode hierarchical cluster analysis (Ward's method, Euclidean distances as a similarity index).

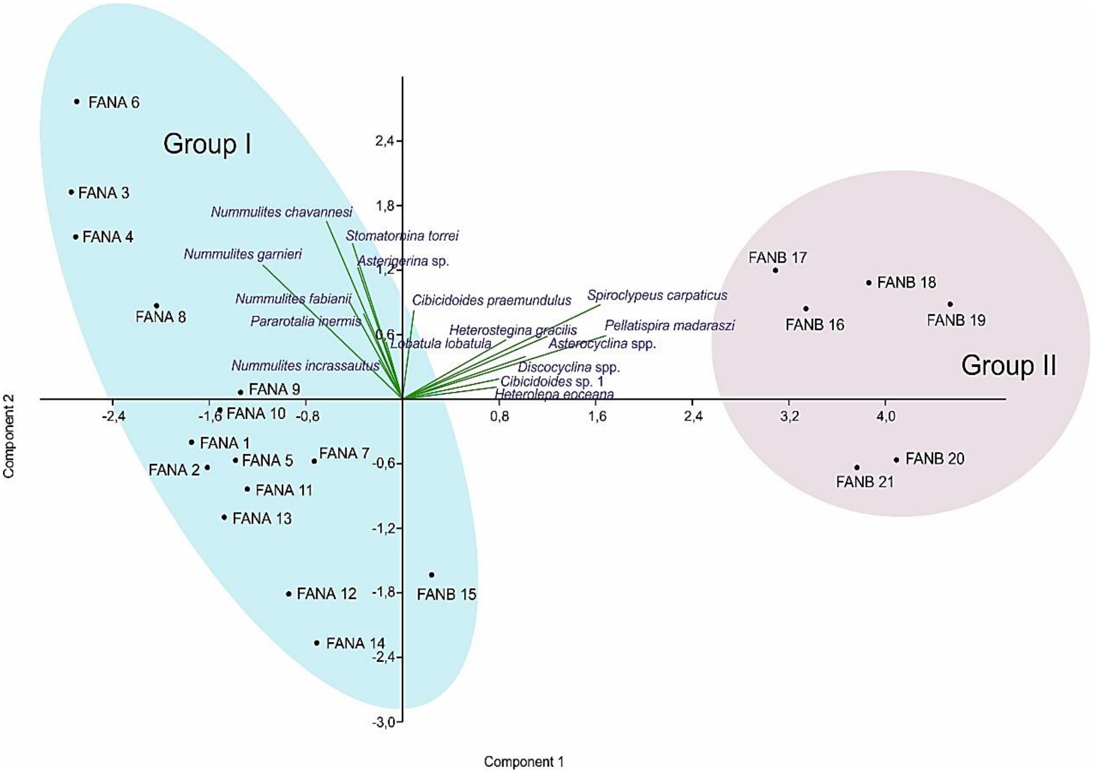


Figure 44. Principal Component Analysis (PCA) showing classification. PC scores of components 1 and 2 are 78,799% while for component 1 the main loadings were *S. carpaticus*, *P. madaraszi* and *N. garnieri* and for component 2 were *N. chavannesi* and *S. torrei*.

The R-mode Cluster analysis shows that the fauna can be divided into two main fauna groups-biofacies (Figs. 45, 46). Group-Biofacies I is related to the fine-grained siltstones of the lower part of the sequence. The assemblage is characterized by the dominance of epifaunal over infaunal species. The most important species are *Nummulites* spp., *H. eoceana*, *C. praemundulus*, *L. lobatula*, *Asterigerina* sp., *S. torrei* and *Pararotalia inermis*.

Group-Biofacies II is correlated to the calcareous sandstones of the upper part of the sequence. The assemblage is also dominated by epifaunal over the infaunal forms. The number of epifaunal species is slightly bigger than in FANA, whereas the number of infaunal species remains the same. The most important species are *S. carpaticus*, *H. gracilis*, *P. madaraszi*, *Asterocyclina* spp., *Discocyclina* spp., and *Cibicidoides* sp. 1.

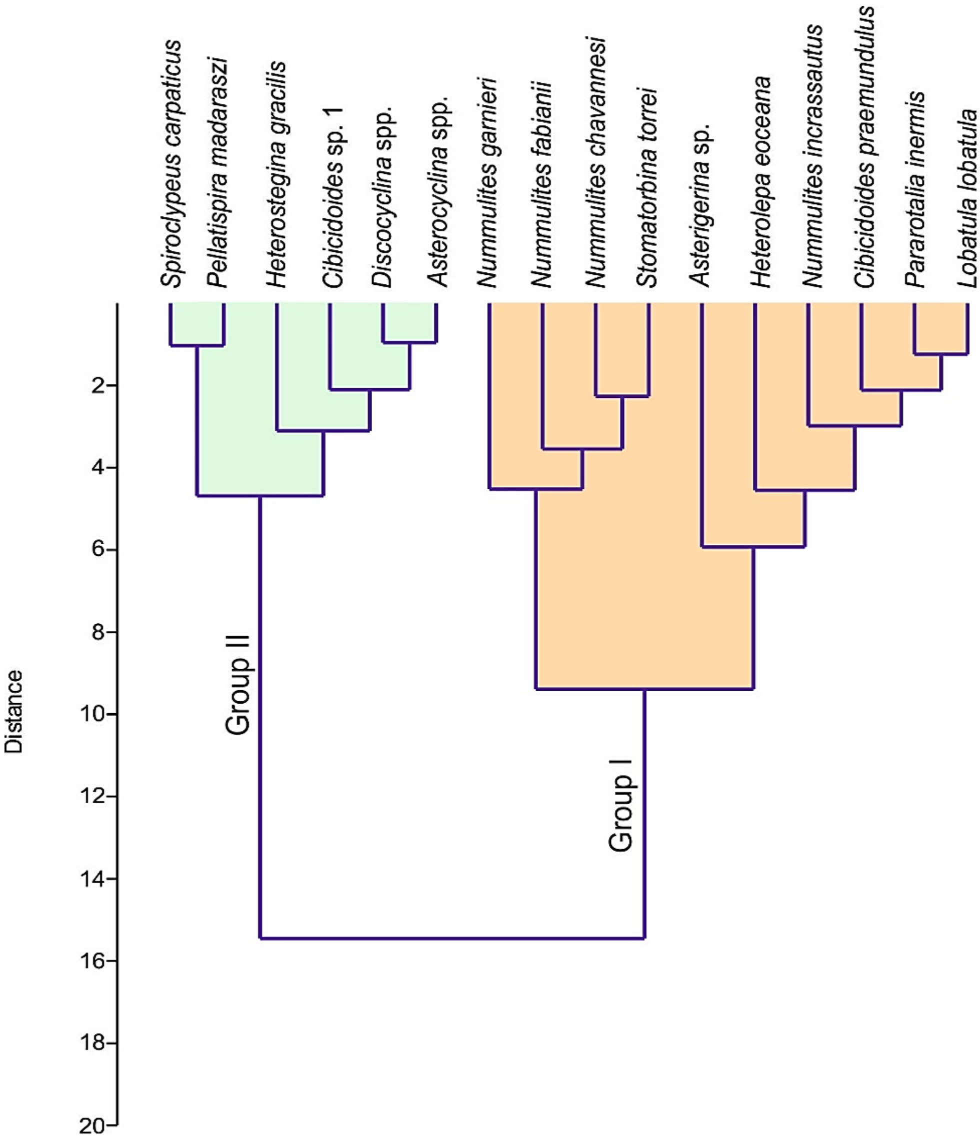


Figure 45. Dendrogramm classification produced by R-mode Hierarchical Cluster analysis (Ward's method, Euclidean distances as a similarity index).

6.5 DISCUSSION

Benthic foraminiferal assemblages of the three distinguished Biofacies comprise a few dominant species. Their composition confirms shallow water conditions already concluded from the previous chapters (chapter 4, 5). The estimation of the paleobathymetry and paleoecology of the foraminiferal associations was obtained after comparison of the ecological distribution patterns of their modern counterparts. Hierharchical Cluster analysis and Principal Component analysis divided two distinct groups, with Group I representing Biofacies I and II and Group II referring to Biofacies III. Minimum values of paleo-water depths 50-60 m are indicated for the lower part of Fanari sequence (Group I; Biofacies I, II; Figs. 44-46), based on the benthic assemblages, consisting mainly of the nummulitids, cibicididae and *Asterigerina* sp. (see Chapter 4). Upwards in the sequence (Group II; Biofacies III; Figs. 44-46) the increase of orthophragmines, *Spiroclypeus*, *Heterostegina*, the occurrence of *Pellatispira* along with the increase of planktonic foraminifera specimens, point to a rapid increase of water depth and paleoceanographic disturbances.

The rare occurrence of the planktonic foraminifera combined with the higher proportion of bolivinids and buliminids in the lower part of the sequence may indicate semi-enclosed, restricted conditions with temporally dysoxic to low oxic conditions at the seafloor (e.g., Hallock 1987; Gebhardt et al. 2013), or plausibly suggest more muddy substrates (Murray 1991, de Stigter et al. 1998). This is amplified by the dark grey color of the sediments and the less diversified microfauna of FANA section. Based on this theory, it is also explained the different and 'peculiar' stages of preservation of the foraminiferal tests. Groups that present low to moderate tolerance under stress conditions (such as LBF, conical group and lagenids) do not display breakages on their tests but they seem to be eroded or missing (completely or evenly) (Hallock and Glenn 1986).

Under normal conditions, the most abundant *Nummulites* spp., who prefer quite environments, would increase their tests. Nonetheless, their tests can be characterized small to normal, even compared to FANB section. This paradox could be explained because of the stress conditions of FANA. In the upper samples of this section, the environmental conditions seem to change. This event was documented from Dimou et al. (2023) from the distribution of LBF and with the data derived from this research is amplified. These samples depict the transitional phase between the shallower lower part and the deeper upper part of the sequence. This is reflected to the reduction of the taxa (S index) occur in the aforementioned samples.

The dominance of epifaunal over infaunal species, indicates a well vegetated platform. FANA section is mostly dominated by temporary motile species (morphotype B) and less with motile species (morphotype C). In FANB section the opposite is evident with the slight increase of motile species. This distribution pattern indicates that the lower part of the sequence was covered by dense arborescent algal substrates that pass into algal and seagrass habitats (Langer 1993). This is confirmed by the abundant corals and coralline algae recovered from Fanari but also recorded from the rest studied localities. Similar conditions were noted by Setawian (1983) from the upper Priabonian of N. Italy.

In the upper section (FANB), the LBF assemblage and the preservation stage of the foraminifera tests, indicate fore-slope environment with smooth inclination. From chapter 4 and Dimou et al. (2023), it was concluded that *P. madaraszi* and *S. carpaticus* were the most abundant species with extreme/ mass abundances, which present an opposite trend. These large size megalospheric forms suggest stable conditions at the most favorable parts of the depth range (K-mode strategy) and the co-occurrence with the abundant perforates indicates oligotrophic, normal marine conditions (Hallock and Glenn 1986).

The rich biodiversity and the high abundances of warm species of shallow water combined with all aforementioned data, suggest a short climatic optimum during the cooling event of Eocene-Oligocene Transition (EOT). The widespread euryhaline taxa and their co-occurrence with bryozoans, brachiopods, echinoids and molluscs suggest normal sea-water salinities.

6.6 CONCLUSIONS

Benthic and planktonic foraminifera occur throughout the sedimentary succession of Fanari. In total 100 species belonging to 60 genera were distinguished and distributed differently through the sequence. Diversity indexes show fluctuation along the sequence, whereas the Dominance_D index values remain more or less stable and low, indicating that in different part of the sequence a few species dominate.

