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PALEOENVIROMENTAL EVOLUTION OF THE EASTERN THERMAIKOS GULF BASED ON SHALLOW CORE DATA FROM THE EPANOMI AREA

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PALEOENVIRONMENTAL EVOLUTION OF EAST THERMAIKOS GULF FROM SHALLOW DRILLING DATA IN THE AREA OF EPANOMI
ΠΑΛΑΙΟΠΕΡΙΒΑΛΛΟΝΤΙΚΗ ΕΞΕΛΙΞΗ ΤΟΥ ΑΝΑΤΟΛΙΚΟΥ ΘΕΡΜΑΪΚΟΥ ΚΟΛΠΟΥ ΜΕ ΒΑΣΗ ΔΕΔΟΜΕΝΑ ΡΗΧΗΣ ΓΕΩΤΡΗΣΗΣ ΑΠΟ ΤΗΝ ΠΕΡΙΟΧΗ ΤΗΣ ΕΠΑΝΩΜΗΣ

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PALEOENVIRONMENTAL EVOLUTION OF THE EASTERN THERMAIKOS GULF BASED ON SHALLOW CORE DATA FROM THE EPANOMI AREA – *Master Thesis*

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PROLOGUE

The present Master thesis titled "Paleoenvironmental evolution of the eastern Thermaikos Gulf based on shallow core data from the Epanomi area" is included within the Postgraduate Studies Program 'Hydrocarbon Exploration and Exploitation' of the Department of Mineralogy-Petrology-Economic Geology, School of Geology of the Aristotle University of Thessaloniki. The benthic foraminifera contribution to paleogeographic and biostrada sciences, as for the determination and evolution of a paleoenvironment but also as indicators of environmental health, is significant. With scientific research methods developing as to foraminifera studies, the previous assumption is constantly proven to be right.

ACKNOWLEDGMENTS

The aim of this Master thesis was interpretation of the paleoenvironment of Epanomi area, based on the study of benthic foraminifera. The microfauna has been collected from sediments from a drilling core that took place in the surrounding area of the Epanomi wetland. An additional core was also analyzed for comparison from Agios Mamas, Chalkidiki area. The cores for the needs of this thesis were provided by the project "Core drilling for environmental samples in central Macedonia", funded along with the radiocarbon datings by the "Paleo-Science and History" Independent Max Planck Research Group, coordinated by Dr. Adam Izdebski and executed by Ass. Prof. Konstantinos Vouvalidis (AUTH). Therefore, thanks are due to Dr. Adam Izdebski for giving permission to Dr. Olga Koukousioura to use the samples for this thesis. Furthermore, special thanks due to Ass. Prof. Elina Aidona which provided the magnetic susceptibility measurements of the cores.

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ABSTRACT

For this Master thesis, the composition of benthic foraminifera found within 48 sediment samples, was studied. The derivation of the samples (33) is from a 3 m depth drilling core (EPN-P), located in the area of Epanomi, Thessaloniki and (15 samples) from a 2 m drilling core (MAM-2P), from Agios Mamas, Chalkidiki area. During the laboratory analysis the foraminifera were collected and counted and 14 benthic foraminifera species from 8 genera were identified. Quantitative analysis of the foraminifera was necessary, to specify their abundance and diversity though a sequence of micropaleontological indicators. Magnetic susceptibility measurements and radiocarbon datings were also performed. Specific changes of a benthic foraminifera assemblage on coastal environments are considered an indispensable paleontological tool, for the determination of the past sea level changes and detailed paleoclimatic and paleoenvironmental reconstruction. In the last decades multiple studies on Holocene coastal plains (Triantaphyllou et al., 2003, 2010, 2021; Pavlopoulos et al., 2007, 2011; Evelpidou et al., 2010; Koukousioura et al., 2012, 2019, 2020; Koukousioura, 2012; Kouli et al., 2021) provided valuable information for the paleoenvironmental evolution. The quantitative analysis of foraminiferal fauna enabled separation of the EPN-P core into five sedimentary Units, representing distinct evolutionary stages of the area. For Unit 1, the high sand proportion, the low magnetic susceptibility values, the presence of gypsum crystals and few marine foraminiferal specimens, indicate an environment with marine influence and possible desiccations due to increased evaporation (Kjerfve et al., 1996). Unit 2 shows transient inputs from the land and sea and unstable hydrodynamic conditions due to the fluctuating sand and mud fractions. It represents a lagoonal environment with marine intrusions (miliolids and *Bolivina spathulata*) and constant freshwater contribution, considering the prevalence of *Ammonia veneta*, *Haynesina germanica* and charophytes. The increased presence of abnormal specimens certifies the fluctuating salinities in an unstable transitional lagoonal environment (Dimiza et al., 2012). In Unit 3, the association of the euryhaline *(H. germanica*, *Haynesina* sp., *A. veneta*) with the marine species (*B. translucens*, miliolids) indicate an open lagoonal environment with a permanent connection to the sea and periodical fresh-water inputs. The assemblages of Unit 2 and Unit 3 are comparable to the adjacent Paliouras lagoon Unit C (7600–6900 cal yr BP) (Koukousioura et al., 2019). Around ~6000 cal yr BP (Unit 4), the area shifts to a low energy closed lagoon, as suggested by the dominance of the oligohaline foraminiferal species, and the increase of magnetic susceptibility measurements. Similar environmental conditions were described in the upper part of Alykes Kitros and Lafrouda Thrace sequences (Koukousioura et al., 2012), as well as in Paliouras lagoon before 5900 cal yr BP (Koukousioura et al., 2019). Unit 5 is characterized by only few foraminiferal specimens which, in association with the high magnetic susceptibility values and the lithological determination, suggests the closing of the lagoon and the dominance of the terrestrial deposits in the area before ~4733 cal yr BP.

ΠΕΡΙΛΗΨΗ

Σκοπός της παρούσας διπλωματικής εργασίας είναι η αναπαράσταση και εξέλιξη του ανατολικού Θερμαϊκού κόλπου βάσει της μελέτης των βενθονικών τρηματοφόρων από 48 συλλεχθέντα δείγματα. Τα δείγματα που μελετήθηκαν (33) προέρχονται από τη ρηχή γεώτρηση EPN-P (3 m βάθος) που πραγματοποιήθηκε στην περιοχή της Επανωμής και από τη γεώτρηση MAM-2P (2 m βάθος, 15 δείγματα), στη περιοχή του Αγίου Μάμα Χαλκιδικής. Τα τρηματοφόρα που εμπεριέχονταν σε κάθε δείγμα συλλέχθηκαν, μετρήθηκαν και προσδιορίστηκαν σε επίπεδο είδους. Υπολογίστηκαν επίσης δείκτες ποικιλότητας, αφθονίας, ο δείκτης *A* καθώς και οι δείκτες Μορφολογικής Διαφοροποίησης Τρηματοφόρων (FAI) και Παρακολούθησης Τρηματοφόρων (FMI). Κατά τη ποσοτική ανάλυση προσδιορίστηκαν 14 διαφορετικά είδη τρηματοφόρων τα οποία ανήκαν σε 8 γένη. Πραγματοποιήθηκαν επίσης μετρήσεις μαγνητικής επιδεκτικότητας και ραδιοχρονολογήσεις. Συγκεκριμένες μεταβολές στις συναθροίσεις των τρηματοφόρων στα παράκτια περιβάλλοντα θεωρούνται αναντικατάστατα παλαιοντολογικά εργαλεία για τον προσδιορισμό και την αναπαράσταση παλαιοπεριβαλλόντων. Τις τελευταίες δεκαετίες πραγματοποιήθηκαν πολυάριθμες μελέτες σε Ολοκαινικά παράκτια πεδία (Triantaphyllou et al., 2003, 2010, 2021; Pavlopoulos et al., 2007, 2010; Evelpidou et al., 2010; Koukousioura et al., 2012, 2019, 2020; Koukousioura, 2012; Kouli et al., 2021), οι οποίες παρείχαν σημαντικές πληροφορίες για την παλαιοπεριβαλλοντική τους εξέλιξη. Η ποσοτική ανάλυση επέτρεψε τον διαχωρισμό της γεώτρησης EPN-P σε πέντε ιζηματογενείς ενότητες, οι οποίες αντιπροσωπεύουν συγκεκριμένα εξελικτικά στάδια για την περιοχή. Στην Ενότητα 1, τα υψηλά ποσοστά άμμου σε συνδυασμό με τις χαμηλές τιμές μαγνητικής επιδεκτικότητας, την παρουσία κρυστάλλων γύψου και ελάχιστων τρηματοφόρων, προσδιορίζουν ένα περιβάλλον με θαλάσσια επίδραση και πιθανά επεισόδια ξήρανσης όγω εξάτμισης (Kjerfve et al., 1996). Στην Ενότητα 2 οι διακυμάνσεις στην αναλογία άμμου/ιλύος-αργίλου αντιστοιχούν σε παροδικές εισροές νερού τόσο από τη χέρσο όσο και από τη θάλασσα και συνεπώς ασταθείς υδροδυναμικές συνθήκες. Η συνάθροιση χαρακτηριστικών ευρύαλων (*Ammonia veneta, Haynesina germanica*) και θαλάσσιων βενθονικών τρηματοφόρων (miliolids and *Bolivina spathulata*), η παρουσία Χαροφύτων καθώς και η αυξημένη παρουσία ατόμων με μορφολογικές ανωμαλίες υποδεικνύουν συνθήκες μεταβαλλόμενης αλατότητας (Dimiza et al., 2012). Όλα τα παραπάνω συνθέτουν ένα ασταθές μεταβατικό περιβάλλον λιμνοθάλασσας με εισροές θαλάσσιων υδάτων και συνεχή συνεισφορά γλυκού νερού. Στην Ενότητα 3 οι συγκεντρώσεις των θαλάσσιων ειδών (*B. translucens,* miliolids) αυξάνονται παράλληλα με την ύπαρξη ευρύαλων ειδών *(H. germanica, Haynesina* sp.*, A. veneta*). Το γεγονός αυτό σε συνδυασμό με τη λιθολογία και τις χαμηλές τιμές μαγνητικής επιδεκτικότητας είναι ενδεικτικά ενός περιβάλλοντος ανοιχτής λιμνοθάλασσας το οποίο βρίσκεται σε μόνιμη επικοινωνία με τη θάλασσα και έχει περιοδικές εισροές γλυκού νερού. Οι συναθροίσεις των Ενοτήτων 2 και 3 είναι παρόμοιες με την ενότητα C της παρακείμενης λιμνοθάλασσας του Πάλιουρα (7600-6900 cal yr BP). Πριν από ~6000 cal yr BP (Ενότητα 4) η περιοχή μεταβάλλεται σε χαμηλής ενέργειας κλειστή λιμνοθάλασσα όπως προκύπτει από την απότομη αύξηση της μαγνητικής

επιδεκτικότητας και την επικράτηση των ειδών που ζουν σε περιβάλλοντα χαμηλής αλατότητας. Παρόμοιες περιβαλλοντικές συνθήκες περιγράφονται στις ανώτερες ακολουθίες στις αλυκές του Κίτρους και στης Λαφρούδας της Θράκης (Koukousioura et al., 2012) καθώς και στης λιμνοθάλασσας του Πάλιουρα πριν ~5900 cal yr BP (Koukousioura et al., 2019). Η Ενότητα 5 χαρακτηρίζεται από ελάχιστα τρηματοφόρα το οποίο σε συνδυασμό με τις υψηλές τιμές μαγνητικής επιδεκτικότητας και τη λιθολογία υποδεικνύουν το κλείσιμο της λιμνοθάλασσας και την επικράτηση των χερσαίων αποθετικών διαδικασιών στην περιοχή πριν ~4733 cal yr BP και έπειτα.

ΠΕΡΙΕΧΟΜΕΝΑ

INTRODUCTION

AIM OF THE STUDY

Paleoenvironmental studies which include foraminifera are increasing in numbers because of their ability to provide detailed results over environmental changes, therefore they are considered exceptional ecological indicators. Both the composition of foraminiferal fauna and the morphology or the morphological abnormalities of foraminiferal tests, are determining factors of possible environmental changes.

The present thesis focuses on the micropaleontological study of Holocene benthic foraminifera, aiming the substantiation of the paleoenvironmental evolution so that a reconstruction of the paleoenvironment of the surrounding study area can be achieved. To accomplice that, it was necessary to study the quantitative and spatial distribution of the benthic foraminifera content recovered from the drilling core sediments (EPN-P) located in the Epanomi wetland. A special focus was given on the description of benthic foraminifera species and the indication of their morphological particularities. The collection and study of benthic foraminifera was conducted with the use of valid sampling and statistical analysis methods.

GENERAL FORAMINIFERA FACTS

The term Foraminifera derives from the world "foramen", meaning "hole" because of the occurring holes on their shell barrier, from which small pseudopods protrude. They are unicellular organisms, characterized by their heterophasic life circle, their pseudopod network and their test. Their cytoplasm classification and their pseudopods are similar with those of the amoeba, with the only difference being that foraminifera developed an extra pseudopod network, with long grained rhizopods and phyllopods which contribute to movement and food search (Travis and Bowser, 1991; Murray, 1991).

Foraminifera were initially studied from van Leeuwenhoek in 1700 (Dobell, 1932). They (Foraminifera Phyllum) (d' Orbigny, 1826) belong to the Rhizopoda class (Dujardin, 1835) of the Protozoa Phyllum (Goldfuss, 1817). Foraminifera can be found in all marine environments and according to their living mode they are divided in benthic and planktonic, with the first representing the majority, as the planktonic represent only 40 to 50 species (Sen Gupta, 2003). They are described as heterotrophic micro-omnivore organisms, while some of them use part of their endosymbiotic organisms' photosynthesis biproducts as food (Hallock, 2000; Lee, 2006).

Although there is a big foraminifera fossil archive, the quantity and abundance of them in present sea environments is very small (Sen Gupta, 2003). In 1846 d'Ordigny counted 68 modern foraminifera strains assuming the existence of 1.000 modern foraminifera species. In the latest systematic classification from Loeblich and Tappan (1988) 878 modern strains were described. The total number of foraminifera is presumed to be near 10.000 (Vickerman, 1992) and are considered as excellent faunal, paleoenvironmental and paleoceanographic indicators (Milker, 2010).

FORAMINIFERA LIFE CYCLE

The foraminifera life cycle is characterized by heterophasic alternations from sexual to asexual reproduction (Haq and Boersma, 1978; Lee et al., 1991). These two ways of reproduction, affect the resulting test, portraying the morphological differentiation (dimorphism). Through multiple fission, a large number of cells is being produced, consequently producing the megalospheric gamont generation which undergoes sexual reproduction as the microspheric agamont generation undergoes asexual reproduction (Fig. 1). The formation of megalospheric schizonts by a microspheric agamont has been observed in some foraminifera species. This finding verifies that the schizont is a separate part of a trimorphic cycle. Depending on the environmental conditions, the foraminifera life cycle’s duration can last from months up to years (Hallock, 1985) and can differ from each other (Gooday and Alve, 2001; Lee et al., 1991). The shell of modern foraminifera is built either by the organism itself either by external building materials and consists of one or more connecting chambers with apertures, inside of which the protoplasm can be found.

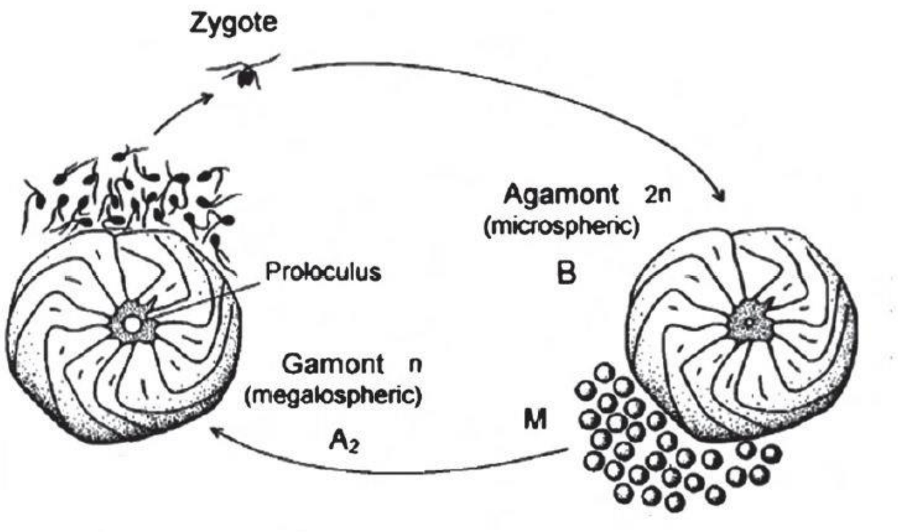

Figure 1. Dimorphic life cycle of foraminifera (modified by Dettmering, 1998).

