

Palynomorph, Foraminifera, and Calcareous Nannoplankton Biostratigraphy of Oligo–Miocene Sediments in the Muş Basin, Eastern Anatolia, Turkey

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Abstract: Oligo–Miocene sediments have not been adequately studied biostratigraphically, and a detailed bio-chronostratigraphic framework has not yet been established in Eastern Anatolian basins. Palynomorphs have therefore been correlated with the biozonations of marine dinoflagellates, planktonic foraminifera and calcareous nannoplankton of similar latitudes in combined samples from the Ebulbahar and Kelereşdere measured stratigraphic sections, which are located in the northeastern part of Muş. Palynological (dinoflagellate), foraminiferal micropalaentological, and nannopalaentological events, correlatable with worldwide defined biozonations, have been documented from uppermost Rupelian to Upper Miocene–Pliocene sediments. First occurrences (FOs) and last occurrences (LOs) of selected dinoflagellates are important in establishing the biostratigraphic framework. The LO of *Wetzeliiella gochti* in the latest Rupelian, the LO of *Deflandrea phosphoritica* in the latest Chattian, peak occurrences of *Chiropteridium* spp. in the early and late Aquitanian, the FO of *Hystrichosphaeropsis obscura*, followed by the FO of *Membranilarnacea? picena* in the late Aquitanian are of particular significance for regional correlations. Based on established marine zonations and the presence of characteristic Oligocene taxa such as *Slowakipollenites hipophæoides* and *Mediocolpopollis compactus*, stratigraphic ranges of relatively less known pollen taxa in the region, especially those of Compositae (tubuliflorae-type), Umbelliferae, Gramineae, considered to have their first occurrences at the beginning of Neogene in earlier studies, have been calibrated. In the light of this study, the Late Oligocene–Early Miocene zonation of some palynomorphs should be emended and the stratigraphic ranges of the Compositae (tubuliflorae-type), Umbelliferae, Gramineae pollen should be extended into the Chattian and even the Rupelian in this region. As far as depositional conditions are concerned, palynomorph and organic facies properties indicate deposition under brackish water, shallow (restricted) and relatively deeper marine conditions related to fluctuating sea level during the Oligocene and Early Miocene. Shallowing-upwards deposition during the Late Oligocene was followed by restricted marine and brackish conditions at the Oligocene–Miocene boundary and in the early Aquitanian. Relatively deeper conditions in the late Aquitanian continued as extensive reef accumulations due to shallowing in the early Burdigalian. Finally, after the last deepening event at the end of Burdigalian and Early Langian, completely terrestrial (lacustrine and fluvial) deposition predominated in the Muş Basin due to withdrawal of the sea. Terrestrial palynomorphs reflect temperate to subtropical climates in which mean annual temperatures vary between 15.6 and 21.3 °C, and mean temperatures of the coldest month (CMT) were between 5.0 and 13.3 °C.

Key Words: Oligocene, Miocene, Eastern Anatolia, palynomorphs, planktonic foraminifera, benthic foraminifera, nannoplankton, palaeoenvironment, palaeoclimate

Oligo–Miyosen Sedimanlarının Palinomorf, Foraminifer ve Nannoplankton Biyostratigrafisi, Muş Havzası, Doğu Anadolu, Türkiye

Özet: Doğu Anadolu Bölgesi sedimanter havzaları biyostratigrafik açıdan yeterince çalışılmadığı için, sedimanter istifin biyo-kronostratigrafik özellikleri tam olarak bilinmemektedir. Bu çalışmada, söz konusu belirsizliklere çözüm sağlamak amacıyla, Ebulbahar ve Kelereşdere (KD Muş) ölçülmüş stratigrafik kesitlerinden derlenen örneklerde, en üst Rupelien–Üst Miyosen/Pliyosen sedimanlarında dinoflagellat biyozonları tanımlanmış ve bu biyozonlar benzer paleoöğrafik kuşaklarda yer alan istiflerde tanımlanan dinoflagellat, foraminifer ve nannoplankton biyozonları ile denştirilmiştir. Bazı indeks dinoflagellat taksonlarının ilk ortaya çıkışı (FO) ve son görünüşlerine (LO) dayanarak tanımlanan bu dinoflagellat zonları arasında, *Wetzeliiella gochti*'nin LOSunun en üst Rupelien; *Deflandrea phosphoritica*'nın LOSunun en üst Şattien, *Chiropteridium* spp.'nin bolluk zonunun alt ve üst Akitanien, *Membranilarnacea? picena*'nin FOSu tarafından izlenen *Hystrichosphaeropsis obscura*'nın FOSunun üst Akitanien'in

bölgesel denetirilmesi için önemli palinolojik deęişimler olduęu ortaya konmuştur. Söz konusu denizel dinoflagellat zonları ile bazı indeks pollenlere dayanarak (*Slowakipollenites hipophæoides* ve *Mediocolpopollis compactus*), Doęu Anadolu Tersiyer çökelleri içindeki stratigrafik dağılımları çok iyi bilinmeyen Compositae (tubuliflorae-tip), Umbelliferae ve Gramineae familyalarına ait taksonların stratigrafik dağılımları da kalibre edilmiş, bölgede ilk ortaya çıkışlarının bilinenin aksine Şattiyen, hatta Rupeliyen'e kadar uzandıęı ortaya konmuştur.

Biostratigrafik veriler ile organik fasiyes özellikleri birlikte deęerlendirildiğinde, Oligosen–Erken Miyosen döneminde çalışılan bölgede deniz seviyesindeki deęişimlere baęlı olarak acı sulu gösel ortamlardan, sıę-derin denizel ortamların etkili olduęu söylenebilir. Geç Oligosen boyunca giderek sıęlaşan bir ortamda süren çökelim, Oligosen–Miyosen sınırında ve erken Akitaniyen'de sınırlı denizel ve acı sulu gösel ortamlarda devam etmektedir. Geç Akitaniyen'deki nispeten derin koşullar erken Burdigaliyen'de meydana gelen sıęlaşma nedeni ile geniş yayımlı resif oluşumları tarafından izlenmiştir. Geç Burdigaliyen–?erken Langiyen'deki son derinleşme fazından sonra ise Muş Havzası'ndan denizin çekilmesi nedeni ile tamamen karasal (gösel ve flüviyal) çökelim koşulları hakim olmaya başlamıştır. Çalışılan karasal palinomorf taksonları ile yapılan paleoklimsel deęerlendirmeler yıllık ortalama sıcaklıkların (MAT) 15,6–21,3 °C, en soęuk ay sıcaklık ortalamasının (CMT) 5,0–13,3 °C olduęu ılıman-yarıtropik iklim koşullarına işaret etmektedir.

Anahtar Sözcükler: Oligosen, Miyosen, Doęu Anadolu, palinomorf, planktonik foraminifer, bentik foraminifer, nannoplankton, paleortam, paleoklim

Introduction

Oligo–Miocene sediments in Eastern Anatolia have not yet been studied adequately palaeontologically and a biostratigraphic framework has not yet been properly established. Palynomorphs have been correlated with biozonations of foraminifera and calcareous nannoplankton in samples from the Ebulbahar and Kelereşdere measured stratigraphic sections in Muş. The aim of this study is to document the distribution of dinoflagellates and identify dinoflagellate events in Oligo–Miocene sediments. Calibration of stratigraphically important dinoflagellate events is achieved by use of planktonic foraminifers. The Muş Basin was chosen for this study because the Oligo–Miocene transition is marine in character in the southern part of the basin and these sediments were expected to be productive for all three fossil groups. Depending on the lithology, palynological, nannopalaeontological, and foraminiferal micropalaeontological analyses have been carried out and bio-chronostratigraphic zones are discussed.

As a pioneering study, the main purpose of this paper is to document the principles of biostratigraphy of Oligo–Miocene sediments in Eastern Anatolia and to establish a biostratigraphic framework for future studies.

As it was indicated by Berger (1992), the disadvantages and advantages of different fossil groups (planktonic foraminifera, palynomorphs and calcareous nannoplankton) should always be kept in mind when establishing biozonations. He summarized the strong and weak aspects of these three disciplines as follows: all three may obtain high resolution biostratigraphical data which may be in the range of 0.5–4.0 Ma for calcareous

nannoplanktons, planktonic foraminifers and marine palynomorphs (dinoflagellates), whereas it is 1.5–4.0 Ma for terrestrial palynomorphs. Biozonations of calcareous nannoplankton and planktonic foraminifers are well established but are found only in marine sediments; whilst terrestrial palynomorphs can be found in both marine and terrestrial successions. Moreover, calcareous nannoplankton and planktonic foraminifers are very rare in shallow marine conditions. Nannoplanktons are very useful biostratigraphic markers but they can easily be reworked, and according to Berger (1992), reworking is the major problem of correlation studies based on calcareous nannoplankton biozonations. On the other hand, the major problem of the palynomorph-based correlation studies is the preservation (oxidation and mechanical destruction). Berger (1992) emphasized that there is also a possibility for terrestrial palynomorphs to reflect climatic changes rather than biostratigraphically meaningful evolutionary trends.

Regional Stratigraphic Framework

The Eastern Anatolian subbasins are bordered by the Pontides to the north, the Southeast Anatolian Suture Zone to the south, the Karlıova Triple Junction of the North Anatolian and South Anatolian faults to the west (Allen 1969; Arpat & Şaroęlu 1972; Şengör 1979), and Georgia, Armenia and Iran to the east (Figure 1). Eastern Anatolia occupies the northwestern part of the Turkey-Iran Plateau (Şengör & Kidd 1979).

This study was carried out in the Muş Basin located in the northern part of the Bitlis Metamorphics and the

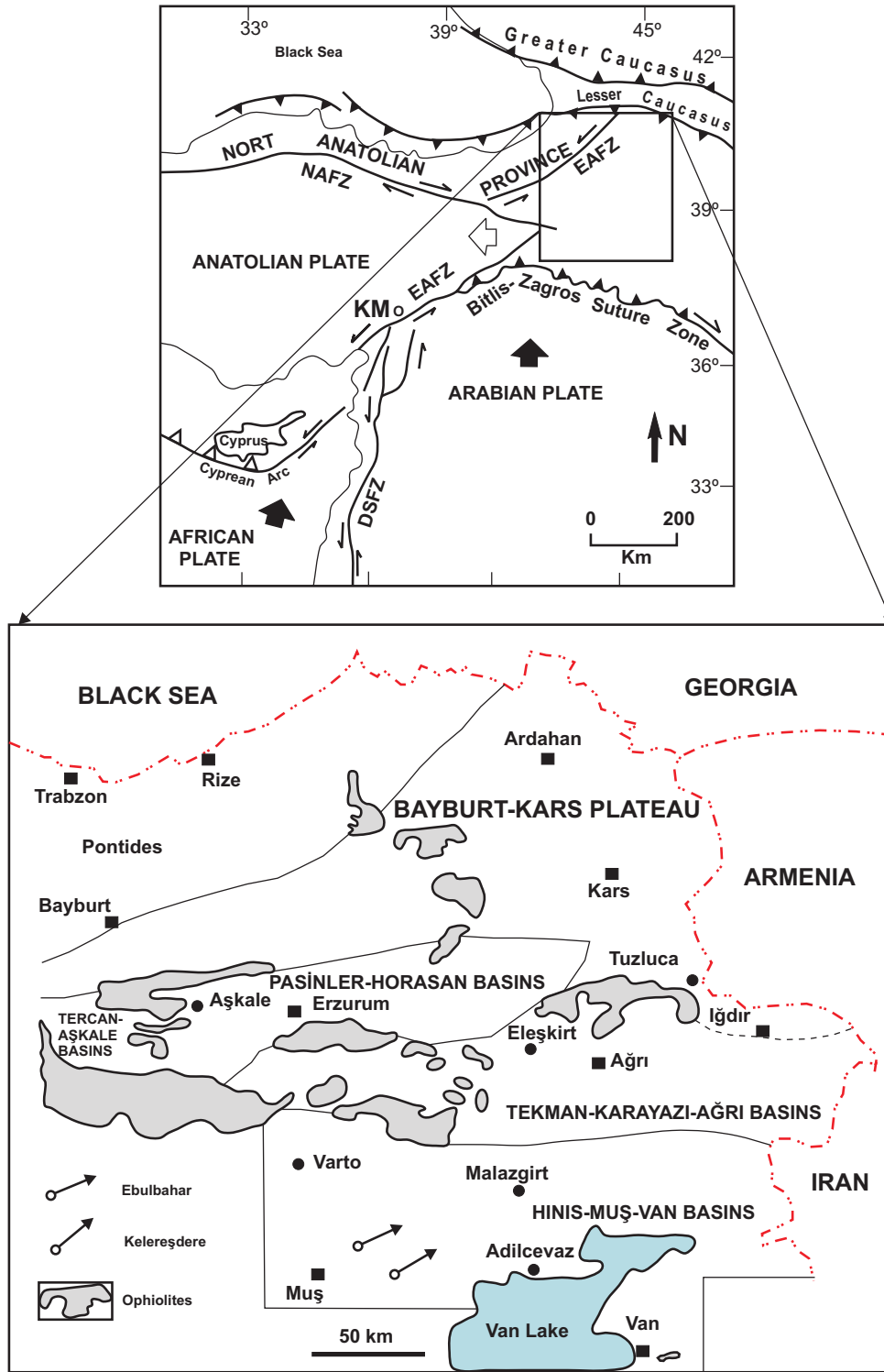


Figure 1. Location map of the Eastern Anatolia subbasins, Ebulbahar and Kelereşdere measured stratigraphic sections. (K– Karlıova, KM– Kahramanmaraş; DSFZ– Dead Sea Fault Zone, NAFZ– North Anatolian Fault Zone, NEAFZ– Northeast Anatolian Fault Zone (modified from Bozkurt 2001; Şahintürk *et al.* 1998).

eastern part of the North Anatolian Fault Zone. The Muş Basin is Mesozoic-Cenozoic in age, intermontane in nature and formed under the influence of the North Anatolian Fault Zone (Şengör 1980; Şengör & Yılmaz 1981; Şaroğlu & Yılmaz 1987).

Şaroğlu & Güner (1981) and Şaroğlu (1985) have identified four depositional/tectonic phases in the Eastern Anatolian basins (Figure 2).

The first and oldest phase is Palaeozoic in age and represented by metamorphics such as gneiss, micaschist,

granite, marble, crystalline limestone, and meta-volcanics, although Savcı *et al.* (1979) and Perinçek (1980) argued that the younger parts of the metamorphics could be of Early Mesozoic age. The second phase is represented by an Upper Cretaceous ophiolitic mélangé, consisting of sandstone, tuff, limestone blocks, basic and ultrabasic rocks, that tectonically overlies the metamorphics. Şengör (1980) and Şengör *et al.* (1980) interpreted this unit as a product of the northern branch of the Neotethys and according to Şengör (1980), these two phases correspond to an East Anatolian Accretionary Complex

| CHRONO-STRATIGRAPHY | LITHOLOGY | EXPLANATIONS |
|---|-----------|--|
| UPPER MIOCENE-QUATERNARY | | volcano-sedimentary rock, sandstone, mudstone, marl, clayey limestone, agglomerate, basalt, tuff, andesite |
| | | <i>angular unconformity</i> |
| PALAEOCENE (?) - EOCENE - LOWER MIOCENE | | conglomerate and flysch at the bottom, sandstone, mudstone, and clayey limestone towards the upper levels |
| | | <i>nonconformity</i> |
| UPPER CRETACEOUS | | ophiolitic melange: blocks of serpentinite and limestone |
| | | <i>tectonic contact</i> |
| PALAEZOIC-LOWER MESOZOIC | | Metamorphic rocks: gneisses, marble, micaschists, metavolcanics, granite |

Figure 2. Columnar section illustrating depositional/tectonic stages in the Eastern Anatolian basins (Şaroğlu 1985).

created by the elongation of Anatolids and Taurids. The third phase is characterized by Palaeocene(?)–Eocene to Lower Miocene sedimentary rocks consisting of limestone, argillaceous limestone, sandstone, and siltstone. These sediments are shallowing-upward in character and unconformably overlie older units belonging to the first and second phases. A compressive regime was active in this phase, related to the collision of the Arabian and Laurasian plates (Yılmaz 1993). Sediments of the third phase began with relatively deeper marine Eocene sediments of limited extent followed by shallower marine Oligocene sediments and ending up with the shallow marine to reefal Lower Miocene sediments of wider extent. The last and youngest phase consists of terrestrial sediments (sandstone, claystone, siltstone, and marl), volcanics (basalt, andesite, rhyolite, dacite, tuff and agglomerate) which originated from N–S-trending tensional fractures (Şaroğlu *et al.* 1980) and associated tectonic events from Late Miocene to Recent. Sediments deposited during the fourth phase overlie unconformably those of the third phase. Eastern Anatolia was affected by an intense tectonic regime at the beginning of the Late Miocene (neotectonic period of Şengör 1980). Figure 3 illustrates the generalized stratigraphic section of the Muş Basin (Şahintürk & Erdem 2002, modified after Soyutürk 1973). The Sakaltutan Ophiolitic Complex and metamorphics constitute the basement and are unconformably overlain by limestones with Rudist bivalves known as the Kapıkaya Formation, Maastrichtian in age and the oldest rocks outcropping in the area. The Kapıkaya Formation is unconformably overlain by the Palaeocene Merttepe Formation, which includes mostly limestone, shale, marl and sandstone. The Sevik and Merttepe formations are conformably overlain by clayey limestone, shale and sandstones of the Lower–Middle Eocene Kösehasan Formation. The Ahlat Formation of Late Eocene age, unconformably overlies the Kösehasan Formation and the the Ahlat Formation is characterized by terrestrial, reddish sandstone, siltstone and conglomerate at the base and marine, clayey limestone, silty marl and sandstone at the top. The Ahlat Formation is unconformably overlain by sandstone-marl intercalations of Late Oligocene–Early Miocene age with limestone interbeds, known as the Kelereş (Yazla Formation of Akay *et al.* 1989) Formation, shallow marine unit measured as 3250 m thick in the Kelereşdere valley but 4250 m in the Ebulbahar valley. Towards the northern part of the Muş Basin, the Kelereş Formation passes into more transitional and terrestrial deposits

characterized by deltaic sandstones, clayey limestones, siltstones, laminated shales and coal interbeds known as the Kömürlü and Penek formations. The Lower–Middle Miocene Aşkale Formation, represented by limestone, shale, marl, sandstone, gypsum, conformably overlies the Kelereş Formation. The Adilcevaz Member of the Aşkale Formation is characterized by reefal limestones of Burdigalian age (Demirtaşlı & Pisoni 1965), and the Aşkale Formation is unconformably overlain by sedimentary and volcano-sedimentary rocks belonging to the Upper Miocene–Pliocene Zırnak Formation. Volcanic rocks known as the Karakurt-Solhan Volcanics have occasionally been seen laterally and vertically transitional to the Zırnak Formation, the dominant lithologies of which are sandstone, mudstone, marl and evaporites. The Bulanık and Elmakaya formations, of Pliocene age, unconformably overlie the Zırnak Formation and are mostly dominated by sandstone, mudstone and marl. Basalt, tuff and agglomerate related to the Nemrut volcanics either rest unconformably upon the Bulanık and Elmakaya formations, or are horizontally transitional to them.

Material and Methods

A very thick succession of Oligo–Miocene sediments crops out near Kelereş village, Muş (Figure 1). The Ebulbahar and Kelereşdere sections, located in the northeastern part of Muş, have been measured and sampled for biostratigraphic analyses. The Ebulbahar section begins at coordinates N 01150, E 35950 in the K47-a3 quadrangle of the topographic map of Turkey, and ends at coordinates N 12650, E 45950 in the K47-b1 (Figure 4); and the Kelereşdere section begins at coordinates N94000, E37000 in the K47-c1, and ends at coordinates N 00000, E 51000 in the K47-b3 (Figure 5). Since the whole Kelereş Formation reflects shallow marine depositional conditions in the study area, palynology, foraminiferal micropalaeontology and nannopalaeontology have all calibrated throughout the sections and with good fossil recoveries. The Ebulbahar and Kelereşdere measured stratigraphic sections are composed mainly of clastic lithologies (shale, marl, silty marl, sandstone, siltstone, claystone, and conglomerate) interfingering with limestones. Palynological and nannopalaeontological slides and washed samples for foraminiferal micropalaeontological analyses have been prepared for siliciclastic lithologies, whereas limestones

| SYSTEM | SERIES | LITHOSTRATIGRAPHY | | THICKNESS (m) | LITHOLOGY | EXPLANATIONS |
|------------|------------------|-------------------------------|-----------------------|---------------|-----------------------------------|--|
| | | FORMATION | MEMBER | | | |
| TERTIARY | Quaternary | Pleist.-Holo. | | | 1000 | alluvium UNCONFORMABLE basalt, agglomerate, tuff UNCONFORMABLE |
| | | | | | 250-2000 | sandstone, conglomerate, marl basalt, agglomerate, tuff, conglomerate, UNCONFORMABLE |
| | | Pliocene | Bulanık-Elmakaya | | | lacustrine limestone GRADITIONAL |
| | | Upper Miocene | Zirnak (Solhan volc.) | Çukurtarla | 200 | sandstone, marl, mudstone, tuff, lignite GRADITIONAL |
| | | | | Develik | 1500 | sandstone, marl, conglomerate, mudstone, evaporites UNCONFORMABLE |
| | | | | Kırmızı Tuzla | 1900 | reefal limestone GRADITIONAL |
| | | Low.-Mid Miocene | Aşkale | Adilcevaz | 50-1000 | shale, marl, sandstone, limestone GRADITIONAL |
| | | Upper Oligocene-Lower Miocene | Kelereş Kömürü+Penek | | 500-3000 | mudstone, siltstone, sandstone, conglomerate (channel fill) UNCONFORMABLE |
| | | Upper Eocene | Ahlat | | 500-2000 | clayey limestone, sandstone, shale GRADITIONAL |
| | | Lower-Middle Eocene | Kösehasan | | 1500 | limestone, sandstone, shale, marl UNCONFORMABLE |
| | Paleocene | Sevik-Mertepe | | 500 | Rudist limestone UNCONFORMABLE | |
| CRETACEOUS | Maastric. | Kapıkaya | | 75 | mélange | |
| | Upper Cretaceous | Sakaltutan ophiolites | | 1500-2000 | | |

Figure 3. Generalized stratigraphic section of the Muş Basin (Şahintürk & Erdem 2002; modified after Soyutürk 1973).

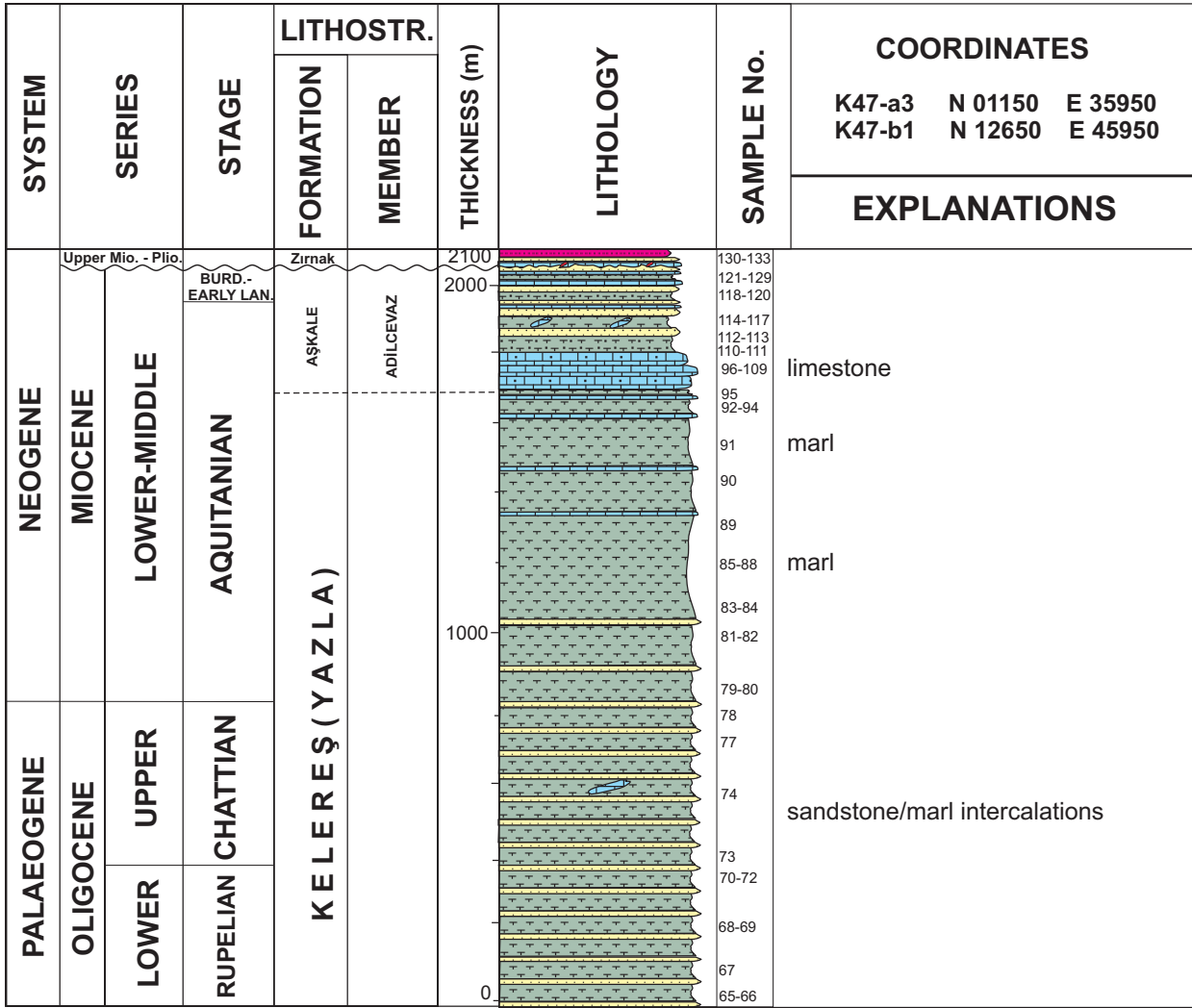


Figure 4. Ebulbahar measured stratigraphic section and sample locations.

were studied only in thin sections. Depending on the lithology, related disciplines were employed to the same samples, and the different biozonations have been correlated on a bio-chronostratigraphic chart.

Relative abundances of the fossils were calculated semiquantitatively and the following terms used: *super abundant* (S): more than 100 specimens, *abundant* (A): 20 to 100 specimens, *common* (C): 6 to 20 specimens, *rare* (R): 2 to 6 specimens, *present* (P): only 1 specimen.

Palaeoclimatologic reconstructions were made using CLIMSAT software (see also Mosbrugger & Utescher 1997 for detailed explanations).

Digital images of the palynomorphs, nannoplanktons, and foraminifers have been taken using a Leica DC200 digital camera system. Fossil distribution charts (biostratigraphic correlation diagram) and the lithostratigraphic log were drawn by using StrataBugs and Corel Draw softwares, respectively.

165 samples were collected from the outcrops (Figures 4 & 5) but only 118 of them were productive and used in biostratigraphical analyses. All analysed materials are stored in the Palynology Laboratory Archive of the Turkish Petroleum Corporation (TPAO) Research Center, Ankara. Distribution of the productive samples is as follows in Table 1.

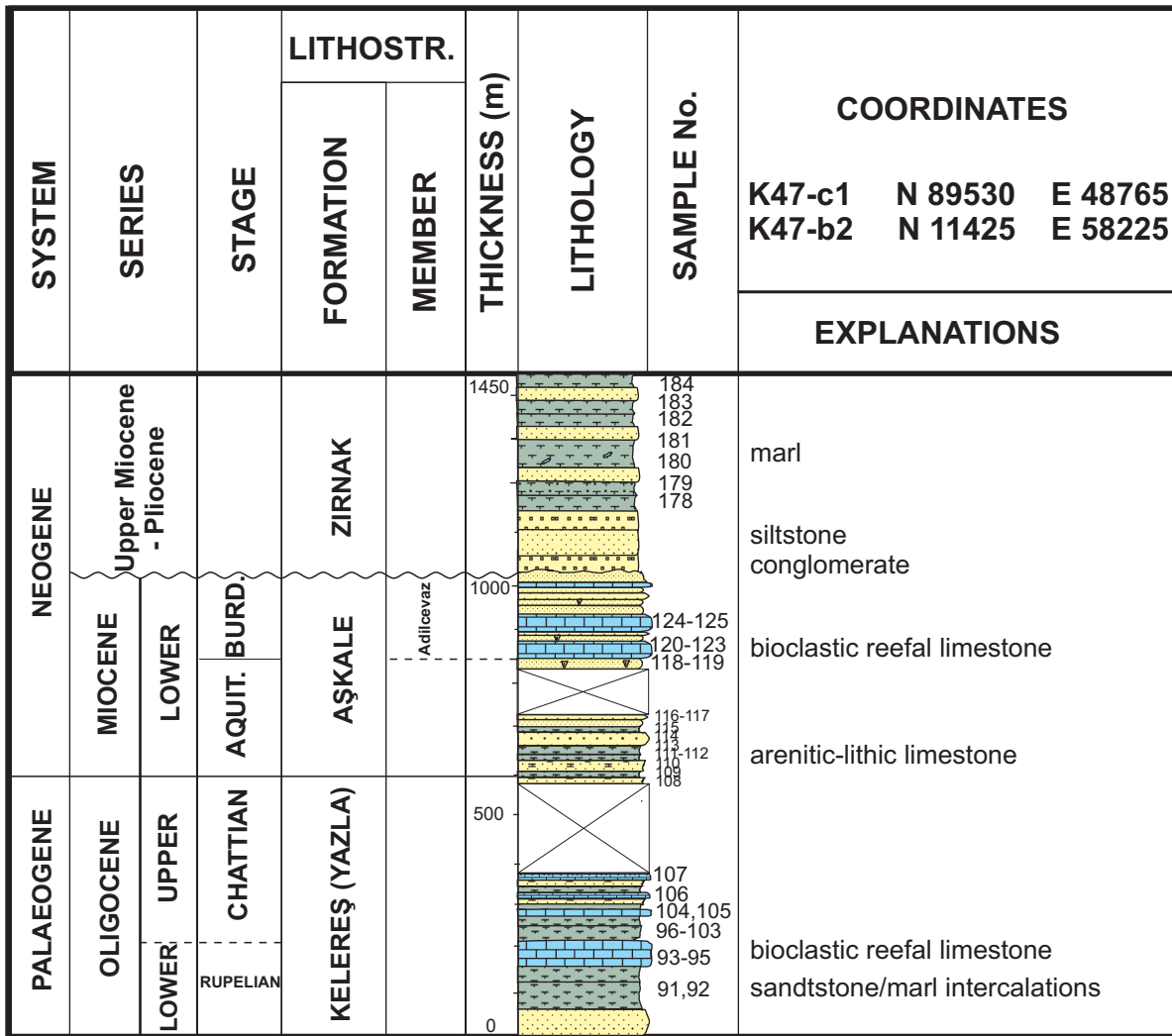


Figure 5. Kelereşdere measured stratigraphic section and sample locations.

Table 1. Distribution of the productive samples.

| Number of samples | Kelereşdere section | Ebulbahar section |
|--------------------|---------------------|-------------------|
| Palynology | 40 | 51 |
| Calc. nanoplankton | 47 | 34 |
| Micropaleontology | 34 | 67 |
| Total | 121 | 152 |

Biozonation

Depending on the lithology, palynological, nannopaleontological and foraminiferal micropaleontological analyses were carried out. Palynomorphs were correlated with biozonations of marine dinoflagellates, planktonic foraminifera and

calcareous nanoplanktons from similar latitudes in combined samples from the Ebulbahar and Kelereşdere measured stratigraphic sections in the field. Relative abundances of fossils have been calculated semiquantitatively ranging from *present* (only one specimen) to *super abundant* (more than 100 specimens).

Dinoflagellate and Acritarch Events (FO: First Occurrence, LO: Last Occurrence)

EO1. *Distatodinium biffii* Interval Zone

Assigned Age: latest Rupelian

Equivalent Planktonic Foraminiferal Zone: P21a

Equivalent Nannoplankton Zone: lower part of NP24

Samples: 66–72 in the Ebulbahar section and 92–95 in the Kelereşdere section

Definition: Interval between the LO of *Ascostomocystis potane* and the LO of *Wetzeliella gochtii*. The eponymous species, *Distatodinium biffii*, ranges above and below the zone. The LO of *Ascostomocystis potane* also coincides with the FO of *Globorotalia opima opima*. *Deflandrea phosphoritica* occurs commonly, and Compositae (tubuliflorae-type) also exist within this zone. The upper part of the zone could not be defined properly in the Kelereşdere section because of the unsuitable lithology (reefal limestone) in samples 93–95.

Discussion: Torricelli & Biffi (2001) reported that the FO and LO of *Wetzeliella gochtii* were in the Early Oligocene from Numidian Flysch in the Oued El Guastal and El Gassaa sections, Tunisia. They suggested that the LO of this taxon can be used as an additional criterion for the identification of the Clo Zone (Early Oligocene) of Wilpshaar *et al.* (1996) in the Mediterranean region. As reported by Pross (2001), the LO of *Wetzeliella gochtii* is a diachronous event that varies from Rupelian to early Chattian. On the other hand, according to Stover & Hardenbol (1994), the FO of *Ascostomocystis potane* is very close to the base of the Rupelian and last occurrence is in the middle Rupelian; in calcareous nannoplankton zone NP23 of Martini (1971), and it never occurs in the late Rupelian. We have not seen any *Ascostomocystis potane* in E01, but Batı and Sancay (2007) observed that this early–middle Rupelian taxon occurs just below the zone and corresponds to the middle/late Rupelian boundary. Reefal limestones (samples 93–95 in the Kelereşdere section) should therefore represent the ?late Rupelian.

LO1. *Deflandrea phosphoritica* Abundance Zone

Assigned Age: Chattian

Equivalent Planktonic Foraminiferal Zones: P21b and P22

Equivalent Nannoplankton Zones: upper part of NP24 and NP25

Samples: 73–78 in the Ebulbahar section and 96–106 in the Kelereşdere section

Definition: The base of the zone is defined by the LO of *Wetzeliella gochtii* and its top by the LO of *Deflandrea phosphoritica*. The base of the zone is not clear because of the unsuitable lithology (reefal limestone) and is still

under investigation (Batı & Sancay 2007). *Distatodinium biffii* makes its last appearance within the zone.

Discussion: The zone may correspond to the lower part of DO3, Late Oligocene, (top of the youngest acme of *Deflandrea* spp.) of Biffi & Manum (1988), the *Distatodinium biffii* (Dbi) Interval Zone of Brinkhuis *et al.* (1992) representing Late Oligocene–Early Miocene, and the *Distatodinium biffii* (Dbi) Interval Zone of Zevenboom (1996) indicating Late Oligocene. The two latter studies suggest that the FO of *Distatodinium biffii* defines the base of the zone whereas the base of the youngest acme of *Deflandrea* spp. can be used as a confirmatory event for the top.

EM1. *Transitional*

Assigned Age: early Aquitanian

Equivalent Planktonic Foraminiferal Zones: ?P22 to M1

Equivalent Nannoplankton Zones: ?NP-25 to NN1

Samples: 79–90 in the Ebulbahar section and 107–114 (partly covered) in the Kelereşdere section.

Definition: This transitional subzone is characterized by only a few occurrences of dinoflagellates such as *Homotryblum* sp. and *Spiniferites* sp., and the terrestrial freshwater alga *Botryococcus braunii*.

Discussion: Brinkhuis *et al.* (1992) reported distinct increases in terrestrial palynomorphs, especially *Chiropteridium* spp. towards the Oligocene–Miocene boundary, and claimed that the sudden increase in shallow-water indicators associated with an increasing amount of reworking might be related to the relative fall in sea level. This regressive event was also reported by Haq *et al.* (1988), indicating that the Oligocene–Miocene transition coincides with the base of their cycle TB1.4 and corresponds to Chron C6Cr3 at about 25 Ma. Moreover, several stable isotope studies (Miller *et al.* 1985, 1987; Biolzi 1983) suggest a global cooling event and confirm the global nature of the relative fall in sea level at the Oligocene–Miocene boundary.

Köthe (1990) studied the Palaeogene dinocysts of northwest Germany. She reported an assemblage which can be compared with D15 of Costa & Manum (1988) and is characterized by the common occurrences of *Homotryblum plectilum*, *Membranophoridium aspinatum* (especially common in the lower part, but rare in the upper part), rare occurrences of *Chiropteridium* and the

absence of *Deflandrea phosphoritica*, which was interpreted as indicating a Late Oligocene age corresponding to Nannoplankton Zone NP25. This assemblage may be compared with sequences A and B, latest Chattian and/or early Aquitanian in age, of Dybkjær (2004). Similar dinoflagellates have also been identified in the transitional zone (EM1) in Eastern Anatolia and interpreted as Early Miocene in age.

EM2. *Chiropteridium* spp. Abundance Zone I

Assigned Age: early-middle Aquitanian

Equivalent Planktonic Foraminiferal Zone: M1

Equivalent Nannoplankton Zones: NN1 and NN2

Samples: 91-92 in the Ebulbahar section and 115-119 (partly covered) in the Kelereşdere section.

Definition: This zone is represented by the peak occurrences (including the first common occurrence) of *Chiropteridium galea* and *Chiropteridium lobospinosum*.

Discussion: The zone may be compared with DN1 (upper Chattian to lower Aquitanian) of de Verteuil & Norris (1996) in which a *Chiropteridium-Homotryblium-Systematophora* assemblage and the LOs of *Chiropteridium* and *Deflandrea phosphoritica* are reported. It also corresponds to the *Chiropteridium* (Chi) Abundance Subzone (uppermost Oligocene-lowermost Miocene) of Brinkhuis *et al.* (1992), to the top P22 through N4 planktonic foraminiferal zone, and to the basal NP25 through NN1 calcareous nannoplankton zones.

EM3. *Hystrichosphaeropsis obscura* Interval Zone

Assigned Age: middle-late Aquitanian

Equivalent Planktonic Foraminiferal Zones: M1 to ?M2

Equivalent Nannoplankton Zones: NN1 and NN2

Samples: 93-94 in the Ebulbahar section, but the interval is covered in the Kelereşdere section.

Definition: Base of the zone is defined by the FO of *Hystrichosphaeropsis obscura* and the last common occurrence of *Homotryblium vallum*. *Chiropteridium galea*, *Heteraulacacysta* sp., *Cribrorperidium tenuitabulatum*, and *Apteodinium spiridoides* occur commonly within this zone which also contains the LO of *Cordosphaeridium cantharellus*. The top of the zone is

not well defined because of the unsuitable overlying lithology (limestone).

Discussion: This zone may be comparable with DN2 (lower Lower Miocene to middle Lower Miocene) of de Verteuil & Norris (1996). It corresponds in part to the *Ectosphaeropsis burdigaliensis* Interval Zone (Lower Miocene) of Brinkhuis *et al.* (1992), defined as an interval between the base of the youngest acme of *Deflandrea* spp., to the FO of *Membranilarnacia? Picena*; corresponds to the basal N4 through N5 planktonic foraminiferal zones and the basal NN1 through NN2 calcareous nannoplankton zones.

Sequence C of Dybkjær (2004) may be compared with Lower Miocene sediments of the Ebulbahar section. Dybkjær (2004) indicated that the abrupt disappearance of *Chiropteridium galea*, *Glaphyrocysta*-group, and *Deflandrea phosphoritica* and low diversity *Homotryblium*-dominated assemblage have been replaced by a high diversity assemblage dominated by *Impletosphaeridium insolitum*, *Operculodinium centrocarpum*, *Spiniferites* spp., and *Cleistosphaeridium placacantha* co-existing *Apteodinium* spp., *Hystrichokolpoma rigaudiae*, *Lingulodinium machaerophorum* and rare *Homotryblium* spp.

The upper four samples of Heilmann-Clausen & Costa (1989) were also reported as Early Miocene in age, comparable with D16/D17 zones of Costa & Manum (1988) based on the presence of *Hystrichokolpoma poculum* and *Hystrichosphaeropsis obscura* and the absence of high abundances of *Chiropteridium* spp., *Deflandrea* spp., and *Homotryblium* spp. This assemblage, which is dated as middle-late Aquitanian (EM3) in the present study, may be comparable with sequence C, early to middle Burdigalian, of Dybkjær (2004).

EM4. *Chiropteridium* spp. Abundance Zone II

Assigned Age: late Aquitanian

Equivalent Planktonic Foraminiferal Zones: M1 to ?M2

Equivalent Nannoplankton Zones: NN1 and NN2

Samples: 110-112 in the Ebulbahar section but could not be detected in the Kelereşdere section due to the unsuitable lithology.

Definition: The last common occurrence of *Chiropteridium* spp. and the first common occurrence of

Homotryblium pusillum fall within this zone. The upper boundary of the zone is not defined palynologically due to the unsuitable lithology (limestone).

Discussion: This zone corresponds in part to the upper portions of the *Ectosphaeropsis burdigaliensis* Interval Zone (Early Miocene) of Brinkhuis *et al.* (1992) which was defined as extending from the base of the youngest acme of *Deflandrea* spp., to the FO of *Membranilarnacia? picena* and corresponding to the basal N4 through N5 planktonic foraminiferal zones and basal NN1 through NN2 calcareous nannoplankton zones.

EM3 and EM4 biozones can be correlated with the third biozone, named the *Hystrichosphaeropsis obscura-Chiropteridium* spp. Assemblage Zone, of Ertuğ *et al.* (1995) and defined in the Akçan Member of the Alibonca Formation, in the Tekman Basin, Eastern Anatolia. This biozone was based on the FO of *Hystrichosphaeropsis obscura* and the epibole of *Chiropteridium* spp. and common occurrences of *Impletosphaeridium* sp. and *Hystrichokolpoma rigaudiae* were also reported from the unit, according to Ertuğ *et al.* (1995), is of Early Miocene (Aquitanian–Burdigalian) age supported by the evidence from nannoplankton, which suggest an Early Miocene (NN2 nannoplankton zone).

EM1 through EM4 zones correspond to the *Ectosphaeropsis burdigaliensis* (Ebu) Interval Zone of Brinkhuis *et al.* (1992), defined as an interval between the base of the youngest acme of *Deflandrea* spp., and the FO of *Membranilarnacia? picena*. They indicated that the zone represents the Early Miocene.

EM5. *Membranilarnacia? picena* Interval Zone

Assigned Age: latest Aquitanian

Equivalent Planktonic Foraminiferal Zone: M2

Equivalent Nannoplankton Zone: NN2

Sample: 116 in the Ebulbahar section but could not be detected in the Kelereşdere section due to the unsuitable lithology.

Definition: Base of the zone is defined by the FO of *Membranilarnacia? picena* but the top of the unit is not defined due to an overlying unconformity. The LOs of *Chiropteridium* spp. and *Thalassiphora pelagica* also fall within this zone.

Discussion: Corresponds to the *Membranilarnacia? picena* (Mpi) Interval Zone (Early Miocene) of Brinkhuis *et al.* (1992) and Zevenboom (1996), and the DM1b

Subzone of Biffi & Manum (1988). Torricelli & Biffi (2001) also reported that *Membranilarnacia? picena* has its FO in Aquitanian deposits from the Numidian Flysch in El Gassaa and Cap Serrat sections in Tunisia.

Due to the unsuitable lithologies (mostly limestone, carbonaceous sandstone with some silty marl intercalations in which palynomorphs occur sporadically) of the uppermost Aquitanian–Burdigalian sediments, some stratigraphically important dinoflagellates such as *Exochosphaeridium insigne*, *Sumatradinium druggii*, *Sumatradinium soucouyantiae* and *Cousteaudinium aubryae* are missing from Eastern Anatolia. Sampling interval may also be another reason for the apparent absence of these taxa because they have short stratigraphic ranges, which could not be correlated regionally on the basis of dinoflagellate events.

EM6. Terrestrial Zone

Assigned Age: Late Miocene to Pliocene

Equivalent Planktonic Foraminiferal Zone: ?

Equivalent Nannoplankton Zone: ?

Sample: 178–184 in the Kelereşdere section but could not be detected in the Ebulbahar section due to the unsuitable lithology.

Definition: Completely terrestrial palynomorphs and freshwater algae dominate this zone, the base of which is not defined satisfactorily properly because of the underlying unconformity. Compositae (liguliflorae-type), Compositae (tubuliflorae-type; small), Dipsacaceae, Umbelliferae, *Periporopollenites multiporatus*, *Polyporopollenites undulosus*, *Monoporopollenites gramineoides*, *Botryococcus braunii* and *Ovoidites parvus* occur commonly in the samples.

Terrestrial Palynomorphs

Palynological studies, mostly carried out by TPAO on wells and surface sections in Eastern Anatolia, are based mainly on terrestrial palynomorphs. Because of the absence of multidisciplinary studies in the region, uncertainties in the stratigraphic ranges of many fossils including dinoflagellates, planktonic and benthonic foraminifera, and nannoplankton still exist. Biozonations established especially in western and central Turkey in earlier studies by Benda (1971a, b); Benda *et al.* (1977, 1979); Ediger *et al.* (1990); Batu (1996) have been used in Eastern Anatolia with only limited success.

As far as terrestrial palynomorphs are concerned, pollen belonging to the Compositae family seem to be very important in establishing a biostratigraphic framework in Eastern Anatolia. Compositae pollen have not been reported from sediments older than Late Oligocene throughout the world (e.g., Germeraad *et al.* 1968; Kemp & Harris 1977; Hochuli 1978; Müller 1981). Barreda (1993) studied the Late Oligocene–Miocene pollen of the Golfo San Jorge Basin, Southeastern Argentina and suggested that the lower part of the Chenque Formation could not be older than Late Oligocene based on the occurrence of pollen grains of the Compositae. Batı & Alişan (1991) in their study on the biostratigraphy of Malazgirt-1 well in the Muş Basin, suspected that the first occurrences of Compositae pollen might be in the Late Oligocene of Eastern Anatolia. The stratigraphic distribution of Compositae pollen in Turkey has been studied by several researchers (Benda 1971a, b; Benda *et al.* 1977, 1979; Akgün *et al.* 1986; Akgün & Akyol 1987, 1992; Ediger *et al.* 1990; Batı 1996) mostly in Western Anatolian Neogene successions. They mainly suggested that Compositae occurred for the first time at the beginning of the Miocene in western Turkey, but palynostratigraphic analysis indicates that Compositae pollen flourished earlier in Eastern Anatolia (Batı & Alişan 1991) and occurrences of *Slowakipollenites hipophæoides* and *Medicolpopollis compactus* together with common to abundant Compositae pollen (tubuliflorae-type) at the bases of studied sections are stratigraphically important. They are found commonly in zones EO1 and LO1, which are dated as late Rupelian and Chattian, respectively, in this study and are very good indicators of the Oligocene. According to Hochuli (1978), *Slowakipollenites hipophæoides* occurs in Lower–Middle Oligocene sediments whereas *Medicolpopollis compactus* has a much longer stratigraphic range, from Late Eocene to Middle Oligocene in the Central and Western Paratethys. Oligocene occurrences of *Slowakipollenites hipophæoides* have also been reported by Gorin (1975) in Grande Limagne, France, and by Chateauneuf (1980) in the Paris Basin. These species have also been identified in the Hayrettin and Tokça formations to which Early to Middle Oligocene and Early Oligocene ages have been assigned by Akkiraz (2000) and by Akkiraz & Akgün (2005) in the Çardak-Tokça Basin, Southwest Anatolia. The earlier flourishing of Compositae pollen (tubuliflorae-type) in Eastern Anatolia have occurred due to changes in climatic conditions. In general, the low abundance of *Quercus* and the high abundance of Compositae pollen

indicates dry to arid conditions (Horowitz 1992). Tropical and subtropical elements such as *Tilia*, *Alnus*, *Carya* etc., recorded in Northwestern and Western Anatolian Tertiary sediments (Batı 1996; Akkiraz 2000), do not exist or are very rare in Eastern Anatolia. According to Akgün *et al.* (2004), mean annual temperatures (MAT) ranged from 17.2 to 20.8 °C and the mean temperatures of the coldest month (CMT) were between 9.6 and 13.3 °C in the Oligocene in Western Anatolia. However, CLIMSAT software results from Oligocene sediments in Eastern Anatolia suggest relatively cooler conditions in which the mean annual temperatures were between 15.6 and 21.3 °C and the mean temperatures of the coldest month (CMT) were between 5.0 and 13.3 °C. Eastern Anatolia was therefore relatively cooler than Western Anatolia during the Tertiary, as it is today.

Tectonism had an important effect on Tertiary deposition in Eastern Anatolia. Because of the collision of the Arabian and Laurasian plates in the Middle Eocene (Yılmaz 1993), Eastern Anatolia was uplifted, converted into positive areas, and eroded after the Late Eocene (Şengör 1980; Şengör & Yılmaz 1981). Erosion from this elevated region into the relatively depressed areas produced terrestrial and/or very shallow marine to transitional lithologies during the Late Oligocene–Early Miocene. This uplifting trend may have been the main reason for relatively cooler climatic conditions and the intense Eocene reworking during the deposition of Oligo–Miocene sediments. Another reason for cooler climatic conditions in Eastern Anatolia may have been intense volcanism. As indicated by Axelrod (1981) and Ediger (1990) large amounts of volcanic dust could have been distributed in the stratosphere and due to the decreasing intensity of solar radiation in the lower atmosphere, relatively lower seasonal mean annual temperatures, colder climatic conditions and less precipitation may have been experienced.

The following palynomorph taxa were identified in samples 66–78 at the Ebulbahar section and 92–106 at the Kelereşdere section; Pollen: Compositae (tubuliflorae-type, less ornamented, thick exine, small and dark coloured), *Dicolpopollis kalewensis*, *Monoporopollenites gramineoides*, *Ephedripites* sp., small/less ornamented Umbelliferae, *Polyvestibulupollenites verus*, Compositae-type pollen, *Tricolpopollenites* sp., *Tricolporopollenites* sp., *Periporopollenites multiporatus*; Spores: *Cingulatisporites* sp., *Retrilites fragilis*, *Lusatisporites*

perinatus, *Echinatisporis* sp. (reworked from Eocene), *Cicatricosisporites* sp.; Fungal spores: *Anatolinites dongyingensis*, *Biporisporites* sp. All *in situ* palynomorphs except Compositae, Umbelliferae and *Monoporopollenites gramineoides* have long stratigraphic ranges (Tertiary). *Monoporopollenites gramineoides* and small/less ornamented Umbelliferae can be traced back to the Upper Oligocene (Bati 1996 and references therein), but Compositae (tubuliflorae-type) and large/well ornamented Umbelliferae pollen were believed to be present at the beginning of the Miocene (Benda 1971a, b; Benda *et al.* 1977, 1979; Ediger *et al.* 1990; Akgün & Akyol 1992; Akgün *et al.* 1995; Bati 1996). However, both calcareous nannofossils and foraminifers suggest a Late Oligocene age for these samples. Oligocene zonation of some palynomorphs should be modified, and the stratigraphic ranges of Compositae (tubuliflorae-type) pollen extended into the Chattian and even the Rupelian in Eastern Anatolia. Recent work at the lowermost parts of the studied sections, where very thick clastic successions were deposited, is still continuing (Bati & Sancay 2007) and where the lowest occurrence of Compositae (tubuliflorae-type) was put in the Rupelian on the basis of worldwide dinoflagellate and acritarch biozonations. When the Lower Miocene part of the sections (samples 79–121 in the Ebulbahar section and 109–118 in the Kelereşdere section) are considered, the palynomorph assemblage is composed mostly of the following; Pollen: Compositae (tubuliflorae-type, well ornamented, large, light-coloured) (common to abundant), *Monoporopollenites gramineoides* (common), large/well ornamented Umbelliferae (common), Dipsacaceae (common), suggesting an Early Miocene age. Relative abundances of Compositae pollen in this interval are much higher compared with Western Anatolia, where average frequencies are around 1 % (Akgün *et al.* 1986; Akgün & Akyol 1987, 1992).

Samples above the unconformity surface labeled as 178–184 in the Kelereşdere section, contain the following palynomorph assemblage; Compositae (liguliflorae-type) (common), Compositae (tubuliflorae-type; small) (common), *Monoporopollenites gramineoides* (rare), large/well-ornamented Umbelliferae (rare), which suggests a Late Miocene–Pliocene age. This zone is not recorded in the Ebulbahar section due to the unsuitability of the lithology for palynological analysis.

Foraminiferal Events (Calibrated With the Zonation of Berggren *et al.* 1995)

ELO1. Late Rupelian–early Chattian (samples 66–74 in the Ebulbahar section and 92–99 in the Kelereşdere Section) *Paragloborotalia opima opima* Range Zone defined by the complete range of the nominal taxon and corresponding to P21.

LO1. Late Oligocene (samples 75–78 in the Ebulbahar section and 100–106 in the Kelereşdere section) Assemblage Zone is distinguished by the absence of *Paragloborotalia opima opima*, and presence of *Globorotalia ciperoensis ciperoensis*, *Globigerina venezuelana*, *Catapsydrax dissimilis*, *Globigerina praebulloides*, *Operculina* sp., and *Globigerina* spp. It corresponds to the P21b (*Globigerina angulisuturalis*/*Paragloborotalia opima opima* interval subzone defined by the biostratigraphic interval between the LO of *Chiloguembelina cubensis* and the LO of *Paragloborotalia opima opima* (early Chattian), 28.5–27.1 Ma) to P22 (*Globigerina ciperoensis* Partial Range Zone defined by the partial range of *Globigerina ciperoensis* between the LO of *Paragloborotalia opima opima* and the FO of *Globorotalia kugleri* (Chattian), 27.1–23.8 Ma). Reworked taxa from the Eocene such as *Nummulites* sp., and *Epiannularis* sp. are also recorded in this zone.

Discussion: The Kelereşdere section (close to Kelereş village) was also measured and analyzed by Sirel (2003) and shallow water, large benthic foraminifer taxa recorded. Sirel suggested that SB 21, 22 zones (Rupelian–early Chattian) were represented by the interval from the first occurrence of *Austrotrillina striata* to the last occurrence of *Nummulites fichteli* and *Nummulites vascus*. On the other hand the SB 23 zone (late Chattian), was represented by the assemblage of *Miogypsinoides complanatus*, *Eulepidina*, *Nephrolepidina* and *Spinoclypeus*. *Nummulites fichteli* and *Nummulites vascus* together with *Globorotalia opima opima*, were been identified in the Muş-2 well, located at the northwestern part of the studied sections drilled by TPAO (Sancay *et al.* 2003). These intervals may correspond to SB 21, 22 zones of Sirel (2003) and may be represented by reefal limestones interpreted as ?late Rupelian in the Kelereşdere section.

EM1. Early Aquitanian (samples 79-90 in the Ebulbahar section and 107-114 in the Kelereşdere section) Transitional Zone is defined by the presence of *Globigerinoides primordius*, a few benthonic foraminifera which have a wide stratigraphic range and intensively reworked Oligocene planktonic foraminifera (including *Paragloborotalia opima opima*). This zone is believed to correspond to Subzone M1a (*Globigerinoides primordius* interval subzone defined by the biostratigraphic interval within the range of *Globigerinoides primordius* between the FO of *Globorotalia kugleri* and the FO of *Globoquadrina dehiscens* (Aquitanian), 23.8-23.2 Ma).

Discussion: The stratigraphic distribution of *Globigerinoides primordius* is problematic. Although found together with *Paragloborotalia opima opima* in the Western Carpathians (Cicha *et al.* 1971), the species was first seen together with *Miogypsina tani* in Aquitaine, where the Aquitanian stage was defined (Anglada 1971; Jenkins 1966). The first occurrence of *Globigerinoides primordius* was found to be without value by Steininger *et al.* (1976) for defining the Oligocene/Miocene boundary, but Berggren *et al.* (1995) suggested that the early forms of *Globigerinoides* (*G. primordius*) are useful for recognition of the Upper Oligocene-Lower Miocene interval.

EM2. ?Middle-late Aquitanian (samples 91-117 in the Ebulbahar section but partly covered in the Kelereşdere section) Assemblage Zone is defined by the presence of planktonic foraminifera: *Globigerinoides sacculifer*, and *Globigerinoides binaensis* and benthonic foraminifera: *Miogypsina* sp., and *Miogypsinoidea* sp. (*M. cf. complanatus*), *Miogypsinoidea bantamensis* corresponding to Subzone M1b (*Globorotalia kugleri*/*Globoquadrina dehiscens* Concurrent Range Subzone defined by the concurrent range of *Globorotalia kugleri* and *Globoquadrina dehiscens* between the FO of *Globoquadrina dehiscens* and the LO of *Globorotalia kugleri* (Aquitanian), 23.2-21.5 Ma).

Discussion: Örcen (2001) investigated the Early-Middle Miocene marine connections of Turkey based on species to the Family Miogypsinidae in the Taurids and Arabic Platform. He postulated that the presence of *Miogypsina gunteri* and *Miogypsinoidea complanatus* in Aquitanian sediments may imply a marine connection with Indo-Pacific. He suggested that

Miogypsinoidea complanatus is the first representative of the Miogypsinidae and that it occurred in the upper Chattian of the Mediterranean region. However, he showed that the first appearance of *Miogypsinoidea complanatus* was diachronous and occurred in the early Aquitanian in Italy, Greece and Turkey (Muş). Similarly, Sakiñç (1982) has distinguished an *Operculina ammonoides-Miogypsinoidea complanatus* biozone indicating its Early Miocene (Aquitanian) age in Eastern Anatolia.

EM3. Early-middle Burdigalian (samples 118-125 in c and 120-125 in the Kelereşdere section) The Assemblage Zone is defined by the presence of *Lepidocyclina gigas*, *Miogypsinoidea dehardtii*, *Miogypsinoidea grandipustulosa*, *Miolepidocyclina* sp., and *Miogypsina* sp.

Discussion: Sakiñç (1982) distinguished a *Miogypsinoidea dehaartii-Lepidocyclina (Eu)Lepidina gigas* biozone for the Lower Miocene (Burdigalian) in Eastern Anatolia. In the study by Örcen (2001), the presence of *Miogypsina irregularis*, *Miogypsina intermedia* and *Miogypsinoidea dehaartii* was interpreted as being Indo-Pacific derived and a marine connection was suggested between Southeastern Anatolia and the Arabic Platform during the Burdigalian. The Kelereşdere section, which was dominated by shallower conditions than the Ebulbahar section during the Oligocene and Miocene, also yielded *Operculina complanata*, *Amphistegina* sp., *Austrotrillina asmariensis*, *Archias kirkukensis*, *Heterostegina* sp., *Nephrolepidina* sp., and *Dendritina* sp.

EM4. Late Burdigalian-early Langhian (samples 126-129 in the Ebulbahar section but not recorded in the Kelereşdere section due to the overlying unconformity). The Assemblage Zone is defined by the presence of *Praeorbulina* spp. (*Praeorbulina glomerosa*, *P. sicana*, *P. transitoria*) and corresponds to the M4 (*Catapsydrax dissimilis-Praeorbulina sicana* Interval Zone defined by the biostratigraphic interval between the LO of *Catapsydrax dissimilis* and the FO of *Praeorbulina sicana* (late Burdigalian), 17.3-16.4 Ma) to M5 (*Praeorbulina sicana-Orbulina suturalis* Interval Zone defined by the biostratigraphic interval between the FO of *Praeorbulina sicana* and the FO of *Orbulina suturalis* (Langhian), 16.4-15.1 Ma). The top of the zone is not defined because of the overlying unconformable surface.

Miogypsina spp. and *Miogypsinoides* spp. are still present in this zone together with *Praeorbulina sicana*, *P. transitoria*, and *P. glomerosa* (Figure 6) which suggests that their ranges should extend at least until the late Burdigalian (M4 zone of Berggren *et al.* 1995) in Eastern Anatolia (Ercüment Sirel, pers. comm. 2005).

Lepidocyclina sp., *Nephrolepidina* sp., *Eulepidina* sp., *Operculina* sp., *Heterostegina* sp., *Amphistegina* sp., *Planorbulina* sp., *Rotalia* sp., *Spiroclypeus* sp., *Globigerinoides* sp.; Globigerinidae, Bryozoa, and red algae occur consistently throughout the section.

Calcareous Nannoplankton (Calibrated Using the Zonation of Martini 1971)

Correlation of dinoflagellate assemblages with calcareous nannoplankton has been always problematic due to reworking, environmental constraints and poor preservation (Berger 1992) particularly in shallow marine conditions. Berggren *et al.* (1995) and references therein also emphasized that many FOs and LOs of Cenozoic calcareous nannofossils are unreliable due to their poor preservation and latitudinal diachrony. Müller (1979) also indicated that, even though the absence of small forms of *Helicosphaera* may reflect the base of NN1, the absence of the biostratigraphic marker *Discoaster druggii* makes detection of the boundaries between NP25, NN1, and NN2 of Martini (1971) almost impossible in the Mediterranean region. As indicated by de Verteuil & Norris (1996), variations in the chronostratigraphic position of the same biostratigraphic event in different basins may be related to reworking at one or both sites, and/or diachrony of a species' range. The shallow marine-dominant nature of the depositional environments and intensive reworking of Upper Cretaceous, Eocene and even Oligocene species make studies of biozonation based on calcareous nannoplankton very difficult in Eastern Anatolia. Since a biozonation based on nannoplankton would be less meaningful for the reasons mentioned above, only different nannoplankton assemblages have been distinguished, three of which are identified in Eastern Anatolia. They were compared with results from planktonic foraminifera and palynology and interpreted as representing latest Rupelian to earliest Chattian, Chattian, and ?Early Miocene periods.

Assemblage 1: May correspond to Zone NP24 (*Sphenolithus distentus* zone), is latest Rupelian–earliest

Chattian in age, defined by the presence of *Sphenolithus ciperoensis*, *Helicosphaera recta*, *Sphenolithus distentus*, *Sphenolithus predistentus*. Intense reworking from Eocene and Upper Cretaceous sediments has also been detected.

Assemblage 2: May correspond to Zone NP25 (*Sphenolithus ciperoensis* zone), is Late Oligocene (Chattian) in age, defined by the presence of *Sphenolithus ciperoensis*, *Helicosphaera recta*, *Sphenolithus distentus*, and the absence of *Sphenolithus predistentus*. Intense reworking from Eocene and Oligocene sediments is also detected.

Assemblage 3: May correspond to Zone NN1 (*Triquetrorhabdus carinatus* Zone), which is latest Oligocene and Early Miocene in age, defined by the absence of the above mentioned Oligocene nannoplankton such as *Sphenolithus ciperoensis*, *Helicosphaera recta*, and *Sphenolithus distentus*. *Helicosphaera obliqua* is the only Oligocene species still present in this interval. Shallow marine conditions and intense reworking from Eocene and Oligocene might be responsible for the absence of Early Miocene zonal markers.

Palaeoenvironments

Information from palynomorphs, nannoplankton, and foraminifera suggests that Upper Oligocene and Lower Miocene sediments were deposited under brackish water, shallow and relatively deeper marine conditions related to fluctuating sea level. Shallowing-upwards deposition occurred during the Late Oligocene and was followed the Early Miocene regional transgression which continued to the end of the Middle Miocene. However, Lower Miocene sediments still represent restricted marine-nearshore environments. Due to withdrawal of the sea, Upper Miocene-Pliocene sediments were deposited in terrestrial (lacustrine and fluvial) environments in the Muş Basin.

Palynofacies analyses have been carried out by means of palynomorph assemblages and sedimentary organic matter. In general, palynomorph assemblages from Upper Oligocene sediments in Eastern Anatolia consist mostly (up to 85–95%) of terrestrial palynomorphs (spores, pollen, and fungal spores). Like the palynomorph content, organic matter assemblages are dominated by terrestrial (woody, coaly and herbaceous) type of organic matter which indicates shallow marine conditions of deposition during the Late Oligocene (Figures 7 & 8).

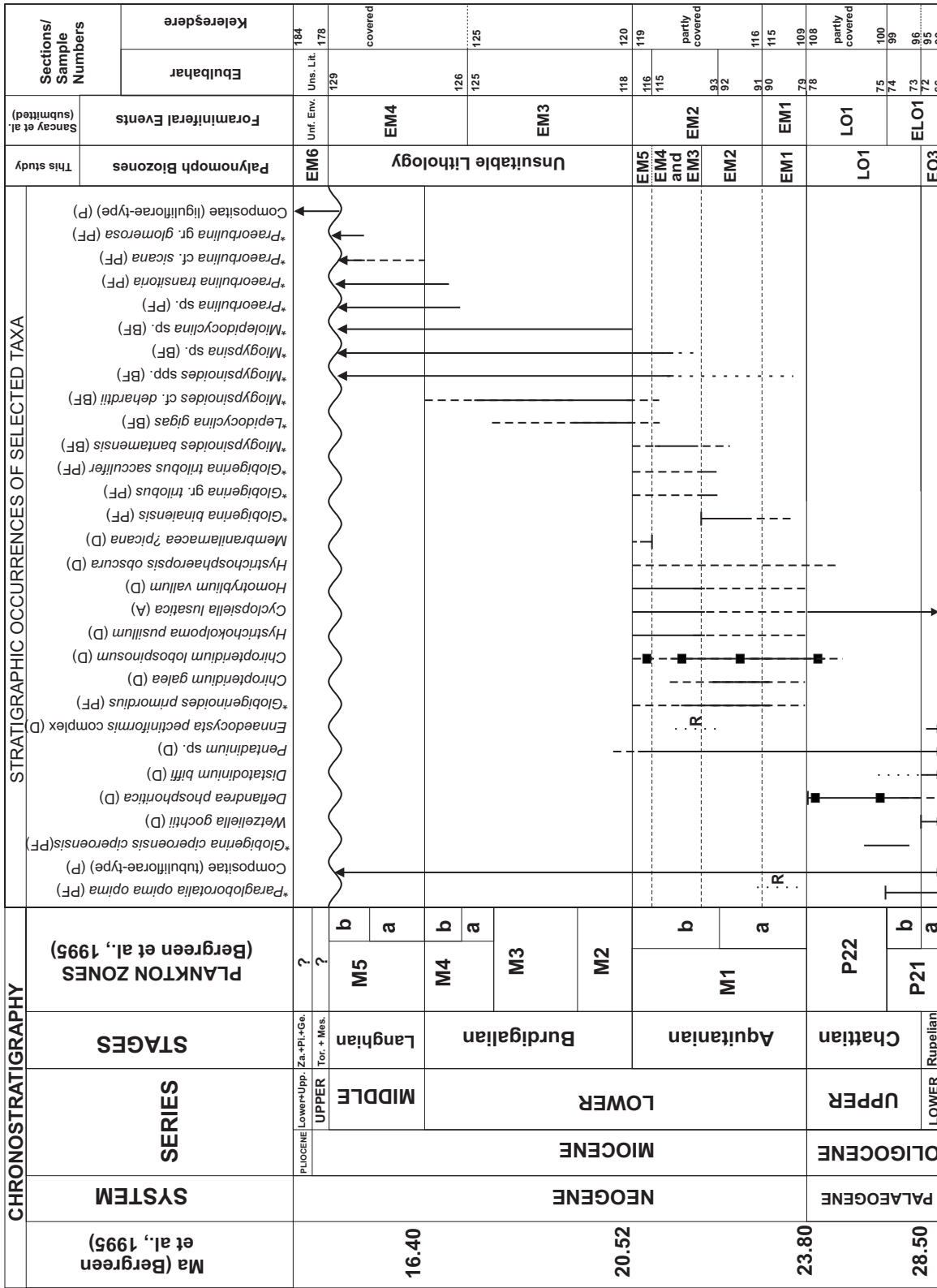


Figure 6. Bio-chronostratigraphic chart and stratigraphic occurrences of selected taxa (A: acritarch; D: dinoflagellate; P: pollen; PF: planktonic foraminifer; BF: benthic foraminifer; R: reworked; Unf. Env: unfavourable environment; Uns. Lit: unsuitable lithology; -; peak occurrences).

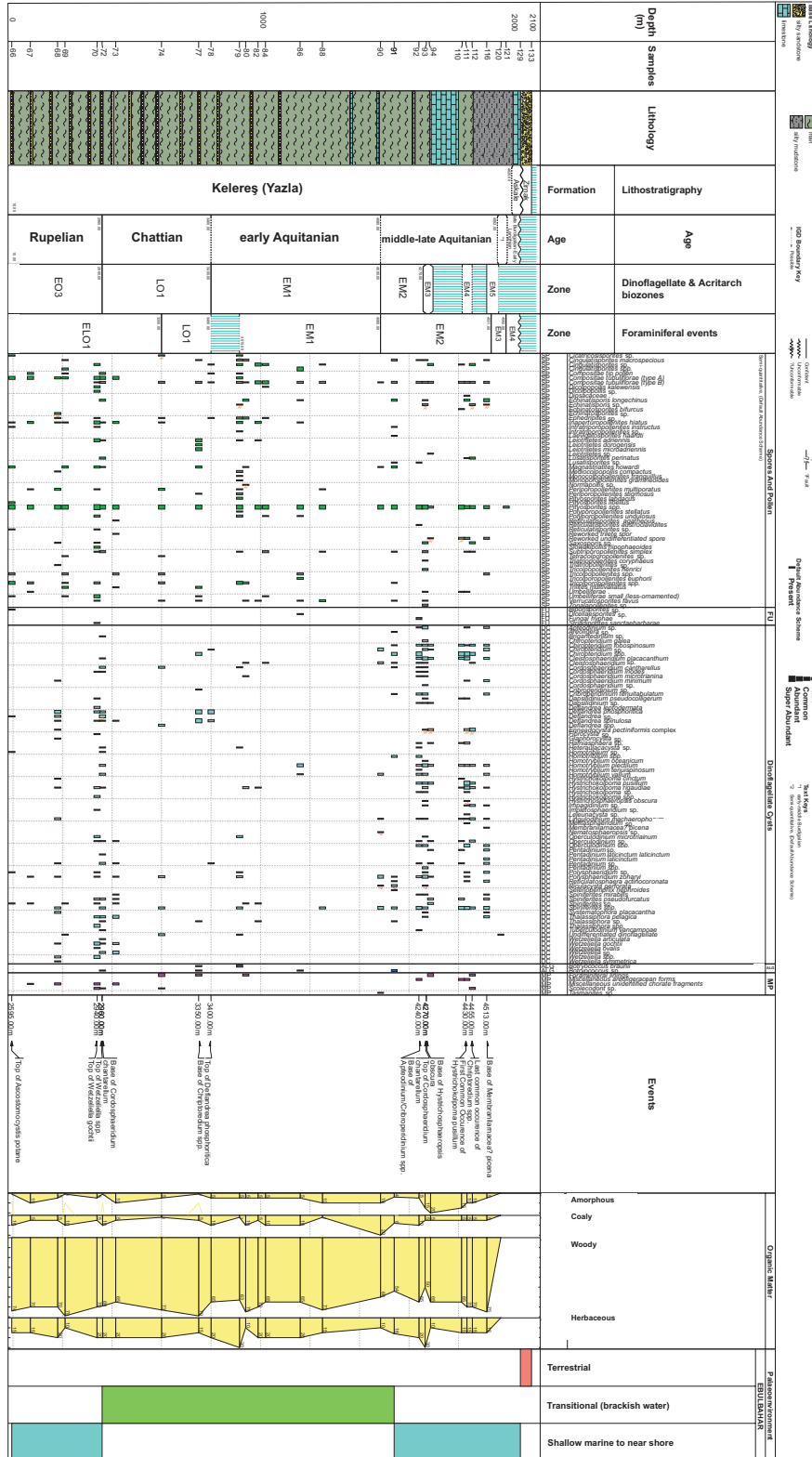


Figure 7. Biostratigraphic log of the Ebulbahar measured stratigraphic section.

OLIGO-MIOCENE BIOSTRATIGRAPHY OF EASTERN ANATOLIA

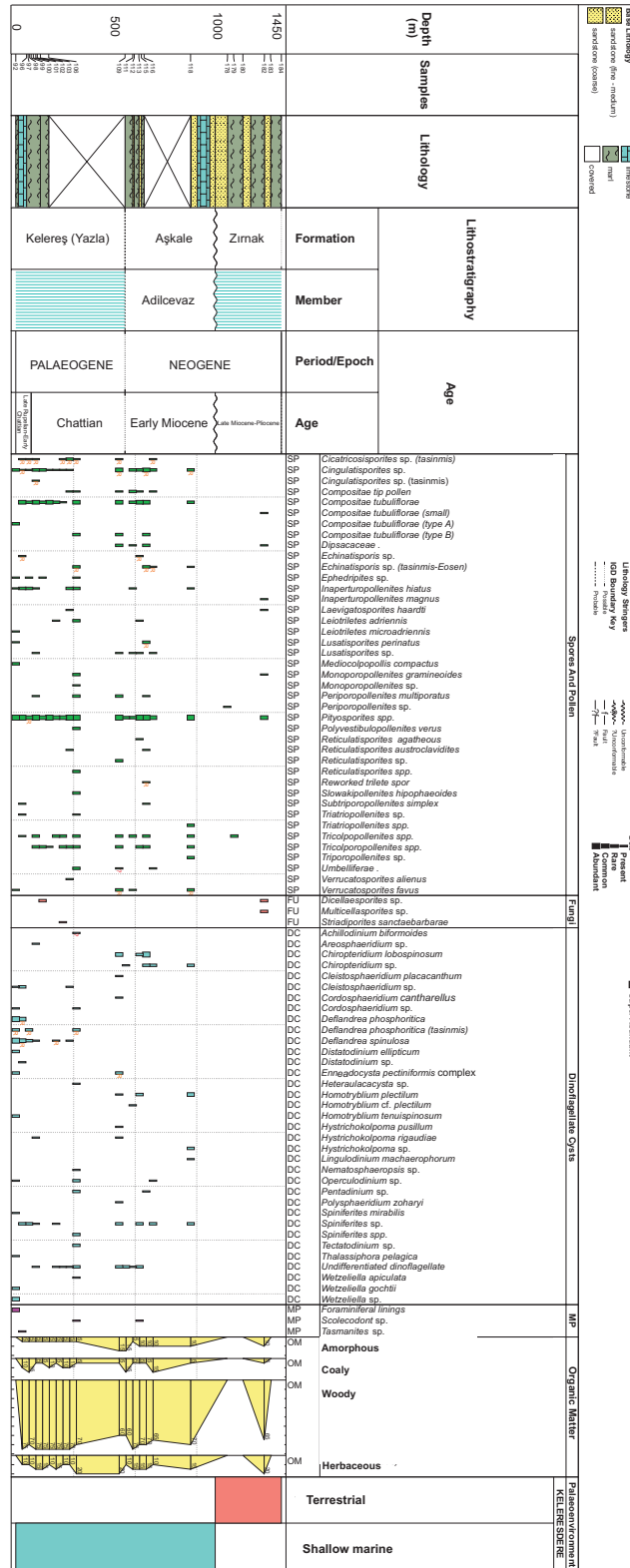


Figure 8. Biostratigraphic log of the Kelereşdere measured stratigraphic section.

Percentages of marine dinoflagellates vary from 5% to 15% in relation to fluctuating sea-level conditions. Like the marine palynomorphs, marine-amorphous organic matter content is in the range of 5–20% in most of the Upper Oligocene samples but reaches more than 40–50% in the late Aquitanian in relation to regional transgression.

Fresh water algae (*Pediastrum* spp., *Botryococcus braunii*, *Ovoidites ligneolus*, *Ovoidites parvus*) have been identified at the end of the Chattian, close to the Oligocene–Miocene boundary, and in the Upper Miocene–Pliocene (immediately above the unconformity surface). The absence of freshwater algae, and the presence of a terrestrial palynomorph-dominated assemblage with some marine dinoflagellates suggest shallow marine deposition during the Late Oligocene. However, freshwater algae found together with marine dinoflagellates at the Oligocene–Miocene boundary show that deposition could have taken place under brackish water and restricted marine conditions without any depositional break in the latest Chattian–earliest Aquitanian. The shallowing-upwards nature of deposition during the Late Oligocene might be responsible for the changes in environment from shallow marine to restricted marine and brackish water conditions. Brackish to restricted marine deposition at the Oligocene–Miocene boundary was followed again by relatively deeper conditions in the late Aquitanian. Shallowing in the early Burdigalian produced reefal limestone deposition at many localities in Eastern Anatolia. The last deepening event at the end of the Burdigalian and the ?early Langhian, was followed by completely terrestrial (lacustrine and fluvial) deposition.

Stable oxygen isotope data can be used successfully as a proxy for changes in eustatic sea-level and ice-sheet volumes at the poles (Zachos *et al.* 2001). Increasingly such records coincide with times of glaciation, growth of ice-sheets, and subsequent falls in relative sea level that may be traced as major unconformities in the shallower settings. Van Simaey (2004) suggested that early Chattian transgression is genetically related to the Late Oligocene Warming Event (LOWE) of Zachos *et al.* (2001), and Rupelian–Chattian unconformity in the stratotype area is also genetically related to Oligocene Glacial Maximum (OGM) in southern North Sea basins. This cooling event, associated relative sea level fall, and the growth of Antarctic ice-sheets in the Oligocene have

also been reported by Miller *et al.* (1991, 1998) from deep-sea benthic foraminiferal ^{-18}O records such as the Oi2b-event which Van Simaey (2004) indicated at the same chronostratigraphic position in the central Mediterranean. As reported by Van Simaey (2004), relative sea level fall related to OGM (approximately between 27.3 and 26.8 Ma) may have caused subaerial exposure, erosion, and a break in sedimentation in marginal marine conditions, when, transgressive deposits related to LOWE (approximately 26.0 Ma) unconformably overlies Rupelian successions in southern North Sea basins. Shallowing at the end of the Rupelian and at the base of the Chattian in Eastern Anatolia may have been caused by a major cooling event so called Oligocene Glacial Maximum (OGM of Van Simaey 2004), and associated sea level fall at the end of the Rupelian. Eustatic sea level rise related to the Late Oligocene Warming Event (LOWE) of Zachos *et al.* (2001) occurred in the early Chattian and may have been responsible for the transgressive deposits conformably overlying Rupelian sediments in Eastern Anatolia. Moreover, eustatic sea level fall indicated by Zachos *et al.* (2001) in the latest Chattian to early Aquitanian should be related to brackish water to transitional conditions in depositional environments (samples 79–89 in Figure 4) following shallow marine conditions during the Chattian in the Muş Basin. Very low diversity in dinoflagellates, accompanied by a fresh water alga called *Botryococcus braunii*, supports this interpretation. Zevenboom (1996) reported two major cooling events and relative falls in sea level at the Lemme-Carrosio section in Italy during the Oligocene/Miocene transition. Since these events can be calibrated with Haq *et al.*'s (1988) third-order sea level cycles, they can be interpreted as global in nature and seem to coincide with the relative sea level fall indicated at the Oligocene/Miocene boundary in the present study. High abundance of marginal marine dinoflagellates such as *Homotryblium* spp. and increasing diversity of dinoflagellates in the overlying samples, (90–94 in Figure 4, correlate with the early Aquitanian sea-level rise of Zachos *et al.*'s (2001) curve. Eustatic sea-level fall in the latest Aquitanian to early Burdigalian may be represented by a very thick succession of limestones (samples 95–109 in Figure 4), consisting mainly of benthonic foraminifers, overlying relatively deeper marine sediments of Aquitanian age in the Muş Basin and followed in turn by much deeper marine conditions represented by samples 110–117 in Figure 4 and related to the early to middle Burdigalian sea level rise documented by Zachos *et al.*

(2001). In general, as reported by Dybkjær (2004) sequence developments seem to match with sea level rises (warmer periods); sequence boundaries, on the other hand, seem to coincide relative sea level falls (colder periods). Relative sea level falls occur at the base of the Rupelian, the end of the Chattian, and in the latest Aquitanian (Haq *et al.* 1987, 1988; Zachos *et al.* 1999, 2001; Van Simaey 2004; Van Simaey *et al.* 2004) might have been traced in the Muş Basin, especially the Kelereşdere section which experienced much shallower conditions than the Ebulbahar section during the Tertiary. Very good correlation between the eustatic sea level changes in Zachos *et al.*'s (2001) curve and the palynological associations may indicate that the main driving mechanism was eustasy during the deposition of Oligocene–Miocene sediments in Eastern Anatolia. However, as reported in several studies (Şengör 1980; Şaroğlu *et al.* 1980; Şaroğlu & Güner 1981; Şengör & Yılmaz 1981; Şaroğlu 1985; Şaroğlu & Yılmaz 1987, 1991; Yılmaz *et al.* 1988), the Eocene and Miocene periods were represented by major tectonic events in Eastern Anatolia. Therefore, even though the main driving mechanism was eustasy during the formation of sequences, the latter were tectonically enhanced.

Conclusions

Biostratigraphically important dinoflagellate events calibrated by means of planktonic foraminifera and calcareous nannoplankton were first documented in the present study for Oligo–Miocene sediments in the Muş Basin, Eastern Anatolia. As shown in detail for the biozonation, FOs and LOs of selected dinoflagellates are important in the establishment of a biostratigraphic framework. The LO of *Wetzeliella gochtii* in the “latest” Rupelian, the LO of *Deflandrea* spp. in the latest Chattian, peak occurrences of *Chiropteridium* spp. in the early and late Aquitanian, the FO of *Hystriosphæropis obscura*, followed by the FO of *Membranilarnacea? picena* in the late Aquitanian have particular relevance for regional correlations.

The following conclusions are suggested from biostratigraphic analysis of Ebulbahar and Kelereşdere's measured stratigraphic sections: the Oligocene–Miocene boundary may be placed by calibration of planktonic foraminifera, nannoplankton, palynological biozonations. This boundary may approximately correspond to the 830–840 m interval, samples labeled as 78–79 in the

Ebulbahar section, and 590–600 m interval, samples labeled as 108–109 in the Kelereşdere section. Similarly, the Rupelian–Chattian boundary may be placed at 390–400 m level, corresponding to the samples labeled as 72–73 in the Ebulbahar section, and 210–220 m level, samples labeled as 95–96 in the Kelereşdere section.

In the earlier studies Compositae, and high abundances of Umbelliferae and Gramineae were suggested as being good indicators of the Miocene in Turkey. Umbelliferae and Gramineae have been reported from Upper Oligocene sediments before in rare occurrences (Benda 1971a, b; Benda *et al.* 1977, 1979; Ediger *et al.* 1990; Batu 1996). The only record of Compositae pollen in Late Oligocene sediments of Eastern Anatolia was by Batu & Alişan (1991). Hochuli (1978) recorded Compositae (tubuliflorae-type) occurrences from Egerian sediments in Central and Western Paratethys, but as the Egerian includes both Upper Oligocene and Lower Miocene, the reliability of Oligocene occurrences of Compositae remains questionable in his paper. In the light of the present study, the Miocene zonation of some palynomorphs has been modified and stratigraphic ranges of the Compositae (tubuliflorae-type), small/less ornamented Umbelliferae and Gramineae pollen should be extended into the Chattian and even Rupelian on the basis of recent work by Batu & Sancay (2007).

The presence of *Miogypsina* spp. and *Miogypsinoides* spp. with *Praeorbulina sicana*, *P. transitoria*, and *P. glomerata* in zone EM4 suggests that their ranges should extend at least until late Burdigalian (M4 zone of Berggren *et al.* 1995) in Eastern Anatolia.

High abundances of *Deflandrea* spp., rare *Polysphaeridium zoharyi*, very rare occurrences of terrestrial warm indicators (such as *Carya*, *Tilia*, *Alnus* etc.) and high abundances of dry-cold indicators (Compositae, Gramineae, Chenopodiaceae, and Umbelliferae) all suggest cold sea surface temperatures with high nutrient contents, and dry, temperate to subtropical climates in which mean annual temperatures varied between 15.6 and 21.3 °C during the deposition of Oligo–Miocene sediments.

Combined information from palynomorphs, calcareous nannoplankton and foraminifer suggests that Upper Oligocene and Lower Miocene sediments were deposited under brackish water, shallow and then

relatively deeper marine conditions related to a fluctuating sea level; Upper Miocene to Pliocene sediments were deposited under lacustrine to fluvial depositional environments in the Muş Basin, Eastern Anatolia.

Relative sea level falls in the late Rupelian and latest Aquitanian (Haq *et al.* 1987, 1988; Zachos *et al.* 1999, 2001; Van Simaey 2004; Van Simaey *et al.* 2004) may be represented by major unconformities in Eastern Anatolia, especially at the Kelereşdere section, which had experienced much shallower conditions than the Ebulbahar section during the Tertiary. However, not only eustasy but also tectonic events made important contributions in the formation of unconformities.

A regional marine transgression suggested by Demirtaşlı & Pisoni (1965), occurred at the beginning of the Miocene, and the sea withdrew at the end of this epoch according to study carried out to the north of Lake Van. The first event could be interpreted as a continuation of a Late Oligocene transgressive peak indicated by Zachos *et al.* (2001), Van Simaey (2004), and Van Simaey *et al.* (2004). As a result, high numbers of *Chiropteridium* spp. occur in samples interpreted as Early Miocene in age in both Ebulbahar and Kelereşdere sections, but this abundance of *Chiropteridium* spp. could be related to the Early Miocene regional transgression indicated by Demirtaşlı & Pisoni (1965).

Demirtaşlı & Pisoni (1965) also reported that the lowest part of the Adilcevaz Limestone contains arenitic limestones of Aquitanian age that can be correlated with strata in the Muş and Van basins. The upper part of the Adilcevaz Limestone of Demirtaşlı & Pisoni (1965) has later named the Burdigalian Reefal Limestone Member of the Aşkale Formation by Şahintürk & Kasar (1980). Therefore Aquitanian arenitic limestones indicated in Demirtaşlı & Pisoni's study correspond to the lowermost part of the Aşkale Formation in the Kelereşdere section (about 620 m level in Figure 5). This information is compatible with the present study in that arenitic and

lithic limestone layers of the lowermost Aşkale Formation conformably overlie sandstone-marl intercalations belonging to the uppermost part of the Kelereş Formation in the Muş Basin. No evidence was seen for a probable unconformity in the field, and the transition between the Aşkale and Kelereş formations, and the boundary between Oligocene and Miocene sediments, seem to be conformable in the Muş Basin even though some local unconformities below the biostratigraphic resolution may be seen in shallower, transitional to terrestrial parts of the region.

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Taxonomic Notes

Alphabetical listing of dinoflagellate cysts and acritarchs identified in this study.

Apteodinium australiense (Deflandre & Cookson 1955) Williams 1978
Chiropteridium galea (Maier 1959) Sarjeant 1983
Chiropteridium sp.
Chiropteridium lobospinosum Gocht 1960
Cleistosphaeridium placacanthum (Deflandre & Cookson 1955) Davey *et al.* 1969;
 Eaton *et al.* 2001 - includes *Systematophora ancyrea*
Cordosphaeridium cantharellus (Brosius 1963) Gocht 1969
Cordosphaeridium fibrospinosum Davey & Williams 1966
Cordosphaeridium inodes (Klumpp 1953) Eisenack 1963 species complex - includes
 forms transitional to *C. fibrospinosum*
Cordosphaeridium minimum (Morgenroth 1966) Benedek 1972
Cribroperidinium tenuitabulatum (Gerlach 1961) Helenes 1984
Cyclopsiella lusatica (Krutzschnig 1970) Strauss & Lund 1992
Dapsilidinium sp.
Dapsilidinium pseudocolligerum (Stover 1977) Bujak *et al.* 1980
Deflandrea leptodermata Cookson & Eisenack 1965
Deflandrea heterophlycta Cookson & Eisenack 1955
Deflandrea phosphoritica Eisenack 1938
Deflandrea spinulosa Cookson & Eisenack 1965
Distatodinium biffii Brinkhuis *et al.* 1992
Ennaeocysta pectiniformis complex (Gerlach 1961) Stover & Williams 1995
 (probably includes *E. arcuatum* and *E. multicornutum*)
Fibrocysta sp.
Glaphyrocysta spp.
Hafniasphaera sp.
Heteraulacacysta sp.
Homotryblium oceanicum Eaton 1976
Homotryblium plectilum Drugg & Loeblich 1967
Homotryblium plectilum/vallum Stover 1977 (transitional forms)
Homotryblium tenuispinosum Dawey & Williams 1966
Homotryblium vallum Stover 1977
Hystrichokolpoma cinctum Klumpp 1953
Hystrichokolpoma spp. Deflandre & Cookson 1955
Hystrichokolpoma pusillum Biffi & Manum 1988
Hystrichokolpoma rigaudiae Deflandre & Cookson 1955
Hystrichosphaeropsis obscura Habib 1972
Impagidinium sp.
Lingulodinium machaerophorum (Deflandre & Cookson 1955) Wall 1967
Membranilarnacea ? picena Biffi & Manum 1988
Operculodinium microtriainum Islam, 1983
Operculodinium spp.
Pentadinium sp.
Pentadinium laticinctum Gerlach 1961 subsp. *laticinctum*
Polysphaeridium sp.
Polysphaeridium zoharyi (Rossignol 1961) Bujak *et al.* 1980
Reticulatosphaera actinocoronata (Benedek 1972) Bujak & Matsuoka 1986
Riculacysta perforata Stover 1977
Selenopemphix nephroides Benedek 1972
Spiniferites mirabilis (Rossignol 1964) Sarjeant 1970
Spiniferites pseudofurcatus (Klumpp 1953) Sarjeant 1970
Spiniferites spp.
Thalassiphora pelagica (Eisenack 1954) Eisenack & Gocht 1960
Tuberculodinium vancampoeae (Rossignol 1962) Wall 1967
Wetzeliella articulata Eisenack 1938
Wetzeliella gochtii Costa & Downie 1976
Wetzeliella symmetrica Weiler 1956
 miscellaneous unidentified chorate fragments
 miscellaneous areoligeracean forms

PLATE 1

Scale bar represents 10 micron for the plates 1-10.

1-7. *Hystriocholpoma pusillum* (Ebulbahar section, Sample No: 70, 92, 93)

8-9. *Dapsilidinium pseudocolligerum* (Ebulbahar section, Sample No: 93)

10. *Dapsilidinium* sp. (Ebulbahar section, Sample No: 92)

11. *Polysphaeridium* sp. (Ebulbahar section, Sample No: 93)

12. *Cleistosphaeridium placacanthum* (Ebulbahar section, Sample No: 93)

13. *Cleistosphaeridium* sp. (Ebulbahar section, Sample No: 92)

14. *Operculodinium* sp. (Ebulbahar section, Sample No: 111)

15. *Operculodinium* sp. (Kelereşdere section, Sample No: 106)

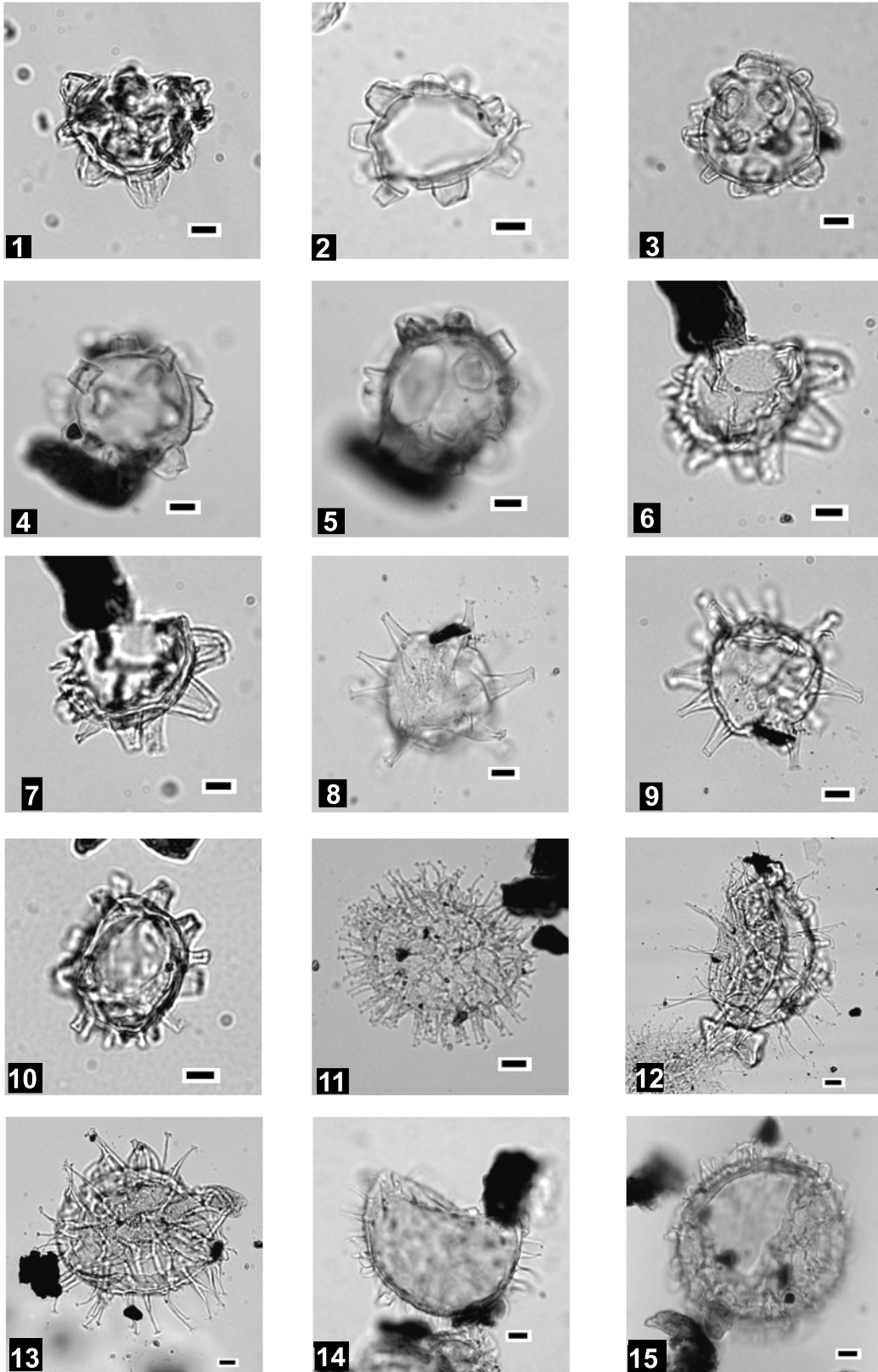


PLATE 2

- 1–5. *Membranilarnacea? picena* (Ebulbahar section, Sample No: 116)
6–7. *Hystrichosphaeropsis obscura* (Ebulbahar section, Sample No: 93)
8–9. *Cleistosphaeridium placacanthum* (Ebulbahar section, Sample No: 116)
10–13. *Impagidinium* sp. (Ebulbahar section, Sample No: 93, 111, 116)
14–15. *Cyclopsiella lusatica* (Ebulbahar section, Sample No: 93)

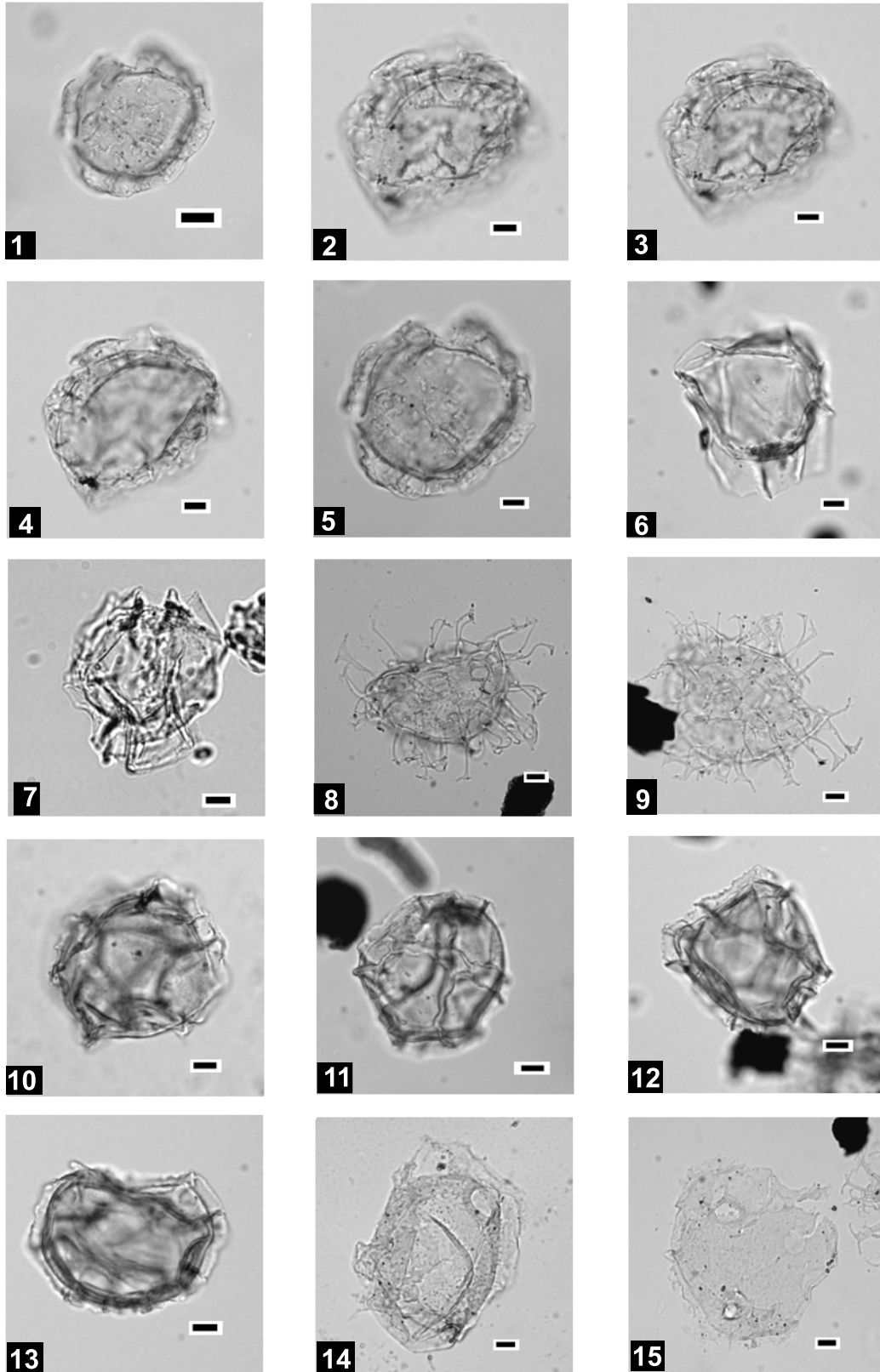


PLATE 3

- 1–3, 8, 9. *Homotryblium plectilum* (Ebulbahar section, Sample No: 72, 93, 115, 118)
4–7. *Homotryblium plectilum/vallum* (transitional forms) (Ebulbahar section, Sample No: 93)
10. *Hystrichokolpoma rigaudiae* (Ebulbahar section, Sample No: 82)
11. *Spiniferites mirabilis* (Ebulbahar section, Sample No: 92)
12–13. *Spiniferites pseudofurcatus* (Ebulbahar section, Sample No: 116)
14–15. *Reticulosphaera actinocoronata* (Ebulbahar section, Sample No: 111, 116)

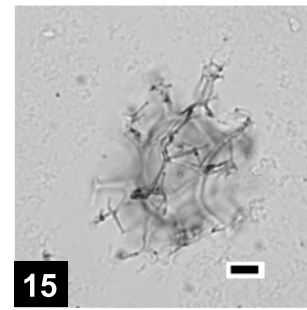
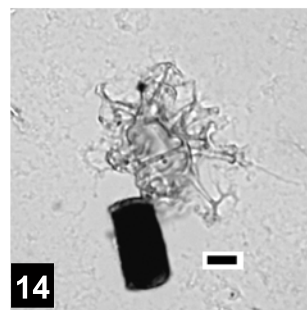
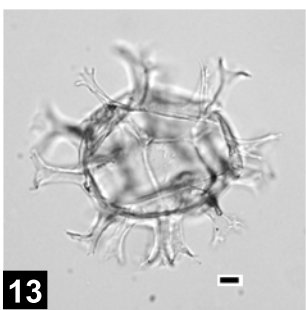
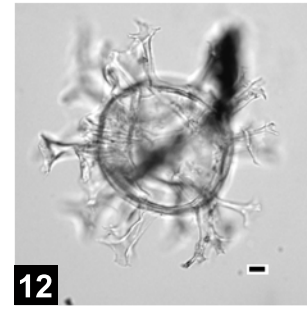
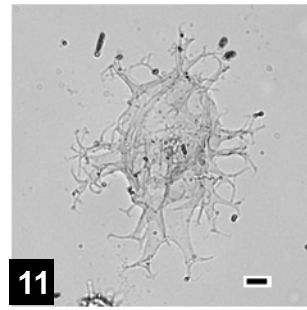
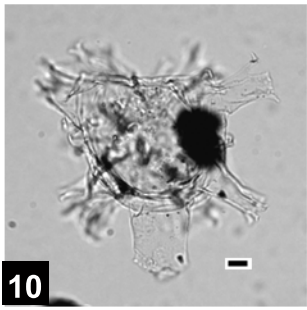
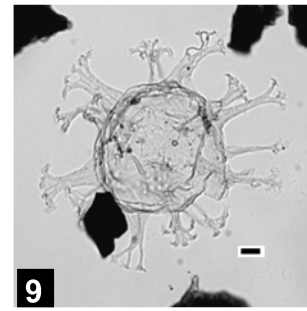
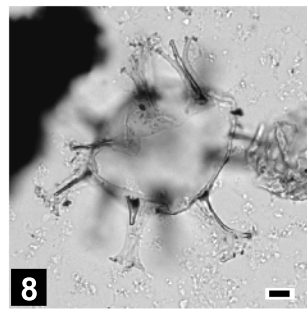
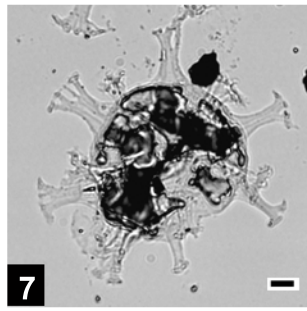
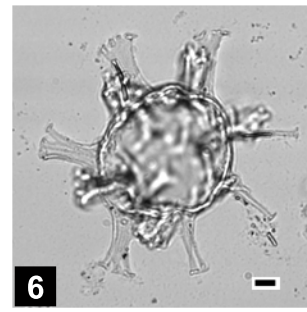
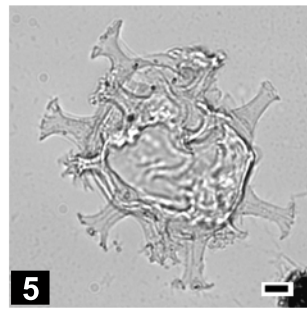
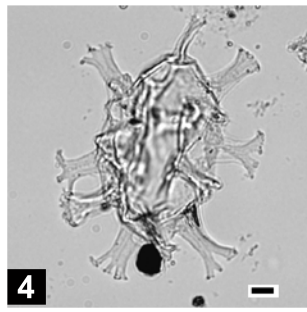
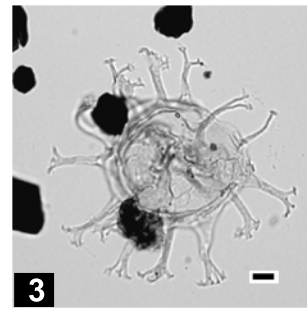
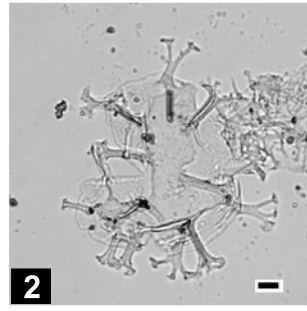
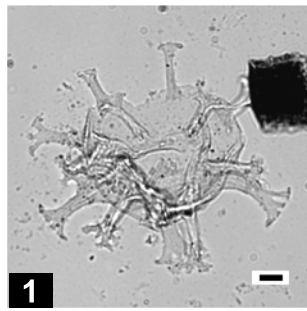


PLATE 4

- 1–4. *Enneadocysta pectiniformis* complex (Ebulbahar section, Sample No: 93, 111; Kelereşdere section, Sample No: 109)
5–8. *Cordosphaeridium fibrospinosum* (Ebulbahar section, