

The Ypresian to Lutetian marine record in NW Turkey: a revised biostratigraphy and chronostratigraphy and implications for Eocene paleogeography

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Abstract: The Eocene sedimentary units in the Kocaeli and Armutlu peninsulas and İznik-Geyve region (northwest Turkey) consist of marine siliciclastic and carbonate deposits, locally intercalated with volcanoclastic rocks and tuffs (Middle Eocene Magmatic Rocks-MEMR). The record of larger benthic fauna (LBF) and pelagic microfossils, such as planktonic foraminifera and calcareous nannoplankton, combined with lithological description, indicate a wide spectrum of depositional environments ranging from shallow- to deep-marine. These deposits contain in situ and/or allochthonous assemblages of orthophragminids, nummulitids, subordinate rotaliids, and sparse alveolinids. The in situ assemblages (mainly orthophragminids) point to several episodes of shallow marine depositional conditions during a) early Ypresian (SBZ 5-7 and 7-9), b) late Ypresian (SBZ 10-11), c) early Lutetian (SBZ 13), and d) middle Lutetian (SBZ 14-15). Upper Ypresian (Cuisian) deposits with rich LBF accumulations are the most ubiquitous, recognized across a wide region from the Thrace Basin to Central Anatolia. Lower Lutetian deposits, on the other hand, occur in a limited area only near the town of Şile, on the coast of the Black Sea. Orthophragminids immediately below the first volcanoclastic beds of the MEMR constrain the initiation of the volcanism to the latest Ypresian or around the Ypresian/Lutetian boundary. The LBF assemblages from the clastic intercalations of the MEMR are referred to SBZ 14-15 and indicate that the marine realm in the Armutlu and Kocaeli peninsulas persisted until middle Lutetian. Since then, continental conditions have prevailed in the region, while a marine realm has developed in the Thrace Basin during the late Middle to Late Eocene and Oligocene. The deep-marine Eocene deposits with pelagic microfossils and allochthonous LBF are mostly confined to the Ypresian. The allochthonous orthophragminids in these deep-marine deposits are also presented here to give a broader picture of their occurrence in NW Turkey.

Key words: Larger benthic foraminifera, orthophragminids, biostratigraphy, chronostratigraphy, Eocene, NW Turkey

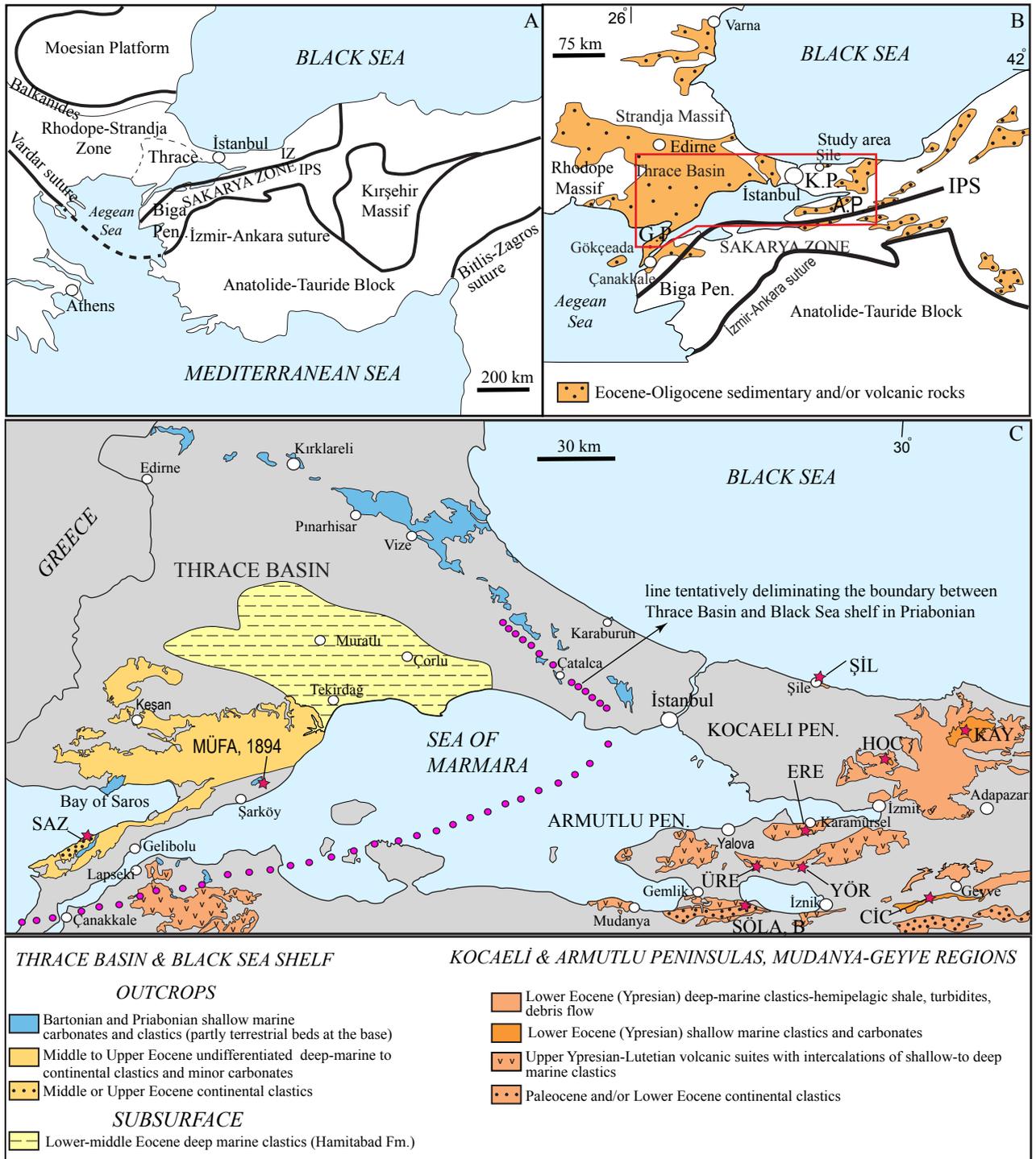
1. Introduction

The Eocene sedimentary record in northwestern (NW) Turkey includes a wide range of deposits ranging from terrestrial and shallow marine siliciclastic and carbonate rocks to deep-marine fine siliciclastic rocks and associated turbidites and mélanges (Baykal, 1943; Akartuna, 1968; Baykal and Önal, 1979; Bargu and Saka, 1990; Genç and Yılmaz 1997; Okay et al., 2010; Less et al., 2011; Özcan et al., 2007, 2010, 2012, 2018; Akbayram et al., 2016a). These deposits are extensively exposed in the Thrace Basin (including the northern part of the Biga Peninsula and Black Sea shelf sensu Okay et al., 2019) in the west and Kocaeli and Armutlu peninsulas in the east and in the İznik-Pamukova-Geyve region in close proximity to the Intra-Pontide suture zone (Figure 1). Eocene deposits

are associated with latest Ypresian-Lutetian volcanoclastic rocks and acidic tuffs in the Armutlu and Biga peninsulas (Özcan et al., 2012; 2018; Gülmez et al., 2013), and present a dynamic and complex stratigraphic development from Ypresian to the late Eocene (Priabonian) (Özcan et al., 2007; 2010; 2012, 2018; Less et al., 2007, 2011). However, these deposits do not present a uniform stratigraphic development and differences become more obvious along an E-W transect when comparing the middle to upper Eocene stratigraphy in the Thrace Basin and of the Kocaeli and Armutlu peninsulas.

We present our paleontological and biostratigraphic results based on the study of larger benthic fauna (LBF), mainly orthophragminids, from various shallow- to deep-marine Ypresian to Lutetian units in NW Turkey.

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Where available, planktonic foraminifera and calcareous nanofossils, either associated with LBF or identified in the same section with LBF, were integrated to present a composite biostratigraphic framework. The biostratigraphy of the Bartonian to Priabonian sequences, which are restricted to the Thrace Basin and its extension to the northern parts of the Biga Peninsula, are recently described in Özcan et al. (2010, 2018), Less et al. (2011), and Okay et al. (2019).

2. Geological setting and stratigraphy

In northwestern Turkey Eocene series crop out over a very wide area comprising the Strandja Massif, Istanbul, and Sakarya zones. At present three large basins are superimposed on this area: the Thrace Basin, the Marmara Sea, and the Black Sea. The Thrace Basin is a Middle-Late Eocene to Oligocene depocenter, (Kopp et al., 1969; Doust and Arıkan, 1974; Turgut et al., 1991) whereas the Marmara Sea started to form during the Pliocene through the activity of the North Anatolian Fault (cf., Yaltrak, 2002; Akbayram et al., 2016b). The Marmara Sea did not exist as a separate basin in the Eocene. The Black Sea has been in existence since its Cretaceous opening as a back-arc basin and has been a site of continuous sedimentation since the Late Cretaceous (e.g., Nikishin et al., 2015).

The Eocene series in northwestern Turkey can be separated into two major groups: a Lower to Middle Eocene (Ypresian-Lutetian) series separated by a major

unconformity from a Middle to Upper Eocene (Bartonian-Priabonian) series. The latter is found only in the Thrace Basin.

2.1. Lower-Middle Eocene (Ypresian-Lutetian) series

The Lower-Middle Eocene series were most probably deposited over the whole of northwestern Turkey including Thrace but were eroded from many areas during Lutetian uplift so that in many regions, such as the Biga Peninsula or the northern margin of the Gulf of Saros, the Middle-Upper Eocene series lies unconformably over basement.

The Lower-Middle Eocene series crop out widely east of the Marmara Sea. On the Armutlu and Kocaeli peninsulas north of İznik Lake, a Lower Eocene turbiditic clastic sequence of sandstone, shale and conglomerate, the Çaycuma Formation, lies stratigraphically over Maastrichtian to Paleocene marl and limestone (Özcan et al., 2012). To the east of the Armutlu Peninsula, Campanian–Lower Eocene debris flows are mapped south of Sapanca Lake (Akbayram et al., 2016a). In the present study, the Çaycuma Formation was biostratigraphically studied in the Hocalar, Kaynarca, Ereğli and Yörükler sections (Figures 1–4). On the Armutlu Peninsula, the Çaycuma Formation is stratigraphically overlain by a thick sequence of Lutetian volcanoclastic and volcanic rocks, the Kızderdent volcanics. Isotopic ages from the Kızderdent volcanics ranging from 52 to 38 Ma indicate a late Ypresian to Bartonian age for the volcanism (Ercan et al., 1998; Kürkçüoğlu et al., 2008; Gülmez et al., 2013).

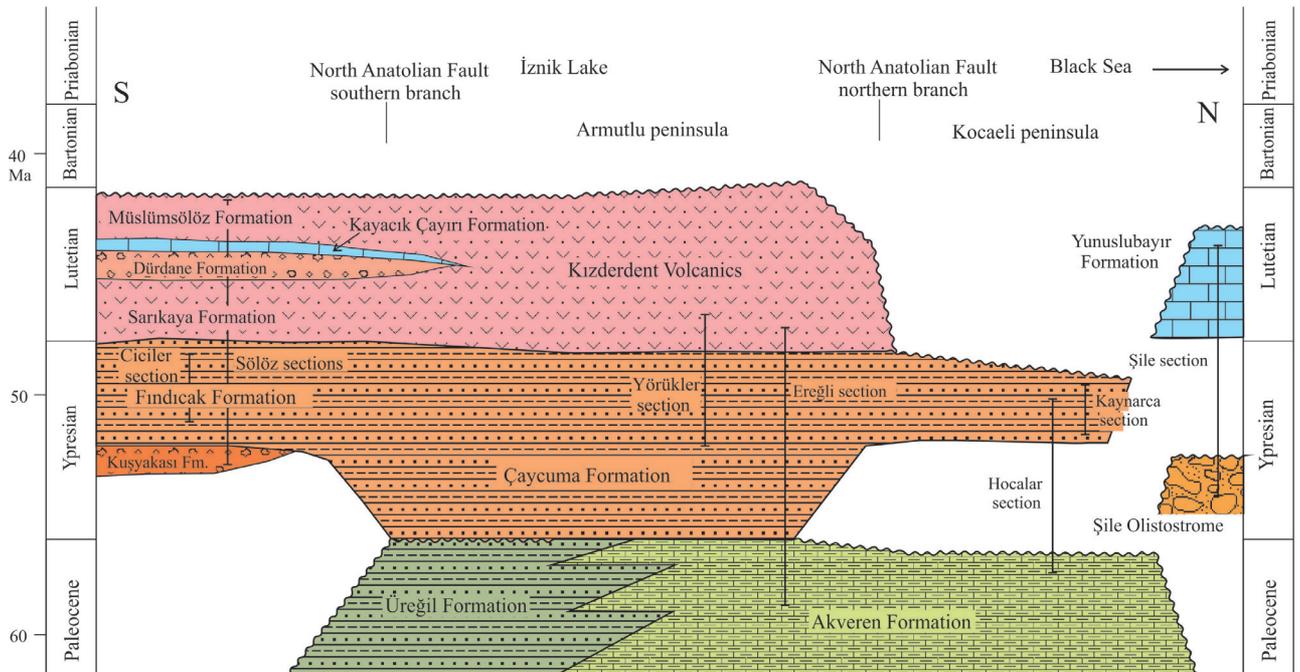


Figure 2. Stratigraphic and chronostratigraphic framework of the Eocene sequences from the Kocaeli and Armutlu peninsulas and İznik-Geyve region (northwestern Turkey) and position of the studied sections.

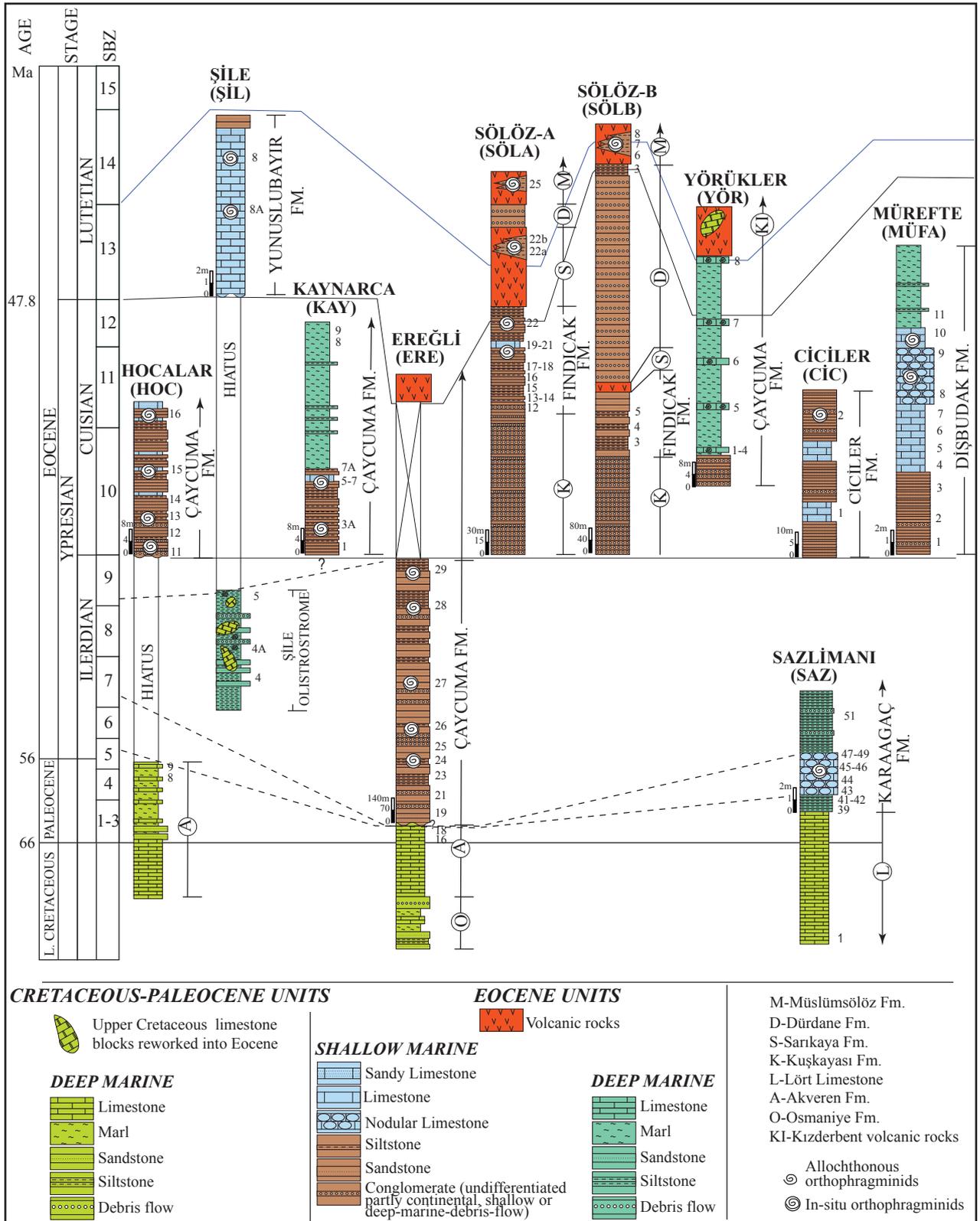


Figure 3. Generalized stratigraphic columns of the studied sections and biostratigraphy. The numbers at the right of the columns indicate sample numbers. The shallow benthic zones (SBZ) follow Serra-Kiel et al. (1998). Correlation of stage boundaries to time scale after Vandenberghe et al. (2012).

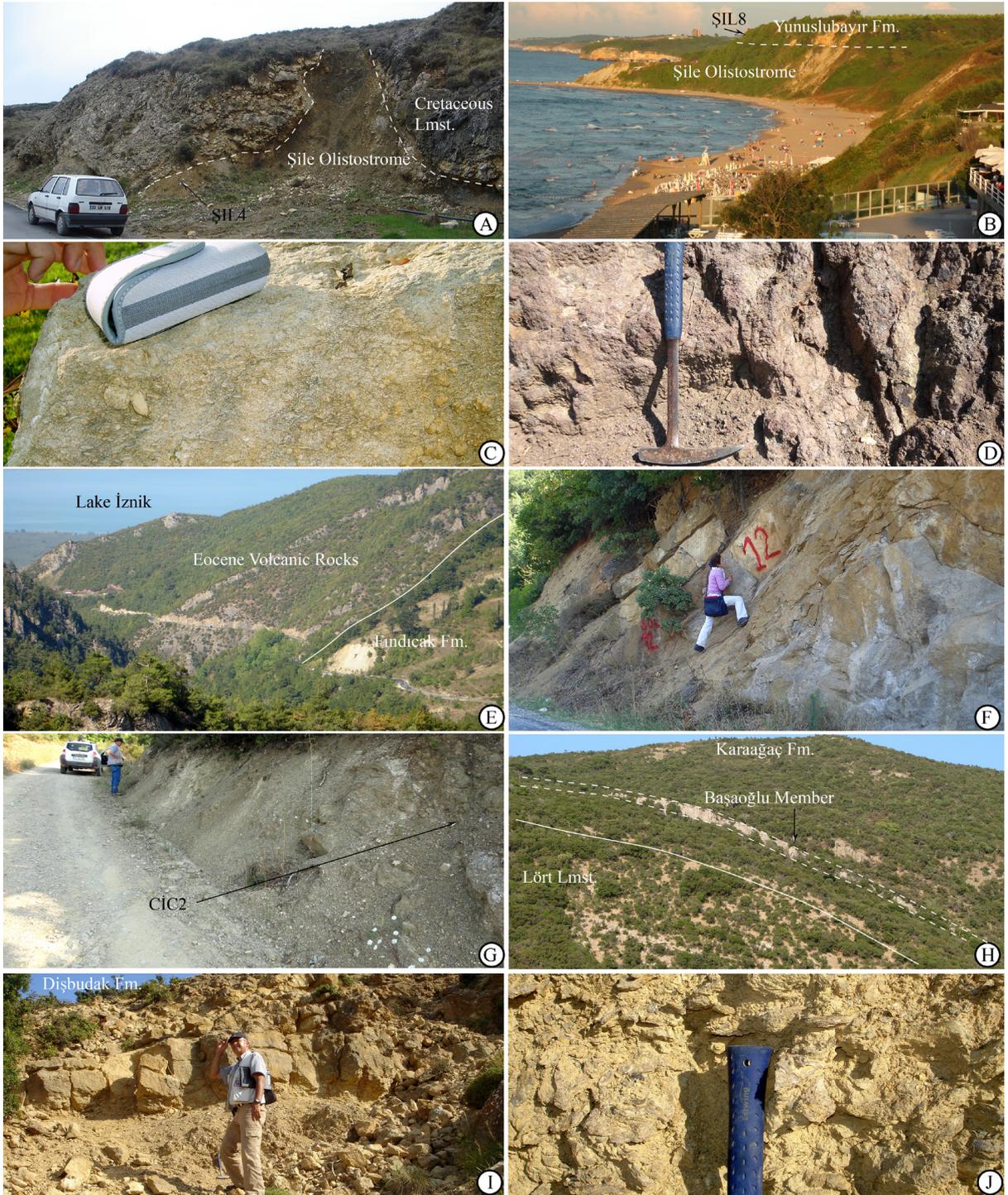


Figure 4. Field aspects of the shallow-to deep-marine Eocene units in NW Turkey. (A), Şile Olistostrome with late Cretaceous limestone blocks. (B), Relation of Şile Olistostrome and unconformable Yunuslubayır Formation near Şile. (C), A fossiliferous limestone bed of the Çaycuma Formation (Kaynarca section, sample 7, Kocaeli Peninsula). (D), Volcanic rocks immediately above the deep-marine sequence of the Çaycuma Formation in the Yörükler section (Armutlu Peninsula). (E), panoramic view of the Fındıcak Formation and overlying volcanoclastic rocks in SölözA section, south of Lake İznik. (F), Fossiliferous beds of the Fındıcak Formation in SölözA section. (G), clastic levels of the Ciciler Formation with abundant LBF (sample 2) in Ciciler section. (H), Panoramic view of the Başağlı Member of the Karaağaç Formation in the Gelibolu Peninsula. (I-J), Dişbudak Formation near Şarköy (Gelibolu Peninsula) with an oyster bed at its base (J).

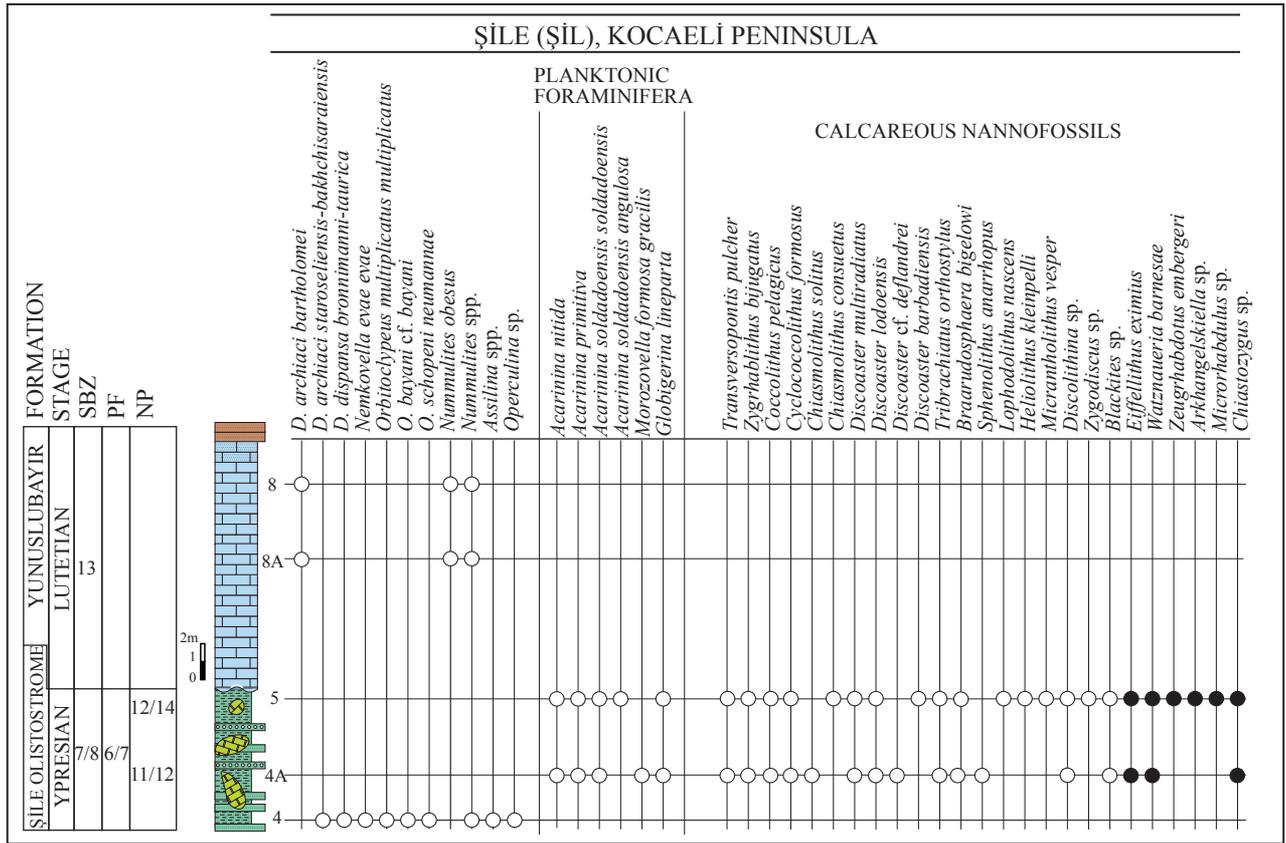


Figure 5. Distribution of LBF, planktonic foraminifera and calcareous nannofossils in Şile (ŞİL) section. Black circles indicate reworked nannofossils.

On the Black Sea coast, the Early Eocene is represented by the Şile Olistostrome consisting of Cretaceous limestone blocks in a silty, sandy matrix (Baykal and Önalın, 1979), which is unconformably overlain by Lutetian limestones of the Yunuslubayır Formation (Özcan et al., 2010).

The region south of the southern strand of the North Anatolian Fault presents a more complex depositional pattern during the Eocene. South of İznik Lake, Lower Eocene conglomerates (Kuşyakası Formation) rest unconformably over Cretaceous series and pass up into a Lower Eocene clastic sequence with limestone intercalations (Fındıcak Formation, Genç, 1986; Özcan et al., 2012). The Fındıcak Formation was studied in the Sölöz A and B sections (Figures 1–4). The Lower Eocene clastic and carbonate rocks extend to the east of İznik Lake, where they are known as the Ciciler Formation. The Çaycuma, Fındıcak and Ciciler formations and their equivalents in Thrace (the Hamitabad Formation) represent a thick and widespread Lower Eocene clastic apron deposited over the whole of northwestern Turkey (Figure 2). South of İznik Lake, the Fındıcak Formation passes up into Lutetian volcanic and volcanoclastic rocks with sandstone and limestone intercalations (Sarıkaya Formation), which

is overlain by thick fluvial conglomerates (Dürdane Formation, Özcan et al., 2012). A thin horizon of Lutetian shallow marine limestones (Kayacık Çayırđ Formation) intervenes between the Dürdane Formation and the overlying Lutetian volcanoclastic and volcanic rocks of the Müslümsölöz Formation (Figure 2, Genç, 1986; Özcan et al., 2012).

The largest single continuous occurrence of the Lower-Middle Eocene series in northwestern Turkey is in the subsurface in Thrace, where it is known through boreholes and traced in seismic sections (e.g., Turgut et al. 1991, Siyako and Huvaz, 2007). It is generally called the Hamitabad Formation, has a thickness of over 1000 m, and consists predominantly of sandstone, conglomerate, shale, and tuff. In many seismic sections it can be seen to be in unconformable contact below Middle-Upper Eocene limestones of the Soğucak Formation (Siyako and Huvaz, 2007; Okay et al., 2019). However, in the center of the Thrace Basin, in the area between Tekirdağ and Muratlı, the Hamitabad Formation can be observed in seismic sections to be conformably overlain by Middle-Upper Eocene clastic rocks (Siyako and Huvaz, 2007). This region is possibly the only locality in northwestern Turkey where

ŞİLE SECTION, ŞİLE OLISTOSTROME & YUNUSLUBAYIR FORMATION, KOCAELI PENINSULA

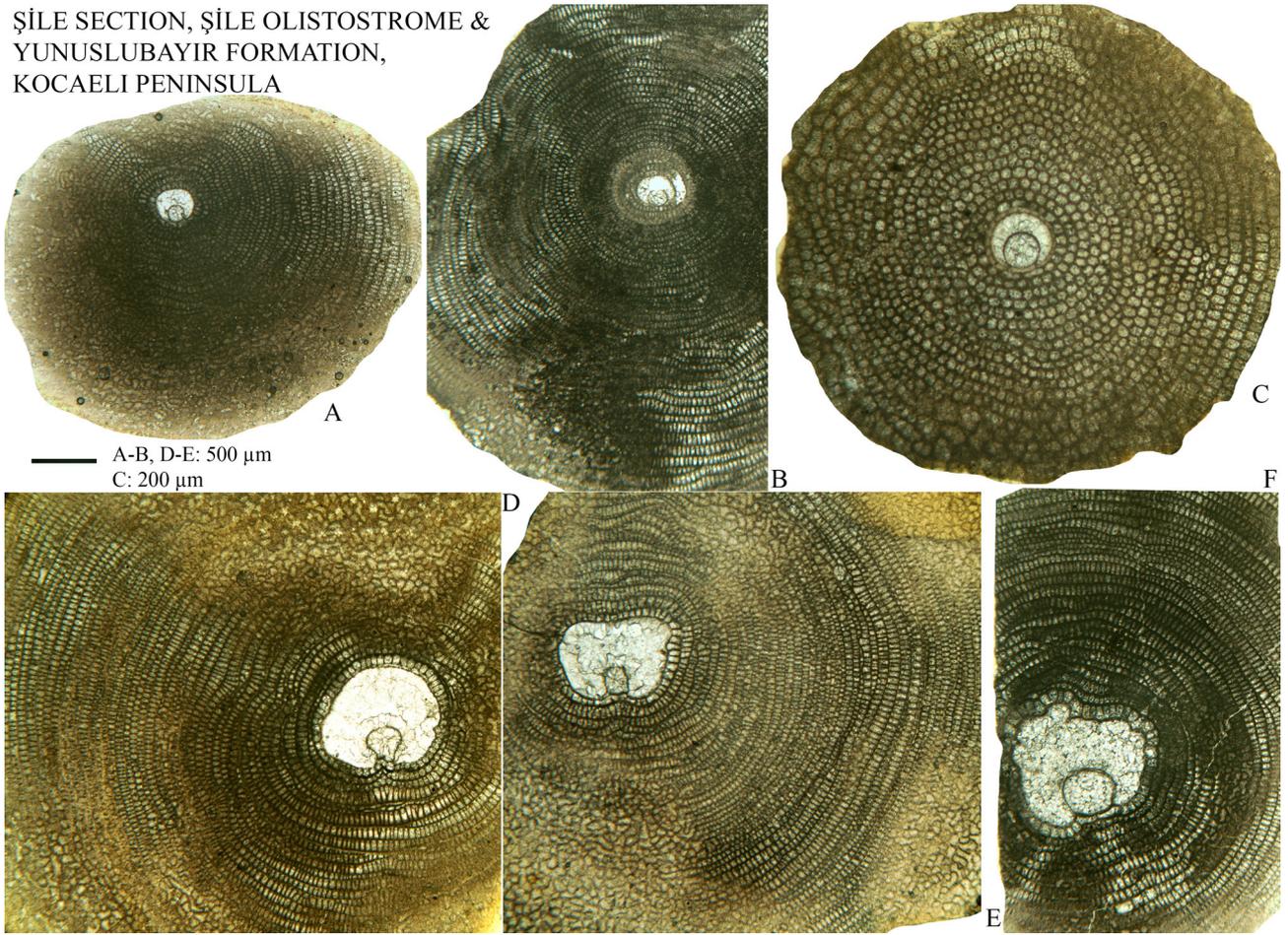


Figure 6. Orthoconchaminids from the Şile section. (A–B), *Discocyclusina archiaci* (Schlumberger) *staroseliensis-bakhchisaraiensis* Less. (C), *Orbitoclypeus schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine). (D–F), *Discocyclusina archiaci bartholomei* (Schlumberger). A: ŞİL4-102, B: ŞİL4-120, C: ŞİL4-106, D: ŞİL8-3, E: ŞİL8-2, F: ŞİL8-4.

there was continuous sedimentation throughout much of the Eocene.