FORAMINIFERA TEST ARCHITECTURE

The test surrounds the organism protoplasm and consists mainly of calcium carbonate. It can be organic, calcareous, aragonitic or agglutinated. Most foraminifera species have a calcareous or agglutinated test (Τριανταφύλλου και Δήμιζα, 2012). The test surface can be smooth or textured, with various adornments such as acanthuses, striations, stripes, grains or can be carinated in test periphery. It is considered as an essential identification characteristic as it can determine the foraminifera classification.

BENTHIC FORAMINIFERA

Benthic foraminifera live either free or attached to the seabed. Although most of them live at the seafloor surface as epifauna, some live within the sediments as infaunal. The test morphology of benthic foraminifera depends on their living environment. More specifically, in low energy environments the tests are thinner and longer, while on the contrary in high energy environments the test shape varies, thickens and is more decorated (Τριανταφύλλου και Δήμιζα, 2012). The tests of some benthic foraminifera species living at shallow depths, host endosymbiotic autotrophic organisms such as algae, diatoms and dinoflagellates. These organisms use the foraminifera as protection in exchange of a large amount of the photosynthesis biproducts, which contribute to their diet and to the test calcification process (Hallock, 1999). Benthic foraminifera can be found both in Polar areas as in coral reefs and both in abyssal planes as in coastal zones (Todo et al., 2005; Gooday, 2002). The main factors that contribute to their distribution in the various environments is the substrate and the environmental parameters (nutrient availability, oxygen levels, salinity, dissolved oxygen's concentration, temperature and water quality).

At benthic ecosystems, the available nutrients and oxygen at the zone between the lower part of the water column and the upper part of the surface sediments, determine the habitat of the organisms, therefore the species diversity (Van der Zwaan et al., 1999; De Rijk et al., 1999; Corliss, 1985; Jorissen et al., 1995). Similar conditions predominate in environments of continental shelfs (Mojtahid et al., 2009; Jorissen et al., 1992). However, in coastal and neritic environments other factors can affect the habitat as well, such as sunlight, temperature, salinity but also the velocity of the surface water currents (Sen Gupta, 2003; Culver et al., 1996). In such environments, large numbers of foraminifera, high diversity, epifaunal and shallow infaunal species domination, are common (Murray, 2006; Semeniuk, 2000). Many shallow water species are strongly connected with the hydrodynamic energy and the analogous sediment of the seafloor (Milker, 2010).

Through studying benthic fauna, remarkable changes can be detected, even in small alternations of the environmental factors. Coasts, lagoons, swamps and deltas i.e. marginal sea environments are considered the most appropriate for recording climate change results but also sea level changes. Because of the aforementioned, foraminifera are considered as excellent paleoenvironmental indicators (Triantaphyllou et al., 2003, 2010, 2021; Pavlopoulos et al., 2007, 2011; Evelpidou et al., 2010; Koukousioura et al., 2012, 2019, 2020; Koukousioura, 2012; Kouli et al., 2021; Jorissen, 1987; Langer et al., 1998; Saraswati, 2002, 2003; Mendes et al., 2004; Lee, 2006; Milker et al., 2009; Dimiza et al., 2016). Their use in paleoenvironmental studies is a significant tool due to a large number of recent studies about their assemblages and distribution in marginal marine environments. Specifically, studies about deep sea hydrothermal planes (Jonasson et al., 1995), low oxygenation lakes (Lipps and Langer, 1999), drilling cores in alluvial plains along the Adriatic and Tyrrhenian coast of Italy (Carboni et al., 2002; Bergamin et al., 2009; Mazzini et al., 1999; Fiorini and Vaiani, 2001) and foraminiferal assemblages in extreme environments such as the Arctic Sea (Dieckman et al., 1991). This ability is the possible reason for their survival through past massive extinctions.

FORAMINIFERA TAXONOMY

Since 1800, when Linné completed the first classification, multiple scientists came up with other classification models. The term "foraminifera" made its appearance in 1826 from d'Orbigny, who designed a system based on the chambers layout and also on the test shape. The system that is currently used is the one from Loeblich και Tappan (1992), based on the Loeblich και Tappan criteria (1988). According to the aforementioned, the division of the foraminifera in 11 different orders is based on the structure and nature of the test (Fig. 2). Also, different combinations of morphological features (barrier pores) are defining the sub-orders. The Family taxonomy takes place according to the chamber arrangement and the varying apertures of the foraminifera (Hamman, 1988; Loeblich and Tappan, 1978). The genus definition is based on the inner test structure, the sutures and the Family characteristics. Lastly, the species are defined by studying the test (size and shape), the chambers (shape and number) and the sutures (Hamman, 1988; Loeblich and Tappan, 1978).

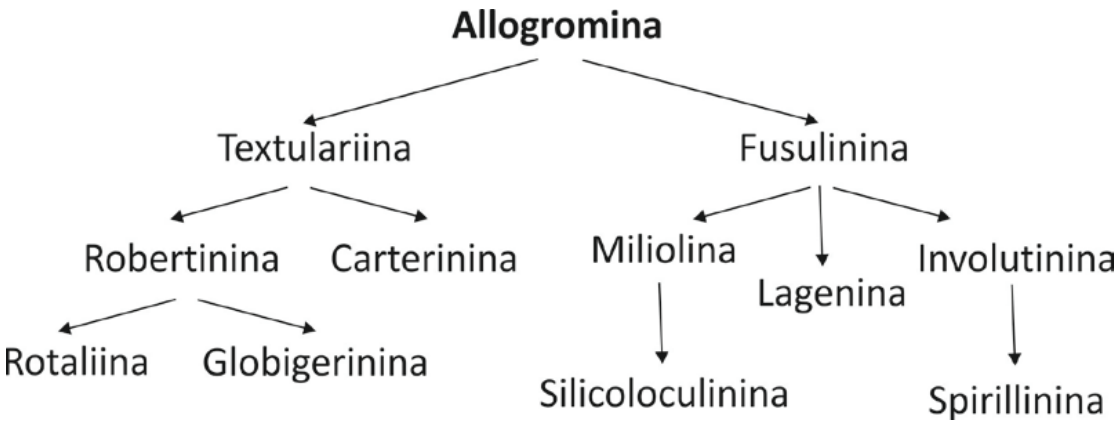

Figure 2. Phylogeny of foraminifera according to Loeblich and Tappan (1984).

STUDY AREA

GENERAL ENVOROMENTAL FACTS ABOUT THE MEDITERRANEAN

The semi-enclosed Mediterranean basin borders Europe to the North and Africa to the South. It is composed of two sub-basins similar of size (East and West) which adjoin near Sicily. The Mediterranean is connected with the Atlantic Ocean through the Strait of Gibraltar and with the Red Sea through the Suez Canal (Robinson et al., 2001). The main oceanographic processes that take place in the Mediterranean Sea are similar of those in bigger oceans, only smaller in size and duration. Therefore, making it ideal for studies about the marine and atmospheric influence on the climate (Robinson et al., 2001). Studies on the Mediterranean Sea related to the various oceanographic processes, have shown its great impact on global salinity and temperature circulation (Bergamasco et al., 2010). In the Mediterranean Sea the evaporation surpasses the precipitation. Thus, a negative hydrological balance occurs (Bergamasco et al., 2010).

THERMAIKOS GULF

Thermaikos Gulf is located at the northwestern part of the Aegean Sea and its surrounding substrate belongs both to the Pelagonian and the Axios Units of the Hellenides. The inner northeast part of Thermaikos Gulf comprises the Bay of Thessaloniki. The Bay of Thessaloniki is defined from the east from Megalo Emvolo Cape and from the west from the Axios river delta. A smaller embayment is noticed between the Cape of Megalo Emvolo and the Gallikos river delta (Vouvalidis et.al, 2005).

The Gulf was entirely formed during the Quaternary and is considered as a part of the Greek volcanic arc, while the shaping of the coastline lasted until the Holocene (Poulos et al., 2000; Piper and Perissoratis, 1991). The early-mid Miocene intense tectonism affected among others the Thermaikos Gulf area due to visible NNW-SSE direction tectonic depressions, forming an elongated basin (Karystineos, 1984; Psilovikos, 1977). This tectonic depression of Thermaikos Gulf-Thessaloniki plain-Lower Axios Valley began to gradually infill with clastic sediments during the Neogene-Pleistocene. The maximum thickness of the sediments in the center of the valley comes up to 3500 m (Faugeres and Robert, 1976). Stratigraphical analysis of the deposited Neogene-Quaternary sediments showed that the filling process differed through space and time, due to the various depositional environments (Syrides, 1990).

From the early-mid Miocene the paleoclimate is considered humid due to the deposition of thick layers, of fluvial origin, coarse clastic sediments. During the late Miocene a paleoenvironmental switch is noticeable. Paleosoils and red-beds of that area containing a variety of savanna type fossil mammalian fauna, indicate a warm terrestrial environment. Fine sands and fine grained silty-clayed fossiliferous sediments and fossiliferous limestones deposited in the uppermost Miocene suggest a Paratethyan Sea invasion in the northern Aegean Sea, that covered the area as a brackish lake. During the Pliocene, fluvial and clastic sediments as well as marly limestone beds were deposited in small shallow lakes. The late Pliocene-Pleistocene was characterized by deposition of red-beds defining an extensive terrestrial paleoenvironment with arid conditions. The hilly terrain of the area was formed during the middle Pleistocene due to intense tectonic activity. This tectonism resulted in the formation of terrestrial and inundated grabens. During the Pleistocene, sedimentation alternates between terrestrial and fluvial, and also paleosoils and red-beds are deposited locally as a result of the paleoclimatic conditions and the fluctuation of the sea level. The sea level lowering by 120 m by the last "Wurmian" glaciation caused the formation of a flat lowland area in the area of present-day Thessaloniki-Thermaikos Gulf-Thessaloniki plain, effecting the shifting of the coasts and Axios, Gallikos and Aliakmon river deltas southwards. This pre-Holocene terrain is composed of clastic Pleistocene sediments deposited on Neogene sediments (Vouvalidis et al., 2005; Syrides, 1990).

THERMAIKOS GULF SEA LEVEL CHANGES

The sea level depends on many factors, but most importantly, the eustatic, isostatic and tectonic movements (Lambeck et al., 2004). After the glaciers began defrosting, the sea level rose up to the present level, with the accession rate constantly dropping during the past 5000-6000 years and showing signs of stabilization (Lambeck et al., 2004). In Greece and specifically at the Aegean area, the subduction of the African plate is creating a marine transgression. On the contrary, past sea level changes during the Quaternary occurred from eustatic movements. Recent sea level changes at the Aegean area are the result of local movements, both tectonic and eustatic, but also of local environmental conditions (Lambeck et al., 2004).

The estimation of the sea level changes of the study area is based on the sea level curve of Thessaloniki bay by Vouvalidis et al. (2005), in accordance with Pavlopoulos et al. (2011). According to this curve, in the last 10.000 years the sea level was 30 m below, and has rapidly risen to -5 m to its present value with an average rate of 4 mm/yr. This rate dropped to 1 mm/yr for the last 4000 years. Therefore, the marine transgression of Thermaikos Gulf took place before 10,000 years, inundating the lowlands, creating a shallow gulf with a depth of 10 m, dominated by marine sedimentation. The reduction of the sea level rise rate was followed by the excessive river delta sedimentation that covered the marine sediments and shifted the shoreline to its present-day position.

The western coastal area of Thermaikos Gulf has been well investigated regarding the Holocene geomorphological and paleoenvironmental reconstruction (Fouache et al., 2008; Ghilardi, 2006; Ghilardi et al., 2010; Koukousioura et al., 2012; Syrides et al., 2009), although for its eastern coastal zone information is significantly limited (Koukousioura et al., 2019). During the last 9500 years the eastern coasts morphology of the gulf has been constantly changing. A low-relief coastal zone featuring lagoons and swamps developed after the coastline retreated (~1400 m) caused by excessive coastal erosion (Albanakis et al., 2005). A subsidence of the area is probably due to intense sediment compaction, as it is reviewed as a tectonically stable area (Pavlopoulos et al., 2011). Most likely subsidence is caused by the load of the Holocene sedimentary cover, which can exceed 30 m at certain places (Fouache et al., 2008).

EAST THERMAIKOS GULF GEOMORPHOLOGY

The geomorphology of Thessaloniki costal area is controlled by the wave action and the sediment deposition rate near the coastline. High amounts of sediment originated from Axios, Aliakmonas, Gallikos and other seasonal streams (Lykousis et al., 2005) are responsible for the overall advance of the coastline and the formation of the Holocene sediment covering on the Thermaikos Gulf's seabed (Vouvalidis et al., 2005). The east coast of Thermaikos Gulf from the Thessaloniki Region is composed of 12 km erosional and ~25 km depositional coasts. The area in general is affected both by fluvial and terrestrial environmental processes and therefore is considered a transient coastal clastic sediment depositional environment. According to Syrides (1990) the east coast of Thermaikos Gulf consists of fluvial and terrestrial Pleistocene deposits alternated with low profile coast sediments and Holocene alluvial deposits. On the contrary the SSW coast is formed by deltaic Holocene sediment deposits. The main morphological characteristic of the area is the low hilly relief, while the thick sediment deposition allowed a hydrographic network development (Syrides, 1990).

GEOMORPHOLOGY OF THE STUDY AREA

Epanomi village is located in Thessaloniki Region, 32 km SE from the town of Thessaloniki. The terrain at the Epanomi area is low and hilly. Specifically, west and south of the Epanomi settlement the altitude is around 60 m, progressing evenly towards the sea, while westwards and eastwards of the settlement the altitudes are higher reaching ~100 m (Fig. 3).

The hydrographic network of the study area is dense and consists of parallel wide valleys directed North to South, across the Anthemous-West Chalkidiki watershed (East-West direction) (Syrides, 1990).

As aforementioned, at the eastern part of Thermaikos Gulf depositional processes are mostly dominant. East Thermaikos Gulf consists of beach terraces with a narrow coastal zone at their base and local low depositional coasts (Albanakis et al., 2005). These depositional coasts extend as very low terrain capes which often host inland lagoons. (Chronis, 1986).

The geology of the east coast, including the study area, comprises almost horizontal layers of Neogene sediments. These layers consist of alternations of silt-clay, silty-clayey sand, sandy marl-sand and fine layers-sand lenses. The sediments were deposited during the Pliocene and are ~200 m thick (Gonia Formation). At specific locations red-beds can be detected (Moudania Formation) (Syrides, 1990).

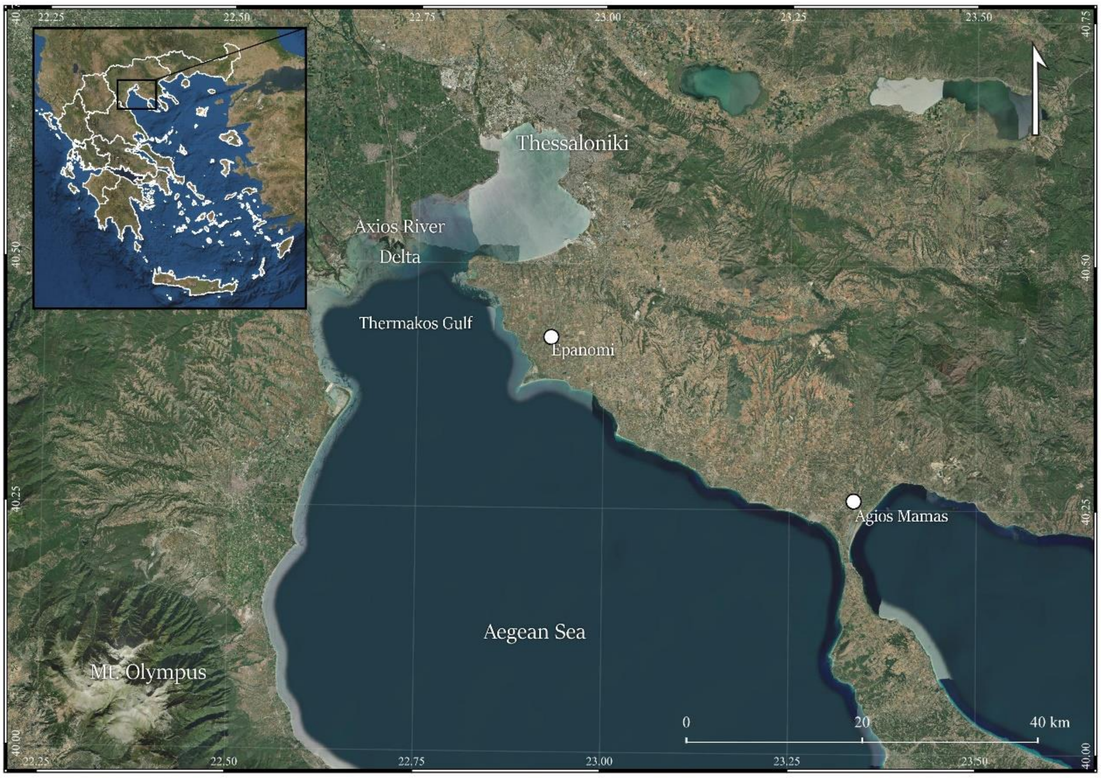

Figure 3. Map of Thermaikos Gulf.

At 10,000 y/BP the sea started entering the gulf, while it was 20-25 m below its present level (Vouvalidis et al., 2005; Pavlopoulos et al., 2011). Specifically, the sea intruded the inner Thermaikos gulf at 8000 yr BP (Koukousioura et al., 2019). Moreover, the eastern coasts of the gulf show a retreat of 1400 m for the last 9500 years, presenting an overall retreat rate of 0.15 m/yr (Albanakis et al., 2005). Based on the above, a graphic model for the eastern Thermaikos coastal evolution was suggested. In accordance with this model, the present even slightly sloping terrain expanded evenly towards the central Thermaikos graben. Present day valleys also expanded toward the center of Thermaikos. The Holocene sea level rise (9000-10,000 BP) affected the coastal terraces by eroding them. It also affected the paleo-valleys as the high energy streams created mass-transport deposits, and therefore reduced their inclination and balanced their profile.

Thus, the coastal areas that were located on the axes of big currents achieved balance. Their retreat rate was by far lower than that of the terrace-creating area. Within time the areas located on the valley axes developed low coast zones with lagoons and swamps, accumulating coastal sediments originated from the eroded terraces and the other ephemeral streams.

MATERIAL AND METHODS

FIELD WORK

In order to contribute to the reconstruction of the paleoenvironmental evolution of eastern Thermaikos gulf a short core (EPN-P) was studied. The drilling of EPN-P core took place in 2019, at Epanomi coastal area (40.396075 N, 22.906914 E) and reached a maximum depth of 3 m (Fig. 4).

Figure 4. Location map of the broader study area and the position of cores EPN-P and MAM-2P.

A petrol powered jackhammer type of drill (Atlas Copco, Cobra MK 1) was used during the drilling, with the method of "Vibrocoring" (Fig. 5). This method is commonly used for shallow Holocene sediments (0-15 m). The equipment includes an empty cylinder tube that is being infixed into the ground. While the tube is being submerged it gets filled with the underground sediments creating a stratigraphic column identical of the stratigraphy of the drilling area. When the tube is full, is extracted hydraulically and the process is repeated with another empty tube for every 1 m depth.

The end of the sampling tube is equipped with a cutting edge and a restraining ring that holds back the sediment from exiting the tube. An inner PVC tube of 1 m length and 40 mm diameter is containing the sediment sample and is extracted when it gets filled. After it's extracted, the code-name of the borehole, the depth and the tube's serial number is written on it. Furthermore, both edges of the tube are sealed with proper tape and bungs until further examination.

Figure 5. Epanomi drilling site.

With the aforementioned process a total of three (3) tubes where received, 1 m in length each. Further examination of the tube cores took place at the School of Geology of the Aristotle University of Thessaloniki. The plastic part of the tubes was cut along and bisected into two semi-cylinders, one for the purpose of analysis whilst the other was documented in detail in November of 2019.

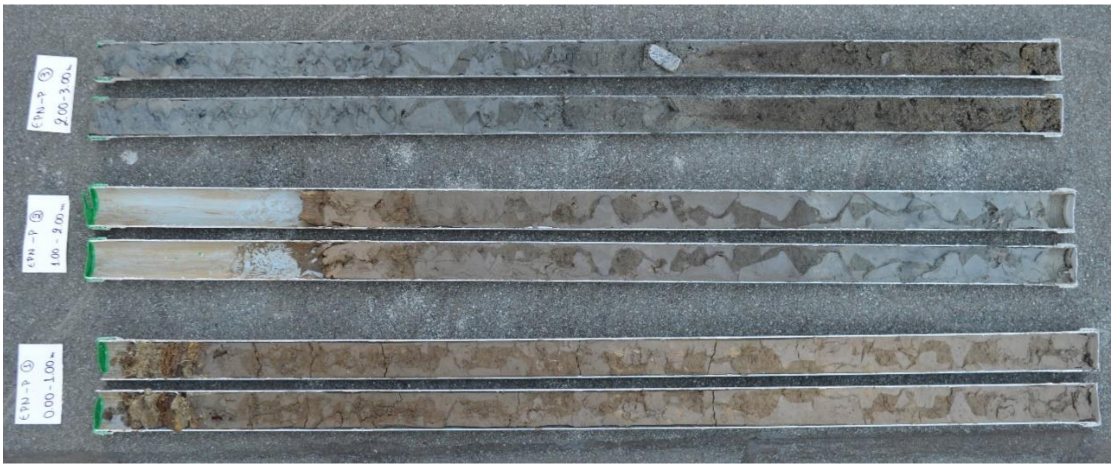

Figure 6. Epanomi (EPN-P) core sample.

The description of the cores included the documentation of the lithology, the recording of the sediment colors (based on Munsell color chart) and the recording of any visible fauna.

Each core was photographed with a scale in a sequence of 20 cm and the three tubes where photographed next to each other before being individually packaged and stored for sampling (Fig 6).

Another drilling (MAM-2P), took place with the exact same process at the coastal area of Agios Mamas, in order to collect paleontological and stratigraphic sedimentary data to compare the paleoenvironmental data with that of the EPN-P core. The MAM-2P core (Fig. 8) was retrieved from Agios Mamas coastal area (Fig. 7) (40.241532 N, 23.339692 E), and reached a maximum depth of 2 m.

Figure 7. Agios Mamas lagoon drilling site.

Figure 8. Agios Mamas (MAM-2P) core sample.

LABORATORY ANALYSES

MAGNETIC SUSCEPTIBILITY ANALYSIS

A total of 240 low-field magnetic susceptibility measurements were carried out in the EPN-P core and 192 in the MAM-2P core using the MS2 Bartington Susceptibility meter and a MB2C sensor (ring sensor). The whole core was measured continuously with a step of 1 cm. The measurements were performed with the ring sensor on the sealed core tube liners. The whole procedure was undertaken twice, and average values were calculated Magnetic Susceptibility measurements have been conducted by Ass. Prof. E. Aidona.

CORE SAMPLING

Samples from along the boreholes were analyzed in order to record the concentration of benthic foraminifera to collect paleontological and stratigraphic sedimentary data, which contributes to the paleoenvironmental evolution of the study area. Samples were collected every 2.5 cm, or even denser where it was considered necessary. In total 33 samples from EPN-P core and 15 samples from MAM-2P core were selected for further micropaleontological analysis. 10 gr of each sample was weighted on an electronic scale before performing the wet sieve analysis (Fig. 9). Then each sample was saturated in water and a solution of Hydrogen Peroxide (H_2O_2, 70%) so that the clay material disaggregates. After all the aforementioned, wet-sieve analysis was performed, using a 63 μm pore size sieve. A 63 μm sieve is equivalent to the size range of very fine sand, therefore it has been used to indicate the sand to clay-silt ratio. After the sieve analysis, the samples were oven-dried (60^{o}C) and then weighted for a second time at the electronical scale to record the exact amount of silt and clay that is missing from the sample thus, to calculate grain size distribution. Grain size analysis can be used as a tool for a better interpretation of various sedimentation changes during time.

Figure 9. Sample weighting process.

Subsequently, every sample has been individually processed under the stereo microscope. Each sample was splitted using a microsplitter depending on foraminiferal consistency, in order to retrieve 200-300 specimens. In case of poor foraminiferal content, the whole sample was examined (Fig. 10).

Figure 10. Stereo microscope foraminiferal analysis.

The foraminifera were picked with a brush (No 000) and stored into micropaleontological slides using Gome Adragante. Then the collected foraminifera from each sample were identified in species level and counted using a stereo microscope (Euromex Nexious Zoom).

The collection of the foraminifera was followed by the foraminifera identification and taxonomy based on the Loeblich and Tappan (1988) classification scheme, and by using the descriptions of Loeblich and Tappan (1988, 1994), Koukousioura (2012), Hottinger et al. (1993), Cimmerman and Langer (1991), Sgarella and Moncharmont Zei (1993), Dimiza et al. (2016) and other scientific papers.

Furthermore, all foraminiferal species were photographed under a ZEISS Stemi 305 trinocular stereoscopic microscope equipped with a MOTICAM S6 camera.

STATISTICAL ANALYSES DESCRIPTION

The main factors used for foraminifera analysis are the faunal density (number of specimens/1 g of dry sediment), the absolute and relative abundances of foraminiferal assemblages and the diversity indices that were calculated in the present study.

A variety of measures have been developed in order to estimate diversity, calculated via Past.exe software (Hammer et al., 2001). The basic idea of a diversity index is to have a quantitative estimation of the biological variability which can be used to compare the various species, composed of diverse components. Therefore, different indices were used for the estimation of the sample diversities. A total of 6 indices were used in order to estimate and interpret the foraminiferal assemblages in the best way possible.

Species richness (S), which represents the total number of species observed in each sample.

The *Shannon-Wiener (H')* diversity index measures the heterogeneity evaluation aka the distribution of individuals in different species (Magurran, 1988). The Shannon index is given by:

H′=−∑Si=1pilnpi,

where pi is the probability to find ni=Npi individuals in the i-th species (∑Si=1pi=1). The number of individuals ni of species I is called the abundance of this species. Varies from 0 for communities with only a single taxon, to high values for communities with many taxa, each with few individuals (Shannon and Weaver, 1949; Pielou, 1975).

The *Simpson's* index a measure of diversity which takes into consideration the number of species present, and the relative abundance of each species. The Simpson 's index is given by:

γ=∑Si=1p2i

If all species are equally represented in the sample, then pi=1/S or γ=1/S (Simpson, 1949).

Fisher's alpha a diversity index, defined implicitly by the formula:

$S=a*\ln(1+n/a)$,

where S is number of taxa, n is number of individuals and a is the Fisher's alpha.

Dominance D = 1-Simpson index. Ranges from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely) (Harper, 1999).

Equitability (also known as Pielou's evenness) is the Shannon diversity divided by the logarithm of number of taxa. This measures the evenness with which individuals are divided among the taxa present (Harper, 1999).

Another important index is the *A* (*Ammonia*) ratio (Koukousioura et al., 2012). The *Ammonia* specimens found in the samples were measured and then distinguished in two categories according to their size, either small (<0.5 mm) or large (>0.5 mm). This distribution of small (S) and large (L) is necessary for the calculation of the *A* index given by the equation:

$A=L/(S+L) \times 100$

This index shows a relation between the test's size and the salinity level.

Other indices used in this thesis is the Foraminifera Abnormality Index (FAI) and the Foraminifera Monitoring Index (FMI). The FAI represents the analogy of abnormal foraminifera in each sample and is given by:

$FAI=(Fabn/n)*100$

where Fabn is the total number of abnormal individuals and n the total number of individuals (Coccioni et al., 2003, 2005).

The FMI represents the proportion of abnormal species within the assemblage in each sample:

$FMI = (FABS /S)*100$

where FABS is the total number of abnormal individuals of each species and S the total number of individuals (Coccioni et al., 2003, 2005).

RADIOCARBON DATING

Two samples were dated using the AMS radiocarbon method. Those samples, with containing organic material, have been collected from different core depths (43.5 cm), and (144.5 cm) and used for radiocarbon AMS (^{14}C) dating. Samples were submitted to CIRCE lab (Naples, Italy). Calibrated and calendar ages are given in Table 1.

Table 1. Radiocarbon samples of core EPN-P conventional and radiocarbon dates through MARINE13 callibration curve (Reimer et al., 2013).

Lab code	**depth (cm)**	**14C age (yr BP)**	**2 σ (cal yr BC/AD)**	**2 σ (cal yr BC/AD)**	**mean BC/AD**	**+/-**	**cal yr BP**	**Marker**
DSH9904_SO	43.5	4205 ± 48	-2905	-2662	-2783.5	243	4733.5	organic matter
DSH9898_SO	144.5	5260 ±37	-4170	-3982	-4076	188	6026	organic matter

RESULTS

CORE EPN-P LITHOLOGICAL DESCRIPTION

The lithology of the EPN-P core consists of very dark gray medium sand with oxidations and organic material from the core's lowest layer till 259 cm followed by a layer of dark greenish gray sand with mollusc fragments up to 240 cm. Subsequently, silty clay with mollusc fragments, gradating from dark gray to gray till 200 cm, is visible. Layers of dark greenish gray silty clay with *Cerastoderma glaucum* molluscs appear till 171 cm and very dark grayish brown clay is distinguishable from 154 to 127.5 cm of depth. Disturbed material from 127.5 to 100 cm is followed by brown clay with organic material and desiccations until a depth of 5 cm. The EPN-P core's 5 cm to the top consist of soil with roots (Fig. 11).

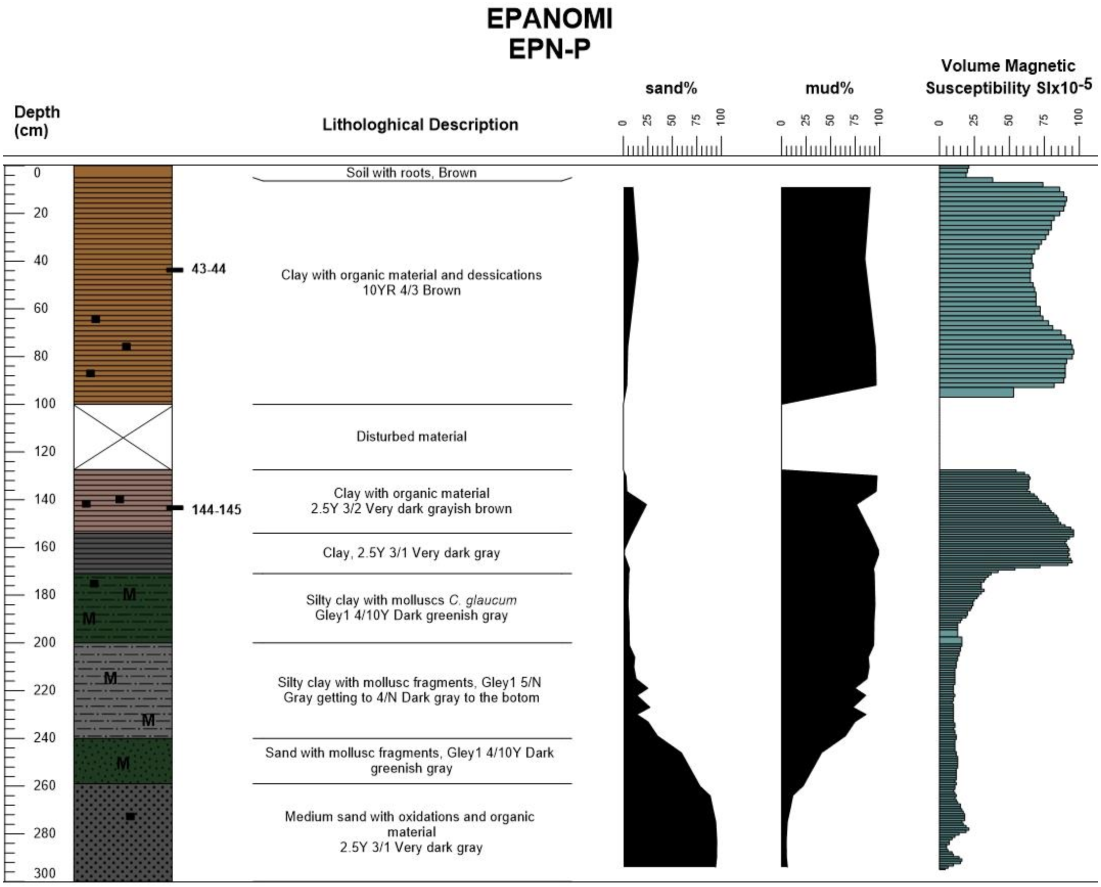

Figure 11. Epanomi core (EPN-P) Lithology, Mud (%), Sand (%) and Magnetic Susceptibility diagram.

Sediments may consist of silicates, carbonates, oxides and sulfides. Therefore, the magnetic properties of sediments can be traced back to the magnetic properties of their mineralogical constituents. Those vary with sediment type, provenance area, and depositional setting. The magnetic susceptibility measurements diagram can be compartmentalized in two groups. In the first group, from 300 cm to 173 cm, the average magnetic susceptibility value is low 10 SIx10^{-5}. From 172 cm till the top of the core the magnetic susceptibility has a noticeable greater value, an average of 85 SIx10^{-5}.

The sedimentary record of EPN-P core can be divided in 5 depositional units:

Unit 1 contains very dark gray medium sand between 300 cm and 259 cm. The sand percentage is over 95% while the magnetic susceptibility is around 25 sIx10^{-5} throughout the unit.

In Unit 2 (259 to 240 cm) the mud percentage is increasing gradually from the bottom (~20%) till the top (~75%) of this unit while magnetic susceptibility slightly decreases to~20 sIx10^{-5}.

Unit 3 represents the layer between 240 to 171 cm, has a high mud percentage (~95%), although the magnetic susceptibility value continues to be around 20 sIx10^{-5}.

In Unit 4, starting from 171 till 127.5 cm, the mud percentage stays at the same level as previous (95%) but the magnetic susceptibility increases significantly (~95 sIx10^{-5}).

The mud percentage in Unit 5 (0 to 100 cm) remains the same as the two previous units (95%) while the magnetic susceptibility is at a stable mean level (~95 sIx10^{-5}).

CORE MAM-2P LITHOLOGICAL DESCRIPTION

The MAM-2P core sequence is mainly composed of silty clay interrupted by gaps or disturbed material and few layers of medium to coarse sand. Specifically, the layer of the core between 200-188 cm includes medium to coarse sand with organic material. From 188 to 157 cm appears dark gray medium to coarse sand with small pebbles with an interfering small gap between 185 cm and 181 cm. A dark gray silty clay layer with organic material is visible until 138 cm followed by 8 cm of disturbed material (138-130 cm) and a 30 cm gap (130-100 cm). Greenish gray silty clay appears from 100 to 84 cm. Till 72 cm greenish gray silty clay with charcoals and plant remains are distinguishable. From 72cm to 60 cm very dark greenish gray silty clay followed by olive grey to dark grey silty clay with several charcoals till 15 cm. The top 15 cm consist of very dark greyish brown clayey silt soil (Fig. 12).

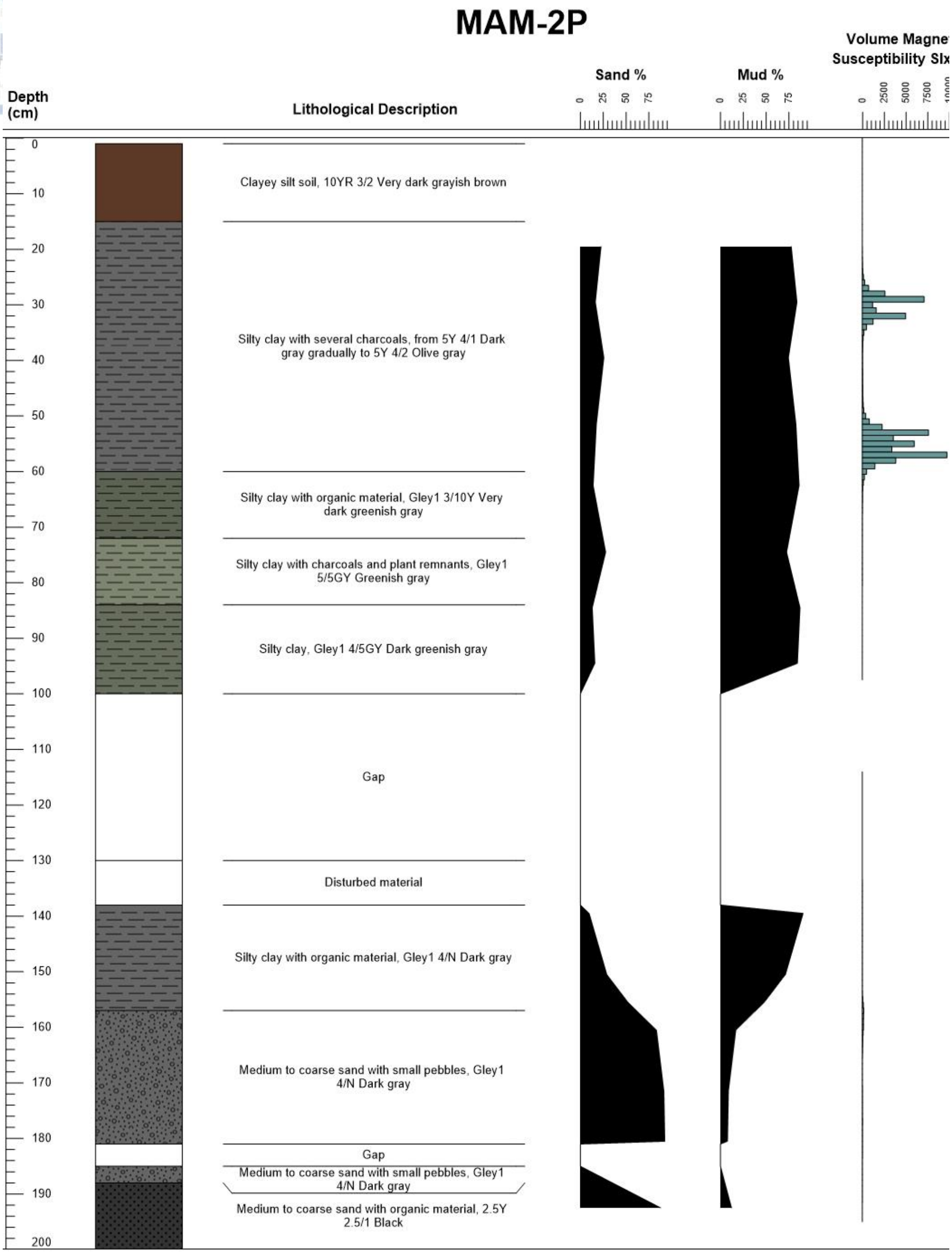

Figure 12. Agios Mamas core (MAM-2P) Lithology, Mud(%), Sand(%) and Magnetic Susceptibility diagram.

The MAM-2P core's magnetic susceptibility has its maximum values in-between 50-60 cm (9748 $Six10^{-5}$) and 25-35cm (4991 $Six10^{-5}$). The mud percentage has relatively low values from the core's end till the depth of 160 cm. From this point until the core top the mud percentage increases significantly up to 85%.

FORAMINIFERAL ANALYSIS

During the micropaleontological study, 33 samples from EPN-P core and 15 from MAM-2P core were analyzed. From MAM-2P core no foraminiferal content has been observed, most probably due to the environmental conditions. Thus, no further micropaleontological analysis was possible to be applied in these samples and only EPN-P core samples have been analyzed.

In the 33 samples analyzed from core EPN-P, a total of 14 foraminiferal species which belong to 8 genera were identified. The samples EPN-P (268-270), EPN-P (282-284), EPN-P (287-289) and EPN-P (293-295) lack foraminifera completely, while samples EPN-P (8-10), EPN-P (38-40), EPN-P (75-77), EPN-P (91-93), EPN-P (141-143), EPN-P (263-268), EPN-P (274-276) and EPN-P (289-291) contained an extremely small number of foraminiferal specimens. The samples that have been statistically analyzed contained at least 30 foraminiferal specimens. The foraminiferal fauna consists mostly of hyaline-perforate species (8 taxa) and 6 porcelaneous taxa. The hyaline species are mainly represented by *Haynesina germanica*, *Ammonia veneta*, *Aubignyna perlucida* and *Haynesina* sp., while the porcellaneous by Miliolidae species (Table 2). The foraminiferal density of the EPN-P core is mostly concentrated between 240-171 cm depth with the maximum value (1801 specimens/g) found within sample EPN-P (205-207). The Dominance index has relatively high values throughout the core showing a maximum again within sample EPN-P (205-207). The other diversity indices present similar fluctuations throughout the core. For instance, their highest values are found within samples EPN-P (129-131), EPN-P (160-162), EPN-P (221-223), EPN-P (245-247). Similarly, their lower values are distinguished within samples EPN-P (229-231), EPN-P (218-220) and EPN-P (183-185). Among the hyaline foraminifera species (*H. germanica*, *Haynesina* sp. and *A. veneta*), individuals exhibiting morphological abnormalities were observed, which were mainly protruding chambers, overdeveloped proloculous and siamese twins (Table 2). Additionally, Gastropods, Ostracoda, Charophyta, seeds and gypsum crystals were also detected (Fig 14).

Table 2. Foraminiferal species identified within EPN-P core samples.

Foraminiferal species
Haynesina germanica (Ehrenberg, 1840)
Haynesina sp.
Ammonia veneta (Schultze, 1854)
Aubignyna perlucida (Heron-Allen and Earland, 1913)
Buccella frigida (Cushman, 1921)
Lobatula lobatula (Walter and Jacob, 1798)
Bolivina translucens Phleger and Parker, 1951
Bolivina spathulata(Williamson, 1858)
Adelosina longinostra (d'Orbigny, 1826)
Quinqueloculina stelligera Schlumberger, 1893
Quinqueloculina seminula (Linné, 1758)
Quinqueloculina bicarinata d'Orbigny, 1826

Quinquelocullina laevigata d'Orbigny, 1826 *Quinqueloculina limbata* d'Orbigny, 1826

Table 3. Foraminiferal species with their total number of abnormal individuals within EPN-P core samples.

Foraminiferal species	Total number of abnormal individuals
Haynesina germanica	50
Haynesina sp.	1
Ammonia veneta	5

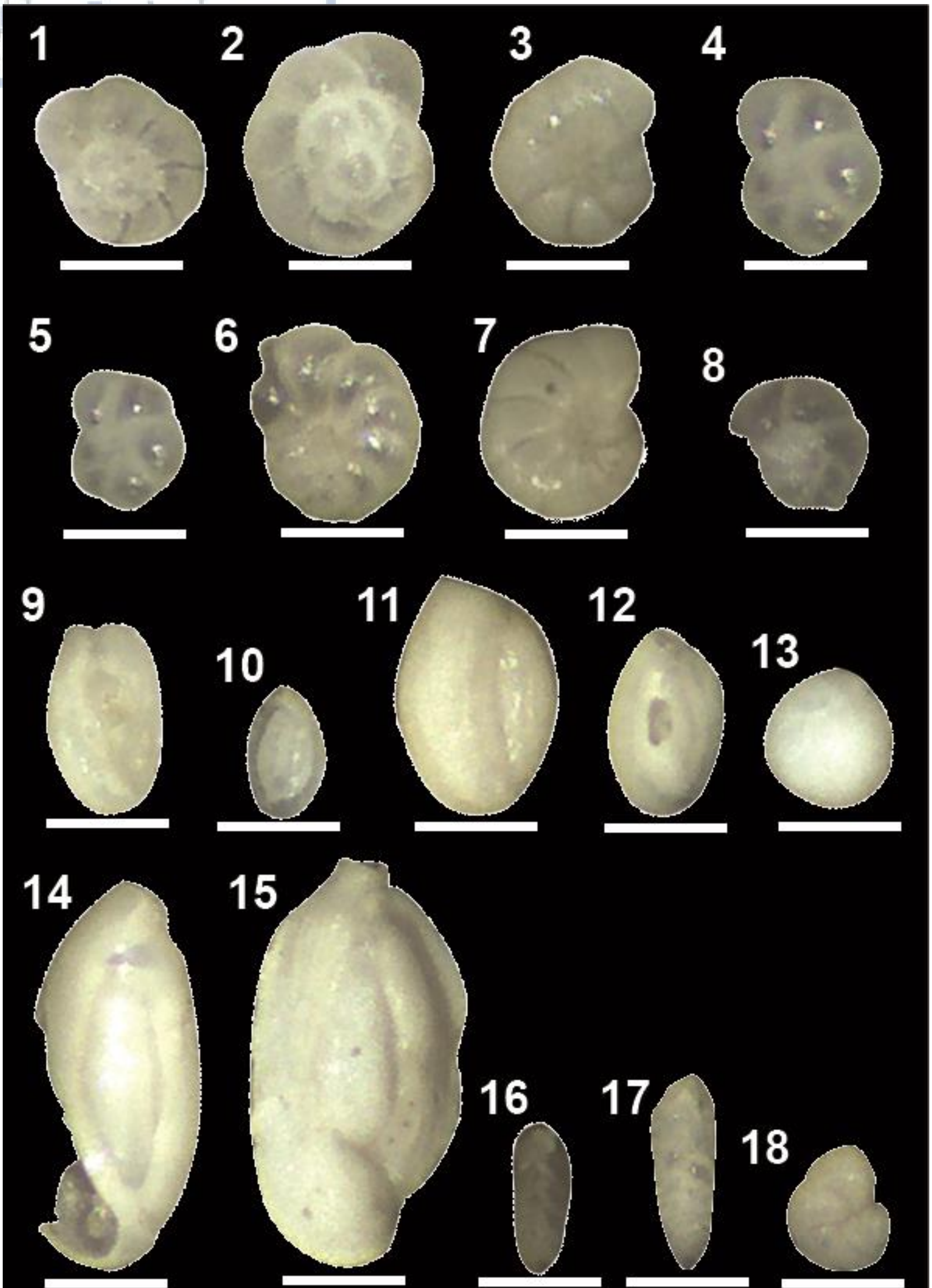

Figure 13. 1-5 *Ammonia veneta*: 1-2 spiral view EPN-P 200-202; 3-5 umbilical side EPN-P 200-202. **6** *Haynesina germanica,* EPN-P 200-202. **7** *Haynesina* sp., EPN-P 209-211 **8** *Aubignyna perlucida,* EPN-P 200-202. **9** *Quinqueloculina stelligera,* EPN-P 200-202. **10** *Quinqueloculina seminula* EPN-P 209-211. **11** *Quinqueloculina limbata,* EPN-P 259-261. **12** *Quinqueloculina bicarinata,* EPN-P 245-247. **13** *Buccella frigida,* spiral view **14** *Quinquelocullina laevigata,* EPN-P 218-220. **15** *Adelosina longinostra,* EPN-P 226-228. **16** *Bolivina translucens,* Phleger and Parker, 1951 EPN-P 221-223. **17** *Bolivina spathulata,* EPN-P 259-261. **18** *Lobatula lobatula,* EPN-P 160-162. The scale is equivalent to 200 μm.

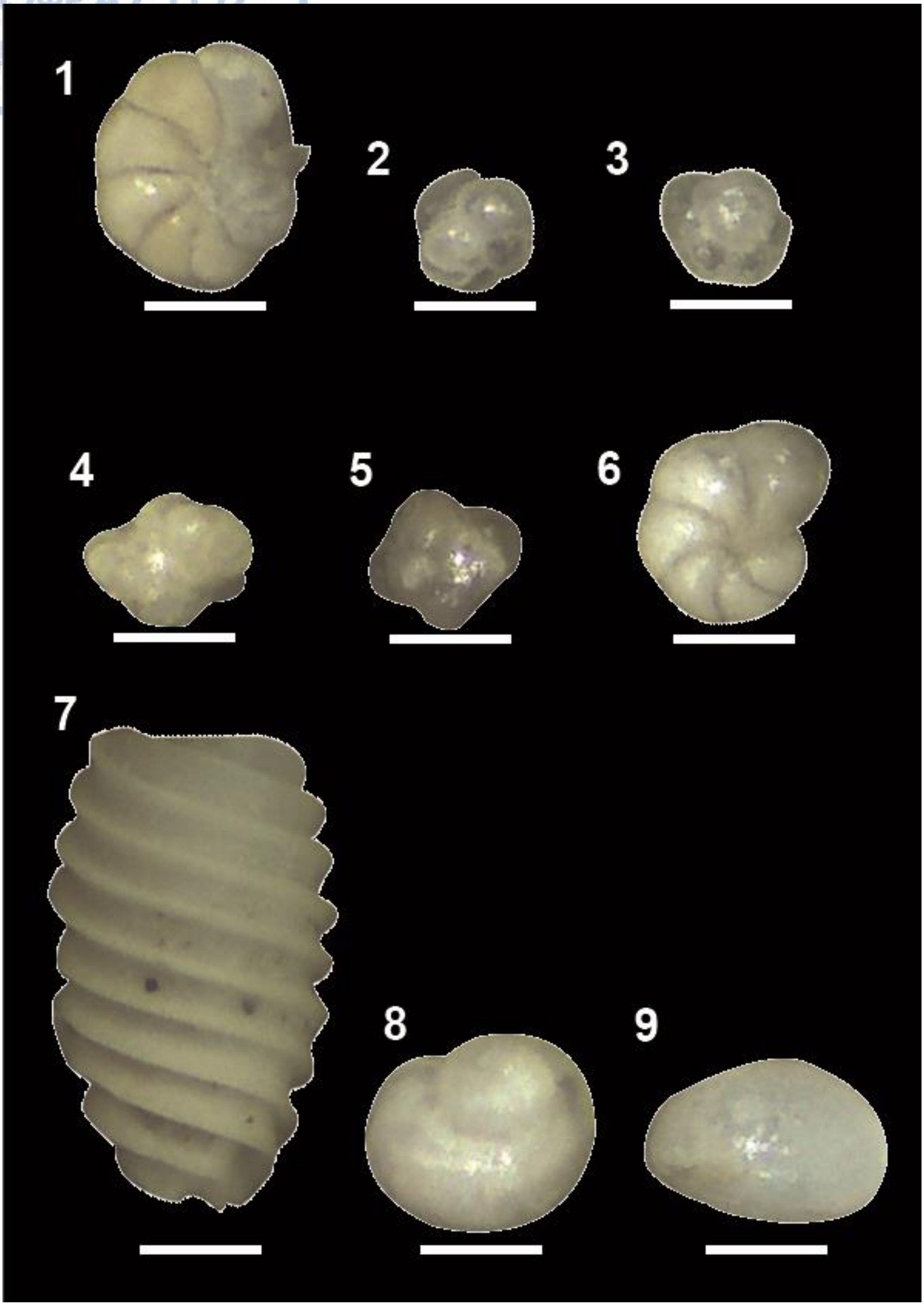

Figure 14. 1-3 *Ammonia veneta*: 1 umbilical view protruding chamber, EPN-P 245-247; 2-3 protruding proloculous, EPN-P 245-247. **4-5** *Haynesina germanica, siamese* twins, EPN-P 259-261. **6** *Haynesina* sp., overdeveloped chamber EPN-P 245-247. **7** Charophyta, EPN-P 245-247. **8** Gastropod, EPN-P 218-220. **9** Ostracod, EPN-P 218-220. The scale is equivalent to 200 μm.

After analyzing the foraminiferal assemblages, the EPN-P core can be divided in 5 distinguished units.

A total of 7 samples represents Unit 1 (300 to 259 cm), which contained only a few gypsum crystals (EPN-P 289-291). Most of the samples were excluded from further statistical analysis due to the low number of foraminiferal individuals (6 specimens). Within this unit the species richness has a mean value of 0.57 species per sample and a mean foraminiferal density of 0.16 specimens/g. Thus only absolute abundances from this unit are presented (Fig. 15).

Unit 2 includes 2 samples, from 259 to 240 cm with a foraminiferal density of 33.33 specimens/gr. The fauna is dominated by the high relative abundance of *H. germanica* (avg. 78.78%), followed by *A. veneta* (avg. 15.86%), *A. perlucida* (avg. 1.78%), *Haynesina* sp. (avg. 4.68%) and the Miliolidae (avg. 0.478%). *B. spathulata* is present too among the hyaline species, but with a significantly small percentage. The species richness index has an avg. value of 6 species per sample. The Dominance index has a mean value of 0.652 which indicates the possibility that one taxon is slightly more dominant than others. Thus, the Simpson's index is 0.347, the Shannon-Wiener diversity index denotes low values with an average of 0.681 and the average Fisher's alpha index is 1.07. Also, the average Equitability index is 0.392. The FAI and FMI present a mean value of 3.09 and 4.55 respectively. The *A* ratio is generally high with an average value of 54.56. Additionally, this unit contains the largest Charophyta concentration of the whole sequence with 41 individuals (EPN-P 245-247) and one seed (EPN-P 259-261) (Fig. 18).

Unit 3 extends from 240 to 171 cm depth and includes 13 samples in total. This unit displays the highest density of all foraminiferal assemblages (max 1801 specimens/g) in opposition to all other units. Furthermore, this is the only unit that includes foraminiferal fragments with the highest value being 35.22% (EPN-P 190-192) and the lowest being 2.199% (EPN-P 160-162). The faunal composition that dominates this unit is similar with the previous Unit 2. For instance, *H. germanica* (avg. 88.03%), *A. veneta* (avg. 7.14%), *A. perlucida* (avg. 2.57%), followed by *Haynesina* sp. (avg. 1.75%) and the Miliolidae group (avg. 0.45%). The majority of miliolid species found in the EPN-P core appear in this unit. Additionally, one *B. translucens* specimen was found within this unit. The species richness index has an avg. value of 4.61 species per sample. The Dominance index has a mean value of 0.78 which indicates that one taxon is more dominant that others. Thus, the Simpson's index is 0.21. The Shannon-Wiener diversity index is even lower than the previous unit with an average value of 0.469. The average Equitability index is 0.309 and the average Fisher's alpha index is 0.829. The FAI and FMI have an average value of 0.957 and 0.985 respectively. The *A* ratio is relatively high with a mean value of 54.83 (Fig. 17).

Unit 4 includes the very dark clay layers and very dark grayish brown between 171 cm and 127.5 cm depth. Moreover, this unit contains in total 7 samples with *H. germanica*, *A. perlucida* and *Haynesina* sp. representing the majority of the foraminiferal individuals. Sample EPN-P 141-143 was excluded from the statistical analysis due to its low individual number (3 specimens). *H. germanica* continues to dominate the assemblage with a maximum rate of 91.81% (EPN-P 168-170) and a minimum rate of 68.75% (EPN-P 129-131). *Aubignyna perlucida* ranges between 1.36% to 18.75%. *Haynesina* sp. presents a maximum abundance of 11.42% (EPN-P 135-138) and a minimum of 4.54% (EPN-P 168-170). The species richness index has an average value of 3.33 species per sample. The Dominance index has a mean value of 0.716 which again indicates that one taxon is more dominant that others. Thus, the average Simpson's index is 0.283. The average Shannon-Wiener diversity index is 0.558. The average Equitability index is 0.484 and the average Fisher's alpha index is 0.742. The FAI and FMI have an average value of 0.469 and 0.497 respectively (Fig 17).

Unit 5 represents the top 100 cm of the core and includes 4 samples. A total of 4 species where distinguished within this unit with *H. germanica* being the most dominant followed by *A. veneta,* and lastly *A. perlucida* and *Lobatula lobatula*. Because of the very small number of individuals (12 specimens) all the samples were excluded from the statistical analysis in order to have more representative results. The foraminiferal density for this unit has an average value of 0.556 specimens/g and the average species richness index is about 1.75.

From the aforementioned it is obvious that *H. germanica* is dominant throughout all five Units of the EPN-P core. Specifically, the foraminiferal relative frequencies diagram (Fig. 17) shows that *H. germanica* has the highest percentages among all other species. The subsequent foraminiferal frequencies are those of *A. veneta, Aubignyna perlucida, Haynesina* sp. and the Miliolidae group. Most species of the Miliolidae group were found in Unit3, however less individuals can be found in Unit 2 and Unit 4. Also, bolivinids representees can be found in Units 2 and 3. Abnormal individuals belonging to *H. germanica, Haynesina* sp. and *A. veneta* are recorded in Units 2, 3 and 4. The majority of the specimens presenting morphological abnormalities are included in Unit 2 in which the FAI and FMI reach their highest mean values 3.09 and 4.55 respectively. Ostracoda Charophyta and Gastropods are also found throughout the core but are mostly concentrated in Unit 2 and 3 (Table 4).

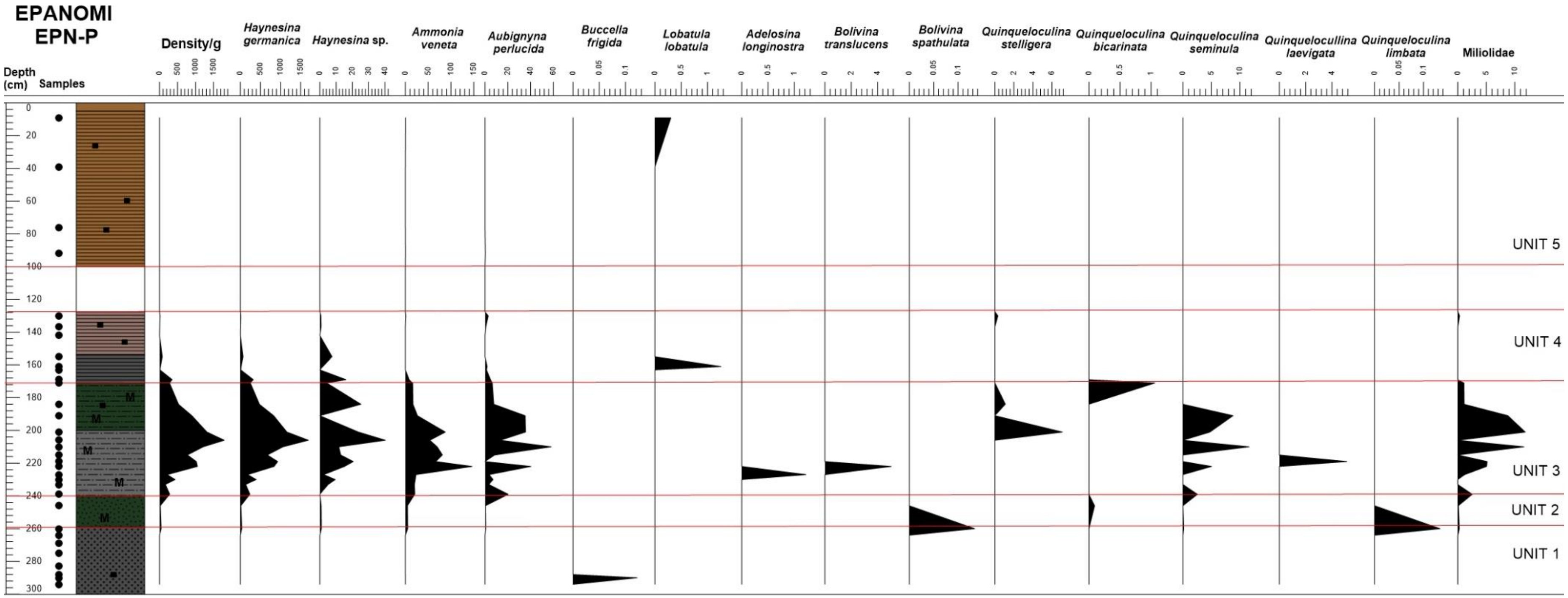

Figure 15. Epanomi core (EPN-P) foraminiferal Density (specimens/g), and absolute abundances of all foraminiferal species.

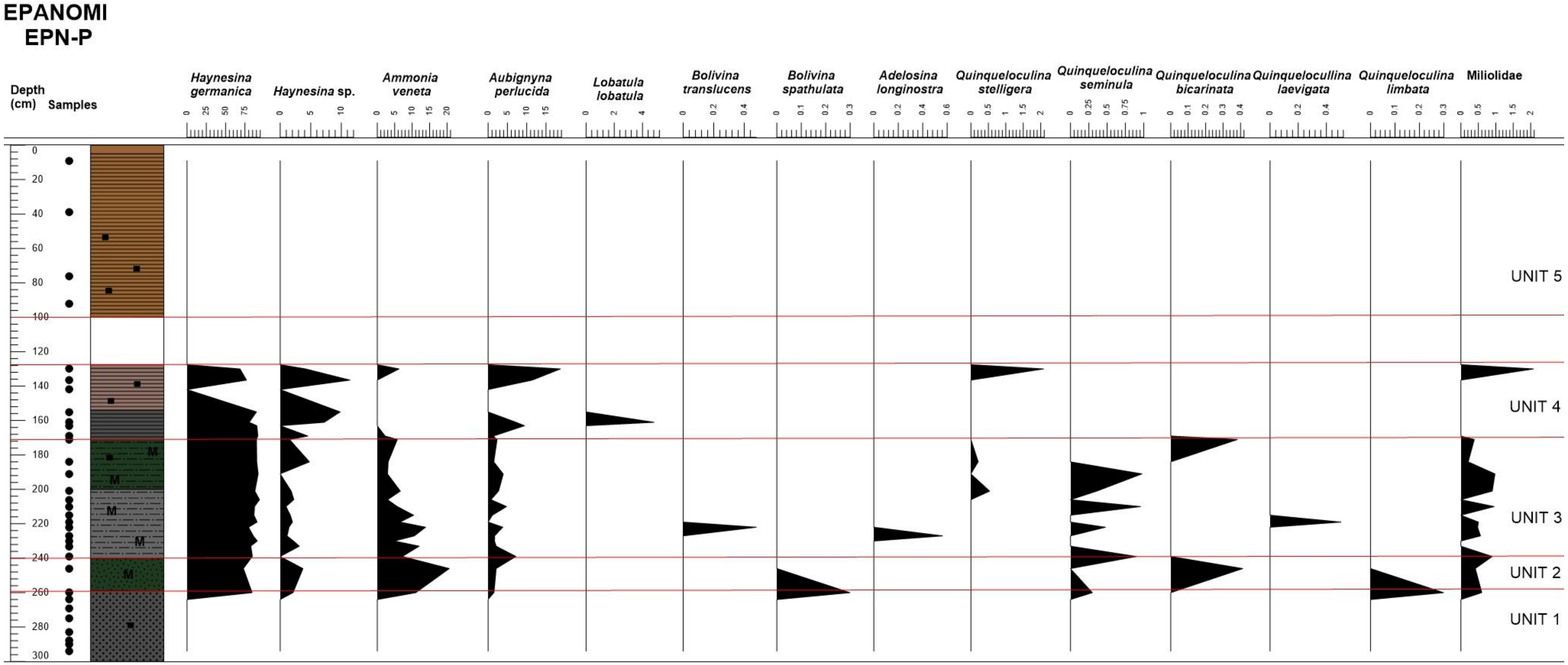

Figure 16. Epanomi core (EPN-P) relative frequencies of all foraminiferal species.

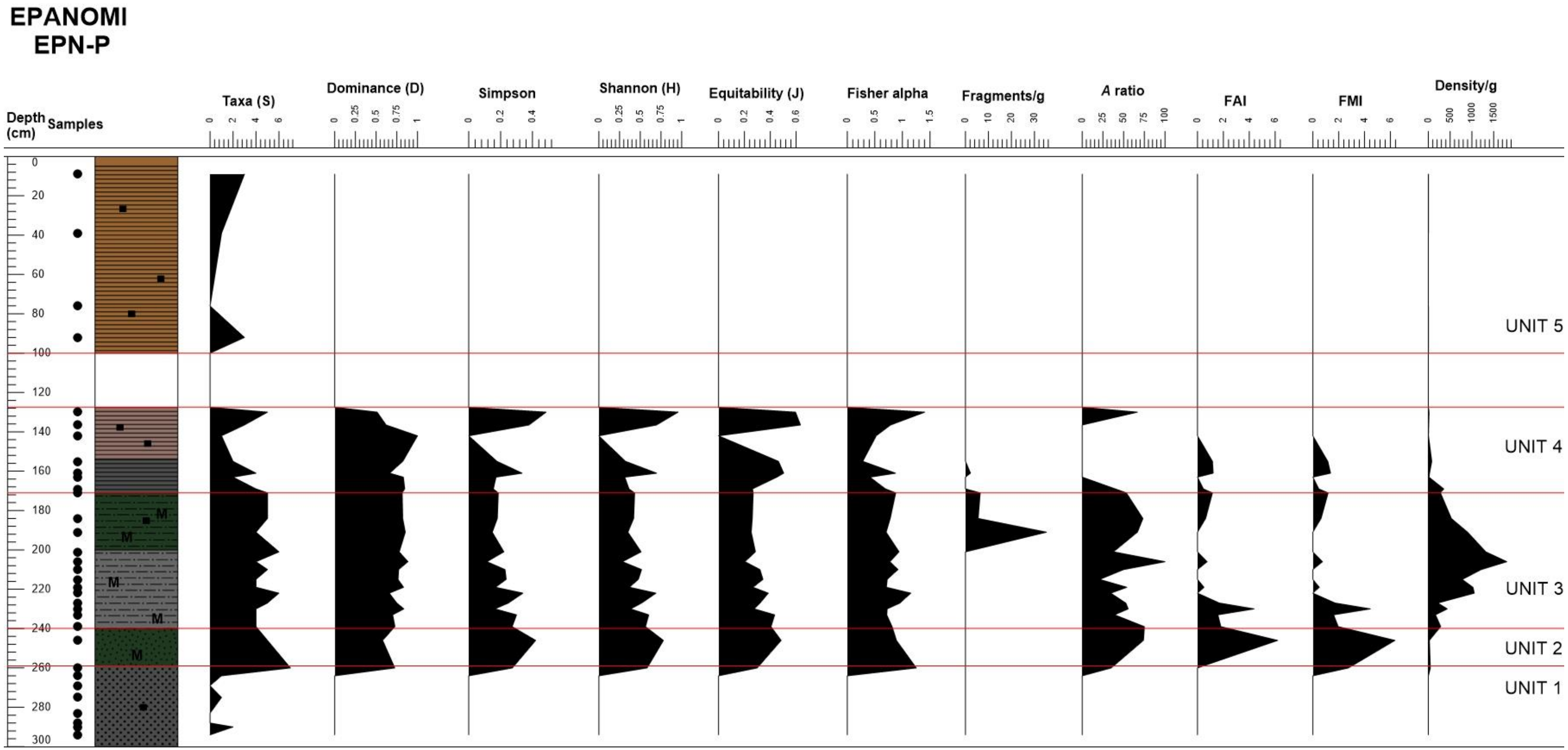

Figure 17. Epanomi core (EPN-P) species richness, diversity indices, Fragments/g, *A* ratio, FAI and FMI indices.

Table 4. Lithology, Magnetic Susceptibility, Quantitative analysis data and additional observed fauna per Unit (EPN-P core).

Unit 1 (300-259cm) 7 samples	Medium sand Sand percentage >95%	Magnetic susceptibility ~25 sIx10^{-5}	Total foraminiferal number: 6 Foraminiferal density avg. 0.16 specimens/g Species richness: 0.57	Ostracoda Gastropods Gypsum crystals Seed
Unit 2 (259-240 cm) 2 samples	Sand Mud percentage 20-75%	Magnetic susceptibility ~20 sIx10^{-5}	Total foraminiferal number: 576 Foraminiferal density avg. 33.33 specimens/g *H. germanica* (avg. 78.78%), *A. veneta* (avg. 15.86%), *A. perlucida* (avg. 0.78%), *Haynesina* sp. (avg. 4.68%), Miliolids (avg. 0.478%) Species richness: 6, Dominance: 0.652, Shannon-Wiener: 0.681, *A* ratio: 54.56, FAI: 3.09, FMI: 4.55	Ostracoda Charophyta
Unit 3 (240-171 cm) 13 samples	Silty clay Mud percentage ~95%	Magnetic susceptibility ~20 Six10^{-5}	Total foraminiferal number: 3.099 Foraminiferal density avg. 769.27 specimens/g *H. germanica* (avg. 88.03%), *A. veneta* (avg. 7.14%), *A. perlucida* (avg. 2.57%), *Haynesina* sp. (avg. 1.75%), Miliolids (avg. 0.45%) Species richness: 4.61, Dominance: 0.78, Shannon-Wiener: 0.469, *A* ratio: 54.83, FAI: 0.957, FMI: 0.985	Ostracoda Charophyta Gastropods
Unit 4 (171-127.5 cm) 7 samples	Clay Mud percentage ~95%	Magnetic susceptibility ~95 Six10^{-5}	Total foraminiferal number: 788 Foraminiferal density avg. 70.74 specimens/g *H. germanica* (avg. 84.17%), *A. perlucida* (avg. 7.21%), *Haynesina* sp. (avg. 6.19%), *A. veneta* (avg. 1.42%) Species richness: 3.33, Dominance: 0.716, Shannon-Wiener: 0.558, FAI: 0.469, FMI: 0.497	Ostracoda Charophyta Gastropods
Unit 5 (100-0 cm) 4 samples	Clay and soil Mud percentage ~95%	Magnetic susceptibility ~95 Six10^{-5}	Total foraminiferal number: 12 Foraminiferal density avg. 0.556 specimens/g Species richness: 1.75	Ostracoda

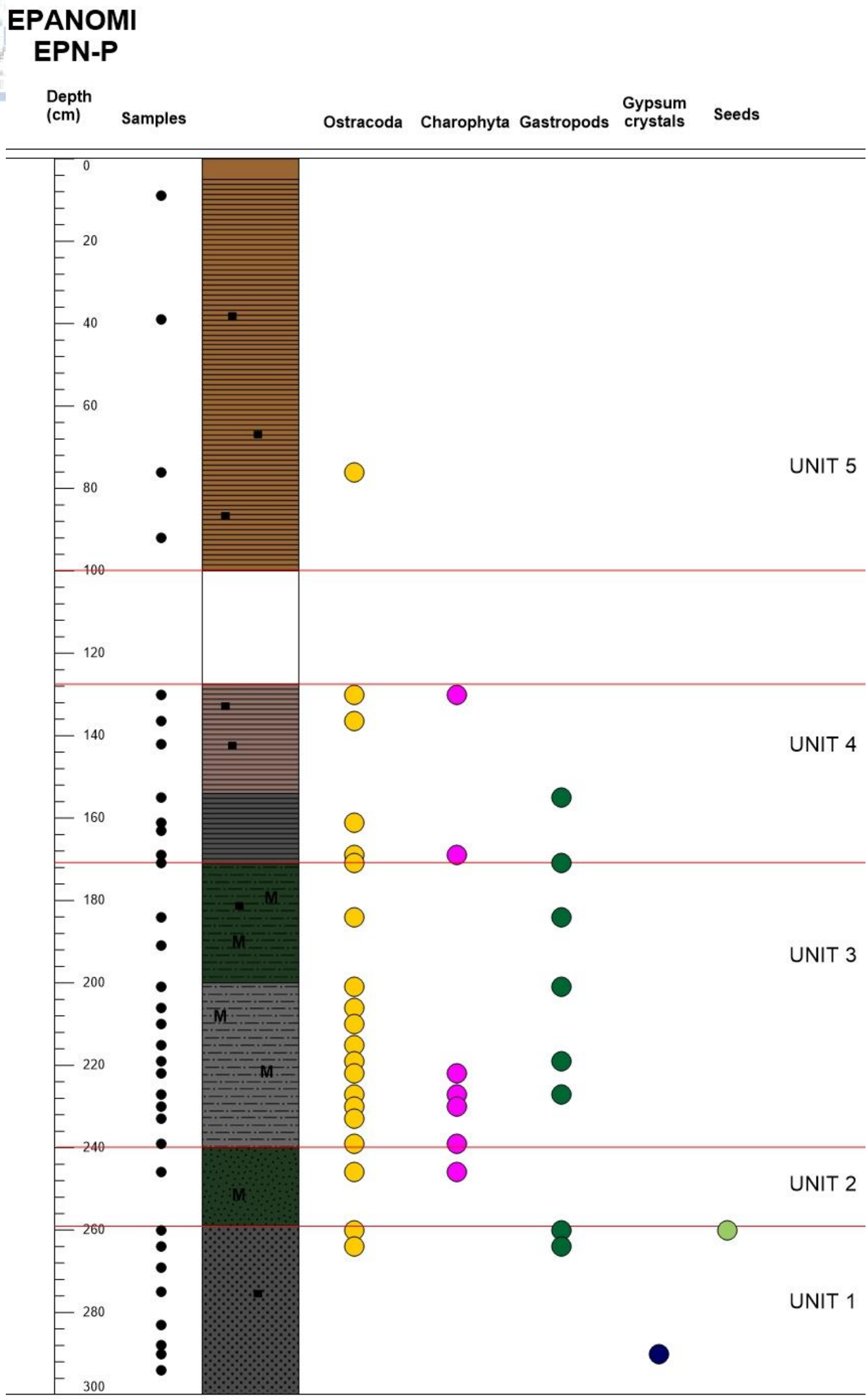

Figure 18. Epanomi core (EPN-P) additional observed fauna.

DISCUSSION

Combining the foraminiferal assemblage, the grain size analysis with the magnetic susceptibility and the radiocarbon dating of EPN-P core resulted to the recognition of the different environmental stages of the Epanomi area.

Paleoenvironmental evolution

Unit 1

For most of Unit 1 the samples did not contain the necessary number of foraminiferal assemblages for it to be included in the statistical analysis. The highest sand ratio values are found within this Unit. This fact, in addition with the low magnetic susceptibility values and gypsum crystals that were found within the Unit, suggest an environment with marine influence and possible desiccations due to increased evaporation (Kjerfve et al., 1996). The low magnetic susceptibility values confirm the presence of marine deposits (Ghilardi et al., 2008; Liu et al., 2012). Gypsum crystals indicate evaporative conditions in isolated aquatic ecosystems. Factors that contribute to gypsum precipitation can be evaporation (e.g., Cann and Cronin 2004; Gomis-Yagües et al., 2000) and desiccation (Reed et al., 2001), being the most significant process. Also, gypsum precipitation results from seasonal drying and water refilling of the system (Reed et al., 2001). For instance, increased evaporation or reduced seawater exchange between the lagoon and the open sea (Kjerfve, 1994) may result to hypersaline conditions. The oxidations described in the sediment may indicate evaporating environmental conditions rather than reduced seawater exchanges.

Unit 2

Unit 2 consists mostly of *H. germanica* and *A. veneta* accompanied by *A. perlucida*, *Haynesina.* sp., miliolids (*Q. limbata*, *Q.bicarinata*, *Q. seminula*), *B. spathulata* and a large concentration of Charophyta. *H. germanica*, which dominates the Unit, is considered as typical species for shallow lagoonal and deltaic environments (e.g., Koukousioura et al., 2012; Martins et al., 2013; Triantaphyllou et al., 2010b) that indicates diverse salinity percentages, for instance, less than 33‰ (Debenay 1978; Redois, 1996) or even higher than 50‰ (hypersaline conditions) (Almogi-Labin et al., 1992; Fatela et al., 2016). Furthermore, it is an euryhaline significant shallow-water inhabitant (Jorissen, 1987; Murray, 2006), which favors shallow silty lagoonal environments (Hottinger et al., 2001). It can also flourish in environments of decreasing marine influence (Alve and Murray, 1994; Debenay and Guillou, 2002; Goiran et al., 2011). *Ammonia veneta* was considered a globally widespread taxon although, a recent morphological and genetic study of Hayward et al. (2021), revealed that many of what were once considered members of *A. tepida* in fact represent other species of *Ammonia*, primarily *A. veneta*. The only true specimens of *A. tepida* were found in Atlantic waters, off the coast of the Americas (Hayward et al., 2021). *A. veneta*, inhabits predominantly near-shore environments of wide ranging salinity and temperature, shallow marine, lagoonal and deltaic zones (Almogi-Labin et al., 1992; Jorissen, 1987; Coccioni, 2000; Melis and Violanti, 2006; Frontalini et al., 2009), with morphological and dimensional test variations (e.g., Carboni et al., 2002; Murray, 2007; Debenay et al., 1996, 2001; Melis and Violanti, 2006). *A perlucida* is a characteristic estuarine and shallow marine environment species (Murray et al., 2000; Carboni et al., 2010; Evelpidou et al., 2010), whereas miliolids occupy the infralittoral and upper circalittoral zones (Sgarrella and Moncharmont Zei, 1993; Moulfi-el-Houari et al., 1999). Miliolids are abundant in shallow waters such as in estuaries and along coastlines, though they also include deepwater oceanic forms (Loeblich and Tappan, 1964). Charophyta tolerate low salinity levels and are found in tropical brackish lagoons, but not in marine environments. The water must be still, or only slow-flowing, oligotrophic or mesotrophic (Palma-Silva et al., 2004). The grain size analysis provided the mud percentage of the Unit which increases gradually from the lower to the upper parts of the unit and displaying overall low magnetic susceptibility measurements confirming again the occurrence of a marine environment (Ghilardi et al., 2008; Liu et al., 2012). The *A* ratio index denotes relatively high values within this Unit which corresponds to larger test size. The test size according to a series of studies (Murray, 1991; Alve and Murray,1994; Debenay et al., 1996; Van Der; Zwaan, 2000; Melis and Violanti, 2006; Frontalini et al., 2009) can be related to certain salinity levels. The *A* ratio index value in combination with the Miliolidae presence indicate a high salinity environment with marine influence. The FAI and FMI indices have relatively small values but the highest among all other units. This, according to Coccioni et al. (2003, 2005) and Dimiza et al. (2012), suggests intense and radical environmental changes specifically about salinity. All the aforementioned indicate that Unit 2 shows transient inputs from the land and sea and unstable hydrodynamic conditions due to the fluctuating sand and mud fractions. It represents a lagoonal environment with marine intrusions (miliolids and *Bolivina spathulata*) and constant freshwater contribution, considering the prevalence of *A. veneta*, *H. germanica* and charophytes. The increased presence of abnormal specimens certifies the fluctuating salinities in an unstable transitional lagoonal environment (Dimiza et al., 2012). Similar environmental stages are described in Ismarida Thrace (ISMR-) sequence which was in direct communication with the sea and shallow marine conditions dominated during ~5500 to ~3500 cal yr BP. Likewise, at Alykes Kitros, from 7800-6500 cal yr BP a semi-enclosed/lagoon was formed.

Unit 3

The composition of Unit 3 includes predominantly *H. germanica* and *A. veneta*, small percentages of *A. perlucida*, miliolids (*Q. stelligera, Q. bicarinata, Q. laevigata, Adelosina longinostra), Bolivina translucens* and *Haynesina* sp. The frequencies of the marine species increase within this unit. The mud percentage provided by the grain size analysis is significantly high with low values of magnetic susceptibility indicating a shallow marine environment. The biometric measurements on the *Ammonia* tests gave high values for the *A* ratio index, which correlates with larger test size. The FAI and FMI indices provided by the statistical analysis denote very low values suggesting relatively stable salinity conditions. Molluscan fauna found within this unit (*Cerastoderma glaucum*) lives in large quantities in shallow lagoons, while salinity and temperature influence shell size and thickness (Eisma, 1965; Tarnowska et al., 2009). The association of the euryhaline (*H. germanica*, *Haynesina* sp., *A. veneta*) with the marine species (*B. spathulata*, miliolids) indicate an open lagoonal environment with a permanent connection to the sea and periodical fresh-water inputs. The assemblage of Unit 3 is comparable to those of Paliouras lagoon Unit C (7600-6900 cal yr BP) (Koukousioura et al., 2019), of the modern Vravron ecosystem (Koukousioura et al., 2012) and of Lake Ismarida which gradually transitioned in between ~3500 and 3000 to more isolated conditions with distinct open lagoonal features, while still in communication with the sea and occasional fresh-water inputs. Similar Holocene foraminiferal assemblages have been characterized as outer lagoon environments (assemblage F2, Carboni et al., 2010).

Unit 4

Around ~6000 cal yr BP (Unit 4), the sedimentary sequence consists of clay deposits (the highest mud percentages out of the entire EPN-P core) and is characterized by high magnetic susceptibility values. The foraminifera assemblages are represented mainly by *H. germanica* and *A. perlucida* followed by *A. veneta*, *Haynesina* sp., *L. lobatula* and remotely miliolids. As mentioned, the dominant species of *H. germanica* tolerates decreasing marine influence (Debenay et al., 2005). The *A* ratio index shows null values indicating smaller tests and therefore low salinity levels (Koukousioura et al., 2012; Murray, 1991; Alve and Murray,1994; Debenay et al., 1996; Van Der; Zwaan, 2000; Melis and Violanti, 2006; Frontalini et al., 2009). The aforementioned show the area shifts to a low energy closed lagoon, as suggested by the dominance of the oligohaline foraminiferal species, and the increase of magnetic susceptibility measurements. Similar environmental conditions were described in Unit C of the Second stage of the Piraeus Lagoon (Unit C) (Triantaphyllou et al., 2021), the upper part of Alykes Kitros and the Lafrouda Thrace sequences which represent a transition from open lagoonal fauna (*Ammonia* spp., miliolids and *A. perlucida* assemblage) to closed lagoonal conditions (Koukousioura et al., 2012), as well as in Paliouras lagoon before 5900 cal yr BP (Koukousioura et al., 2019) and Ismarida lake at ~3000 cal yr BP (Koukousioura et al., 2020). Additional described assemblages in Venice Lagoon (Serandrei Barbero et al., 1997; Coccioni et al., 2009), with meso-oligohaline environments in several Aegean coastal plains (Triantaphyllou et al., 2003; Evelpidou et al., 2010) define inner lagoonal conditions (assemblage F1; Carboni et al., 2009, 2010).

Unit 5

Unit 5 included extremely small foraminiferal assemblages which, in association with the high magnetic susceptibility values and the lithological description, suggests the closing of the lagoon and the dominance of the terrestrial deposits in the area before ~4733 cal yr BP. The samples from this unit were excluded from the statistical analysis.

The ENP-P core can be compared to the Paliouras (PLR-1) core located also on the eastern Thermaikos gulf, near the study area (Koukousioura et al., 2019), to the Alykes Kitros (KIT1) core on the western part of Thermaikos gulf (Koukousioura et. al., 2012), to the Lafrouda lagoon (LAF8) core (Koukousioura et al., 2012) and the Ismarida lake (ISMR-2) core in Thrace (Koukousioura et al., 2020). The comparison of the evolutionary stages of those cores provides data about the coastal processes, sea level fluctuations and general climatic conditions in North Aegean Sea during the Holocene.

Epanomi, Alykes Kitros, Paliouras Ismarida and Lafrouda boreholes show similarities. For instance, all five boreholes are transitioning from an open lagoonal environment to closed lagoon conditions. This transition took place around 6000 cal yr BP in Epanomi, before 5900 cal yr BP in Paliouras (Koukousioura et. al., 2019) after 6500 cal yr BP in Alykes Kitros and around 3000 cal yr BP at Ismarida lake (Koukousioura et al., 2020) and Lafrouda lagoon in Thrace (Koukousioura et. al., 2012).

The present thesis confirms the coastal evolutionary model of east Thermaikos Gulf by Albanakis et al. (2005). According to that model, the present-day low terrain as well as the valleys extended gradually towards the Thermaikos Gulf basin. As aforementioned, the inner Holocene marine transgression occurred at the area at ~8000 cal yr BP (Koukousioura e al., 2019). From then on the marine erosion formed coastal terraces. The marine transgression progressed until entering the paleovalleys. Currents with sediment contribution created deposits which resulted to a balanced profile, also affecting the coastal areas which were on the axes of those currents, characteristic of an estuarine ecosystem. These areas gradually formed low coastal planes with lagoons and marshes (Albanakis et al., 2005) (Fig. 19).

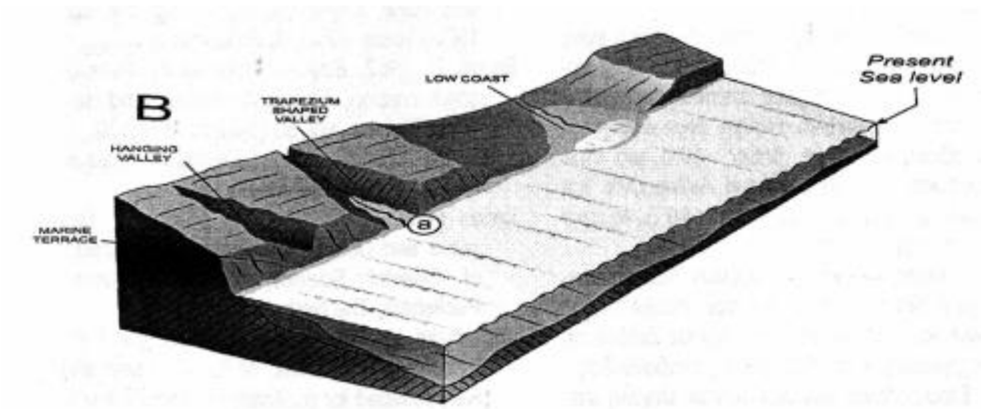

Figure 19. Coastal evolutionary model of east Thermaikos Gulf from Albanakis et al. (2005).

CONSCLUSIONS

The lithological, micropaleontological (benthic foraminifera), magnetic susceptibility and radiocarbon data, of a 3m-long sediment core (EPN-P) in the eastern Thermaikos coastal plain, enabled the following conclusions:

- The study area was initially an environment with marine influence and possible desiccations due to increased evaporation characterized by high sand proportion, low magnetic susceptibility values, the presence of gypsum crystals and only few marine foraminiferal specimens.
- Afterwards, the Epanomi area represents an unstable lagoonal environment with marine intrusions (miliolids and *Bolivina spathulata*) and constant freshwater contribution, considering the prevalence of *Ammonia veneta*, *Haynesina germanica* and charophytes. The major characteristics of the transitional lagoon are the transient inputs from the land and sea, which result to unstable hydrodynamic conditions due to the fluctuating sand and mud fractions.
- Thereafter, an open lagoonal environment with a permanent connection to the sea and periodical fresh-water inputs is established, indicated by the association of the euryhaline (*H. germanica*, *Haynesina* sp., *A. veneta*) with the marine species (*B. spathulata*, miliolids).
- Around ~6000 cal yr BP, the area shifts to a low energy closed lagoon, as suggested by the dominance of the oligohaline foraminiferal species, and the increase of magnetic susceptibility measurements.
- Before ~4733 cal yr BP to the present day, the area is gradually tending to more isolated conditions characterized by only few foraminiferal specimens which, in association with high magnetic susceptibility values and the lithological determination, suggests the closing of the lagoon and the dominance of the terrestrial deposits in the area.
- Primarily responsible for this evolutionary transition is the diminishing rate of the sea level rise prior to 4000 yr BP, that the Aegean coastal plains sea level curves show, and the sediment distribution rates near the coastline.
- The data are confirming the coastal evolutionary model of east Thermaikos Gulf by Albanakis et al. (2005).

BIBLIOGRAPHY

Τριανταφύλλου, Μ.Β., Δήμιζα, Μ.Δ., 2012. Μικροπαλαιοντολογία & Γεωπεριβάλλον, Εκδοτικός όμιλος Ίων, Αθήνα, σ. 168.

Albanakis, K., Styllas, M., Vouvalidis, K., Syrides, G., 2005. Geomorphological changes in Thermaikos Gulf area as a result of the Holocene sea level increase. Bulletin of the Geological Society of Greece, XXXVIII, 77-85 (in greek).

Almogi-Labin, A., Perelis-Grossovicz, L., Raab, M., 1992. Living ammonia from a hypersaline inland pool, Dead Sea area, Israel. Journal of Foraminiferal Research, 22, 257-266.

Alve, E., Murray, J.W., 1994. Ecology and taphonomy of benthic foraminifera in a temperate mesotidal inlet. Journal of Foraminiferal Research, 24 (1), 18-27.

Bergamin, L., Romano, E., Finoia, M.G., Venti, F., Bianchi, J., Colasanti, A., Ausili, A., 2009. Benthic foraminifera from the coastal zone of Baia (Naples, Italy): Assemblage distribution and modification as tools for environmental characterization. Marine Pollution Bulletin, 59 (8-12), 234-244.

Bergamasco, A., Malanotte-Rizzoli, P., 2010. The circulation of the Mediterranean Sea: a historical review of experimental investigations. Advances in Oceanography and Limnology, 1, 11-28.

Carboni, M.G., Bergamin, L., Di Bella, L., Iamundo, F., Pugliese, F., 2002. Paleoecological evidences from foraminifers and ostracods on Late Quaternary sea-level changes in the Ombrone river plain (central Tyrrhenian coast, Italy). Geobios, 35, 39-50.

Carboni, M.G., Succi, M.C., Bergamin, L., Di Bella, L., Fezza, V., Landini, B., 2009. Benthic foraminifera from two coastal lakes of Southern Latium, (Italy). Preliminary evaluation of eliminary of Environmental quality. Marine Pollution Bulletin, 59, 268-280.

Carboni, M.G., Bergamin, L., Di Bella, L., Iamundo, F., Pugliese, F., 2010. Palaeoenvironmental reconstruction of Late Quaternary foraminifera and molluscs from the ENEA borehole (Versilian plain, Tuscany, Italy). Quaternary Research, 74, 265-276.

Cimerman, F., Langer, M.R., 1991. Mediterranean foraminifera. Academia Scientarium et. Artium Slovenica, Dela, Opera 30, Classis IV, Historia Naturalis, pp. 118.

Coccioni, R., 2000. Benthic foraminifera as bioindicators of heavy metal pollution. A case study from the Goro Lagoon (Italy). In: Martin, R.E., (Ed.), Environmental Micropaleontology: The Application of Microfossils to Environmental Geology. Kluwer Academic/Plenum Publishers, New York, p. 71-103.

Coccioni, R., Marsili, A., Venturati, A., 2003. Foraminiferi e stress ambientale. Quad Centro Geobiol Univ Stud Urbino, 1, 99-118.

Coccioni, R., Frontalini, F., Marsili, A., Troiani, F., 2005. Foraminiferi benthonici ii i traccia: Implicazioni ambientali. Quad Centr Geobiol Univ Stud Urbino, 3, 57-92.

Corliss, B.H., 1985. Microhabitats of benthic foraminifera within deep-sea sediments. Nature, 314, 435-438.

Chronis, G., 1986. Recent dynamic and Holocene sedimentation of Thermaikos Bay, Unpub. Ph.D. Thesis, Univ. Athens (In Greek), 228pp.

Culver, S.J., Woo, H.J., Oertel, G.F., Buzas, M.A., 1996. Foraminifera of coastal depositional environments, Virginia, U.S.A., distribution and taphonomy, Palaios, 11, 459-486.

d'Orbigny, A., 1826. Tableau Méthodique de la Classe des Céphalopodes. Annales des Sciences Naturelles, Paris (Série 1), 7, 245-314.

d'Orbigny, A.D., 1846. Foraminifères Fossiles du Bassin Tertiare de Vienne (Autriche), Gide, Paris.

De Rijk, S., Jorissen, F.J., Rohling, E.J., 1999. Benthic foraminifera distribution in the Mediterranean Sea. Journal of Foraminiferal Research, 29 (2), 93-103.

Debenay, J.-P., 1978. Distribution des foraminifères vivants et des tests vides en Baie de Bourgneuf. Thèse de Docteur, Universite Pierre et Marie Curie, pp. 196.

Debenay, J.-P., Guillou, J.-J., Lesourd, M., 1996. The texture of the foraminiferal tests in relation with the crystallogenesis od colloidal calcite. Comptes Rendues de l' Academie de Sciences-Serie iIa: Sciences de la Terre des Planetes, 323 (2), 171-178.

Debenay, J.P., Geslin, E., Eichler, B.B., Duleba, W., Sylvestre, F., Eichler, P., 2001. Foraminiferal assemblages in a hypersaline lagoon, Araruama (R.J.) (Brazil). Journal of Foraminiferal Research, 31 (2), 133-151.

Debenay, J.-P., Guillou, J.-J., 2002. Ecological transitions indicated by foraminiferal assemblages in paralic environments. Estuaries, 25 (6A), 1107-1120.

Debenay, J.-P., Millet, B., Angelidis, M.O., 2005. Relationships between foraminiferal assemblages and hydrodynamics in the gulf of Kalloni, (Greece). Journal of Foraminiferal Research, 35 (4), 327-343.

Dettmering, C., Röttger, R., Schmaljohann, R., and Hohenegger, J., 1998. The trimorphic life cycle in foraminifera: observations from cultures allow new evaluation. European Journal of Protistology, 34, 363-368.

Dieckman, G.S., Spindler, M., Lange, M.A., Ackley, S.F., Eicken H., 1991. Antarctic Sea ice: a habitat for the foraminifer *Neogloboquadrina pachyderma*. Journal of Foraminiferal Research, 21, 182-189.

Dimiza, M.D, Koukousioura, O., Triantafyllou, M.V., 2012. Benthic foraminiferal morphological abnormalities from Holocene sediments of the Aegean Sea, (Greece): Paleoenvironmental implications. 10th Symposium on Oceanography and Fishery, p. 12.

Dimiza, M.D, Koukousioura, O., Triantaphyllou, M.V., Dermitzakis, M.D., 2016. Live and dead benthic foraminiferal assemblages from coastal environments of the Aegean Sea (Greece): Distribution and diversity. Revue de Micropaléontologie, 59(1), 19-32.

Dobell, C., 1932. Antony van Leeuwenhoek and his 'Little Animals', Harcourt. Brace and Company, New York.

Dujardin, F., 1835. Observations nouvelles sur les Céphalopodes microscopiques. Annales des Sciences Naturelles, 3, 108-109.

Eisma, D., 1965. Shell characteristics of *Cardium edule* L. as indicators of salinity. Netherlands Journal of Sea Research, 2 (4), 493–540.

Evelpidou, N., Pavlopoulos, K., Vassilopoulos, A., Triantaphyllou, M., Vouvalidis, K., Syrides, G., 2010. Sea level changes in Upper Holocene and palaeogeographical reconstruction. Geodinamica Acta, 23 (5-6), 233-240.

Fatela, F., Moreno, J., Cabral, C.M., 2016. Salinity and water temperature assessment of the tidal marshes from the W Portuguese coast, as an ecological tool to paleoenvironmental reconstructions based on foraminifera and ostracoda assemblages. Estud Quatern, 14, 73-81.

Faugeres, L., Robert, Ch., 1976. Etude sedimentologique et mineralogique de duex forages du golfe thermaïque (mer Egée). Géologie Méditerranéenne, 3-4, 209-218.

Fiorini, F., Vaiani, S.C., 2001. Benthic foraminifera and transgressive-regressive cycles in the Late Quaternary subsurface sediments of the Po Plain near Ravenna (Northern Italy). Bollettino della Società Palaeontologica Italiana, 40 (3), 357-403.

Frontalini, F., Buosi, C., Da Pelo, S., Coccioni, R., Cherchi, A., Bucci, C., 2009. Benthic foraminifera as bio-indicators of trace element pollution in the heavily contaminated Santa Gilla lagoon (Cagliari, Italy). Marine Pollution Bulletin, 58, 858-877.

Fouache, E., Ghilardi, M., Vouvalidis, K., Syrides, G., Styllas, M., Kunesch, S., Stiros, S., 2008. Contribution of the Holocene Reconstruction of Thessaloniki Coastal Plain (Greece). Journal of Coastal Research, 24 (5), 1161-1173.

Ghilardi, M., 2006. Apport et intérêt de la modélisation numérique de terrain en géomorphologie: étude du site antique de Méthoni (Piérie-Grèce). Mémoire du laboratoire de Géomorphologie et environnement littoral, 45, Dinard (France), pp 114.

Ghilardi, M., Fouache, E., Queyrel, F., Syrides, G., Voulalidis, K., Kuneshc, S., Styllas, M., Stiros, S., 2008. Human occupation and geomorphological evolution of the Thessaloniki plain (Greece) since Mid Holocene. Journal of Archaeological Science, 35, 111-125.

Ghilardi, M., Genç, A., Syrides, G., Bloemendal, J., Psomiadis, D., Paraschou, T., Kunesch, S., Fouache, E., 2010. Reconstruction of the landscape history around the remnant arch of the Klidhi Roman Bridge, Thessaloniki plain, (north central Greece). Journal of Archaeological Science, 37 (1), 178-191.

Goiran, J.-P., Pavlopoulos, K.P., Fouache, E., Triantaphyllou, M., Etienne, R., 2011. Piraeus, the ancient island of Athens: evidence from Holocene sediments and historical archives. Geology, 39 (6), 531-534.

Goldfuss, G.A., 1817. Ueber die Entwicklungsstufen des Thieres. Nürnberg, Leonhard Schrag.

Gooday, A., Alve, E., 2001. Morphological and ecological parallels between sublittoral and abyssal foraminiferal species in the NE Atlantic: a comparison of *Stainforthia fusiformis* and *Stainforthia* sp.. Progress in Oceanography, 50, 261-283.

Gooday, A., 2002. Organic-walled Allogromiids: aspects of their occurrence, diversity and ecology in marine habitats. Journal of Foraminifera Research, 32, 384-399.

Hallock, P., 1985. Why are larger Foraminifera large?. Paleobiology, 11, 195-208.

Hallock, P., 1999. Symbiont-bearing foraminifera. In: Sen Gupta, B.K., Ed., Modern foraminifera. Kluwer Academic Publishers, Great Britain, pp. 123-139.

Hallock, P., 2000. Symbiont-bearing foraminifera: harbingers of global change. Micropaleontology, 46, 95-104.

Hamman, D., 1988. Book Review: Foraminiferal Genera and their Classification, by Alfred R, Loeblich and Helen Tappan. Journal of Foraminiferal Research, 18, 271-274.

Hammer, O., Harper, D.A.T., Ryan, P.D., 2001. Past Paleontological statistics software. Package for education and data analysis. Paleontologia Electronica.

Harper, D.A.T., (ed.) 1999. Numerical Palaeobiology. Computer-Based Modelling and Analysis of Fossils and their Distributions. Geol. Mag., 137 (4), 463-79.

Haq, B.U., Boersma, A., 1978. Introduction to Marine Micropaleontology. Elsevier Science, pp. 376.

Hayward, B.W., Holzmann, M., Pawlowski, J., Parker, J.H., Kaushik, T., Toyofuku, M.S., Tsuchiya, M., 2021. Molecular and morphological taxonomy of living *Ammonia* and related taxa (Foraminifera) nd their biogeography. Micropaleontology, 67 (2–3), 109-313.

Hottinger, L., Reiss, Z., Langer, M., 2001. Spiral canals of some Elphidiidae. Micropaleontology, 47 (2), 5-34.

Jonasson, K.E., Schroder-Adams, C.J., Patterson, R.T., 1995. Benthic foraminiferal distribution at Middle Valley, Juan de Fuca Ridge, a northeast Pacific hydrothermal venting site. Marine Micropaleontology, 25, 151-167.

Jorissen, F.J., 1987. The distribution of benthic foraminifera in the Adriatic Sea. Marine Micropaleontology, 12, 21-48.

Jorissen, F.J., Barmawidjaja, D.M., Puskaric, S., Van Der Zwaan, G.J., 1992. Vertical distribution of benthic foraminifera in the northern Adriatic Sea: the relation with the organic flux. Marine Micropaleontology, 19, 131-146.

Jorissen, F.J., De Stigter, H.C., Widmark, J.G.V., 1995. A conceptual model explaining benthic foraminiferal microhabitats. Marine Micropaleontology, 26, 3-15.

Karystineos, N., 1984. Paleogeographic evolution of the Serres Basin. Lithostromatography, Biostromatography and Tectonics. Doctorate Thesis, Aristotle University of Thessaloniki, pp. 1-230 (in Greek).

Kjerfve, B.,1994. Coastal lagoon processes. Elsevier Oceanography Series, Amsterdam.

Kjerfve, B., Schettini, C.A.F., Knoppers, B., Lessa, G., Ferreira, H.O., 1996. Hydrology and Salt Balance in a large, hypersaline coastal lagoon: Lagoa de Araruama, Brazil. Estuarine Coastal and Shelf Science, 42 (6), 701-725.

Koukousioura, O., Dimiza, M.D., Triantaphyllou, M.V., 2010. Alien foraminifers from Greek coastal areas (Aegean Sea, Eastern Mediterranean). Mediterranean Marine Science, 11(1), 155-172.

Koukousioura, O., Dimiza, M.D., Triantafyllou, M.V., Hallock, P., 2011. Living benthic foraminifera as an environmental proxy in coastal ecosystems: a case study from the Aegean Sea (Greece, NE. Mediterranen). Journal of Marine Systems, 88(4), 489-501.

Koukousioura, O., 2012. Benthic foraminifera as environmental health indices in Holocene Greek coastal environments. Doctoral thesis, Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens, pp. 161 (in Greek).

Koukousioura, O., Triantafyllou, M.V., Dimiza, M.D., Pavlopoulos, K., Syrides, G., Vouvalidis, K., 2012. Benthic foraminiferal evidence for and Paleoenvironmental evolution of Holocene coastal plains in the Aegean Sea (Greece). Quaternary International, 261, 105-117.

Koukousioura, O., Dimiza, M.D., Kyriazidou, E., Triantaphyllou, M.V., Syrides, G., Aidona, E., Vouvalidis, K., Panagiotopoulos, I.P., Papadopoulou, L., 2019. Environmental evolution of the

Paliouras coastal lagoon in the eastern Thermaikos gulf (Greece) during Holocene. Environ. Earth Sci., 78, 313.

Koukousioura, O., Kouli, K., Vouvalidis, K., Aidona, E., Karadimou, G., Syrides, G., 2020. A multi-proxy approach for reconstructing environmental dynamics since the mid Holocene in Lake Ismarida (Thrace, N. Greece). Revue de Micropaleontologie, 68, 100443.

Kouli, K., Triantaphyllou, M.V., Koukousioura, O., Dimiza, M.D., Parinos, C., Panagiotopoulos, I.P., Tsourou, T., Gogou, A., Mavrommatis, N., Syrides, G., Kyrikou, S., Skampa, E., Skylaki, E., Anagnostou, C., Karageorgis, A.P., 2021. Late glacial marine transgression and ecosystem response in the landlocked Elefsis bay (Northern Saronikos gulf, Greece). Water (Switzerland), 13, 1-25.

Lambeck, K., 2004. Sea-level change through the last glacial cycle: geophysical, glaciological and palaeogeographic consequences. Comptes Rendus Geoscience, 336 (7-8), 677-689.

Langer, M.R., Frick, H., Sil, M.T., 1998. Photophile and sciaphil foraminiferal assemblages from marine plant communities of Lavezzi Islands (Corsica, Mediterranean Sea). Review de Paléobiologie, 17 (2), 525-530.

Lee, J.J., Faber, W.W.Jr., Anderson, O.R., Pawlowski, J., 1991. Life-cycles of foraminifera. In: Lee, J.J., Anderson, O.R., Eds, Biology of foraminifera, London, Academic Press, pp. 285-334.

Lee, J.J., 2006. Algal symbiosis in larger foraminifera. Symbiosis, 42, 63-75.

Lipps, J.H., Langer, M.R., 1999. Benthic foraminifera from the meromictic Mecherchar Jellyfish Lake, Palau (western Pacific). Micropaleontology, 45 (3), 278-284.

Liu, Q., Roberts, A., Larrasoaña, J., Banerjee, S., Guyodo, Y., Tauxe, L., Oldfield, F., 2012. Environmental Magnetism: Principles and applications. Reviews of Geophysics, 50, 393-442.

Loeblich, A. R., Tappan, H., 1964. Treatise on Invertebrate Paleontology, R.C. Moore (Ed) Protista-Sarcodina, 11, pp. 436-510.

Loeblich, A.R., Tappan, H., 1984. Suprageneric Classification of the Foraminiferida (Protozoa). Micropaleontology, 30 (1), 1-70.

Loeblich, A.R., Tappan, H., 1987. Foraminiferal Genera and Their Classification. Van Nostrand Reinhold, New York, 2 vols., 1182 p.

Loeblich, A.R., Tappan, H., 1988. Foraminiferal Genera and their classification Van Nostrand Reinhold, New York, pp. 545.

Loeblich, A. R., Tappan, H., 1992. Present status of foraminiferal classification. In "Studies in Benthic foraminifera. Proceedings of the Fourth Symposium on benthic foraminifera, Sendai, 1990". (Y. Takayanagi, and T. Saito, Eds.) Tokai University Press, Tokyo, pp. 93-102.

Loeblich, A.R., Tappan, H., 1994. Foraminifera of the Sahul Shelf and Timor Sea. Cushman Foundation for Foraminiferal Research Special Publication, 31, Washington.

Lykousis, V., Karageorgis, A.P., Chronis, G.Th., 2005. Delta progradation and sediment fluxes since the last glacial in the Thermaikos Gulf and the Sporades Basin, NW Aegean Sea, (Greece). Marine Geology, 222-223, 381-397.

Magurran, A.E., 1988. Ecological Diversity and Its Measurement. Princeton University Press, Princeton, N J.

Martins, M.V.A., Frontalini, F., Tramonte, K.M., Figueira, R.C., Miranda, P., Sequeira, C., Fernández-Fernández, S., Dias, J.A., Yamashita, C., RenóR, Laut, L.L., Silva, F.S., Rodrigues, M.A., Bernardes, C., Nagai, R., Sousa, S.H., Mahiques, M., Rubio, B., Bernabeu, A., Rey, D., Rocha, F., 2013. Assessment of the health quality of Ria de Aveiro (Portugal): Heavy metals and benthic foraminifera. Marine Pollution Bulletin, 70, 18-33.

Mazzini, I., Anadon, P., Barbieri, M., Castorina, F., Ferreli, L., Gliozzi, E., Mola, M., Vittori, E., 1999. Late Quaternary sea-level changes along the Tyrrhenian coast near Orbetello (Tuscany, Central Italy): palaeoenvironmental reconstruction using ostracods. Marine Micropalaeontology, 37, 289-311.

Melis, R., Violanti, D., 2006. Foraminiferal biodiversity and Holocene evolution of the Phetchaburi coastal area (Thailand Gulf). Marine Micropaleontology, 61 (1-3), 94-115.

Mendes, I., Gonzalez, R., Dias, J.M.A., Lobo, F., Martins, V., 2004. Factors influencing recent benthic foraminifera distribution on the Guandiana shelf (Southwestern Iberia). Marine Micropaleontology, 51, 171-192.

Milker, Y., 2010. Western Mediterranean shelf foraminifera: Recent distribution, Holocene sea level reconstructions, and paleoceanographic implications. PhD Thesis, Hamburg, pp. 191.

Milker, Y., Schmiedl, G., Betzler, C., Römer, M., Jaramillo-Vogel, D., Siccha, M., 2009. Distribution of recent benthic foraminifera in neritic carbonate environments of the western Mediterranean Sea, Marine Micropaleontology, 70, 207-225.

Mojtahid, M., Jorissen, F., Landsard, B., Fortanier, C., Bombled, B., Rabouille, C., 2009.Spatial distribution of live benthic foraminifera in the Rhone prodelta: faunal response to a continental-marine organic matter gradient. Marine Micropaleontology, 70, 177-200.

Moulfi-El-Houari, L., Ambroise, D., Mathieu, R., 1999. Distribution des foraminifères bentiques actuels sur la marge continentale Argéroise (Baie de Bou-Ismaıl). Revue Micropaléontologique, 42, 315-327.

Murray, J.W., 1991. Ecology and Palaeoecology of Benthic Foraminifera. Longman, Wiley, Harlow /Essex, New York, p. 397.

Murray, J.W., 2006. Ecology and applications of Benthic Foraminifera. Cambridge University Press, New York, p. 426.

Murray, J.W., 2007. Ecology and Applications of Benthic Foraminifera. Cambridge University Press, p. 426.

Palma-Silva, C., Albertoni, E.F., Esteves, F.A., 2004. Charophytes as a nutrient and energy reservoir in a tropical coastal Lagoon impacted by humans (RJ, Brazil). Brazilian Journal of Biology, 64 (3A), 479-87.

Pavlopoulos, K., Theodorakopoulou, K., Bassiakos, Y., Hayden, B., Tsourou, T., Triantaphyllou, M., Kouli, K., Vandarakis, D., 2007. Paleoenvironmental evolution of Istron (N.E. Crete), during the last 6000 years: depositional environment, climate and sea level changes. Geodinamica Acta, 20 (4), 219-229.

Pavlopoulos, K., Kapsimalis, V., Theodorakopoulou, K., Panagiotopoulos, I.P., 2011. Vertical displacement trends in the Aegean coastal zone (NE Mediterranean) during the Holocene assessed by geoarchaeological data. The Holocene, 22 (6), 717-728.

Pielou, E.C., 1975. Ecological Diversity. John Wiley and Sons. New York, pp 165.

Piper, D.J.W., Perissoratis, C., 1991. Late Quaternary sedimentation on the north Aegean continental margin, Greece. American Association of Petroleum Geologists Bulletin, 75 (1), 46-61.

Poulos, S.E., Chronis, G.T., Collins, M.B., Lykousis, V., 2000. Thermaikos Gulf coastal system, NW Aegean Sea: an overview of water/sediment fluxes in relation to air–land–ocean interactions and human activities. Journal of Marine Systems, 25, 47-76.

Psilovikos, A., 1977. Paleogeographic evolution of the Megdonia Basin, PhD, Aristotle University of Thessaloniki, Greece (in Greek).

Redois, F., 1996. Les foraminifères benthiques actuels bioindicateurs du milieu marin: Exemples du plateau continental Sénégalais et de l'estran du Golfe du Morbihan (France). Thèse de Doctorat, Université d'Angers, 1-2, pp. 450.

Robinson, A.R., Leslie, W.G., Theocharis, A., Lascaratos, A., 2001. Mediterranean Sea circulation. Encyclopedia of Ocean Science, 3, 1689-1705.

Saraswati, P.K., 2002. Growth and habitat of some recent miliolid foraminifera: Paleogeological implications. Current Science, 82 (1),81-84.

Saraswati, P.K., Shimoike, K., Iwao, K., Mitra, A., 2003. Distribution of larger foraminifera: in the reef sediments of Akajima, Okinawa, Japan. Journal of Geological Society of India, 61, 16-21.

Simpson, E.H., 1949. Measurement of Diversity. Nature, 163, 688.

Sgarrella, F., Moncharmont-Zei, M., 1993. Benthic foraminifera of the Gulf of Naples (Italy): systematics and autoecology. Bollettino della Società Paleontologica Italiana, 32, 145-264.

Semeniuk, T.A., 2000. Spatial variability in epiphytic foraminifera from micro- to regional scale. Journal of Foraminifera Research, 30, 99-109.

Sen Gupta, B.K. (Ed.), 2003. Modern Foraminifera. Kluwer Academic Publishers, Dordrecht.

Serandrei-Barbero, R., Albani, A.D., Zecchetto, S., 1997. Palaeoenvironmental significance of a benthic foraminiferal fauna from an archaeological excavation in the Lagoon of Venice, Italy. Palaeogeography, Palaeoclimatology, Palaeoecology, 136, 41-52.

Shannon, C. E., Weaver, W.,1949. The Mathematical Theory of Communication. Urbana, IL: The University of Illinois Press, 1-117.

Syrides, G., 1990. Lithostratigraphical, biostratigraphical and paleogeographical study of the Neogene-Quaternary sedimentary sequence of Chalkidiki peninsula. Doctorate Thesis, School of Geology, Aristotle University of Thessaloniki, Thessaloniki, pp. 320 (in Greek).

Syrides, G., Albanakis, K., Vouvalidis, K., Pilali-Papasteriou, A., Papaefthimiou-Papanthimou, A., Ghilardi, M., Fouache, E., Paraschou, T., Psomiadis, D., 2009. Holocene Palaeogeography of the Northern Margins of Giannitsa Plain in Relation to the Prehistoric Site of Archontiko (Macedonia-Greece). Z. Geomorphol. Suppl., 53, 71-82.

Tarnowska, K., Wołowicz, M., Chenuil, A., Féral, J.P., 2009. Comparative study on the morphometry and physiology of the European populations of the lagoon specialist *Cerastoderma glaucum* (Bivalvia). Oceanologia, 51 (3), 437-458.

Todo, Y., Kitazato, H., Hashimoto, J., Gooday, A.J., 2005. Simple Foraminifera flourish at the ocean's deepest point. Science, 307, 689.

Tragou, E., Josey, S., Zervakis, V., Maderich, V., Theocharis A., 2005. Identifying signatures of dense water formation events over the Aegean Sea in the last fifty years. European Geosciences Union, 7, 08769.

Travis, J.L., Bowser, S.S., 1991. The motility of foraminifera, in: Biology of Foraminifera. J. Lee and O. R. Anderson, eds., Academic Press, London, pp. 91-155.

Triantaphyllou, M.V., Pavlopoulos, K., Tsourou, T., Dermitzakis, M.D., 2003. Brackish marsh benthic microfauna and paleoenvironmental changes during the last 6.000 years on the coastal plain of Marathon (SE Greece). Rivista Italiana Paleontologia et Stratigrafia, 109 (3), 539-547.

Triantaphyllou, M.V., Tsourou, T., Koukousioura, O., Dermitzakis, M.D., 2005. Foraminiferal and ostracod ecological patterns in coastal environments of SE Andros Island (Middle Aegean Sea, Greece). Revue de Micropaléontologie, 48 (4), 279-302.

Triantaphyllou, M.V., Kouli, K., Tsourou, T., Koukousioura, O., Pavlopoulos, K., Dermitzakis, M.D., 2010b. Paleoenvironmental changes since 3000 BC in the coastal marsh of Vravron (Attica, SE Greece). Quaternary International, 216, 14-22.

Triantaphyllou, M. V., Tsourou, T., Kouli, K., Koukousioura, O., Dimiza, M.D., Aidona, E.V., Syrides, G., Antoniou, V., Panagiotopoulos, I.P., Vandarakis, D., Pallikarakis, A., Cheilaris, S., Skampa, E., Goiran, J.P., Fouache, E., Pavlopoulos, K.P., 2021. Paleoenvironmental evolution and sea level change in Saronikos gulf (Aegean sea, Greece): Evidence from the Piraeus coastal plain and elefsis bay sedimentary records. Water, 13, 1-23.

Van der Zwaan, G.J., Duijnstee, I.A.P., den Dulk, M., Ernst, S.R., Jannick, N.T, Kouwenhoven, T.J., 1999. Benthic foraminifers: proxies or problems? A review of paleoecological concepts. Earth-Science Reviews, 46, 213-236.

Van Der Zwaan, G.J., 2000. Variation in natural vs. anthropogenic eutrophication in shelf areas in front of major rivers. In: Martin, R.E. (Ed.), Environmental Micropaleontology. Kluwer Acad., New York, pp. 385-404.

Vickerman, K., 1992. The diversity and ecological significance of Protozoa. Biodiversity and Conservation, 1, 334-341.

Vouvalidis, K., Syrides, G., Albanakis, K.S., 2005. Holocene morphology of the Thessaloniki Bay: impact of sea-level rise. Zeitsch Geomorphol N.F, 137, 147-158.