Foraminifera in the lower part of the section (Biofacies I, II) present moderate abrasion of their tests and especially miliolids are represented only by casts. However, the rest of the microfauna present excellent test preservation. Planktonic foraminifera are outnumbered by benthic ones. Dominant species are *Nummulites* spp., *Asterigerina* sp. and cidicidae, implying vegetated covered bottoms. However, mud-dwellers occur, pointing to a mud input. Fish bones and other fossil groups are present.

In Biofacies III, the LBF group occurs in rock forming quantity. The quantitative analysis of foraminiferal assemblage and the hierarchical classification derived from R-mode cluster analysis enable us to improve the paleoenvironmental framework. Resulting, two groups were determined. Group A consists of a restricted/ semi-ecnclosed conditions assemblage (e.g. nummulitids and miliolids), while Group B comprise fore-slope assemblage dominated by P. *madaraszi*, *S. carpaticus*, *H. gracilis*, *Asterocyclina* spp, and *Cibicidoides* sp1. Some taxa are abundant throughout the entire study interval.

Based on all analyzed data, it is evident that the Fanari sequence grades from a semi-closed/ protected environment into deeper upper fore-slope settings. Even though the deepening caused by an abrupt/intense event, the small benthic assemblages did not suffer of severe changes. In contrast, in the LBF assemblanges where large changes were recorded. The dominating epifaunal morphotypes suggest oligotrophic conditions during this time interval.

CHAPTER 7. CONCLUSIONS

Through this thesis new data on LBF assemblages and events during the uppermost Eocene are presented from the Greek part of Thrace Basin. An overview of the results of the previous chapters are summarized here.

1. The full spectrum of large benthic foraminiferal content from Fanari was analyzed, comprising a rich and diverse assemblage of orthophragmines, nummulitids, and other benthic taxa. Their detailed systematic description is presented, which refines the biostratigraphic age SBZ 20 corresponding to late Priabonian for the whole sequence. Twenty-four taxa among which six at (chrono)subspecies level belonging to twelve genera were identified and morphometrically analyzed for the first time from Greece. The foraminiferal assemblage was characterized by the constant presence of *N. fabianii* almost throughout the whole sequence. The most abundant species are *P. madaraszi* and *S. carpaticus* although they occur in the upper part of the sequence, along with orthophragmines. Their mass abundance could be characterized as a *Pellatispira*-bed or a *Pellatispira-Spiroclypeus*-bed. *S. carpaticus* showed an increase in the inner cross section of the proloculus, distinguishing two groups. The foraminiferal distribution in the sequence enabled paleoenvironmental observations and the reconstruction of the evolution of the Fanari area. Three main depositional marine shelf facies were distinguished that operated at the shallow upper foreslope of the carbonate platform. Comparing Fanari to other localities ranked to SBZ 20, it stands as a key area of the latest Priabonian (SBZ 20) and of outer shelf biofacies and as one of the most diverse in LBF sequences of the Tethys realm and a possible hot spot of biodiversity.
2. The paleoenvironmental evolution of the middle-upper Eocene deposits from the Greek part of the Thrace basin is depicted, drawn on several outcrops along the mainland (Kirki, Avantas, Maronia, Pylaea, Didymoticho) and on the north-eastern

Aegean islands (Samothraki and Lemnos). Paleontological and sedimentological data distinguish 16 microfacies types that represent inner, middle and outer shelf environments. Their analysis suggests the development of a rimmed carbonate shelf with isolated platforms with marginal rims, which is characterized by restricted to open water circulation and high biotic diversity. The depositional model is reconstructed and proposed. Triggered and modified by the syn-rifting, this evolutionary pattern generates topographic highs where these ancient reef buildups thrive. Two stages of platform development were detected, followed by two transgressional episodes (T1, T2) during Bartonian-Priabonian. The first one is evidenced by the remains (late Lutetian to early Bartonian assemblages) of the demolished distinct “Phantomas” Formation (named sensu). Nothing like, the second stage is found widespread, characterized by a fully developed (Bartonian-) Priabonian platform with several sub-environments.

3. In total 100 species were identified, belonging to benthic foraminifera (small and large) recovered from Fanari loose sediments and also identified from the thin sections. This research provides a revision of the existing taxonomic notes and describes species found for the first time from the area. The paleoenvironmental analysis is expanded by the combination of the morphological features with the life strategy of both LBF and small benthic foraminifera. From this research, the distinguished assemblages, their distribution and response to the paleoenvironmental conditions compared to the equivalent recent indicate to a climatic optimum that took place during the latest Priabonian, SBZ 20.

ABSTRACT

The Greek part of Thrace basin is an ideal field of research of Paleogene carbonate platform deposits, as many sites with the dominant fauna of Large Benthic Foraminifera (LBF) have been recorded. The scope of the present thesis is to study in detail the composition and distribution of both LBF and smaller benthic foraminifera from 7 sites, aiming to create a paleoenvironmental model for the region. For this purpose, the research focused on the following aspects: 1) Study of LBF in order to provide a revised and integrated systematic description. One of the best sites in terms of preservation, biodiversity and sediment type is located along the coastline of Fanari village (SW of Komotini city). Two outcrops, consisting of shallow marine sediments of the upper Eocene, were sampled to analyze the full spectrum of LBF content, which includes a rich and diverse assemblage of orthophragmines, nummulitids and other benthic foraminifera. Based on the detailed systematic description, the sedimentary sequence was dated to the Shallow Benthic Zone (SBZ) 20 corresponding to upper Priabonian. For the first time in Greece, 24 species were identified and analyzed morphometrically, including 6 species at the chrono-subspecies level belonging to 12 genera. The composition of foraminifera assemblage is characterized by the constant presence of *Nummulites fabianii* almost throughout the sequence. The most abundant species are *Pellatispira* madaraszi and *Spiroclypeus carpaticus* although they occur in the upper part of the sequence, together with orthophragmines. The distribution of foraminifera in the sequence allowed paleoenvironmental observations and the reconstruction of the Fanari area. Three main categories of deposits were distinguished that functioned in the shallow upper anterior part of the carbonate platform, making the Fanari section a key area not only of the upper Priabonian but also of the biofacies of the outer shelf. 2) Detailed microfacies analysis of carbonate deposits. The paleoenvironmental evolution of the middle-upper Eocene deposits were investigated from several outcrops along the mainland (Kirki, Avantas, Maronia, Pylaea, Didymoticho) and on Samothraki and Lemnos Islands. All samples collected were examined in thin sections. The paleontological and sedimentological data distinguished 16 types of microfacies representing internal to external platform environments. Their analysis suggests the development of a marginal carbonate platform with isolated reefs, characterized by limited to open water circulation and high

biodiversity. Due to the simultaneous tectonic activity, topographic ridges are created where these 'ancient' reefs develop. 3) The study of small benthic foraminifera was carried out to provide a revised and comprehensive systematic description. In addition, species found for the first time from the area were recorded. Their biodiversity and distribution pattern was investigated to extend the paleoenvironmental analysis by combining morphological characteristics with the life strategy of both LBF and SBF. In total 106 species were identified; 46 belong to LBF. Based on the above, the carbonate platform of the Greek part of the Thrace basin has already been classified as one of the most species-rich sites of the Tethyan Ocean and as a biodiversity hotspot for the upper Priabonian.

ΠΕΡΙΛΗΨΗ

Το ελληνικό τμήμα της λεκάνης της Θράκης αποτελεί ένα ιδανικό πεδίο έρευνας των Παλαιογενών αποθέσεων ανθρακικής πλατφόρμας, καθώς έχουν καταγραφεί πολλές θέσεις με την επικρατούσα σε αυτές πανίδα μεγάλων βενθονικών τρηματοφόρων (Large Benthic Foraminifera, LBF). Σκοπός της παρούσας διδακτορικής διατριβής είναι η λεπτομερής μελέτη της σύνθεσης και κατανομής των LBF, αλλά και των μικρότερων βενθονικών τρηματοφόρων από 7 θέσεις, στοχεύοντας στη δημιουργία ενός μοντέλου παλαιοπεριβαλλοντικής ανασύστασης της περιοχής. Για αυτόν το σκοπό η έρευνα εστιάστηκε στις εξής επιμέρους κατευθύνσεις: 1) Μελέτη των LBF με σκοπό την αναθεωρημένη και ολοκληρωμένη συστηματική περιγραφή τους. Μια από τις καλύτερες θέσεις από άποψη διατήρησης, βιοποικιλότητας και τύπου ιζημάτων εντοπίζεται στο Φανάρι (ΝΔ της Κομοτηνής). Δύο εμφανίσεις, οι οποίες αποτελούνται από ρηχά θαλάσσια ιζήματα του ανώτερου Ηωκαίνου, δειγματίστηκαν για να αναλυθεί όλο το φάσμα του περιεχομένου των LBF, το οποίο περιλαμβάνει μια πλούσια και ποικιλόμορφη συνάθροιση από orthophragmines, nummulitids και άλλων βενθονικών τρηματοφόρων. Βάσει της λεπτομερούς συστηματικής περιγραφής, η ιζηματογενής ακολουθία χρονολογήθηκε στη βιοζώνη Shallow Benthic Zone (SBZ) 20, που αντιστοιχεί στο άνω Πριαμπόνιο. Προσδιορίστηκαν και αναλύθηκαν μορφομετρικά, για πρώτη φορά από τον ελληνικό χώρο, 24 είδη μεταξύ των οποίων 6 σε επίπεδο υποείδους (chrono-subspecies) που ανήκουν σε 12 γένη. Η σύνθεση των τρηματοφόρων χαρακτηρίζεται από τη σταθερή παρουσία του *Nummulites fabianii* σχεδόν σε όλη την ακολουθία. Τα πιο άφθονα είδη είναι τα *Pellatispira madaraszi* και *Spiroclypeus carpaticus* αν και εμφανίζονται στο ανώτερο τμήμα της ακολουθίας, μαζί με τα orthophragmines. Η κατανομή τους επέτρεψε την παλαιοπεριβαλλοντική αναπαράσταση της εξέλιξης της περιοχής του Φαναρίου. Διακρίθηκαν τρεις κύριες κατηγορίες αποθέσεων που λειτούργησαν στο ρηχό ανώτερο πρόσθιο τμήμα της ανθρακικής πλατφόρμας, καθιστώντας το Φανάρι μια περιοχή-κλειδί όχι μόνο του άνω Πριαμπονίου αλλά και των βιοφάσεων της εξωτερικής υφαλοκρηπίδας. 2) Λεπτομερής ανάλυση και καθορισμός Μικροφάσεων των ανθρακικών αποθέσεων. Η παλαιοπεριβαλλοντική εξέλιξη των αποθέσεων του μέσου-ανώτερου Ηωκαίνου ερευνήθηκε από πολλές εμφανίσεις της ηπειρωτικής χώρας (Κίρκη, Άβαντας, Μαρώνεια, Πυλαία,

Διδυμότειχο) και στα νησιά Σαμοθράκη και Λήμνο. Όλα τα δείγματα που συλλέχθηκαν εξετάστηκαν σε λεπτές τομές. Τα παλαιοντολογικά και ιζηματολογικά δεδομένα διακρίνουν 16 τύπους μικροφάσεων που αντιπροσωπεύουν περιβάλλοντα εσωτερικής έως και εξωτερικής πλατφόρμας. Η ανάλυσή τους υποδηλώνει την ανάπτυξη μιας περιθωριοποιημένης ανθρακικής πλατφόρμας με απομονωμένους υφάλους, η οποία χαρακτηρίζεται από περιορισμένη έως ανοικτή κυκλοφορία νερού και υψηλή βιοποικιλότητα. Εξαιτίας της ταυτόχρονης τεκτονικής δραστηριότητας, δημιουργούνται τοπογραφικά υψώματα όπου αναπτύσσονται αυτοί οι «αρχαίοι» ύφαλοι. 3) Πραγματοποιήθηκε η μελέτη των μικρών βενθονικών τρηματοφόρων με σκοπό την αναθεωρημένη και ολοκληρωμένη συστηματική περιγραφή τους. Επιπλέον, καταγράφηκαν είδη που βρέθηκαν για πρώτη φορά από την περιοχή. Η βιοποικιλότητα τους και το πρότυπο κατανομής τους διερευνήθηκαν προκειμένου να επεκταθεί η παλαιοπεριβαλλοντική ανάλυση συνδυάζοντας τα μορφολογικά χαρακτηριστικά με τη στρατηγική ζωής τόσο των LBF όσο και των μικρών βενθονικών τρηματοφόρων. Συνολικά προσδιορίστηκαν 106 είδη, εκ των οποίων τα 46 να ανήκουν στα LBF. Βάσει των προαναφερθέντων, η ανθρακική πλατφόρμα του ελληνικού τμήματος της λεκάνης της Θράκης έχει ήδη χαρακτηριστεί ως μία από τις πιο πλούσιες σε είδη θέση του ωκεανού της Τηθύος και ως ένα hotspot βιοποικιλότητας για το άνω Πριαμπόνιο.

REFERENCES

Accordi, G., Carbone, F. and Pignatti, J., 1998. Depositional history of a Paleogene carbonate ramp (Western Cephalonia, Ionian Islands, Greece). *Geologica Romana*, 34, 131-205.

AGIP Mineralia, 1982. Foraminiferi padani (Terzinario e Quarternario), Atlante Iconografico e Distribuzione Stratigrafica. 2nd ed., pls 52, Milano.

Agnini, C., Fornaciari, E., Giusberti, L., Grandesso, P., Lanci, L., Luciani, V., Muttoni, G., Pälike, H., Rio, D., Spofforth, D. J. A. and Stefani, C., 2011. Integrated bio-magnetostratigraphy of the Alano section (NE Italy): a proposal for defining the middle-late Eocene boundary. *Geological Society of America Bulletin*, 123, 841-872.

Aigner, Th., 1983a. Facies and origin of nummulitic buildups: an example from the Giza Pyramids Plateau (Middle Eocene, Egypt). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, 166, 347-368.

Aigner, Th., 1983b. Pliocene cliff-line around the Giza Pyramids Plateau, Egypt. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 42, 313-322.

Alegret, L. and Thomas, E., 2001. Upper Cretaceous and lower Paleogene benthic foraminifera from northeastern Mexico. *Micropaleontology*, 47, 269-316.

Alegret, L., and Thomas, E., 2013. Benthic foraminifera across the Cretaceous/Paleogene boundary in the Southern Ocean (ODP Site 690): Diversity, food and carbonate saturation. *Marine Micropaleontology, 105,* 40-51.

Ali, N., Özcan, E., Yücel, A. O., Hanif, M., Hashmi, S. I., Ullah, F., Rizwan, M. and Pignatti, J., 2018. Bartonian orthophragminids with new endemic species from the Pirkoh and Drazinda formations in the Sulaiman Range, Indus Basin, Pakistan. *Geodinamica Acta*, 30 (1), 31-62.

Allison, A., Miller, S. E. and Nishida, G. M., 1995. Hawaii Biological Survey: a model for the Pacific Region. In: Marine and coastal biodiversity in the tropical island Pacific Region. Species systematics and information management priorities. Program on Environment, East-West Center, Honolulu, 1, 349-55.

Arni, P. 1965. L’evolution des Nummulitinae en tant que facteur de modifi cation des depots littoraux. *Memoires du Bureau de Recherches Geologiques et Minieres,* 32, 7-20.

Aubouin, J., 1958. Sur la signification paléogéographique du massif du Gavrovo (Makrinoros) (Nome d'Arta, Epire). *Annales Géologiques des Pays Helléniques*, 4, 165-170.

Aubouin, J., Brunn, J. H. and Celet, P., 1958. Les massifs du Klokova et Varassova (Akarnanie). *Annales Géologiques des Pays Helléniques*, 9, 256-259.

Barattolo, F., Bassi, D. and Romano, R., 2007. Upper Eocene larger foraminiferal-coralline algal facies from the Klokova Mountain (southern continental Greece). *Facies*, 53 (3), 361-375.

Bassi, D., 2005. Larger foraminiferal and coralline algal facies in an Upper Eocene storm-influenced, shallow-water carbonate platform (Colli Berici, north-eastern Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 226, 17-35.

Bassi, D., Ćosović, V., Papazzoni, C. A. and Ungaro, S., 2000. The Colli Berici. *Annali dell' Universita di Ferrara*, 8, 43-57.

Beavington-Penney, S. J., 2004. Analysis of the effects of abrasion on the test of *Palaeonummulites venosus*: implications for the origin of nummulithoclastic sediments. *Palaios*, 19, 143155.

Beavington-Penney, S. J. and Racey, A., 2004. Ecology of extant nummulitids and other larger benthic foraminifera: applications in palaeoenvironmental analysis. *Earth-Science Reviews*, 67, 219-265.

Beavington-Penney, S. J., Wright, V. P. and Racey, A., 2006. The middle Eocene Seeb Formation of Oman: An investigation of acyclicity, stratigraphic completeness, and accumulation rates in shallow marine carbonate settings. *Journal of Sedimentary Research*, 76, 1137-1161.

Blondeau, A., 1972. Les Nummulites. Vuibet, Paris, 254 pp.

Bolli, H. M., Beckmann, J. P. and Saunders, J. B. 1994. Benthic Foraminiferal Biostratigraphy of the South Caribbean region. Cambridge University Press, 408 pp.

Boltovskoy, E. and Wright, R., 1976. Recent Foraminifera. Dr. W. Junk, The Hague.

Boltovskoy, E., Giussani, G., Watanabe, S. and Wright, R., 1980. Atlas of benthic shelf foraminifera of the Southest Atlantic. Dr W. Junk bv. Publishers, The Hague, p. 147.

Bonev, N., Burg, J.-P. and Ivanov, Z., 2006. Mesozoic-Tertiary structural evolution of an extensional gneiss dome - the Kesebir-Kardamos dome, eastern Rhodope (Bulgaria-Greece). *International Journal of Earth Sciences*, 95 (2), 318-340.

Bosellini, F. R. and Papazzoni, C. A., 2003. Palaeoecological significance of coralencrusting foraminiferan associations: a case-study from the upper Eocene of northern Italy. *Acta Paleontologica Polonica,* 48, 279-292.

Boussac, J., 1911. Etudes stratigraphiques et paléontologiques sur le Nummulitique de Biarritz. *Annales Hébert,* 5, 1-95.

Bowser, S. S., Alexander, S. P., Stockton, W. L. and DeLaca, T. E., 1992. Extracellular matrix augments mechanical properties of pseudopods in the carnivorous foraminiferan Astrammina rara: Role in prey capture. *The Journal of Protozoology,* 39, 724-732.

Bowser, S. S., and. Travis, J. L., 2000. Methods for structural studies of reticulopodia, the vital foraminiferal ‘‘soft part’’. *Micropaleontology,* 46 (1), 4756.

Bradshaw, J. S., 1957. Laboratory studies of the rate of growth of the foraminifera *Steblus beccarii* (Linné), var. *tepida* Cushman. *Journal of Paleontology,* 31, 1138-1147.

Brady, H. B., 1884. Report on the Foraminifera dredged by H.M.S. 'Challenger' during the years 1873-1876. Report on the Scientific Results of the Voyage H.M.S. 'Challenger' during the years 1873-1876. *Zoology,* 9, 1-814.

Bralower, T. J. and Thierstein, H. R., 1984. Low productivity and slow deep-water circulation in Mid-Cretaceous oceans. *Geology*, 12, 614-618.

Brasier, M. D., 1980. Microfossils. London, George Allen and Unwin, 193.

Briguglio, A. and Hohenegger, J., 2011. How to react to shallow water hydrodynamics: the larger benthic foraminifera solution. *Marine Micropaleontology*, 81, 63-76.

Bromley, G. R. and Asgaard, U., 1993. Endolithic community replacement on a Pliocene rocky coast. *Palaeontology,* 27, 4, 793-807.

Brunn, J. H., 1956. Etude géologique du Pinde septentrional et de la Macédoine occidentale. Thèse, Paris, 1955. *Annales Géologiques des Pays Helléniques*, 7, 358 pp.

Burchfiel, B. C., Nakov, R. and Tzankov, T., 2003. Evidence from the Mesta half-graben, SW Bulgaria, for the Late Eocene beginning of Aegean extension in the Central Balkan Peninsula. *Tectonophysics*, 375, 61-76.

Buxton, M. W. N. and Pedley, H. M., 1989. A standardised model for Tethyan Tertiary carbonate ramps. *Journal of the Geological Society of London*, 146, 746-748.

Caracciolo, L., Von Eynatten, H., Tolosana-Delgado, R., Critelli, S., Manetti, P. and Marchev, P. 2012. Petrological, geochemical, and statistical analysis of Eocene-Oligocene sandstones of the western Thrace basin, Greece and Bulgaria. *Journal of Sedimentary Research*, 82, 482-498.

Chatalov, A., Ivanova, N. and Bonev, N., 2015. Transgressive Eocene clastic-carbonate sediments from the Circum-Rhodope belt, northeastern Greece: implications for a rocky shore palaeoenvironment. *Geological Journal*, 50, 799-810.

Christodoulou, G., 1957. Über das Alter einiger Formationen von Samothraki. *Bulletin of the Geological Society of Greece*, 3 (1), 40-45 (in Greek with German summary).

Christodoulou, G., 1965. Der geologische bau der ebene von Thessaloniki-Jannitza nach den ergebnissen der mikropalaeontologichen untersuchungen am bohrgut von drei tiefbohrungen. *Bulletin of the Geological Society of Greece*, 6 (2), 249-296 (in Greek with English abstract).

Christodoulou, G., 1967. An Upper Eocene Foraminiferal Fauna from the Flysch of Karpathos Island. *Epistimoniki Epetiris Fysikomathimatikis Sxolis*, Aristotle University of Thessaloniki, 10, 163-171 (in Greek with English summary).

Christodoulou, G., 1968. Über den geologischen bau der kleinen Insel Pserimos (Dodekanes) und das alter ihrer oesteine. *Annales Géologiques des Pays Helléniques*, 21, 320-333 (in Greek with German summary).

Christofides, G., Pecskay, Z., Eleftheriadis, G., Soldatos, T. and Koroneos, A., 2004. The Tertiary Evros volcanic rocks (Thrace, Northeastern Greece): petrology and K/Ar geochronology. *Geologica Carpathica*, 55, 397-409.

Cimerman, F., Jelen, B. and Skaberne, D., 2006. Late Eocene benthic foraminiferal fauna from clastic sequence of the Socka - Dobrna area and its chronostratigraphic importance (Slovenia). *Geologija,* 49, 1, 7-44.

Cimerman, F. and Langer, M. R., 1991. Mediterranean foraminifera. Academia Scientarium et Artium Slovenica, Dela, Opera 30, Classis IV: Historia Naturalis, p. 119.

Cole, W. S., 1970. Larger foraminifera of the Late Eocene age from Eua, Tonga. *United States Geological Survey*, Professional Paper, 640-B, 1-15.

Colom, G. and Bauza, J., 1950. *Operculina canalifera gomezi* n. subsp. de Bartoniense de Cataluña. *Boletín de la Real Sociedad Española de Historia Natural*, 47, 219-221.

Ćosović, V., Drobne, K. and·Moro, A., 2004. Paleoenvironmental model for Eocene foraminiferal limestones of the Adriatic carbonate platform (Istrian Peninsula). *Facies*, 50, 61-75.

Cowen, R., 1983. Algal symbiosis and its recognition in the fossil record. In: Tevesz M.J.S. and McGall P.L. (eds), Biotic interactions in recent and fossil benthic communities, Plenum, New York, 432-478.

Cummings, R. H. 1950. Orientated thin-sectioning of microfossils. *Cushman Laboratory for Foraminiferal Research*, 1, (3-4), 66-67.

Cushman, J. A., 1926. Recent foraminifera from Porto Rico. Washington, Publication of Carbegie Institute 344, Department of Marine Biology Papers, 23, 73-84.

Cushman, J. A., 1935. Upper Eocene foraminifera of the southeastern United states. United States Geological Survey, Professional Paper 181, 1-88.

Cushman, J. A., 1937. A Monograph of the foraminiferal family Valvulinidae. *Cushman Laboratory for Foraminiferal Research, Special Publication* 8, 210 pp.

Cushman, J. A. and Applin, E. R., 1926. Texas Jackson Foraminifera. *American Association of Petroleum Geologists Bulletin*, 10, 154-189.

Cushman, J. A. and Bermúdez, P. J. 1937. Further new species of foraminifera from the Eocene of Cuba. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 13, 1-29.

D' Archiac, E. J. A., 1846. Description des fossils recueillis par M. Thorent, dans les couches nummulines des environs de Bayonne. *Mémoires de la Société Géologique de France*, 2, 189-217.

D' Archiac, E. J. A., 1850. Description des fossiles du groupe nummulitique recueillis par M. S.-P. Pratt et M. J. Delbos aux environs de Bayonne et de Dax. *Mémoires de la Société Géologique de France*, 2, 397-456.

Dalloni, M., 1923. Contribution a l'etude des terrains tertiaries de la Thessalie et de l'Epire. *Bulletin de la Société Géologique de France*, (4) 23, 284-294.

De la Harpe, Ph., 1878. Note sur les Nummulites des Alpes occidentales. *Actes de la Société Helvétique des Sciences Naturelles*, 60, 227-232.

De la Harpe, Ph., 1883. Étude des Nummulites de la Suisse et revision des espèces éocènes des genres *Nummulites* et *Assilina*. Troisième et dernièrepartie. *Mémoires de la Société Paléontologique Suisse*, 10, 141-180.

Dercourt, J., 1964. Contribution àl'étude géologique d'un secteur du Péloponnèse septentrional. *Annales Géologiques des Pays Helléniques,* 15, 151-41.

De Stirger, H. C., Jorissen, F. J. and Van der Zwaan, G. J., 1998. Bathymetric distribution and microhabitat partitioning of live (Rose Bengal stained) benthic foraminifera along a shelf to bathyal transect in the southern Adriatic Sea. *Journal of Foraminiferal Research*, 28, 40-65.

Dimou, V. G., Koukousioura, O., Dimiza, D. M., Triantaphyllou, V. M., Less, G., Pomoni-Papaioannou, F. and Syrides, G., 2021. A preliminary investigation of Eocene larger benthic foraminifera assemblages from Alpine and molasse-type deposits of the Hellenic peninsula (Greece). *Revue de Micropaléontologie,* 70, 100468.

Dimou, V. G., Koukousioura, O., Less, G., Triantaphyllou D. M., Dimiza, V. M and, Syrides, G., 2023. Systematic paleontology and biostratigraphy of the upper Eocene Large Benthic Foraminifera of Fanari (Thrace Basin, Greece). *Micropaleontology*, 69 (4-5), 451-480.

Douvillé, H., 1916. Le Cretace et le Tertiaire aux environs de Thones (Haute Savoie). *Comptes Rendus de l'Academie des Sciences*, 163 (14), 324-331.

Drooger, C. W. and Roelofsen, J. W., 1982. *Cycloclypeus* from Ghar Hassan, Malta. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen*, 85 (B), 203-218.

Drooger, C. W., 1993. Radial Foraminifera; morphometrics and evolution. *Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, Afdeling Natuurkunde*, 41, 1-242.

Dujardin, F., 1835. Observations nouvelles sur les prétendus Céphalopodes microscopiques. *Annales des Sciences Naturelles*, 2 (3), 108-109.

Dunham, R. J., 1962. Classifcation of carbonate rocks according to depositional texture. *American Association of Petroleum Geologists Memoir,* 1, 108-121.

Eames, F. E., 1951. A contribution to the study of the Eocene in Western Pakistan and Western India: A. the geology of standard sections in the western Punjab and in the Kohat district. *Quarterly Journal of the Geological Society*, 107, 159-171.

Ellis, B. F. and Messina, A. R., 1940. Catalogue of Foraminifera. American Museum of Natural Sciences, New York.

Embry, A. F. and Klovan, J. E., 1972. Absolute water depth limits of late Devonian paleoecological zones. Geol. *Rundschau*, 61, 2,672-686.

Fabiani, R., 1905. Studii geo-paleontologichi dei Colli Berici. *Atti del Reale Istituto Veneto di Scienze Lettere ed Arti*, 64, 1805-1825.

Ferrández-Cañadell, C. and Serra-Kiel, J. 1992. Morphostructure and paleobiology of *Discocyclina* Gumbel, 1870. *Journal of Foraminiferal Research*, 22, 147-165.

Ferràndez-Cañadell, C., 1997. A new, ribbed species of *Nemkovella* Less 1987 (Discocyclinidae), and discussion of the genus *Actinocyclina* Gümbel, 1870. *Journal of Foraminiferal Research*, 27 (3), 175-175.

Ferrández-Cañadell, C., 1998. Morphostructure and paleobiology of Mesogean orthophragminids (Discocyclinidae and Orbitoclypeidae, Foraminifera). *Acta Geologica Hispanica*, 31, 183-187.

Ferràndez-Cañadell, C., 2018. Serpulids on living Eocene larger foraminifer *Discocyclina*. *Symbiosis*, 76 (3-4), 229-242.

Fichtel, L. Von and Moll, J. P. C. Von, 1798. Testacea microscopica aliaque minuta ex Argonauta et Nautilus Camesina, 1798 (1803 reprint), Wien, Österreich, 123 pp.

Fleury, J. J., 1980. Les zones de Gavrovo-Triplolitza et du Pinde- Olonos (Grèce continentale et Péloponnèse du Nord). Evolution d’une plateforme et d’un bassin dans leur cadre alpine. *Société Géologique du Nord*, Publ. Lille 4 (Thèse Sci), 1-651.

Florida, G. B., 1932. Alcuni nummuliti dell’isola di Caso (Dodekaneso). *Bollettino Della Società Geologica Italiana*, A 289 (1362), 405-458.

Flügel, E., 1982. Microfacies analysis of limestones. Springer, Berlin Heidelberg New York, 633 pp.

Flügel, E., 2004. Microfacies of carbonate rocks: analysis, interpretation, and application: Springer-Verlag Publishers, Berlin, Heidelberg, New York, 976 pp.

Fornasini, C., 1902. Contributo a la conoscenzo de le Bulimine Adriatici. *Rendiconto delle Sessioni della Academia delle Scienza Fisichi et Naturali*, 5, 9, 1901-1902.

Fytikas, M., Innocenti, F., Manetti, P., Mazzuoli, R., Peccerillo, A. and Villari, L., 1984. Tertiary to Quaternary evolution of volcanism in the Aegean region. In: Dixon, E. J., Robertson, A. H. F. (eds) The Geological Evolution of the Eastern Mediterranean. London, *Geological Society*, Special Publication, 17, 687-699.

Galloway, J. J. and Morrey, M., 1929. A lower Tertiary foraminiferal fauna from Manta, Ecuador. *Bulletins of American Paleontology,* 15, 55, 1-56.

Gebhardt, H., Ćorić, S., Darga, R., Briguglio, A., Schenk, B., Werner, W. Andersen, N. and Sames, B., 2013. Middle to Late Eocene paleoenvironmental changes in a marine transgressive sequence from the northern Tethyan margin (Adelholzen, Germany). *Austrian Journal of Earth Sciences,* 106 (2), 45-72.

Geel, T., 2000, Recognition of stratigraphic sequences in carbonate platform and slope deposits: empirical models based on microfacies analysis of Palaeogene deposits in southeastern Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 155, 211-238.

Ghose, B. K., 1977. Paleoecology of the Cenozoic reefal foraminifers and algae - a brief review. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 22, 231-256.

Glaessner, M. F., 1937. Studien über Foraminiferen aus der Kreide und dem Tertiär des Kaukasus; I-Die Foraminiferen der altesten Tertiärschichten des Nordwest-kaukasus. *Laboratory of Paleontology Moscow Universit).* 2-3, 349-410.

Goldstein, S. T., 1999. Foraminifera: A biological overview. In: Sen Gupta, B. K. (ed) *Modern Foraminifera,* Kluwer Academic Publishers, Great Britain, 37-55.

Green, O. R., 2001. A manual of practical laboratory and field techniques in palaeobiology. Springer Dordrecht, 538 pp.

Gümbel, C. W., 1861. Geognostische Beschreibung des bayerischen Alpengebirges und seines Vorlandes I. *Gotha*, 950 pp.

Gümbel, C. 1868. Beiträge zur Foraminiferenfuna der nordalpinen, alteren Eocängebilde oder Kressenberger Nummulitenschichten. *Abhandlungen der Bayerische Akademie der Wissenschaften*, 10, 580-730.

Gümbel, C. W., 1870. Beiträge zur foraminiferenfauna der nordalpinen Eozängebilde oder der kressenberger Nummuliten Schisten. *Abhandlungen der Mathematisch-Physikalischen Klasse der Königlich Bayerischen Akademie der Wissenschaften*, 10, 581-720.

Hagn, H. 1953. A new method for preparing orientated thin sections of foraminifera and. other small paleontological specimens. *Micropaleontologist,* 7 (1), 34-43.

Hagn, H., 1958. Mikropaläontologische untersuchungen an gesteinen der Insel Kephallinia (Adriatisch-Jonische zone Griechenlands). *Annales Géologiques des Pays Helléniques*, 9, 89-118.

Hallock, P., 1979. Trends in test shape with depth in large, symbiont-bearing foraminifera. *Journal of Foraminiferal Research*, 9, 61-69.

Hallock, P., 1980. The application of ecologic studies of living, algal symbiont-bearing foraminifera to paleoecologic interpretation. *American Association of Petroleum Geologists Bulletin*, 47, 716-717.

Hallock, P., 1984. Distribution of larger foraminiferal assemblages on two Pacific coral reefs. *Journal of Foraminiferal Research*, 14, 250-261.

Hallock, P., 1987, Fluctuations in the trophic resource continuum: A factor in global diversity cycles? *Paleoceanography*, 2, 457-471.

Hallock, P., 1998. Habitats of modern larger foraminifera: taxonomic, depth and regional comparisons. Conference abstract, Tertiary to Recent larger foraminifera-their depositional environments and importance as petroleum reservoirs (Kingstonupon-Thames), 13.

Hallock, P. and Glenn, C. E., 1986. Larger Foraminifera: A tool for paleoenvironmental analysis of Cenozoic carbonate depositional facies. *Palaios,* 1 (1), 55-64.

Hallock, P. and Hansen, H. J., 1979. Depth adaptation in *Amphistegina*: change in lamellar thickness. *Bulletin of the Geological Society of Denmark*, 27, 99-104.

Hammer, O., Harper, D. A. T., and Ryan, P. D., 2001. Past Paleontological statistics software. Package for education and data analysis. Paleontologica Electronica.

Hantken, M. von, 1875. Die Fauna der *Clavulina-Szaboi*–Schichten. I. Foraminiferen. *Mitteilungenaus dem Jahrbuche der Königlich Ungarischen Geologischen Anstalt*, 4 (1), 1-93.

Hantken, M. von, 1883. Die Clavulina Szabói-Schichten im Gebiete der Euganeen und der Meeralpen und die Cretacische Scaglia in den Euganeen. *Mathematische und naturwissenschaftliche Berichte aus Ungarn*, 2, 121-169.

Haque, A. F. M. M., 1960. ome middle to late Eocene smaller foraminifera from the Sor Range, Quetta District, West Pakistan. *Palaeontologia Pakistanica, Memoirs of the Geological Survey of Pakistan,* 2, 2, 1-79.

Haynes, J. R., 1965. Symbiosis, wall structure and habitat in foraminifera. *Special Publication-Cushman Foundation for Foraminiferal Research*, 16, 40-43.

Haynes, J. R., 1981. Foraminifera. Wiley, New York, 433.

Herb, R., 1978. Some species of *Operculina* and *Heterostegina* from the Eocene of the Helvetic nappes of Switzerland and from Northern Italy. *Eclogae Geologicae Helvetiae*, 71, 745-767.

Herb, R. and Hekel, H., 1973. Biostratigraphy, variability and facies relations of some Upper Eocene *Nummulites* from Northern Italy. *Eclogae Geologicae Helvetiae,* 66 (2), 419-445.

Herb, R. and Hekel, H., 1975. Nummuliten aus dem Obereocaen von Possagno. *Schweizerische Paläontologische Abhandlungen,* 97, 113-135 (in German with English abstract).

Heron-Allen, E., and Earland A., 1928. On the Pegididae, a new family of foraminifera. *Journal of the Royal Microscopical Society of London*, 48, 3, 283-299.

Hochstetter, F., 1870. Die geologischen Verhältnisse des östlichen Theiles der europäischen Türkei. *Jahrbuch der Kaiserlich Königlichen Geologischen Reichsanstalt*, 20, 365-461.

Hohenegger, J., 1995. Depth estimation by proportions of living larger foraminifera. *Marine Micropaleontology*, 26, 31-47.

Hohenegger, J. and Yordanova, E. K., 2001. Displacement of larger foraminifera at the western slope of Motobu Peninsula (Okinawa, Japan). *Palaios*, 1, 53-72.

Holbourn, A., Henderson, A. S. and MacLeod, N., 2013. Atlas of benthic foraminifera. John Wiley and Sons.

Holzmann, M., Gooday, A. J., Siemensma, F. and Pawlowski, J., 2021. Review: Freshwater and Soil Foraminifera - A Story of Long-Forgotten Relatives. *Journal of Foraminifera Research*, 51 (4), 318-331.

Hottinger, L., 1977. Foraminiferes operculiniformes. *Memoires du Museum National d'Histoire Naturelle*, 59, 1-159.

Hottinger, L., 1983. Processes determining the distribution of larger foraminfera in space and time. *Utrecht Micropaleontological Bulletins*, 30, 239-253.

Hottinger, L., 2000. Functional morphology of benthic foraminiferal shells, envelopes of cells beyond measure. *Micropaleontology*, 46 (1), 57-86.

Hottinger, L. and Dreher, D., 1974. Differentiation of protoplasm in Nummulitidae (Foraminifera) from Elat, Red Sea. *Marine Biology*, 25, 41-61.

Hottinger, L., Halicz, E. and Reiss, Z., 1991. The foraminiferal genera *Pararotalia, Neorotalia* and *Calcarina*: Taxonomic revision. *Journal of Paleontology*, 65, 1, 18-33.

Hottinger, L., Halicz, E. and Reiss, Z., 1993. Recent foraminifera from the Gulf of Aqaba, Red Sea. *Slovenska Akademija Znanosti in Umetnosti,* 33, 179.

Hottinger, L., Romero, J. and Caus, E., 2001. Architecture and revision of the Pellatispirines, planispiral canaliferous foraminifera from the Late Eocene Tethys. *Micropaleontology,* 47 (2), 35-77.

I.G.M.E., 1980a. Geological map of Greece, Sheet Mesi - Xilagani, 1:50.000.

I.G.M.E., 1980b. Geological map of Greece, Sheet Ferai - Peplos - Ainos, 1:50.000.

I.G.M.E., 1982. Geological map of Greece, Sheet Maronia, 1:50.000.

I.G.M.E., 1983. Geological map of Greece,1:500.000.

I.G.M.E., 1993. Geological map of Greece, Sheet Limnos Island, 1:50.000.

I.G.M.R., 1977. Geological map of Greece, Sheet Alexandroupolis, 1:50.000.

I.G.S.R., 1972. Geological map of Greece, Sheet Samothraki, 1:50.000.

Innocenti, F., Kolios, N., Manetti, P., Rita, F. and Villari, L., 1982. Acid and basic late Neogene volcanism in central Aegean Sea: its nature and geotectonic significance. *Bulletin Volcanologique*, 45 (2), 87-97.

Innocenti, F., Manetti, O., Mazzuoli, R., Pertusati, P., Fytikas, M. and Kolios, N., 1994. The geology and geodynamic significance of the island of Limnos, North Aegean Sea, Greece). *Neues Jahrbuch für Geologie und Paläontologie,* 11, 661-691.

Jepps, M. W., 1942. Studies on *Polystomella* Lamarck. *Journal of the Marine Biological Association of the United Kingdom,* 25, 607-666.

Kaminski, M. A. and Gradstein, F. M. 2005. Atlas of Paleogene Cosmopolitan Deep-Water Agglutinated Foraminifera. *Grzybowski Foundation Special Publication* n.10.

Karageorgiou, E. and Christodoulou, G., 1957. Ueber die anwesenheit eineger foraminiferen. A) Des Maastricht sim bereich von Nevropolis, B) Des oberen Lutets im bereich von Kirki. *Bulletin of the Geological Society of Greece,* 3 (I), 46-49.

Kaufmann, F. J., 1867. Geologische Beschreibung des Pilatus. *Beiträgezur Geologischen Karteder Schweiz*, 5, 1-169.

Kilias, A., Falalakis, G., Sfeikos, A., Papadimitriou, E., Vamvaka, A. and Gkarlaouni, C., 2013. The Thrace basin in the Rhodope province of NE Greece - a tertiary supradetachment basin and its geodynamic implications. *Tectonophysics*, 595-596, 90-105.

Kilias, A., Falalakis, G., Sfeikos, A., Papadimitriou, E., Vamvaka, A. and Gkarlaouni, C., 2011. Architecture of Kinematics and Deformation History of the Tertiary Supradetachment Thrace Basin: Rhodope Province (NE Greece). In: Schattner, U. (ed) New Frontiers in Tectonic Research - At the Midst of Plate Convergence, Croatia, InTech Publisher, 241-268 pp.

Kilias, A., Vamvaka, A., Falalakis, G., Sfeikos, A., Papadimitriou, E., Gkarlaouni, C. and Karakostas, B., 2015. The Mesohellenic Trough and the Paleogene Thrace Basin on the Rhodope Massif, their Structural Evolution and Geotectonic Significance in the Hellenides. *Journal of Geology & Geosciences*, 4, 2.

Kinne, O., 1970. Temperature: general introduction. In: Kinne, O. (ed.), Marine Ecology 1 (1), Wiley, New York, 321-346.

Kleemann, K. H., 1980. Boring bivalves and their host corals from the Great Barrier Reef. *Journal of Molluscan Studies*, 46, 1, 13-54.

Kopp, K. O., 1964. Geologie Thrakiens II: Die Inseln und der Chersones. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, 119, 172-214.

Kopp, K. O., 1965. Geologie Thrakiens III: Das Tertiaer zwischen Rhodope und Evros. *Annales Géologiques des Pays Helléniques*, 16, 315-362.

Kremp, G. 1953. Preparation of orientated thin sections of microfossils. M*icropaleontologist*, 7 (1), 29-33.

Kulka, A., 1985. Arni sedimentological model in the Tatra Eocene. *Kwartalnik Geologiczny*, 29, 31-64.

Langer, M. R., 1993. Epiphytic foraminifera. *Marine Micropaleontology*, 20, 235-265.

Langer, M. R., and Bell, C., 1995. Toxic Foraminifera: Innocent Until Proven Guilty. Marine *Micropaleontology*, 24, 205-214.

Langer M. R., and Hottinger, L., 2000. Biogeography of selected larger foraminifera. *Micropaleontology*, 46 (1), 105-126.

Langer, M. R., Makled, W. and Pietsch, S. J. and Weinmann, A, 2009. Asynchronous calcification in embryonic megalospheres from Chuuk Island (Micronesia): An ontogenetic window into the life cycle and polymorphism of the foraminifer Peneroplis. *Journal of Foraminiferal Research*, 39 (1), 8-14.

Larsen, A. R. and Drooger, C. W. 1977. Relative thickness of the test in the *Amphistegina* species of the Gulf of Elat. *Utrecht Micropaleontological Bulletin*, 15, 225-240.

Lee, J. J., 1974. Towards understanding the niche of the foraminifera. In: Hedley, R.H. and Adams, C.G. (eds.), Foraminifera vol. 1. Academic Press, London, 207-260.

Lee, J. J. and Anderson, O. R., 1991. Symbiosis in foraminifera. In: Lee, J.J. and Anderson, O.R. (eds), *Biology of Foraminifera*. Academic Press, New York, 157-220.

Lee, J. J., McEnery, M. E., Kahn, E. G., and Schuster, F., 1979, Symbiosis and the evolution of larger foraminifera. *Micropaleontology*, 25, 118.

Lescuyer, J. L., Bailly, L., Cassard, D., Lips, A. L. W., Piantone, P. and McAlister, M., 2003. Sediment hosted gold in south-eastern Europe: the epithermal deposit of Perama, Thrace, Greece. In: Eliopoulos, D. G., (eds) Mineral Exploration and Sustainable Development. Millpress, Rotterdam, pp. 499-502.

Less, G., 1987. Paleontology and stratigraphy of the European Orthophragminae. *Geologica Hungarica Series Palaeontologica*, 51, 1-373.

Less, G., 1993. Numeric characterization of ‘Orthophragmina’ populations. *Acta Geologica Hungarica*, 35, 193-215.

Less, G., 1998. The zonation of the Mediterranean Upper Paleocene and Eocene by Orthophragminae. *Opera Dela Slovenska Akademija Znanosti in Umetnosti*, 34, 21-43.

Less, G., 1999. The late Paleogene larger foraminiferal assemblages of the Bükk Mts. (NE Hungary). *Revista Española de Micropaleontología*, 31, 51-60.

Less, G., Kecskeméti, T., Ozsvárt, P., Kázmér, M., Báldi-Beke, M., Kollányi, K., Fodor, L., Kertész, B. and Varga, I., 2000. Middle-Upper Eocene shallow water benthos in Hungary. In: Bassi, D., Ed., Shallow Water Benthic Communities at the Middle-Upper Eocene Boundary, Southern and North-eastern Italy, Slovenia, Croatia, Hungary. *Annali dell’Università di Ferrara*, 8 (Supplement), 151-181.

Less, G., Kertész, B. and Özcan, E., 2006. Bartonian to end-Rupelian reticulate *Nummulites* of the Western Tethys. *Anuário do Instituto de Geociências*, 29 (1), 344-345.

Less, G. and Özcan, E., 2008. The late Eocene evolution of nummulitid foraminifer *Spiroclypeus* in the Western Tethys. *Acta Palaeontologica Polonica,* 53, 303-316.

Less, G., Özcan, E., Papazzoni, C. A. and Stockar, R., 2008. The middle to late Eocene evolution of nummulitid foraminifer *Heterostegina* in the Western Tethys. *Acta Palaeontologica Polonica*, 3, 317-350.

Less, G., Özcan, E. and Okay, I.-A., 2011. Stratigraphy and Larger Foraminifera of the Middle Eocene to lower Oligocene shallow-marine units in the northern and eastern parts of the Thrace Basin, NW Turkey. *Turkish Journal of Earth Sciences*, 20, 793-845.

Less, G. and Özcan, E., 2012. Bartonian-Priabonian larger benthic foraminiferal events in the Western Tethys. *Austrian Journal of Earth Sciences,* 105 (1), 129-240.

Leutenegger, S., 1977, Reproductive cycles of larger foraminifera and depth distribution of generations. *Utrecht Micropaleontological Bulletin*, 15, 27-34.

Leutenegger, S., 1984. Symbiosis in benthic foraminifera: Specificity and host adaptations. *Journal of Foraminiferal Research*, 14, 16-35.

Lipps, J. H., 1982. Biology/paleobiology of foraminifera. In: Broadhead, T.W. (ed.), Foraminifera, Notes for a Short Course. Palaeontological Society, University of Tennessee, 37-50.

Lipps, J. H., 1983. Biotic interactions in benthic foraminifera. In: Tevesz, M. J. S., and McCall, P. L. (eds) *Biotic interactions in Recent and fossil communities*. New York, 331-376.

Lipps, J. H. and Langer, M. R., 1999. Benthic foraminifera from the meromictic Mecherchar Jellyfish Lake, Palau (western Pacific). *Micropaleontology*, 45 (3), 278-284.

Lister, J. J. 1903. The Foraminifera, In: Lankester, E. R., *A Treatise on Zoology,* London, 47-149.

Loeblich, A. R. and Tappan, H., 1984. Suprageneric classification of the Foraminiferida (Protozoa). *Micropaleontology*, 30, 1-70.

Loeblich, A. R. and Tappan, H. 1988. Foraminiferal Genera and their Classification: Van Nostrand Reinhold, Co, New York, 970 pp.

Loeblich, A. R. and Tappan, H.,1964. Protista 2. Sarcodina chiefly 'Thecamoebians' and Foraminiferida, Part C. In: Moore, R. C. (ed) *Treatise on Invertebrate Paleontology,* Geological Society of America and University of Kansas Press, 1-900.

MacVicar, D. G. 1951. Extraction of fossils by heat. *Micropaleontologist*, 5 (3), 15.

MacVicar, D. G. 1952. Thermal disintegration of sedimentary rocks. *American Journal of Science*, 250, 271-274.

Makled, W. and Langer, M. R., 2009. Preferential selection of titanium-bearing minerals in agglutinated Foraminifera: Ilmenite (FeTiO3) in Textularia hauerii d'Orbigny from the Bazaruto Archipelago, Mozambique. *Revue de Micropaléontologie*, 53, 163-173. DOI:10.1016/j.revmic.2009.11.001

Marie, P. 1950. *Queraltina*, nouveau genre de Foraminifère de l'Éocene pyrénéen. *Bulletin de la Société Géologique de France*, 5, 20, 73-80.

Meinhold, G. and BouDagher-Fadel, M., 2009. Geochemistry and biostratigraphy of Eocene sediments from Samothraki Island, NE Greece *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, 256 (1), 17-38.

Mendes, I., Gonzalez, R., Dias, J. M. A., Lobo, F. and Martins, V., 2004. Factors influencing recent benthic foraminifera distribution on the Guandiana shelf (Southern Iberia). *Marine Micropaleontology*, 51, 171-192.

Mercier, J., 1960. Sur la géologie de la Macédoine occidentale: Remarques sur l´ Eocène transgressif de Choryghi. *Annales Géologiques de Pays Helléniques*, 11, 313-319.

Mirkou-Peripopolou, R. M., 1975. Stratigraphie et géologie de la partie septentrionale de l'île de Zanthe (Grèce). *Annales Géologiques des Pays Helléniques*, 26, 35-109 (in Greek with French summary).

Moore, C. H. and Wade, W. J., 2013. Chapter 6 - Marine Diagenetic Environment. Developments Sedim. 67, 93-131.

Mountrakis, D., Tranos, M., Papazachos, C., Thomaidou, E., Karagianni, E. and Vamvakaris, D., 2006. Neotectonic and seismological data concerning major active faults, and the stress regimes of Northern Greece. In: Robertson, A. H. F. and Mountrakis, D. (eds) *Tectonic Development of the Eastern Mediterranean Region*, Geological Society, London, Special Publication, 260, 649470.

Moura de Mello, R., 2016. A Paleobathymetric Model and Evolution of the Brazilian Marginal Basins during the Late Maastrichtian to Eocene based on Benthic Foraminiferal Biofacies. PhD Thesis, 288 pp.

Murray, J. W., 1973. Distribution and Ecology of Living Benthic Foraminiferids. Heinemann, London, 288.

Murray, J. W., 1991. Ecology and Palaeoecology of Bnthic Foraminifera. Longman, Wiley, Harlow/Essex, New York, 397 pp.

Murray, J., 2006. Ecology and Applications of Benthic Foraminifera. Cambridge University Press, 1-426.

Nebelsick, J. H. and Bassi, D., 2000. Diversity, growth-forms and taphonomy: key factors controlling the fabric of coralline algal dominated shelf carbonates. In: Insalaco, E., Skelton, P. W. and Palmer, T. J. (eds) *Carbonate platform systems: components and interactions*. Geological Society, London, Special Publication, 178, 89-10.

Nuttall, W. L. F., 1926. The zonal distribution and description of the larger foraminifera of the middle and lower Kirthar Series (Middle Eocene) of parts of Western India. *Records of the Geological Survey of India*, 59, 115-164.

Nuttall, W. L. F., 1930. Eocene foraminifera from Mexico. *Journal of Paleontology*, 4, 3, 271-293.

Odin, G. S. and Matter, A., 1981. De glaucodiarum origine. *Sedimentology*, 28, 611-641.

of larger foraminifera. *Micropaleontology*, 25, 118.

Okay, A., Özcan, E., Cavazza, W., Okay, N. and Less, G., 2010. Upper Eocene olistostromes, two contrasting basement types and the initiation of the Thrace basin, NW Turkey. *Turkish Journal of Earth Sciences*, 19, 1-24.

Oppenheim, P. 1896. Das Alttertiär der Colli Berici in Venetien, die Stellung der Schichten von Priabona, und die Oligocäne transgression in alpinen Europa. *Zeitschrift der Deutschen Geologischen Gesellschaft*, 48, 27–152.

Orbigny, A. d', 1826. Tableau methodique de la classe des Céphalopodes. *Annales des Sciences Naturelles*, 7, 245-314.

Orbigny, A. d', 1846. Foraminiferes Fossiles du Bassin Tertiaire de Vienne (Autriche). Gide de Comp., Paris. 312 pp.

Orbigny, A. d', 1850. Prodrome de paléontologie stratigraphique universelle des animaux mollusques et rayonnes. Paris, Masson.

Ortiz, S. and Thomas, E., 2006. Lower-middle Eocene benthic foraminifera from the Fortuna Section (Betic Cordillera, southeastern Spain). *Micropaleontology*, 52,2, 97-150.

Özcan, E., Less, G., Báldi-Beke, M., Kollányi, K. and Acar, F., 2009. Oligo-Miocene Foraminiferal record (Miogypsinidae, Lepidocyclinidae and Nummulitidae) from the Western Taurides (SW Turkey): biometry and implications for the regional geology. *Journal of Asian Earth Sciences*, 34, 740-760.

Özcan, E., Less, G., Báldi-Beke, M., Kollányi, K. and Kertesz, B., 2007. Biometric analysis of middle and upper Eocene Discocyclinidae and Orbitoclypeidae (Foraminifera) from Turkey and updated orthophragmine zonation in the Western Tethys. *Micropaleontology*, 52, 485-520.

Özcan, E., Less, G., Okay, I.-A., Báldi-Beke, M., Kollányi, K. and Yilmaz, Ö., 2010. Stratigraphy and Larger Foraminifera of the Eocene Shallow-marine and Olistostromal Units of the Southern Part of the Thrace Basin, NW Turkey. *Turkish Journal of Earth Sciences*, 19, 27-77.

Özcan, E., Okay, A. I., Bürkan, K. A., Yücel, A. O. and Özcan, Z., 2018. Middle-Late Eocene marine record of the Biga Peninsula, NW Anatolia, Turkey. *Geologica Acta*, 16 (2), 163-187.

Özcan, E., Saraswati, P. K., Hanif, M. and Ali, N., 2016. Orthophragminids with new axial thickening structures from the Bartonian of the Indian subcontinent. *Geologica Acta*, 14 (3), 261-282.

Özcan, E., Yücel, A. O., Erbay, S., Less, G., Kayğili, S., Ali, N. and Hanif, M., 2019. Reticulate *Nummulites* (*N. fabianii* Linage) and Age of the *Pellatispira*-Beds of the Drazinda Formation, Sulaiman Range, Pakistan. *International Journal of Paleobiology and Paleontology*, 2 (1), 1-10.

Özcan, E., Yücel, A. O., Erkizan, S. L., Gültekinl, N. M., Kayğili, S. and Yurtsever, S., 2022. Atlas of the Tethyan Orthophragmines. *Mediterranean Geoscience Reviews*, 4, 3-213.

Papanikolaou, D. and Triantaphyllou, M., 2010. Tectonostratigraphic observations in the western Thrace Basin in Greece and correlations with the eastern part in Turkey. *Geologica*. *Balcanica*, 39 (1-2), 293-294.

Papanikolaou, D. and Triantaphyllou, M., 2019. New stratigraphic data of the Limnos volcano-sedimentary sequence and correlations with the Thrace Basin. Proceedings of the 15th

International Congress of the Geological Society of Greece, 22-24 May, Athens, Greece, *Bulletin of the Geological Society of Greece*, Special Pubication, 7, Extended Abstracts, GSG2019-240, 71-72.

Papazzoni, C. A., 1998. Biometric analyses of *Nummulites ''ptukhiani''* Z. D. Kacharava, 1969 and *Nummulites fabianii* (Prever in Fabiani, 1905). *Journal of Foraminiferal Research*, 28 (3), 161-176.

Papazzoni, C. A. and Sirotti, A., 1995. Nummulite Biostratigraphy at the Middle/Upper Eocene Boundary in the Northern Mediterranean Area. *Rivista Italiana di Paleontologia e Stratigrafia*, 101 (1), 63-80.

Papp, A. and Schmid, M. E., 1985. Die Fossilen Foraminiferen des Tertiären Beckens von Wien. Revision der Monographie von Alcide d´Orbigny (1846). *Abhandlungen der Geologischen Bundesanstalt*, 73, 1-311.

Racey, A., 2001. A review of Eocene nummulite accumulations: structure, formation and reservoir potential. *Journal of Petroleum Geology*, 24, 79-100.Reed, S. F. and Mergren, L. J., 1953. Preparation of rock thin sections. *American Mineralogist*, 38, 1184-1203.

Renema, W., 2002. Larger benthic foraminifera as marine environmental indicators. *Scripta Geologica*, 124, 1-263.

Renema, W., 2005. Depth estimation using diameter-thickness ratios in larger benthic foraminifera. *Lethaia*, 38,137-141.

Rasmussen, T. L., 2005. Systematic paleontology and ecology of benthic foraminifera from the Plio-Pleistocene Kallithea Bay, Rhodes, Greece. *Cushman Foundation Special Publication*, 39, 53-157.

Reuss, A. E., 1848. Die Fossilen Polyparien des Wiener Tertiärbeckens. *Haidingers Naturwissenschaftlichen Abhandlungen*, 2 (1), 11-09.

Romero, J., Hottinger, L. and Caus, E., 1999. Early appearance of larger foraminifera supposedly characteristic for Late Eocene in the Igualada Basin (NE Spain). *Revista Española de Paleontología*, 14, 79-92.

Rondoyanni, Th., Georgiou, Ch., Galanakis, D. and Kourouzidis, M., 2004. Evidence of active faulting in Thrace region (northeastern Greece). Proceedings of the 10th International

Congress, Thessaloniki, April 2004, *Bulletin of the Geological Society of Greece*, 36 (4), 1671-1678.

Ross, C., 1974. Evolutionary and ecological significance of large calcareous foraminiferida (protozoa), Great Barrier Reef: Proceedings of Second International Coral symposium 1, Great Barrier Reef Committee, 327-333.

Roveda, V., 1961. Contributo allo studio di alcuni macroforaminiferi di Priabona. *Rivista Italiana di Paleontologia*, 6, 153-224.

Rütimeyer, L., 1850. Über das schweizerische Nummuliten terrain, mit besonderer Berücksichtigung des Gebirgeszwischen dem Thunersee und der Emme. *Denkschriften der Schweizerischen Naturforschenden Gesellschaft*, 11 (2), 1-120.

Rupp, C., 1986. Paläoökologie der Foraminiferen in der Sandschalerzone (Badenien, Miozän) des Wiener Banchens. University of Wien, Bieträge zur paläontologie von Österreich, 12, 180 pp.

Samanta, K. B., 1982. *Fabiania* Silvestri (Foraminiferida) from India, with notes on its global distribution. Geological Magazine, 119 (3), 257-267.

Schaub, H., 1981. Nummulites et Assilines de la Téthys Paléogène; taxinomie, phylogenèse et biostratigraphie. *Mémoires Suisses de Paléontologie*, 104, 238.

Schmiedl, G., Mackensen, A. and Müller P. J., 1997. Recent benthic foraminifera from the eastern South Atlantic Ocean: Dependence on food supply and water masses. *Marine Micropaleontology*, 32, 249-287.

Schönfeld, J., 2002. Recent benthic foraminiferal asseblanges in deep high-energy environments from Gulf of Cadiz (Spain). *Marine Micropaleontology*, 44, 141-162.

Sellier de Cirvieux, J. M., 1981. Las Buliminidae del Mar Caribe, frente a Venezuela. *Boletín del Instituto Oceanográfico de la Universidad de Oriente*, 19, 15-51

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferràndez, C., Jauhri, A.K., Less, G., Pavlovec, R., Pignatti, J., Samso, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J. and Zakrevskaya, E., 1998. Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. *Bulletin de la Société Géologique de France*, 169, 281-299.

Serra-Kiel, J., Mató, E., Saula, E., Travé, A., Ferràndez-Cañadell, C., Álvarez-Pérez, C., Busquets, P., Samsó, J. M., Tosquella, J., Franquès, J., Romero, J. and Barnolas, A., 2003.

An inventory of the marine and transitional Middle/Upper Eocene deposits of the Southeastern Pyrenean Foreland Basin (NE Spain). *Geologica Acta*, 1, 201-229.

Setiawan, J. R., 1983. Foraminifera and microfacies of the Type Priabonian. *Utrecht Micropaleontological Bulletins*, 29, 1-173.

Severin, K. P. and Lipps, J. H., 1989. The weight-volume relationship of the test of *Alveolinella quoyi*: implications for the taphonomy of large fusiform foraminifera. *Lethaia*, 22, 1-12.

Sgarella, F. and Moncharmont Zei, M., 1993. Benthic foraminifera of the Gulf of Naples (Italy): systematics and autoecology. *Bollettino della Società Paleontologica Italiana*, 32, 145-264.

Sirel, E. and Acar, S., 1982. *Praebullalveolina*, a new foraminiferal genus from the Upper Eocene of the Afyon and Çanakkale region (west of Turkey). *Eclogae Geologicae Helvetiae*, 75 (3), 821-839.

Sirotti, A., 1978. Discocyclinidae from the Priabonian type-section (Lessini Mountains, Vicenza, Northern Italy). *Bollettino della Società Paleontologica Italiana*, 17 (1), 49-67.

Soldatos, T., Koroneos, A., Christofides, G. and Del Moro, A., 2001a. Geochronology and origin of the Elastic plutonite (Hellenic Rhodope Massif, N. Greece) constrained by new Sr isotopic data. *Neues Jahrbuch fur Mineralogie Abhandlungen*, 176, 179-209.

Soldatos, T., Koroneos, A., Christofides, G. and Del Moro, A., 2001b. Evolution of Elatia Plutonite (Hellenic Rhodope Massif, N. Greece). Chemie der Erde Geochemistry, 61, 92-116.

Soliman, H. A. and Zygojannis, N., 1977. Foraminiferal assemblages from the Eocene of the Mesohellenic Basin, Northern Greece. *VI Colloquium on the Geology of the Aegean Region*, 3, 1095-1104.

Soliman, H. A. and Zygojannis, N., 1979. On the biozonation of the Oligocene sequences by foraminifera in the South Mesohellenic Basin, Northern Greece. *VI Colloquium on the Geology of the Aegean Region*, 3, 1095-1104.

Sowerby, J. DE C., 1840. Systematic list of organic remains. Appendix to: Grant, C. W., Memoir to illustrate a geological map of Cutch. *Transactions of the Geological Society of London*, 5 (2), 317-329.

Terquem, M. 1882. Les Foraminiféres de l'Éocénes des environs de Paris. *Mémoires de la Société Géologique de France, Paléontologie* 3, 2, 1-193.

Thiebault, F., 1982. Evolution géodynamique des Héllénides externes en Péloponnèse méridional (Grèce). *Société Géologique du Nord publication*, 6, 574.

Todd, R., Low, D. and Mello, J. F., 1965. Smaller foraminifera, pp 14-20. In: Kummel, B. and Raup, D. (eds) *Handbook of Paleontological Techniques*, San Francisco, W. H. Freeman and Co., Xiii 852p.

Torres-Silva, A. I., Eder, W., Hohenegger, J. and Briguglio, A., 2019. Morphometric analysis of Eocene nummulitids in western and central Cuba: taxonomy, biostratigraphy and evolutionary trends. *Journal of Systematic Palaeontology*, 17 (7), 557-595.

Tranos, M. D., 2009. Faulting of Lemnos Island: a mirror of the North Aegean Trough (Northern Greece). *Tectonophysics,* 467, 72-88.

Trevisani, E. and Papazzoni, C.A., 1996. Paleoenvironmental control on the morphology of *Nummulites fabianii* (Prever) in the Late Priabonia parasequences of the Mortisa Sandstone (Venetian Alps, northern Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, 102, 363-366.

Turgut, S. and Eseller, G., 2000. Sequence stratigraphy, tectonics and depositional history in eastern Thrace Basin (NW Turkey). *Marine and Petroleum Geology*, 17, 61-100.

Uhlig, V., 1886. Über eine Mikrofauna aus dem Alttertiar der westgalizischen Karpathen. *Jahrbuch der Kaiserliche und Königliche Geologische Reichsanstalt*, 36, 141-214.

Van Morkhoven, F. P. M., Berggren, W. A. and Edwards, A. S., 1986. Cenozoic Cosmopolitan Deep-Water Benthic Foraminifera. *Bulletin des centres de recherchers exploration-production Elf-Aquitaine, Memoire*, 11, p. 421.

Weijden, W. J. M. van der, 1940. Het genus *Discocyclina* in Europa. Een monografie naar aanleiding van een heronderzoek van het Tertiair-profiel van Biarritz. Thesis, Rijkuniversiteit Leiden, 116 pp.

Whipple, G. L., 1932. Eocene Foraminifera. In: Hoffmeister, J. E., Ed., Geology of Eua, Tonga. *Bernice P. Bishop Museum Bulletin,* 96, 79-86.

White, M. P., 1928. Some index foraminifera of the Tampico Embayment area of Mexico. Parts 1, 2. *Journal of palaeontology,* 2, 3-4, 177-215; 280-317.

Whittaker, R. H., 1978. Direct gradient analysis. In: R.H. Whittaker (ed) *Ordination of Plant Communities*. Junk, The Hague, 7-50.

Williamson, W. C., 1848. On the recent British species of the genus *Lagena*. *Annals and Magazine of Natural History*, 2, 1, 1-20.

Wilson, J. L., 1975. Carbonate Facies in Geologic History. Springer Verlag, New York, 471p.

Yücel, A. O., Özcan, E. and Erbil, Ü., 2020. Latest Priabonian larger benthic foraminiferal assemblages at the demise of Soğucak Carbonate Platform (Thrace Basin and Black Sea shelf, NW Turkey): implications for the shallow marine biostratigraphy. *Turkish Journal of Earth Sciences*, 29, 85-114.

Zagorchev, I. S. 1998. Pre-Priabonian Paleogene formations in southwest Bulgaria and northern Greece: stratigraphy and tectonic implications. *Geological Magazine*,135, 101-119.

Zagorchev, I., Ivanova, D., Stoykova, K. and Bassi, D., 2010. Palaeogene of Samothraki Island: Correlations with the basins of Thrace and Rhodope. Bulgarian Geological Society. National Conference with international participation “Geosciences 2010” 111-112.

Zakrevskaya, E., Less, G., Bugrova, E., Shcherbinina, E., Grigoryan, T. and Sahakyan, L., 2020. Integrated biostratigraphy and benthic foraminifera of the middle-upper Eocene deposits of Urtsadzor section (Southern Armenia). *Turkish Journal of Earth Sciences*, 29, 896-945.

Zygojannis, N. and Müller, C., 1982. Nannoplankton Biostratigraphie der Tertiären Mesohellenischen Molasse (Nordwest-Griechenland). *Zeitschrift der Deutschen Geologischen Gesellschaft*, 133, 445-455.

APPENDIX

Table 1. Summary of distinguished facies of carbonate deposits of Thrace (NE Greece) and their descriptions.

Major MF type	Age	Main components	Subordinate components	Texture	Interpretation
MF1: LBF packstone (PYL 1-4, 9)	Priabonian (SBZ 19-20)	Orthophragminids, nummulitids	Other LBF, small rotaliids, miliolids, planktonic foraminifera, CRA, bryozoan, echinoids, molluscs, worm tubes	packstone	Outer platform
MF2: Coralline bindstone (5-8)	Priabonian (SBZ 19-20)	CRA, corals, *Silvestriella tetraedra*	Other LBF, small rotaliids, miliolids, planktonic foraminifera, molluscs	wackestone/packstone	Middle platform, shallower than MF1
MF3: encrusting and other rotaliids-miliolids grainstone (PYL 10, S3.1.1-2)	Priabonian (SBZ 20)?	Encrusting rotaliids, other rotaliids CRA, textulariids, miliolids	*Nummulites*	grainstone	Inner shelf, protected environment, lagoon
MF4: Coralline bindstone (MAR 1.1-MAR 1.2)	Priabonian (SBZ 19-20) Oligocene?	CRA rhodoliths, corals, molluscs, bryozoans, small rotaliids	*Nummulites fabianii*, miliolids, peneroplids, textulariids, planktonic foraminifera, worm tubes, ostracods	packstone (locally boundstone)	Middle platform, shoal, winnowed platform edge sands, areas with constant wave action at or above the wave action
MF5: bryozoan packstone (MAR1)	Priabonian (SBZ 19-20)	Bryozoans, small rotaliids, miliolids	*Operculina* ex. gr. *gomezi*, planktonic foraminifera, echinoids, worm tubes	packstone	Middle platform, upper fore-slope
MF6: Nummulitic packstone (MAR, S2F)	Priabonian (SBZ 19)?	*Nummulites fabianii*	*Operculina* ex. gr. *gomezi*, *Discocyclina* sp., small rotaliids, CRA, molluscs	packstone/grainstone	Middle platform, Nummulites bank
MF7: coral-CRA-nummulitid boundstone/framestone (DDM1-4)	Priabonian (SBZ 19-20)	Coral patches, CRA, nummulitids	Other lbf, small rotaliids, miliolids, planktonic foraminifera, bryozoan, echinoids	wackestone/packstone	Middle platform, shoal reef areas

MF8: coralline-bivalve wackestone/packstone (DDM 5)	Priabonian (SBZ 19-20) Oligocene?	Corals, CRA, endolithic bivalves	Small rotaliids	wackestone/packstone	Middle platform, up to 20m
MF9: coral-CRA-bryozoan wackestone/packstone (AVT 1-2)	Priabonian (SBZ 20)?	Corals, CRA, bryozoans	Orthophragminids, nummulitids, miliolids, small rotaliids, planktonic foraminifera, echinoids, molluscs, worm tubes	wackestone/packstone	Middle platform, near the fair weather wave base
MF10: Aragonite/magnesian calcite cemented wackestone/packstone (AVT 1-2)	Priabonian (SBZ 20)?	Radial fibrous aragonite cement, CRA, corals	LBF, small rotaliids, miliolids, molluscs, ostracods	wackestone/packstone	Shelf margin, marine phreatic environment
MF11: Heterosteginid-orthophragminid packstone (AVT 5-13.1)	Priabonian (SBZ 20)?	Orthophragminids, heterosteginids, CRA	Other nummulitids, small rotaliids, miliolids, agglutinants, bryozoans, corals, molluscs, worm tubes	micritic matrix	Back reef, close to the reef or as reef flat
MF12: coral/coralline algae framestone/ boundstone (AVT 14-15.1)	Priabonian (SBZ 19-20)	Corals, CRA	Small rotaliids, miliolids, bryozoans, molluscs	micritic matrix	Reef core
MF13: LBF packstone/wackestone (S1)	Priabonian (SBZ 20)?	LBF, CRA	Small rotaliids, agglutinants, miliolids, bryozoans, echinoids, worm tubes, molluscs	grainstone	Middle platform
MF14: LBF packstone/wackestone (LM1-ML2)	redeposited	LBF	Small rotaliids, planktonic foraminifera, CRA, bryozoans, worm tubes	grainstone	Middle platform
MF15: *Assilina*- coral packstone (SAM1-SAM1.1)	Priabonian (SBZ 19B-20)	*Assilina alpina*	Other nummulitids, *Discocyclina* sp., *Silvestriella tetraedra*, corals, small rotaliids, miliolids, echinoids, bryozoans	micritic matrix	Distal outer platform deposits
MF16: coral-gastropod wackestone (SAM2-SAM2.1)		Corals, gastropods	Nummulitids, orthophragminids, miliolids, small rotaliids, CRA, bryozoans, echinoids	micritic matrix	Middle platform

Table 2. Absolute abundances of species of Fanari sequence**.**

Species/ samples	FAN B 21	FAN B 20	FAN B 19	FAN B 18	FAN B 17	FAN B 16	FAN B 15	FAN A 14	FAN A 13	FAN A 12	FAN A 11	FAN A 10	FAN A 9	FAN A 8	FAN A 7	FAN A 6	FAN A 5	FAN A 4	FAN A 3	FAN A 2	FAN A 1
Ammodiscus sp.	0	10	0	0	0	25	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
Anomalinoides capitatus	10	21	18	6	16	78	3	4	1	2	12	5	8	1	11	18	9	14	5	3	12
Assilina alpina	108	5	95	32	10	27	0	0	0	0	0	0	10	18	6	19	0	6	4	0	1
Asterigerina brencei	0	0	0	0	8	15	0	4	6	3	3	4	16	7	10	32	3	18	4	14	17
Asterigerina sp.	57	32	65	58	153	245	2	213	67	17	67	191	323	417	182	4456	188	492	841	113	70
Asterocyclina spp.	150	39	150	105	40	138	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina sp. 1	0	0	0	1	0	2	0	0	0	0	0	3	4	4	0	7	0	3	0	1	0
Bolivina sp. 2	0	1	1	0	0	1	0	0	0	0	0	1	2	0	0	1	1	0	2	0	0
Bolivina sp. 3	0	9	2	0	0	5	2	0	0	0	1	1	0	0	0	3	2	1	1	2	2
Bolivina sp. 4	2	1	3	0	0	5	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0
Bulimina bradyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Bulimina elongata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Bulimina gibba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Bulimina sp. 1	0	0	0	0	0	0	0	0	0	1	2	2	4	8	8	3	0	7	0	0	0
Bulimina sp. 2	0	0	0	0	0	0	0	0	0	0	2	0	4	1	0	24	0	0	4	0	0
Bulimina sp. 3	0	0	6	1	0	5	3	0	0	0	0	0	0	1	0	6	12	5	0	2	4
Cancris sp.	0	0	1	0	0	0	2	0	0	0	0	0	1	0	1	3	0	0	0	0	0
Cibicidoides grimsdalei	0	0	0	5	0	0	0	0	0	2	17	13	7	15	11	333	6	5	23	1	2
Cibicidoides praemundulus	17	5	61	32	105	93	7	6	2	14	33	26	38	59	3	13	3	66	90	23	18
Cibicidoides sp. 1	4	17	75	17	23	31	21	0	0	0	0	0	0	0	24	0	0	0	0	0	0
Cibicidoides sp. 2	63	48	60	32	22	47	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cibicidoides variabilis	1	0	0	0	0	4	1	4	0	0	1	0	0	1	0	9	3	1	7	0	0

Discocyclina radians	10	7	10	14	4	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Discocyclina* spp.**	51	93	52	55	30	27	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Fabiania cassis	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	4	2	3	7	0	0
Favulina hexagona	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Favulina* sp.**	0	0	0	0	1	0	0	0	0	0	2	6	0	0	1	7	8	4	16	3	2
Fursenkoina subacuta	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	6	0	1	0	2	3
Gaudryina pyramidata	5	12	20	3	13	48	0	0	0	1	2	1	3	0	1	17	5	13	15	6	7
Globocassidulina globosa	0	19	18	6	3	71	0	1	0	0	1	0	0	0	0	2	0	0	0	1	1
Globulina gibba	15	7	19	0	7	1	1	0	1	0	2	0	1	0	2	2	0	2	0	0	0
***Gyroidinoides* sp.**	0	0	0	0	6	3	0	0	0	0	1	2	2	2	1	3	0	5	1	0	0
Hanzawaia mantaensis	3	6	3	2	2	7	0	0	0	1	0	0	0	1	0	0	0	3	2	0	0
***Haplophragmoides* sp.**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
***Heterolepa eoceana* *(perlucidus* type)**	20	0	59	0	0	1	0	0	0	0	2	0	1	0	0	11	0	0	21	0	0
***Heterolepa eoceana* *(tuxpamenis-eoceanus* type)**	350	224	614	125	70	306	95	68	12	16	18	45	26	14	77	55	17	0	7	9	12
Heterostegina gracilis	0	97	103	388	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heterostegina reticulata	74	27	0	0	0	0	0	0	0	0	0	0	0	1	1	9	0	0	2	0	0
***Hormosinella* sp.**	0	11	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Hyalononetrion* sp. 2**	0	2	9	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	4	0	0
Hyperammina rugosa	1	5	7	0	0	18	0	0	0	0	0	4	0	0	7	0	4	0	0	0	0
Lenticulina calcar	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Lenticulina carinata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lenticulina inornata	17	10	42	3	8	16	16	6	1	1	3	5	11	7	5	21	7	13	9	4	0
***Laevidentalina* sp.**	3	0	6	0	4	1	0	0	0	0	0	0	0	1	0	1	0	7	2	4	1
Lagena paucistriata	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Lagena* sp.**	0	6	8	0	2	8	0	0	0	0	0	0	0	0	0	3	0	0	0	0	4
Lobatula lobatula	21	15	30	5	17	46	9	15	3	6	74	40	23	45	6	112	32	48	33	36	21

Melonis pompiloides	3	1	12	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
miliolid casts	1	0	0	0	0	0	1	1	0	0	11	0	0	23	2	86	27	1	2	15	28
Neoconorbina terquemi	4	11	18	2	4	1	7	0	0	2	10	17	10	3	15	65	22	7	25	7	16
Neugeborina longiscata	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nodosaria latejugata	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Nodosaria* sp. 1**	0	4	2	0	5	6	0	0	0	0	1	0	0	0	3	2	1	6	0	0	1
***Nodosaria* sp. 2**	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Nodosaria* sp. 3**	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nonion commune	0	0	0	0	2	0	0	0	0	1	1	1	1	4	2	9	1	8	3	2	9
Nummulites budensis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nummulites chavannesi	0	0	0	8	5	0	0	0	13	0	0	7	12	48	4	425	7	131	169	2	0
Nummulites fabianii	0	0	0	18	20	11	40	0	9	0	4	10	8	14	5	200	4	18	18	17	643
Nummulites garnieri	0	0	0	0	0	0	0	0	41	8	14	19	25	62	4	448	4	458	1532	59	68
Nummulites incrassautus	38	14	152	4	16	15	76	13	14	11	12	84	10	208	21	19	13	132	233	69	118
Nummulites stellatus	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuttalides florealis	0	0	0	0	22	8	0	0	0	2	6	13	0	3	1	0	0	0	0	0	4
Operculina gomezi	34	30	11	3	17	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orbitoclypeus* cf. *scalaris	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orbitoclypeus furcatus	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Osangularia* sp.**	4	1	0	0	11	7	0	0	0	0	0	0	2	7	1	3	7	1	0	0	21
Pararotalia audouini	0	0	3	0	0	1	0	0	0	0	3	4	11	18	7	164	0	11	15	0	0
Perarotalia inermis	1	5	24	8	14	39	1	5	1	14	115	27	11	28	32	122	49	43	75	33	41
Pellatispira madaraszi	1226	768	620	660	173	358	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planorbulina meditteranensis	7	7	0	0	0	4	10	18	1	4	8	4	3	25	6	5	3	14	9	6	0
***Planulina* sp.**	0	0	5	1	4	1	0	1	2	2	0	12	15	0	7	153	11	1	7	0	10
Pleurostomella acuta	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1

Pleurostomella incrassata	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polymorphinid genus	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Praebullalveolina afyonica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1
***Rhizammina* sp.**	3	6	0	0	0	7	1	0	0	0	0	0	0	1	1	0	0	0	0	2	1
Psammoshiphonella cylindrica	2	12	4	0	1	7	1	0	0	0	0	1	2	1	0	0	6	0	0	2	0
Queraltina epistominoides	0	0	6	6	11	5	15	4	1	2	9	6	16	26	12	25	10	30	19	9	22
***Quinqueloculina* sp. 1**	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Quinqueloculina* sp. 2**	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Rosalina* sp.**	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
***Rupertia* sp.**	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sigmavirgulina turtuosa	2	0	0	0	0	1	0	0	0	0	0	1	0	2	2	7	0	5	3	0	2
Silvestriella tetraedra	44	3	144	58	4	74	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Siphonodosaria jacksonensis	3	10	22	5	10	25	0	0	0	0	0	3	4	0	0	0	0	3	0	1	2
***Siphonodosaria* sp. 1**	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0	4	0	0
***Siphonodosaria* sp. 2**	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kuremsia papillata	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerogypsina globulus	24	6	39	12	7	8	1	6	0	0	0	2	0	1	0	3	0	1	1	0	0
Spiroclypeus carpaticus	269	249	1659	388	649	689	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
Stomatorbina torrei	0	0	16	17	24	15	28	0	3	7	11	24	28	58	44	1030	38	93	85	1	3
***Textularia* sp. 1**	1	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0
***Textularia* sp. 2**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
***Textularia* sp. 3**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
***Uvigerina* sp.**	0	0	0	0	1	2	0	0	0	0	1	0	1	1	3	1	0	6	0	0	0
***Varginulinopsis* sp.**	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktonic Foraminifera	10	19	39	5	7	64	20	0	3	0	1	0	1	2	2	1	0	2	0	0	1