The probable equivalents of the Hamitabad Formation crop out in three localities in Thrace. The best and most continuous section is in the Ganos Mountain southwest of Tekirdağ, where there is an over-3-km-thick regressive Eocene clastic series ranging from distal to proximal turbidites and to deltaic deposits (Kopp et al., 1969; Doust and Arıkan, 1974). At the base of the exposed section, there is a shale and siltstone succession, 855-m thick, called the Gaziköy Formation. Scattered zircon U-Pb ages from a single tuff sample from the Gaziköy Formation suggest an Early Eocene (ca. 51 Ma) depositional age (Elmas et al., 2016). The Gaziköy Formation passes up into the more proximal turbidites of the Middle Eocene Keşan Formation, which is in turn overlain by the deltaic shales and sandstones of the Upper Eocene–Lower Oligocene Mezardere Formation. In subsurface in the Thrace, the

Mezardere Formation is mostly Oligocene in age (Gürgey and Batı, 2018). Documented biostratigraphic data on the age of the thick, continuous, and well-exposed Ganos Eocene section is lacking.

In Thrace, south of the Ganos Fault there are two isolated outcrops of Lower Eocene rocks. In the Mürefte section northeast of Şarköy, a 30-m thick sequence of sandstone, conglomerate, and limestone of late Ypresian age is unconformably overlain by Upper Bartonian–Priabonian limestones of the Soğucak Formation (Özcan et al., 2010; Okay et al., 2010). This Dişbudak series has wide distribution in the subsurface. The second known outcrop of the Lower Eocene is on the northern shores of the Gelibolu Peninsula, where a fine-grained clastic sequence with limestone intercalations or olistoliths, the Karaağaç Formation, lies over Upper Cretaceous–Paleocene pelagic limestones (Önal, 1986; Özcan et al., 2010).

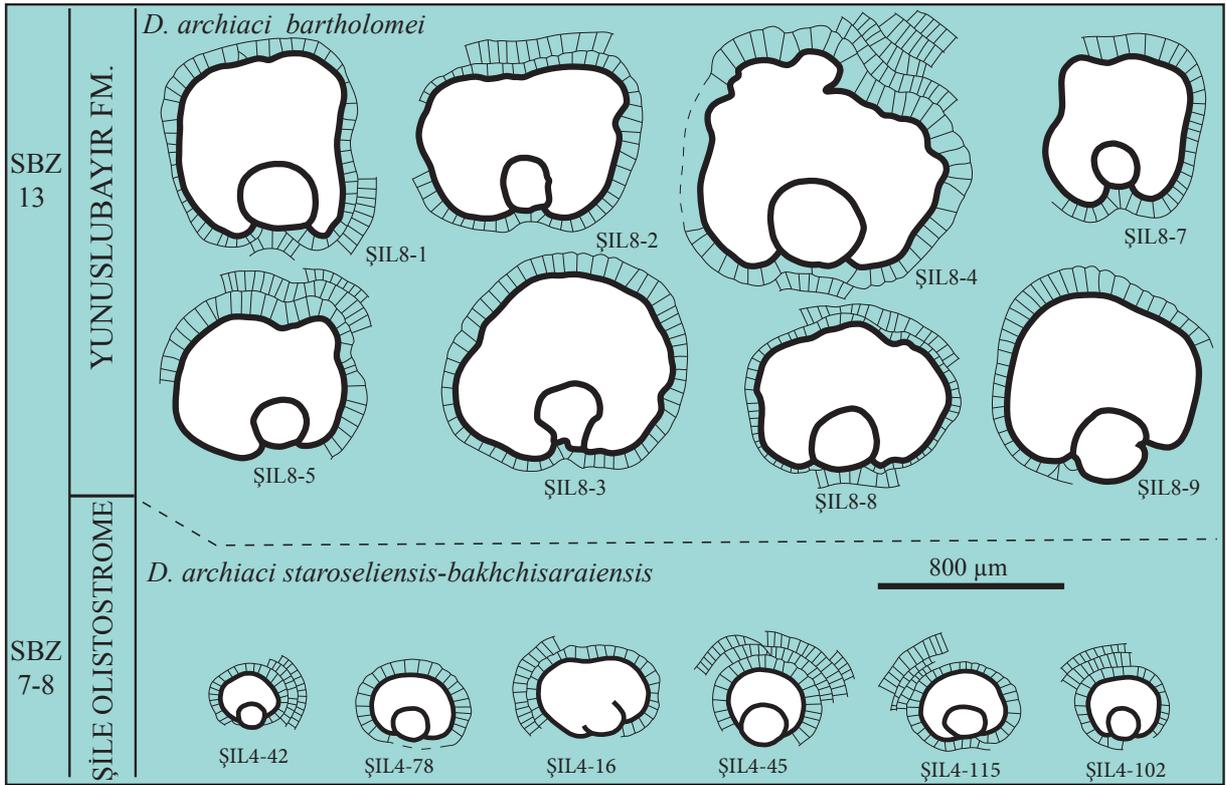


Figure 7. Comparison of the embryonic stages of the *Discocyclina archiaci* specimens from the Şile Olistostrome and the Yunuslubayır Formation.

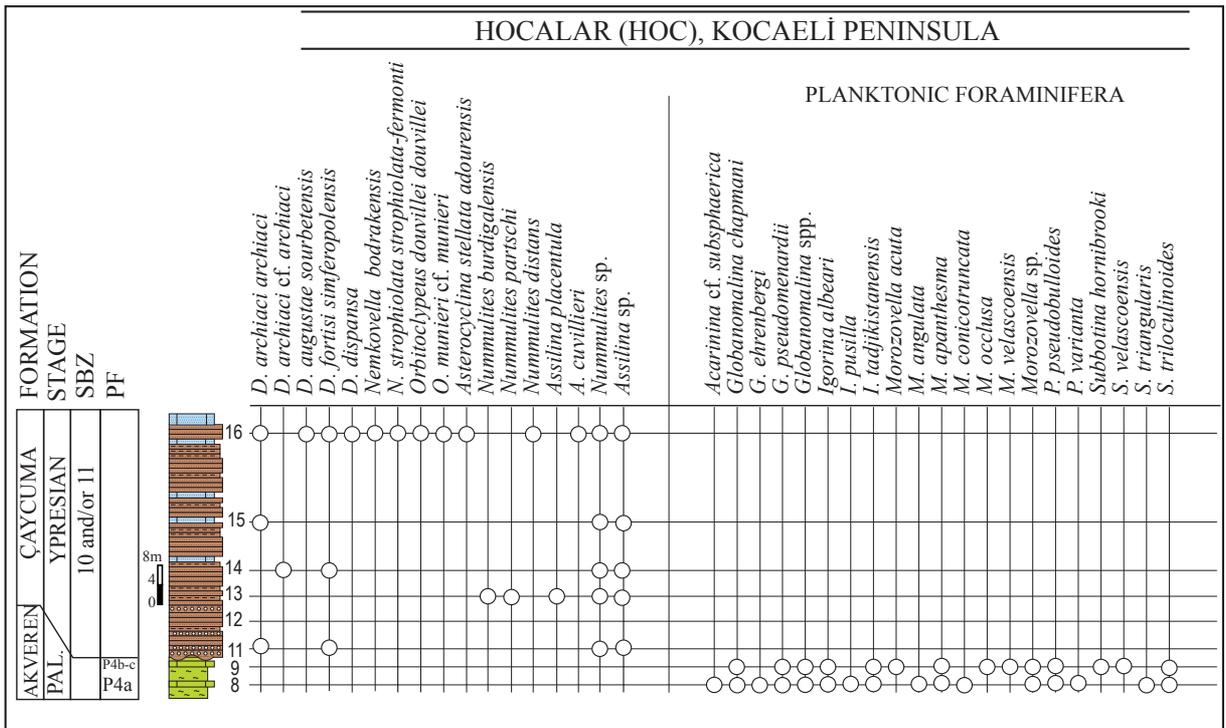


Figure 8. Distribution of LBF and planktonic foraminifera in Hocalar (HOC) section.

KAYNARCA SECTION, ÇAYCUMA FORMATION, KOCAELI PENINSULA

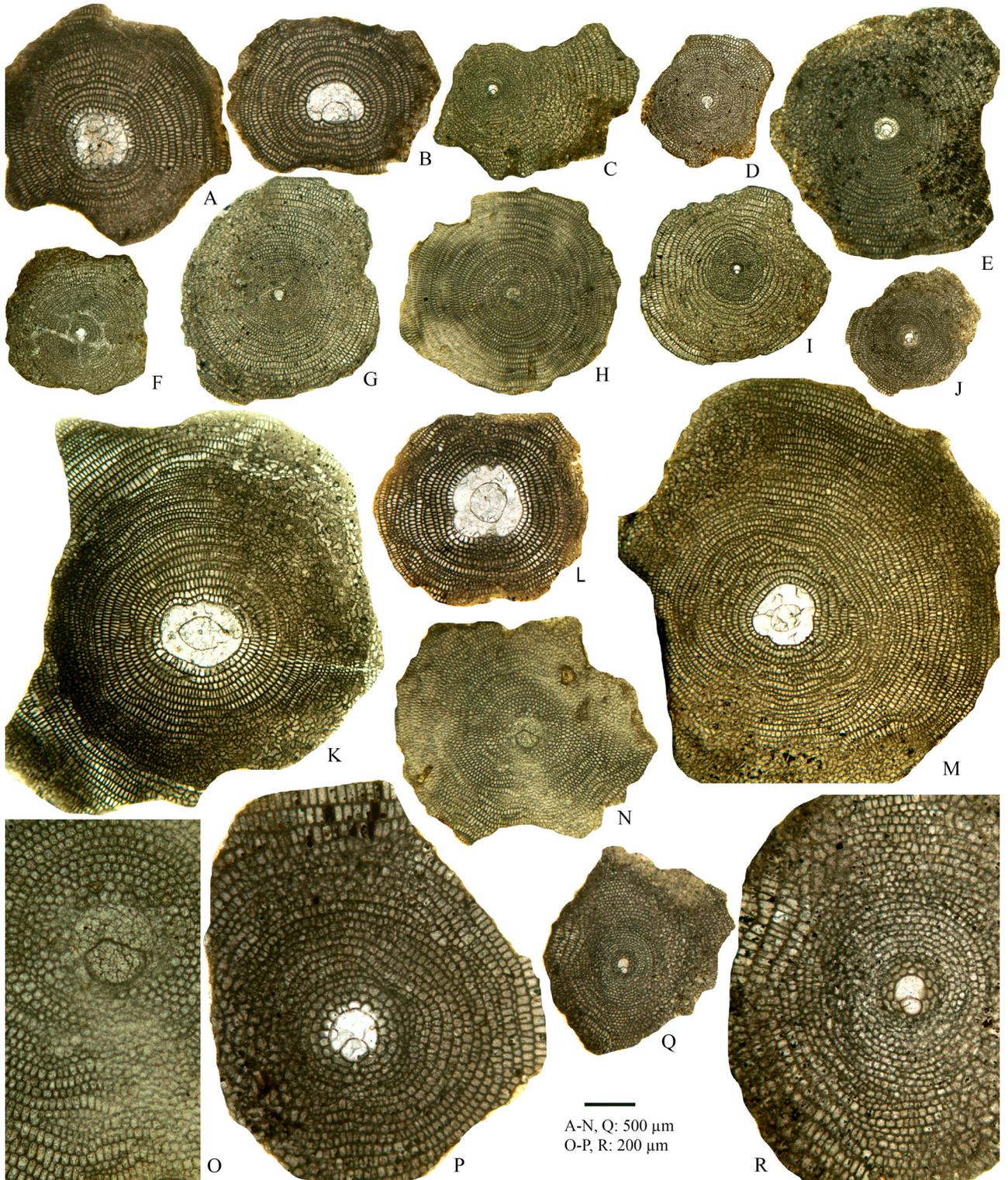


Figure 11. Orthophragminids from the Kaynarca section. (A–B), *Discocyclusina archiaci archiaci* (Schlumberger). (C–H), *D. augustae sourbetensis* Less. (I–J), *D. trabayensis* Neumann. (K–M), *D. fortisi fortisi* (d’Archiac). (N–R), *Nemkovella evae evae* Less. A: KAY3A-39, B: KAY3A-55, C: KAY3A-64, D: KAY3A-62, E: KAY3A-60, F: KAY3A-59, G: KAY3A-78, H: KAY5-10, I: KAY3A-45, J: KAY3A-79, K: KAY3A-1, L: KAY3A-6, M: KAY3A-20, N–O: KAY5-18, P: KAY3A-70, Q–R: KAY3A-71.

KAYNARCA SECTION, ÇAYCUMA FORMATION, KOCAELI PENINSULA

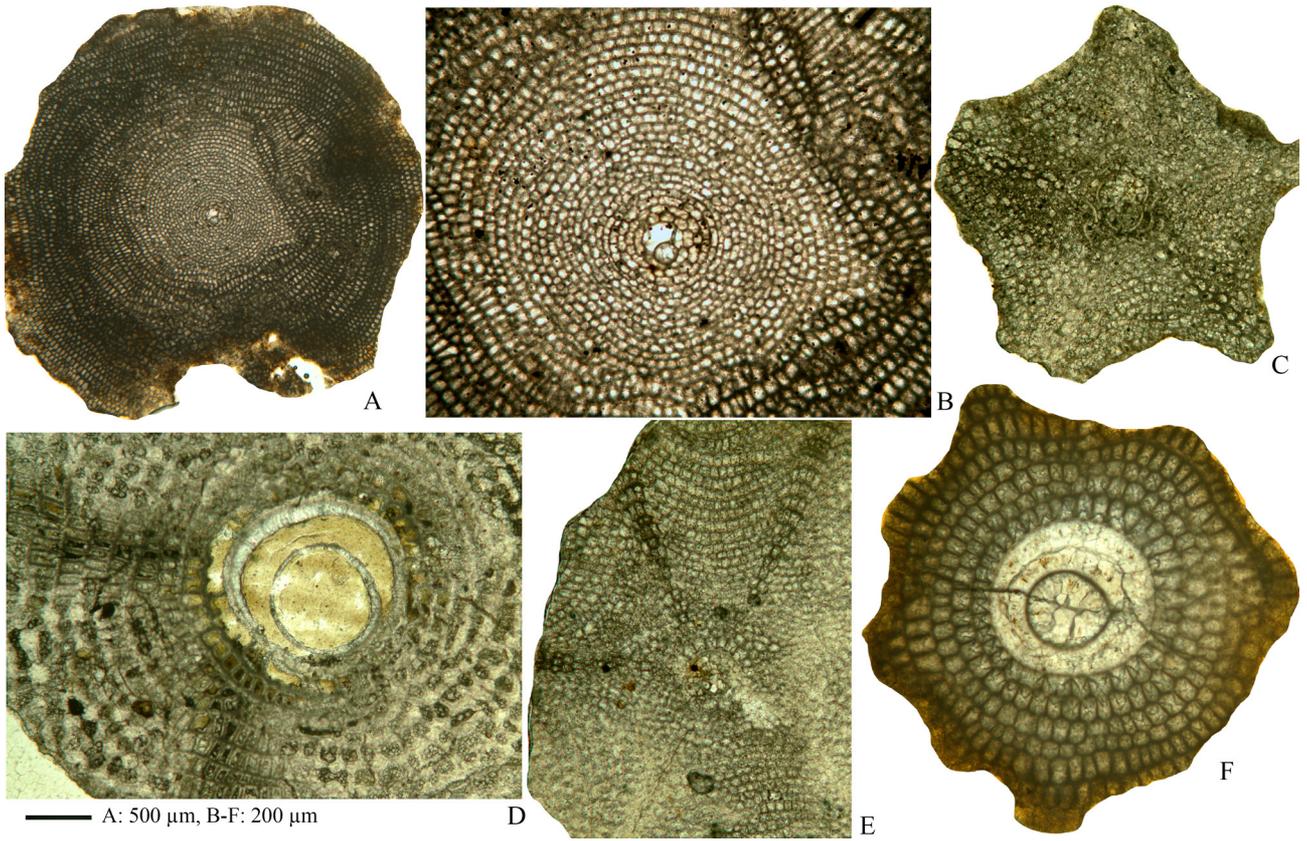


Figure 12. Orthoconch fossils from the Kaynarca section. (A–B), *Nemkovella strophiolata strophiolata* (Gümbel)-*fermonti* Less. (C), *Asterocyclina alticostata* (Nuttall) *gallica* Less. (D), *Orbitoclypeus multiplicatus kastamonuensis* Less & Özcan. (E), *O. furcatus* (Rüttimeyer). (F), *O. koehleri* Less. A-B: KAY3A-73, C: KAY7-23, D: KAY7A-20, E: KAY7A-18, F: KAY7-12.

2.2. Middle-Upper Eocene (Bartonian-Priabonian) series

The deposition of the Lower-Middle Eocene series was followed by regional uplift and erosion during the Lutetian. The subsequent marine transgression in the Middle-Late Eocene (Bartonian-Priabonian) occurred only in Thrace and on the northern margin of the Biga Peninsula; the rest of northwestern Turkey stayed above sea-level. The base of the Eocene transgression in Thrace is commonly marked by a shallow marine limestone series, the Soğucak Formation. On the margins of the Thrace Basin, the Soğucak Formation rests unconformably on the metamorphic rocks of the Strandja Massif and Circum-Rhodope Massif in Thrace (Özcan et al. 2010; Okay et al., 2010; Less et al., 2011) and on the Çamlıca metamorphic rocks in the Biga Peninsula (Özcan et al., 2018). In the Thrace Basin itself the Soğucak Formation lies unconformably over the Lower-Middle Eocene (Ypresian-Lutetian) Hamitabad and Dişbudak formations; only in the center of the basin in the Ganos Mountain and in the Tekirdağ-Gelibolu area, the Soğucak Formation is absent and there was probably continuous clastic deposition

from the Ypresian to the Bartonian (Siyako and Huvaz, 2007). The age of the Soğucak Formation, hence the age of the transgression, ranges from late Lutetian to Bartonian and Priabonian. The Soğucak Formation is overlain by Priabonian and Oligocene clastic sequences, which characterize the bulk of the Thrace Basin sequence (Turgut et al., 1991; Özcan et al., 2010; Okay et al., 2010; Less et al., 2011).

3. Materials and methods

The studied material was collected from ten stratigraphic sections in the Kocaeli and Armutlu peninsulas, the İznik-Geyve region and the southern part of the Thrace Basin (Figures 1–3). The stratigraphic sections include the Şile, Hocalar, and Kaynarca sections from the Kocaeli Peninsula; the Ereğli and Yörükler sections from the Armutlu Peninsula; the SölözA, SölözB and Ciciler sections in the İznik-Geyve region. The Sazlıman and Mürefte sections are from the southern part of the Thrace Basin (Figure 3).

All LBF specimens were studied as loose specimens after isolating them from a matrix of siliciclastics

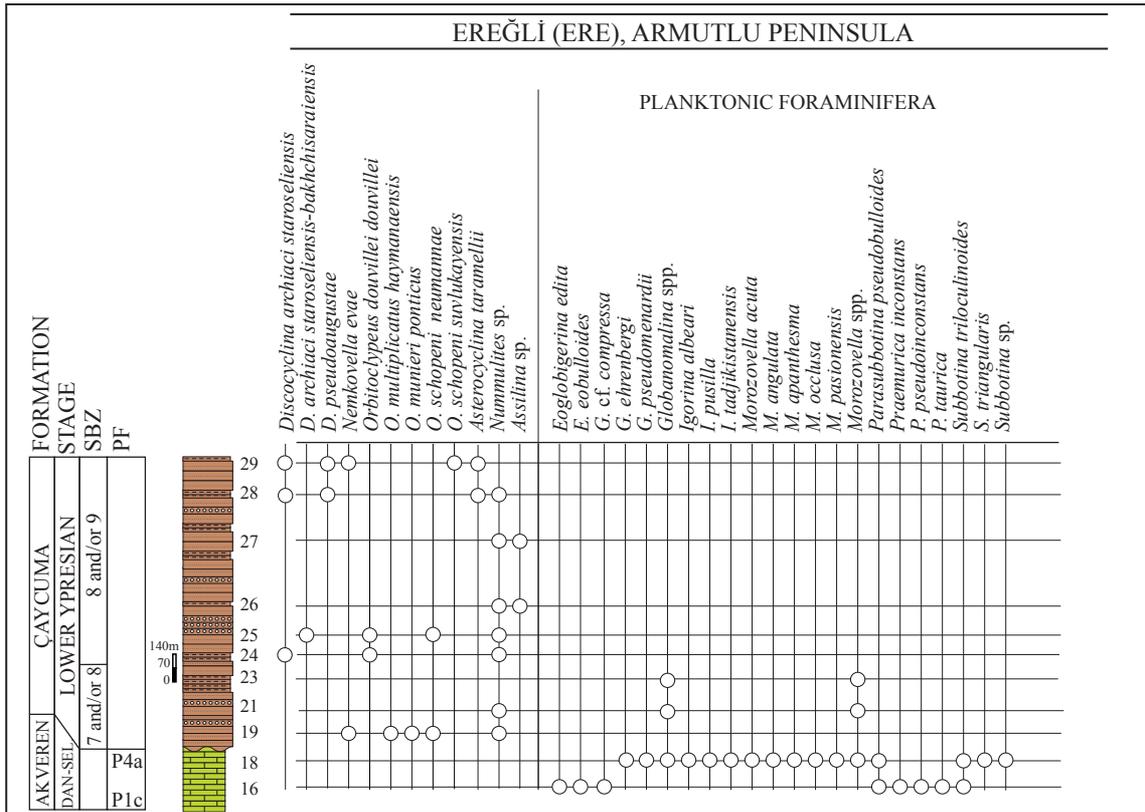


Figure 13. Distribution of LBF and planktonic foraminifera in Ereğli (ERE) section.

and carbonates. The axial and equatorial sections of isolated LBF specimens were prepared for taxonomic identifications. Taxonomy of the orthophragminids is based on the morphometry at the species and subspecies rank following the studies of Less (1987, 1998) Less et al. (2007), and Özcan et al. (2007, 2010).

4. The fossil assemblages in the studied sections

4.1. Kocaeli Peninsula

The upper Cretaceous-Eocene stratigraphy of the Kocaeli Peninsula was recently summarized by Özcan et al. (2012). The Cretaceous-Paleocene transition occurs in a deep-marine setting (Sargül et al., 2017). The Eocene shallow-to deep-marine units are exposed near Şile and in the region to the north of İzmit and Adapazarı (Figures 1B and 1C). The Ypresian Şile Olistostrome and overlying lower Lutetian Yunuslubayır Formation are recorded in a limited area near Şile town, and their relationships to underlying units are not observed in the region (Baykal and Önalán, 1979; Less et al., 2007). The Çaycuma Formation crops out extensively in the region and consists of both shallow and deep-marine deposits (Özcan et al., 2012).

4.1.1. Şile (ŞİL) section

Eocene deposits crop out in the town of Şile and its vicinity, to the east of İstanbul (Figure 1). The succession is divided

into two parts: a lower, deep-marine chaotic sedimentary unit, the Şile Olistostrome; and an upper, unconformable unit of neritic nummulitic carbonates and clastics of the Yunuslubayır Formation (Figures 2, 3, and 5). The Şile Olistostrome, which is exposed in a narrow strip along the Black Sea coast, is composed of sandstone beds with marly and silty intercalations and Late Cretaceous carbonate blocks (Baykal and Önalán, 1979). Several levels yielded allochthonous LBF, among which one of them (sample ŞİL4), has a remarkable quantity of orthophragminids (Figures 4A, 4B, and 5). This level contains *Discocyclina archiaci* (Schlumberger) *staroseliensis-bakhchisaraiensis* Less (Figure 6A-B), *Discocyclina dispansa* (Sowerby) *broennimanni-taurica* Less, *Nemkovella evae evae* Less, *Orbitoclypeus schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine) (Figure 6C), *Orbitoclypeus multiplicatus multiplicatus* (Gümbel), and *Orbitoclypeus bayani* cf. *bayani* (Munier-Chalmas). This assemblage indicates SBZ 7 and/or 8 and an early Ypresian (Ilerdian) age for the unit. Planktonic foraminifera from two samples in the shaly matrix of the Olistostrome (ŞİL4A) laterally interfingering with ŞİL4 and ŞİL5 about 2 km to the WSW) suggest P 6 and P 7 zones after Berggren et al. (1995) (Figure 5). The calcareous nannoplankton (based on Martini, 1971) of both samples contain reworked Late Cretaceous forms

EREGLI SECTION, ÇAYCUMA FORMATION, ARMUTLU PENINSULA

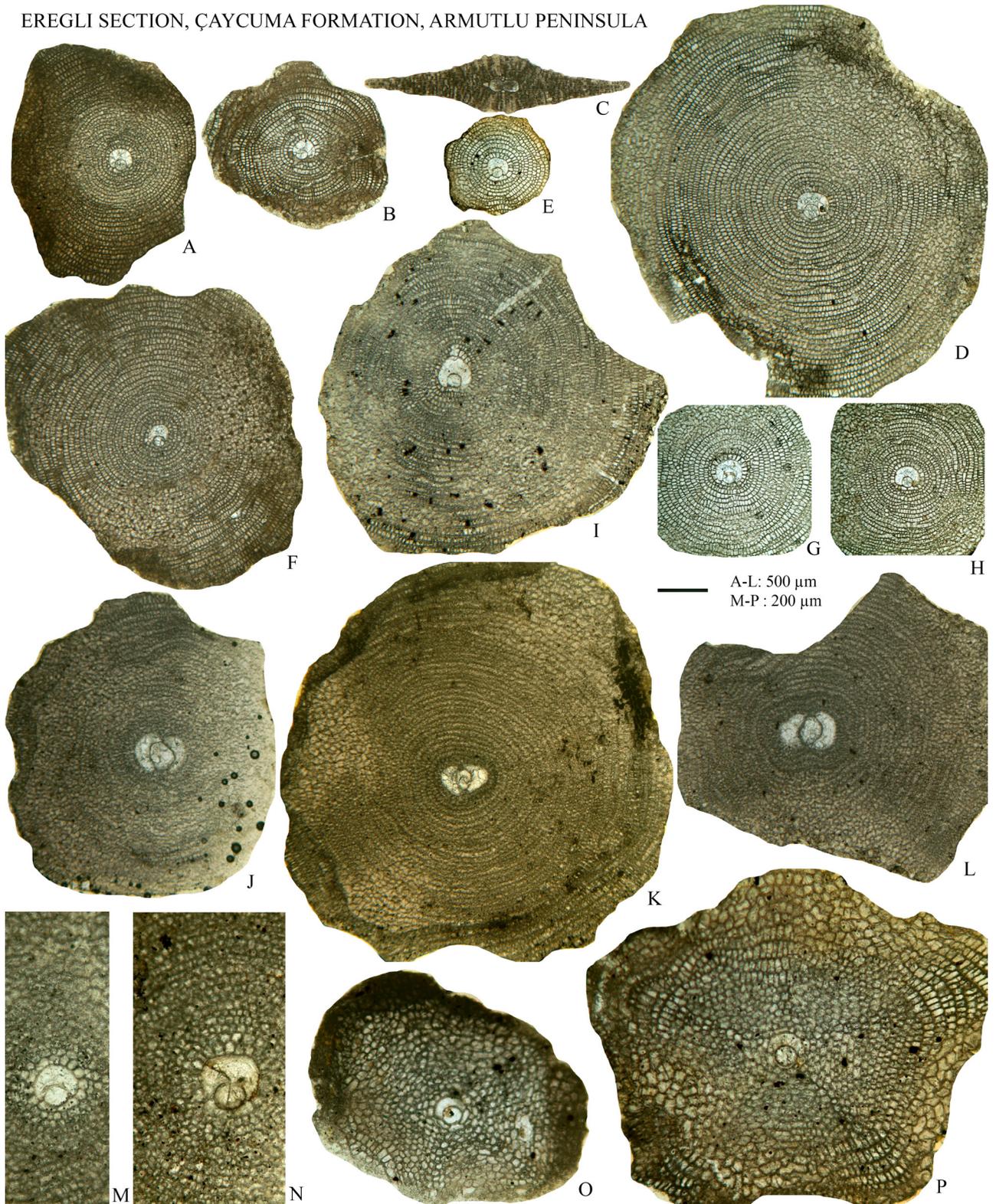


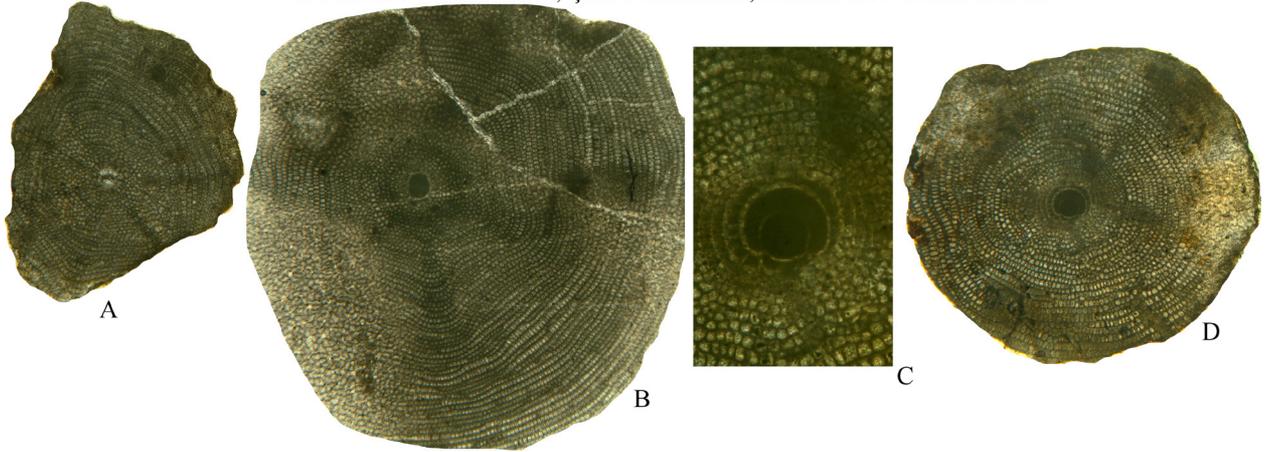
Figure 14. Orthophragminids from the Ereğli section. (A–C, I), *Discocyclina archiaci* (Schlumberger) *staroseliensis* Less. (D–H), *D. archiaci* (Schlumberger) *staroseliensis-bakhchisaraiensis* Less. (J–L), *D. pseudoaugustae* Portnaya. (M–N), *Nemkovella evae evae* Less. (O–P), *Asterocyclina taramellii* (Munier-Chalmas). A: ERE24-18, B: ERE24-22, C: ERE24-39, D: ERE25-15, E: ERE25-6, F: ERE25-5, G: ERE25-8, H: ERE25-19, I: ERE29-44, J: ERE29-20, K: ERE29-22, L: ERE29-24, M: ERE29-19, N: ERE29-53, O: ERE28-30, P: ERE28-27.

EREĞLİ SECTION, ÇAYCUMA FORMATION,
ARMUTLU PENINSULA



Figure 15. Orthophragminids from the Ereğli section. (A–B, K), *Orbitochypeus munieri* (Schlumberger) *ponticus* Less & Özcan. (C–I), *O. schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine). (J), *O. schopeni* (Checchia-Rispoli) *suvlukayensis* Less. (L), *O. multiplicatus* (Gümbel) *haymanaensis* Özcan, Sirel, Özkan-Altiner, Çolakoğlu. (M–V), *O. douvillei douvillei* (Schlumberger). A–B: ERE19-28, C–D: ERE19-21, E–F: ERE25-39, G–H: ERE25-35, I: ERE24-26, J: ERE29-52, K: ERE19-27, L: ERE19-14, M–N: ERE24-25, O–P: ERE25-23, Q–R: ERE25-25, S–T: ERE25-45, U–V: ERE25-47.

YÖRÜKLER SECTION, ÇAYCUMA FM., ARMUTLU PENINSULA



CİCİLER SECTION, CİCİLER FM., MEKECE, PAMUKOVA

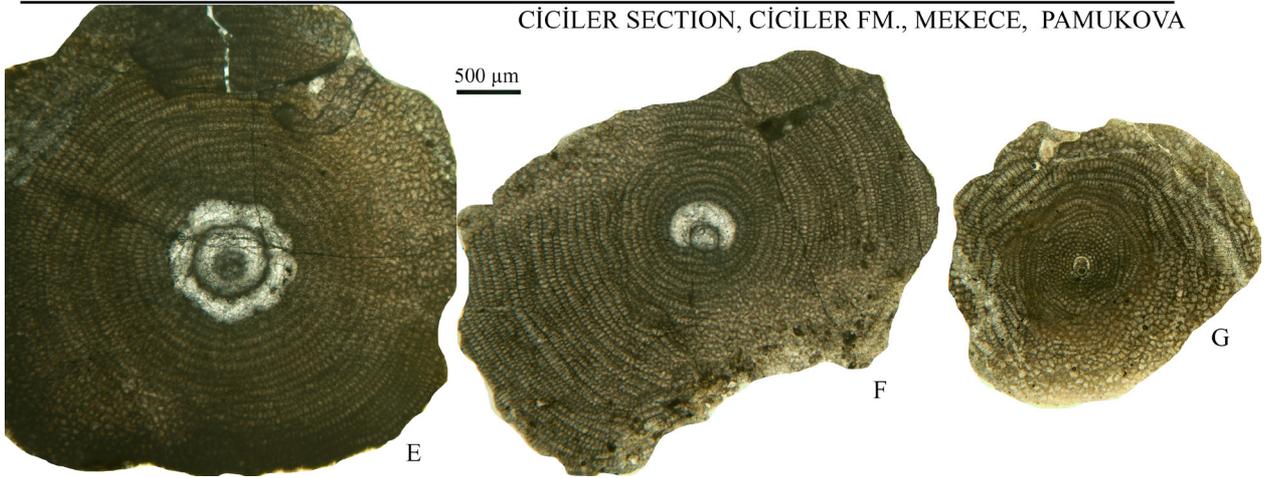


Figure 16. Orthophragminids from Yörükler (YÖR) and Cıçiler (CİC) sections. (A–B), *Orbitoclypeus varians* (Kaufmann) *ankaraensis* Özcan & Less. (C–D), *O. schopeni* (Checchia-Rispoli) *crimensis* Less. (E), *D. fortisi* (d'Archiac) *simferopolensis* Less. (F), *Discocyclus archiaci archiaci* (Schlumberger). (G), *O. douvillei douvillei* (Schlumberger). A: YO7-4, B: YO8-14, C-D: YO8-32, E: CİC2-10, F: CİC2-17, G: CİC2-24.

with in situ fauna suggesting NP 11/12 zone for the lower sample and NP 12/14 zone for the upper sample.

The upper unconformable shallow marine unit, the Yunuslubayır Formation (Figure 4B), attains a minimum thickness of about 25 m and contains abundant in situ nummulitids and sporadic tests of orthophragminids in its upper levels (ŞİL8A and ŞİL8 respectively). Orthophragminids in this level are monospecific and are dominantly represented by *Discocyclus archiaci bartholomei* (Schlumberger, 1903) (Figure 6D-F). A comparison of the embryonic developmental stages of *Discocyclus archiaci* from the underlying Şile Olistostrome and from the Yunuslubayır Formation is shown in Figure 7. *Discocyclus archiaci bartholomei* suggests a transitional early to middle Eocene age. The evolutionary degree of *Nummulites* of the *N. perforatus*-group (*N. obesus* d'Archiac) from sample ŞİL8A indicates SBZ 13 Zone, corresponding to the early Lutetian.

4.1.2. Hocalar (HOC) section

A shallow-marine sequence of the Çaycuma Formation (ca. 50-m-thick) overlying the Late Cretaceous-Paleocene Akveren Formation, crops out to the southeast of Şile. This unit consists of yellowish, medium- to thickly-bedded fine to coarse sandstone and siltstone intercalations with LBF, locally in rock-forming abundance (Figure 3) (Özcan et al., 2012). The LBF and planktonic foraminifera identified from this unit are shown in Figure 8. Samples from this section contain the following benthic foraminiferal taxa: *Discocyclus archiaci archiaci* (Schlumberger) (Figure 9A-B), *Discocyclus fortisi* (d'Archiac) *simferopolensis* Less, *Discocyclus augustae* van der Weijden *sourbetensis* Less (Figure 9C), *Discocyclus dispansa* (Sowerby), *Nemkovella stropholata* (Gümbel) *stropholata-fermonti* Less (Figure 9D-E), *Nemkovella bodrakensis* Less (Figure 9F-G), *Orbitoclypeus munieri* cf. *munieri* (Schlumberger), *Orbitoclypeus douvillei douvillei* (Schlumberger).

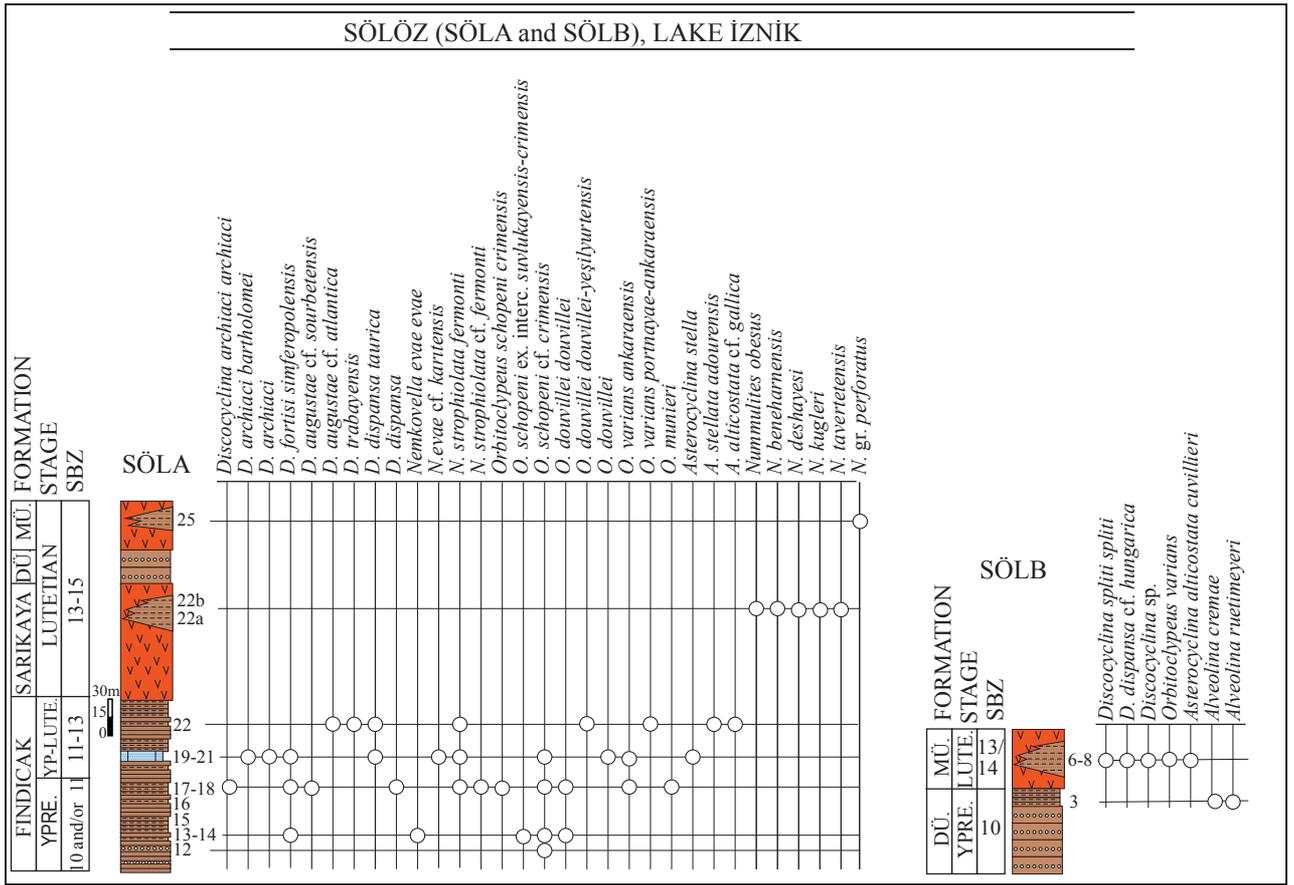


Figure 17. Distribution of LBF in SölözA (SÖLA) and SölözB (SÖLB) sections.

Asterocyclina stellata (d'Archiac) *adourensis* Less (Figure 9H). Sample 13 contains *Nummulites burdigalensis* de la Harpe, *Nummulites partschi* de la Harpe and *Assilina placentula* (Deshayes), characteristic for SBZ 10, while in sample 16, *Nummulites distans* Deshayes and *Assilina cuvillieri* Schaub marking SBZ 11 have been identified. Thus, the Çaycuma Formation at this locality is referred to SBZ 10 and 11, suggesting a late Ypresian age (lower and middle part of the Cuisian). The planktonic foraminifera from the upper beds of the underlying Akveren Formation (sample 9) indicate P4b-c subzones, implying an unconformity between units.

4.1.3. Kaynarca (KAY) section

The Kaynarca section, first described by Özcan et al. (2012), is located ca. 29 km northeast of the Hocalar section (Figure 1). The section includes only a part of the Çaycuma Formation, which has a thickness of 75 m. The section starts with yellowish shallow-marine siltstones with intercalations of coarse sandstone beds and sandy limestone and continues upward with deep-marine shale-siltstone intercalation (Figure 3, 4C, 10). A sample from the basal siltstone beds (sample 1) contains Lower

Eocene planktonic foraminifera *Acarinina primitiva* (Finlay) (Figure 10). A composite LBF assemblage for samples 3a, 7, and 7a includes *D. archiaci archiaci* (Figure 11A-B), *D. fortisi fortisi* (d'Archiac) (Figure 11K-M), *D. augustae* van der Weijden *sourbetensis* (Figure 11C-H), *D. trabayensis* Neumann (Figure 11I-J), *N. evae evae* Less (Figure 11N-R), *N. strophiolata strophiolata* (Gümbel) *-fermonti* Less (Figure 12A-B), *Orbitoclypeus douvillei* (Schlumberger) *yesilyurtensis* Özcan, *O. multiplicatus* (Gümbel) *kastamonuensis* Less and Özcan (Figure 12D), *O. munieri* (Schlumberger), *Orbitoclypeus furcatus* (Rutimeyer) (Figure 12E), *Orbitoclypeus koehlerii* Less (Figure 12F), *Orbitoclypeus droogeri* Less, *Asterocyclina stella* (Gümbel), *Asterocyclina alticostata* (Nuttall) *gallica* Less (Figure 12C), *Nummulites rotularius* Deshayes, *Nummulites irregularis* Deshayes, and *Assilina plana* Schaub (Figure 10). This assemblage is referred to SBZ 10 (lower part of the upper Ypresian) and is comparable with the foraminiferal assemblage of the Hocalar section. The planktonic foraminifera in sample 7a are indicative of the *Morozovella aragonensis* (P 7) zone (late Early Eocene) and the nannoplankton from the same sample NP 12 zone. The nannoplankton assemblage in samples 8 and 9 could

SÖLÖZ A SECTION, FINDICAK FORMATION, LAKE IZNIK

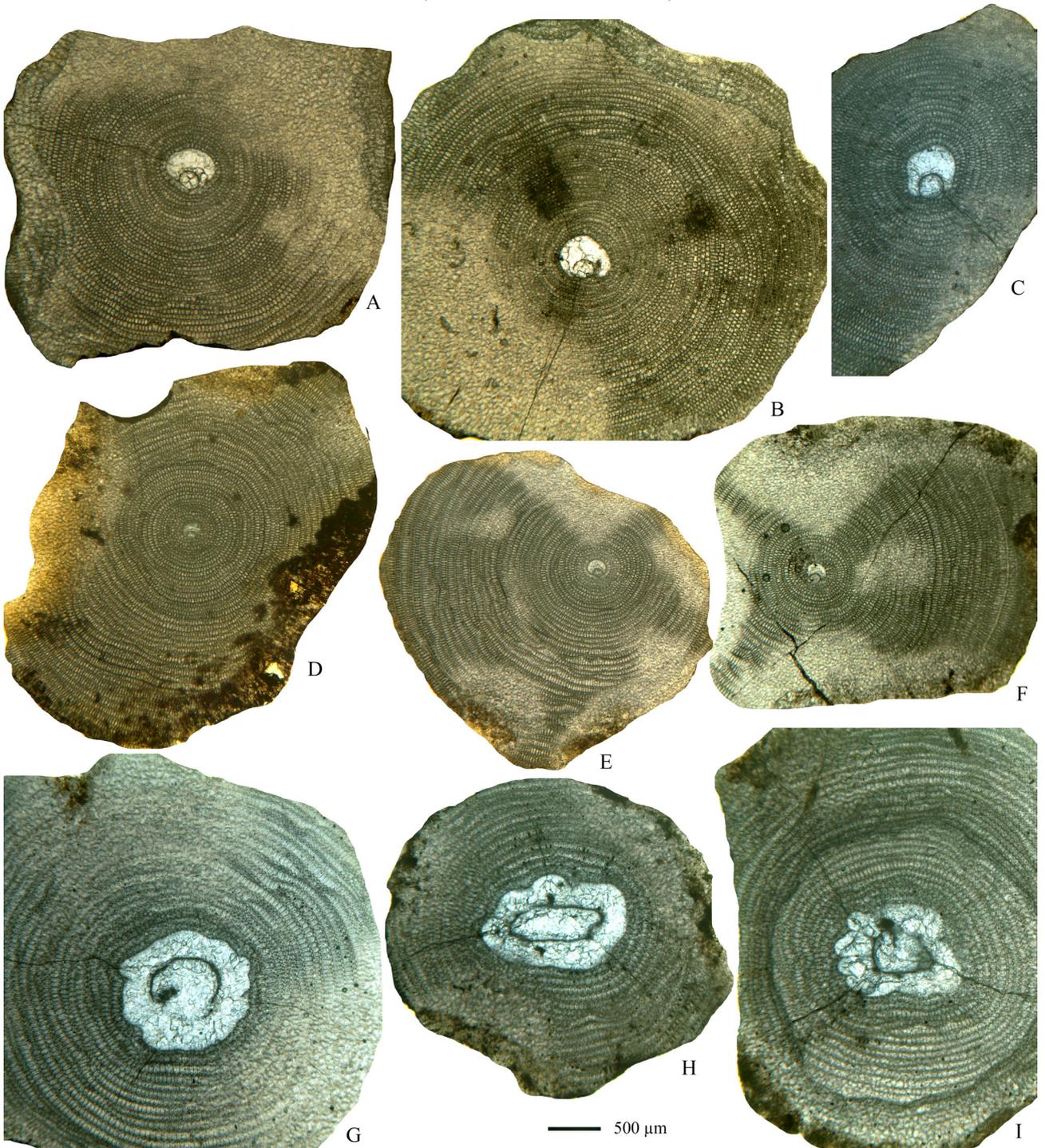


Figure 18. Orthofragminids from SölözA section. (A–C), *Discocyclus archiaci archiaci* (Schlumberger). (D–F), *D. dispansa* (Sowerby) *taurica* Less. (G–I), *D. fortisi* (d’Archiac) *simferopolensis* Less. A: SÖLA18-9, B: SÖLA18-1, C: SÖLA18-3, D: SÖLA21-18, E: SÖLA17-25, F: SÖLA22-2, G: SÖLA14-6, H: SÖLA14-1, I: SÖLA14-2.

be assigned to the NP 14 zone according the ranges of *Discoaster lodoensis* (NP 12-14) and *Helicosphaera lophota* (NP 14).

4.2. Armutlu Peninsula

The Eocene stratigraphy of the Armutlu Peninsula was described by Akartuna (1968), Erendil et al., (1991) and

SÖLÖZ B SECTION, MÜSLÜMSÖLÖZ FORMATION, LAKE IZNIK

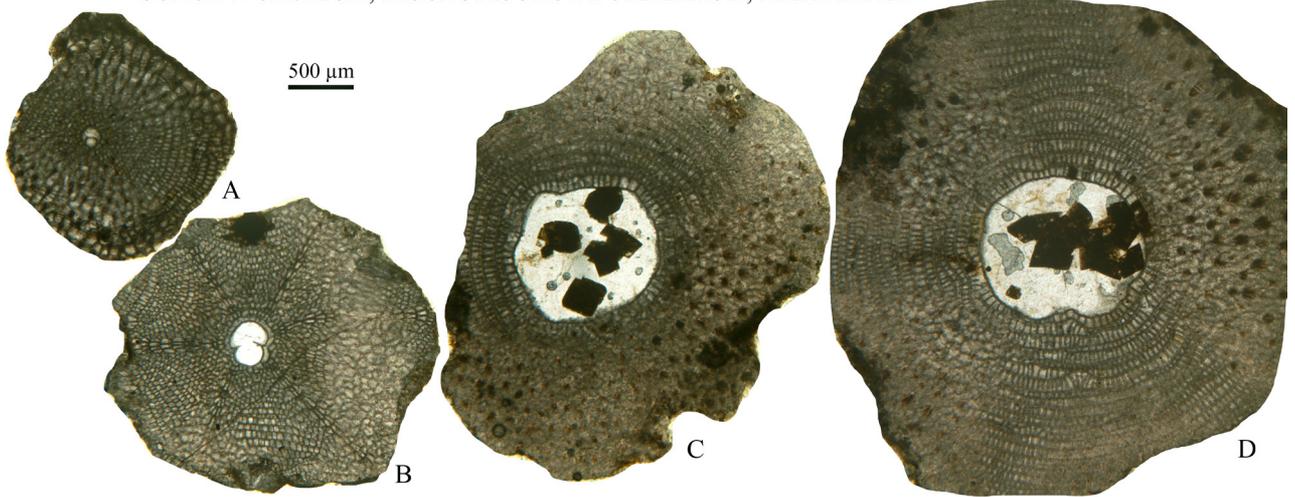


Figure 19. Orthophragminids from SölözB section. (A), *Orbitoclypeus varians* (Kaufmann). (B), *Asterocyclina alticostata* (Nuttall) *cuvillieri* (Neumann). (C–D), *Discocyclina spliti spliti* Butterlin and Chorowicz. A: SÖLB6-2, B: SÖLB6-16, C: SÖLB6-15, D: SÖLB6-8.

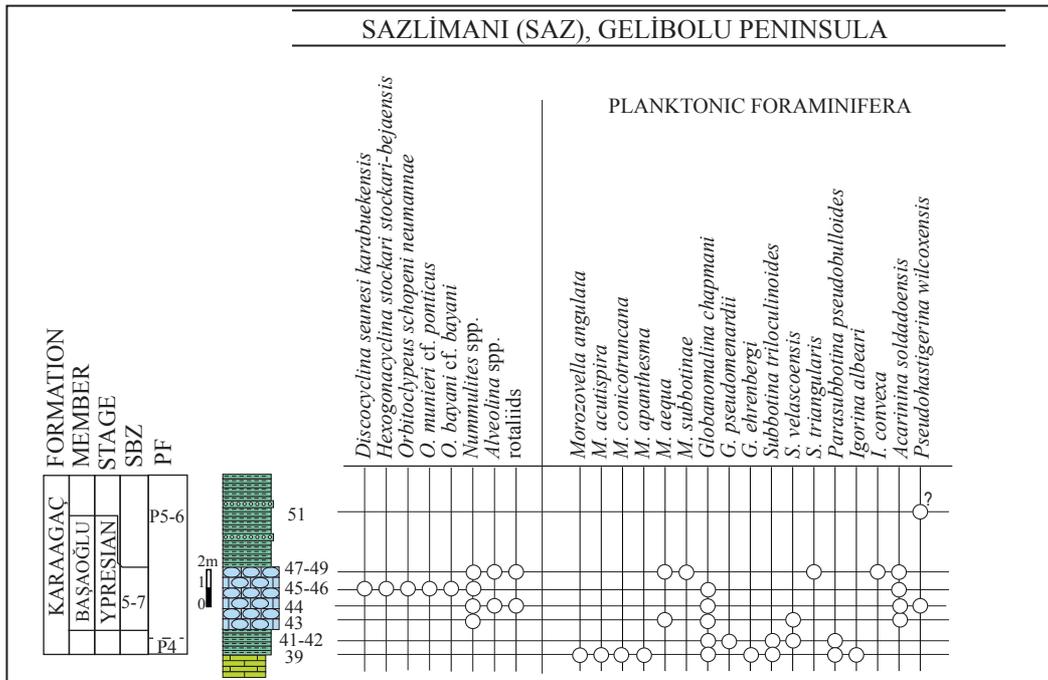


Figure 20. Distribution of LBF and planktonic foraminifera in Sazlımani (SAZ) section.

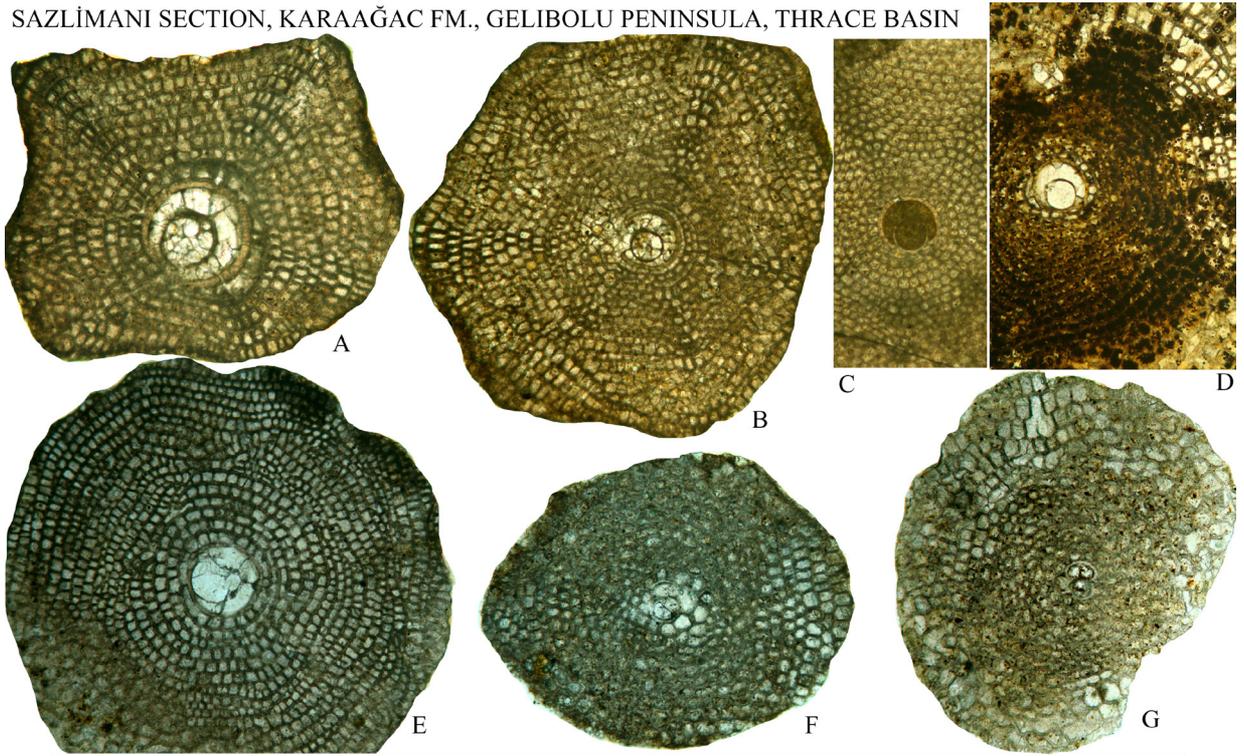
Sakınç and Bargu (1990), and revised by Özcan et al. (2012). A thick sequence of the Çaycuma Formation is overlain by volcanoclastic rocks represented by acidic to andesitic tuffs, agglomerates, and rare sandstone and marl.

4.2.1. Ereğli (ERE) section

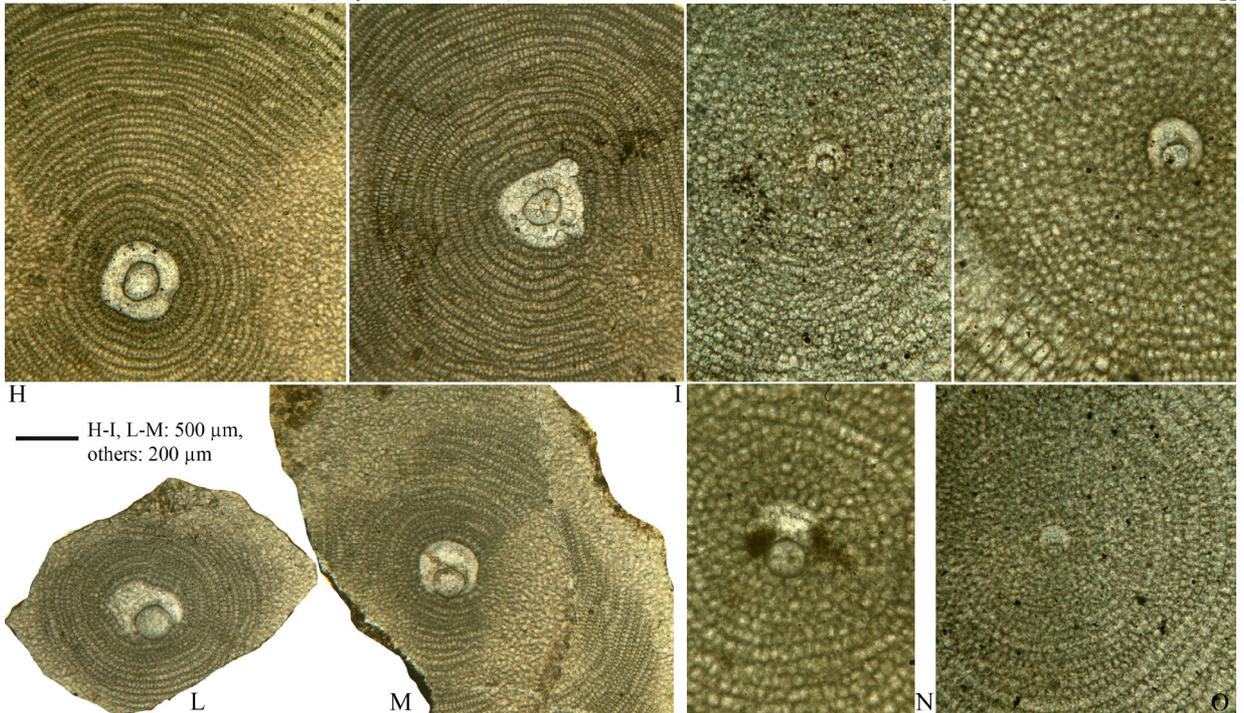
The Ereğli section, first described by Özcan et al. (2012) who listed its paleontologic context, is located to the west of Osmaniye village in the northern part of the Armutlu Peninsula (Figure 1). The Çaycuma Formation consists

of sandstone, conglomerate and shale over 1000 m thick and lies with a probable unconformity over the middle-? upper Paleocene deep-marine deposits of the Akveren Formation. The Çaycuma Formation yielded abundant orthophragminids in certain levels, identified as (Figure 13); *Discocyclina archiaci staroseliensis* (Figure 14A-C, I), *D. archiaci staroseliensis-bakhchisaraiensis* (Figure 14D-H), *D. pseudoaugustae* Portnaya (Figure 14J-L), *Orbitoclypeus munieri* (Schlumberger) *ponticus* Less &

SAZLIMANI SECTION, KARAAĞAC FM., GELIBOLU PENINSULA, THRACE BASIN



MÜREFTE SECTION, DİŞBUDAK FM., THRACE BASIN



H-I, L-M: 500 µm,
others: 200 µm

Figure 21. Orthophragminids from Sazlımani and Mürefte sections. (A), *Orbitoclypeus bayani bayani* (Munier-Chalmas), (B-C), *O. munieri* (Schlumberger) *ponticus* Less & Özcan. (D-E), *O. schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine). (F-G), *Hexagonocyclina stockari stockari* (Less & Özcan)-*bejaensis* Özcan, Boukhalfa, Scheibner. (H-I), *Discocyclina fortisi fortisi* (d'Archiac). (J-K), *Orbitoclypeus douvillei* cf. *douvillei* (Schlumberger). (L-M), *Discocyclina archiaci archiaci* (Schlumberger). (N), *Nemkovella evae* Less. (O), *N. strophiolata* (Gümbel). A: SAZ46-31, B: SAZ46-16, C: SAZ46-17, D: SAZ46-22, E: SAZ46-47, F: SAZ46-51, G: SAZ46-59, H: MÜFA10-2, I: MÜFA10-5, J: H: MÜFA10-37, K: 1894-29, L: 1894-18, M: 1894-20, N: 1894-27, O: MÜFA10-46.

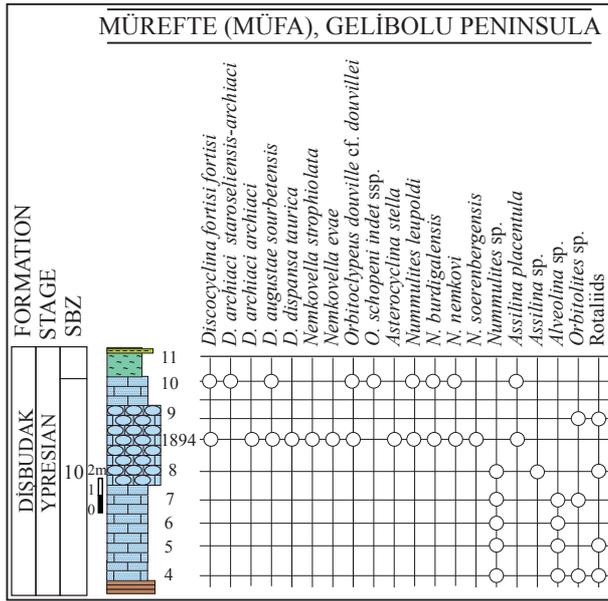


Figure 22. Distribution of LBF in Mürefte (MÜFA) section.

Özcan (Figure 15A-B, K), *O. schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine) (Figure 15C-I), *Orbitoclypeus schopeni* (Checchia-Rispoli) *svvlukayensis* Less (Figure 15J), *Orbitoclypeus multiplicatus* (Gümbel) *haymanaensis* Özcan, Sirel, Özkan-Altınler, Çolakoğlu (Figure 15L), *O. douvillei douvillei* (Figure 15M-V), *Nemkovella evae evae* (Figure 14M-N), and *Asterocyclina taramellii* (Munier-Chalmas) (Figure 14O-P). The assemblage characterized by *O. schopeni neumannae*, *O. multiplicatus haymanaensis* and *O. munieri ponticus* at the base of the section indicates SBZ 7 and/or 8. The assemblage of *D. pseudoaugustae*, *O. schopeni svvlukayensis*, and *A. taramellii* in the upper part, on the other hand, is referred to SBZ 8 and/or 9. The overall assemblages are typical for the lower Ypresian.

4.2.2. Yörükler (YÖR) section

Ypresian deep-marine siliciclastic deposits with turbidites and debris flows crop out extensively to the north of Lake İznik. The Yörükler section, located 1.5 km to the northwest of Yörükler village (Figure 1), is ca. 70 m-thick and starts with conglomerates (debris-flows) and turbidites of the Çaycuma Formation consisting of planktonic foraminifera and resedimented LBF (Figure 3). It continues upward with deep-marine marls and turbiditic interbeds with abundant orthofragminids and subordinate nummulitids. The boundary between these marine beds and the Kızderbent volcanic rocks is easily observed in the section (Figure 4D). The orthofragminids, identified in two samples, YÖR7 and 8, from the upper part of the section yielded *Orbitoclypeus varians* (Kaufmann) *ankaraensis* Özcan & Less (Figure 16A-B), and *O. schopeni* (Checchia-Rispoli)

crimensis Less (Figure 16C-D). This assemblage indicates SBZ 12-13 (upper Ypresian-lower Lutetian).

4.3. İznik-Geyve region

4.3.1. Ciciler (CİC) section

The Ciciler Formation consists of sandstone, shale, conglomerate, and limestone and is equivalent of the Çaycuma and Findıcak formations. It was studied at its type-locality near Ciciler village, south of Mekece (Pamukova) (Figures 1–3, 4G). Orthofragminids, common in one sample (sample 2), are represented by several key-species suggesting SBZ 10/11 and a late Ypresian age. These taxa are represented by *Discocyclusina fortisi simferopolensis* (Figure 16E), *Discocyclusina archiaci* (Figure 16F), and *Orbitoclypeus douvillei douvillei* (Figure 16G) associated with *Assilina* spp. and *Nummulites* spp.

4.3.2. Sölöz A (SÖLA) section

This section encompasses the various stratigraphic units, including the Findıcak, Sarıkaya, Dürdane, and Müslümsölöz formations (Figures 3 and 4E). LBF occur in all units except Dürdane Formation (Figure 3). The details of the stratigraphy of Sölöz sections were explained by Özcan et al. (2012).

The Findıcak Formation yielded the following LBF (Figure 17): *Discocyclusina archiaci archiaci* (Figure 18A-C), *Discocyclusina archiaci bartholomei*, *D. dispansa* (Sowerby) *taurica* Less (Figure 18D-F), *D. fortisi simferopolensis* (Figure 18G-I), *D. augustae* van der Weijden cf. *soubretensis*, *D. augustae* van der Weijden *atlantica* Less, *D. trabayensis*, *Nemkovella evae evae*, *N. evae* Less cf. *karitensis* Özcan and Less, *N. strophiolata* (Gümbel) *fermonti* Less, *Orbitoclypeus schopeni* (Checchia-Rispoli) *crimensis* Less, *O. douvillei douvillei*, *O. douvillei douvillei* (Schlumberger)-*yeşilyurtensis* Özcan, *O. varians* (Kaufmann) *ankaraensis* Özcan and Less, *O. varians* (Kaufmann) *portnayae* Less-*ankaraensis* Özcan and Less, *O. munieri*, *Asterocyclina stella*, *Asterocyclina stellata* (d'Archiac) *adourensis* Less, and *Asterocyclina alticostata* (Nuttall) cf. *gallica* Less. LBF assemblages from samples 12-18 in the lower half of the section indicate SBZ 10/11 (upper Ypresian), while those from samples 19-22 indicate SBZ 11 and/or 13, referable to the Ypresian-Lutetian transition.

The Sarıkaya Formation yielded mainly nummulitids, represented by *Nummulites obesus* d'Archiac and Haime, *N. beneharnensis* de la Harpe, *N. deshayesi* d'Archiac and Haime, *N. kugleri* Schaub, and *N. tavertetensis* Reguant and Clavell. This assemblage implies SBZ 13-15 (middle Eocene). The occurrence of *N. deshayesi*, confined to SBZ 16 (Schaub, 1981) is somewhat contradictory to this assignment, but may indicate the lower part of the range of the species needs to be extended.

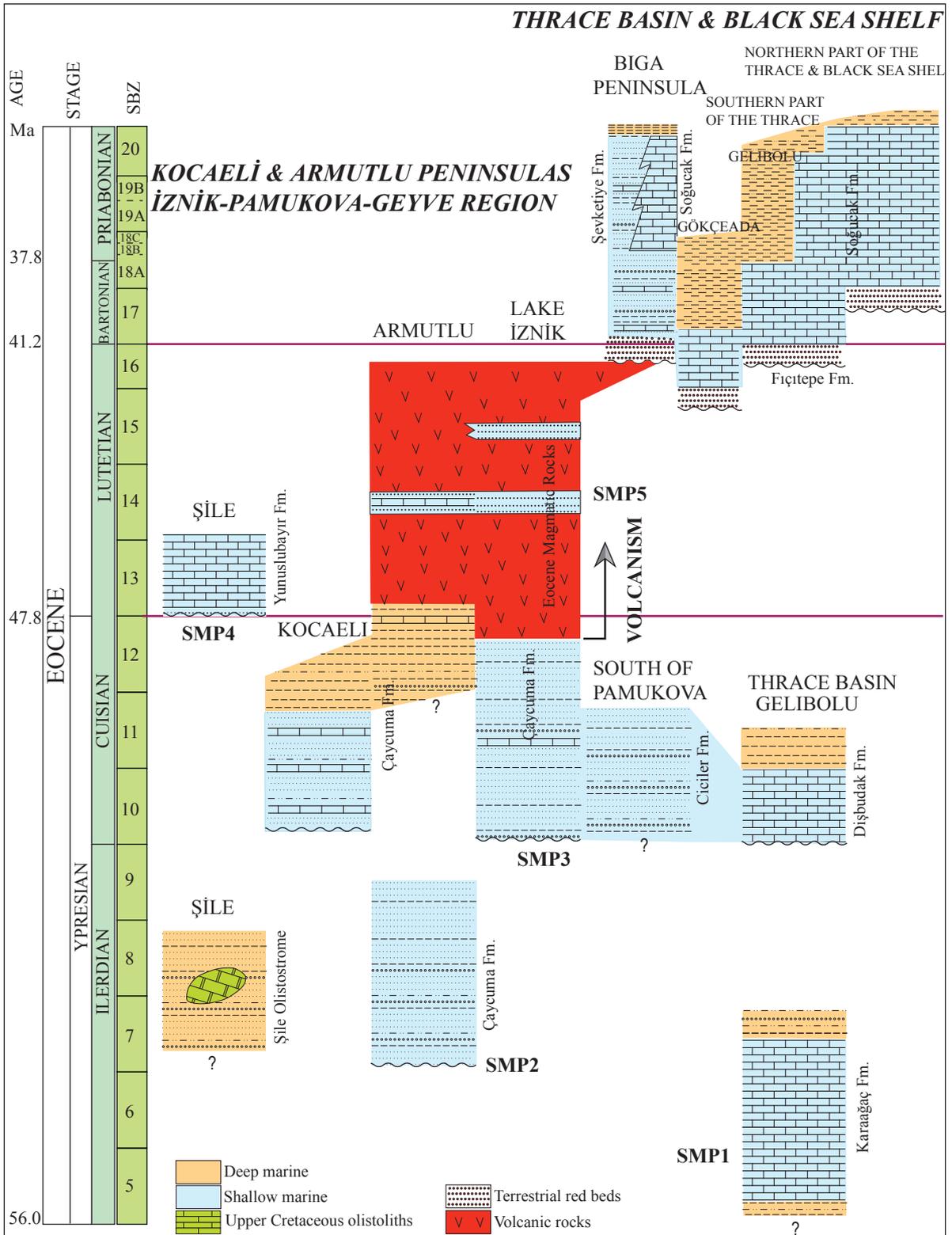


Figure 23. Bio-chronostratigraphic framework for the marine Eocene units in NW Turkey. The data for upper middle Eocene to upper Eocene (Bartonian-Priabonian) units of the Thrace Basin and Black Sea shelf are from Özcan et al. (2010, 2018), Less et al. (2011), and Okay et al. (2010, 2019). Correlation of stage boundaries to time scale after Vandenberghe et al. (2012). SMP: Shallow Marine Depositional Phase.

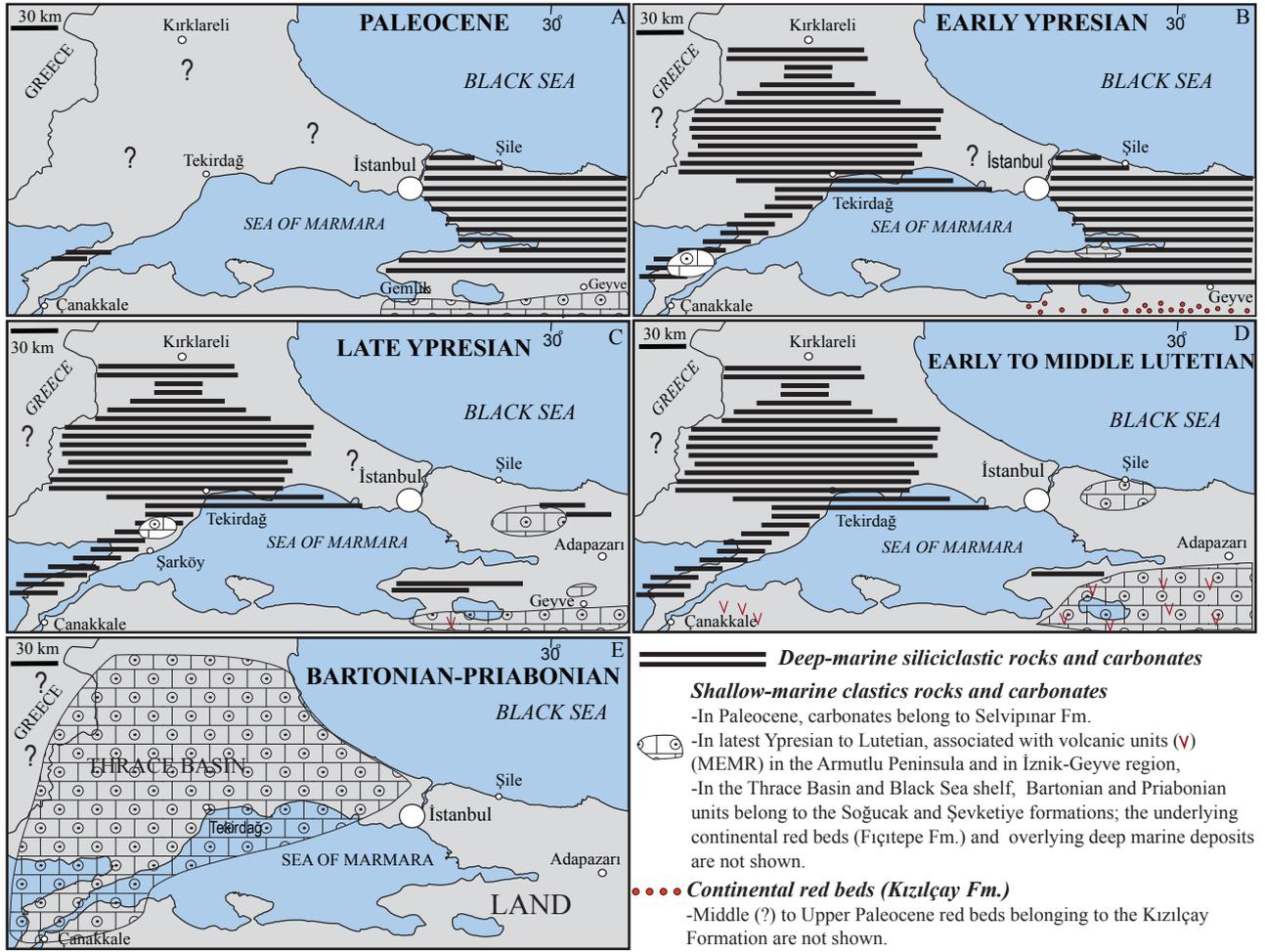


Figure 24. Cartoons depicting the tentative paleogeography of NW Turkey during the Paleocene-Priabonian time interval. The islands in the Marmara Sea are not shown.

4.3.3. Sölöz B (SÖLB) section

This section encompasses the Kızderbent volcanic rocks and the Findıcak, Sarıkaya, Dürdane, and Müslümsölöz formations. LBF were identified in the upper part of the Dürdane Formation and Müslümsölöz Formation (Figure 3).

The Dürdane Formation yielded *Alveolina cremae* Checchia-Rispoli, 1905 and *Alveolina ruetimeyeri* Hottinger, 1960. This assemblage suggests SBZ 10 (Late Ypresian). The Müslümsölöz Formation LBF fauna consists of *Discocyclus spliti spliti* Butterlin and Chorowicz (Figure 19C-D), *D. dispansa* (Sowerby) cf. *hungarica* Less, *Orbitoclypeus varians*, *Asterocyclina alticostata* (Nuttall) *cuvillieri* (Neumann) (Figure 19B), indicating SBZ 13 and/or 14 (early/middle Lutetian) (Figure 17).

4.4. Thrace Basin

Ypresian shallow-to deep-marine sedimentation was recorded in a limited area in the Thrace Basin: in the Sazlımanı section on the Gelibolu Peninsula (Sümengen

and Terlemeç, 1991; Temel and Çiftçi, 2002; Özcan et al., 2010) and in the Mürefte section near Şarköy (Okay et al., 2010).

4.4.1. Sazlımanı (SAZ) section

Deep-marine upper Cretaceous limestone and marls are overlain by a thin succession of sandy to nodular limestone of the Başaoglu Member of the Karaağaç Formation with abundant LBF (Figures 3 and 4H). The limestone has a limited lateral extent and was previously interpreted as an olistolith in the Karaağaç Formation by Özcan et al. (2010). It comprises a rich assemblage of *Nummulites* and orthoherminids (Figure 20). Sample 46 yielded *Discocyclus seunesi karabuekensis*, *Orbitoclypeus bayani bayani* (Munier-Chalmas) (Figure 21A), *O. munieri ponticus* (Figure 21B-C), *O. schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine) (Figure 21D-E), *Hexagonocyclina stockari stockari* (Less and Özcan)-*bejaensis* Özcan, Boukhalfa, Scheibner (Figure 21F-G). This assemblage indicates SBZ 5-7 (early Ypresian).

The planktonic foraminifera from the lower part of the Karaağaç Formation just below the Başaoğlu member indicate P4 zone. The rare planktonic foraminifera from the marls above this unit do not provide a reliable age assignment. These assemblages may indicate P5-6.

4.4.2. Mürefte (MÜFA) section

The Mürefte section is a sequence of siliciclastics and carbonates of the Dişbudak Formation, about 30-m thick, exposed to the east of Doluca Hill, north-east of Şarköy (Özcan et al., 2010) (Figures 1–3, 4I–J). The observed lowest part of the sequence comprises conglomerates and sandstones with an oyster bed at its base. This passes upwards into sandstones with intercalated conglomerate horizons, that grade into limy sandstone and/or sandy limestones containing a rich assemblage of *Nummulites*, *Orbitolites* and alveolinids (Figure 22). These levels, devoid of orthophragminids, are interpreted to have been deposited in an inner shelf environment. The top of the section is characterized by a nodular limestone containing a diverse assemblage of nummulitids such as *Assilina placentula* (Deshayes). Orthophragminids in the nodular limestone and at the uppermost level of the Dişbudak Formation consist of *Discocyclina fortisi fortisi* (Figure 21H–I), *D. archiaci archiaci* (Figure 21L–M), *D. augustae sourbetensis*, *D. dispansa* (Sowerby) *taurica*, *Orbitoclypeus douvillei* cf. *douvillei* (Figure 21J–K), *Nemkovella evae* (Figure 21N), and *N. strophiolata* (Figure 21O). This assemblage indicates SBZ 10 (late Ypresian).

5. Biostratigraphic and paleogeographic evaluations

5.1. A biostratigraphic–chronostratigraphic framework for the Ypresian-middle Lutetian shallow marine deposits in NW Turkey

The in situ LBF assemblages in shallow marine successions and allochthonous LBF and pelagic fossils in spatially associated deep-marine strata, supplemented by previous works from the Thrace Basin, permit us to apply the biostratigraphic framework of Serra-Kiel et al. (1998) and a correlation scheme for NW Turkey (Figure 23). The orthophragminid and nummulitid assemblages indicate shallow marine depositional conditions during a) early Ypresian (SBZ 5-7); b) early Ypresian (SBZ 7-9); c) late Ypresian (SBZ 10 and/or 11); d) early Lutetian (SBZ 13); and e) middle Lutetian (SBZ 14 and/or 15), respectively. Thus, five shallow marine phases (SMP) are recognized during a time span from Ypresian to the middle Lutetian. In the Thrace Basin (including the northern part of the Biga Peninsula and Black Sea shelf), a new shallow marine depositional regime initiated during the latest Lutetian and Bartonian (SBZ 15 and 16-17) times that persisted into the Priabonian (SBZ 18-20) with the deposition of carbonates of the Soğucak Formation, dominated by corals and LBF, and clastics of the Şevketiye Formation. These units display

a diachronous depositional relationship and are overlain by Priabonian to lower Oligocene pelagic siliciclastic rocks (Özcan et al., 2010, 2018; Less et al., 2011; Okay et al., 2019) (Figure 23).

The oldest samples with LBF belong to the Başaoğlu Member of the Karaağaç Formation (Sazlımanı section) indicates SBZ 5/7. This member has a limited vertical and lateral extent in the Gelibolu Peninsula. The Başaoğlu Member, underlain and overlain by pelagic beds, corresponds to an intermittent carbonate deposition in the region. An almost coeval shallow marine realm is also recognized in the Armutlu Peninsula, where an expanded clastic sequence of the Çaycuma Formation (Ereğli section) yielded orthophragminids, assigned to SBZ 7-9. The unit is referable to SBZ 7 and/or 8 at its base and to SBZ 8 and/or 9 at its upper part. The early Ypresian in NW Turkey is mainly characterized by deep-marine sedimentation as recognized in the Şile section in the Kocaeli Peninsula, and Sazlımanı section in Gelibolu Peninsula. The allochthonous orthophragminids from the matrix of the Şile Olistostrome appear to be almost contemporaneous with the planktonic foraminifera (P7/8) and calcareous nannofossils (NP11-14), studied from the matrix. These orthophragminids assemblages indicate SBZ 7/8.

The most widespread shallow marine sedimentation in Eocene is recognized by the abundant and diverse occurrence of orthophragminids assigned to SBZ 10-12 (late Ypresian) in many sections from Kocaeli and Armutlu peninsulas (Figure 23). The Çaycuma, Fındıcak, Ciciler, and Dişbudak formations yielded various assemblages of *Discocyclina*, *Nemkovella*, *Orbitoclypeus*, *Asterocyclina*, *Nummulites*, and *Assilina*. These assemblages, also previously discovered in central and north Anatolia (e.g., Çayraz Formation in the Haymana Basin and Safranbolu Formation in the Safranbolu-Karabük Basin) (Özcan, 2002; Özcan et al., 2007) suggest a rich development of LBF accumulations during the late Ypresian. Our data show that a wide area in the Central and NW Anatolia was occupied by a shallow sea during the late Ypresian. The deposits from this sea laterally and/or vertically pass to deep-marine sediments (e.g., Çayraz Formation in central Anatolia, Safranbolu Formation in Safranbolu-Karabük Basin, hemipelagic sediments of Çaycuma and Dişbudak formations in NW Turkey) because of tectonic instability.

Samples from the Yunuslubayır Formation in the Kocaeli Peninsula yielded predominantly nummulitids and sparse orthophragminids belonging to *N. obesus* and the *D. archiaci* lineage. The assemblage of *Discocyclina archiaci* and *N. perforatus*-group indicates SBZ 13. This unit crops out in a limited area near Şile town. The Lower Lutetian shallow marine deposits consisting of carbonates have not yet been described elsewhere in NW Turkey. The Yunuslubayır Formation is partly correlated with the

upper part of the Findıcak Formation and clastic beds of the lower part of the MEMR in SölözB section in the İznik region.

The clastic levels of the Sarıkaya Formation in SölözA section (samples 22a and 22b) yielded an assemblage of *Nummulites obesus*, *N. beneharnensis*, *N. deshayesi*, *N. kugleri* Schaub, and *N. tavertetensis*, indicating SBZ 13-15 (early to middle Eocene). These taxa belong to the youngest Eocene LBF assemblages in the studied sections. A horizon (sample 25) in the MEMR has yielded only *Nummulites gr. perforatus*. A specific age cannot be assigned to this level.

The clastic beds intercalated with the volcanic rocks of the Müslümsölöz Formation in SölözB section yielded assemblages of *Discocyclina spliti*, *D. dispansa cf. hungarica*, *Orbitoclypeus varians*, *Asterocyclina alticostata cuvillieri*, indicating SBZ 13-14 (early/middle Lutetian).

5. 2. Paleogeographic evaluations

Our results, combined with the available data in the literature, permit us to interpret the paleogeography of the NW Turkey region in the early Paleogene. During the Paleocene, the Thrace Basin and Armutlu and Kocaeli peninsulas are characterized by a deep-marine setting (Saner, 1980; Özcan et al., 2012) (Figure 24A). The data from Thrace, however, are limited. A shallow marine environment occurs only to the south of İznik-Pamukova-Geyve regions in the south of Intra-Pontide suture where the carbonates of Selvipınar Formation were extensively deposited (Saner, 1978a, 1978b, 1980; unpublished data by Özcan and Okay). The red beds of the Kızılçay Formation overlying the Selvipınar Formation (early to middle Paleocene) suggest the retreat of the sea and development of continental conditions in the middle to late Paleocene to the south of the Armutlu Peninsula.

The early Ypresian is predominantly characterized by deep-marine sedimentation while intermittent carbonate deposition of the Başağaç Member of the Karaağaç Formation in the Gelibolu Peninsula records a shelfal depositional setting (Figure 24B). A part of the Armutlu Peninsula is also characterized by a clastic shelf environment in the early Ypresian (Figure 24B). The late Ypresian saw the maximum areal extension of clastic and carbonate shelves as the shallow marine sediments of this period occur both in the Thrace, Kocaeli, and Armutlu peninsulas, as well as in the İznik-Pamukova-Geyve area (Figure 24C). These deposits, called 'nummulitic accumulations' because of rich development of LBF (e.g., lower unit of the Çayraz Formation and Safranbolu Formation in Haymana and Safranbolu-Karabük basins respectively), extend eastwards into central Turkey (Özcan et al., 2007; Özcan et al., in review). The Upper Ypresian deep-marine deposits overlying these units in the Thrace (Dişbudak Formation) and in the Kocaeli Peninsula (Çaycuma Formation) imply that almost all shelves

subsided before the onset of middle Eocene. This was also recently discovered in the Haymana basin in central Anatolia where lower and upper members of the Haymana Formation are separated by a deep-marine middle unit of the Çayraz Formation (Özcan et al., in review). The deep-marine marls (Karabük Fm.) overlying the Ypresian shallow marine deposits (Safranbolu Fm.) in the Safranbolu-Karabük basin correspond to Lutetian (Saner et al., 1980; Özcan et al., 2007). Shallow marine conditions, however, prevailed in the İznik-Geyve region (Sölöz sections) during latest Ypresian, where shallow marine deposits pass upward to volcanoclastic units (MEMR). On the Armutlu Peninsula, volcanoclastic units are underlain by deep-marine turbiditic siliciclastic deposits (Yörükler section), implying that initial depositional setting of volcanoclastic units was not uniform, but varying from shelf to bathyal zone in NW Turkey.

The early Lutetian, recorded only near Şile on the Kocaeli Peninsula (Yunuslubayır Formation) and in the İznik region corresponds to a narrowing of the shelf environment (Figure 24D). In central Turkey, the lower Lutetian shallow marine deposits are best known from the upper unit of the Çayraz Formation in the Haymana Basin. In the Safranbolu-Karabük Basin, the early Lutetian is represented by deep-marine beds (Özcan et al., 2007). The middle Lutetian saw extensive volcanism and limited shallow water sedimentation in NW Turkey (Figure 24D). Shallow marine clastic and carbonate beds intercalated with volcanic rocks are extensively developed on the Armutlu Peninsula and further in the south in the İznik-Pamukova-Geyve region and in the northern part of the Biga Peninsula. The sea retreated from the region in the middle Lutetian and the area became land.

The Bartonian-Priabonian saw the development of a new marine realm in the north of Biga Peninsula and in the Thrace Basin (including the Black Sea shelf) where continental red beds of the Fiçitepe formation and overlying carbonates and clastics of the Soğucak and Şevketiye formations were deposited extensively (Özcan et al., 2010, 2018; Less et al., 2011; Okay et al., 2019) (Figure 24E). The carbonate platform was drowned diachronously and pelagic siliciclastic rocks were deposited during the latest Bartonian-Oligocene time interval (Özcan et al., 2018; Okay et al., 2019).

6. Conclusions

Eocene seas in NW Turkey led to the deposition of shallow-to deep-marine siliciclastic and carbonate deposits that show notable lateral and vertical facies changes. These clastics and carbonates are also associated with volcanoclastic deposits on the Biga and Armutlu peninsulas and in the İznik-Geyve region. The LBF, supplemented by calcareous nannoplankton and planktonic foraminiferal

data from the shallow- to deep-marine Eocene successions from the Thrace Basin, the Armutlu and Kocaeli peninsulas and the İznik-Geyve region allow us to revise the biostratigraphy of these units and to establish a time-framework of the marine events. Orthophragminids, the most dominant group in some levels, are characterized by the species of the genera *Discocyclina*, *Nemkovella*, *Asterocyclina*, and *Orbitoclypeus*. Orthophragminid and nummulitid assemblages suggest several shallow marine depositional phases (SMP) in the early Ypresian (SBZ 5/7 and 7/9), late Ypresian (SBZ 10/11), early Lutetian (SBZ 13), and middle Lutetian (SBZ 14/15) respectively (Figures 23, 24). Among them, the middle Ypresian (early Cuisian) deposits are the most widespread, also recognized over a wider region in central Anatolia, whereas the lower Lutetian deposits occur only in a limited area near Şile, along the coast of Black Sea and near İznik. In the Thrace Basin, the correlatives of the lower and middle Ypresian deposits are only recognized in two areas on the Gelibolu Peninsula with limited outcrops.

A volcanoclastic unit (MEMR) rests on various rocks ranging from deep-marine turbiditic beds to shallow marine deposits. This suggests a nonuniform setting for the deposition of this unit. The fossiliferous beds below the first volcanic level of MEMR yielded various developmental stages of *Discocyclina archiaci* (Schlumberger), *D. fortisi* (d'Archiac) and *Orbitoclypeus douvillei* (Schlumberger), suggesting a late Ypresian age or transitional late Ypresian/early Lutetian age. Thus, our data constrain the age of the initiation of volcanism to upper Ypresian. This is consistent with the ages of

planktonic foraminifera in shale intercalations between the tuff beds (*Morozovella aragonensis* (Nuttall), *M. caucasica* (Glaessner), *A. pentacamerata* (Subbotina), *A. bullbrooki* (Bolli), *Acarinina broedermanni* (Cushman and Bermudez), *Acarinina* spp. and *Subbotina* spp.) identified by Özcan et al. (2012) suggesting late Ypresian- early Lutetian age for the volcanoclastic rocks.

The marine realm had vanished in the middle Lutetian in the Kocaeli and Armutlu peninsulas and since then the area has been a land with continental deposition and erosion (Figure 24). In the meantime, a new shallow marine sea transgressed the Biga Peninsula and the Thrace Basin in Bartonian and Priabonian times. This marine realm extended towards the north and joined with the Black Sea shelf in the Priabonian.

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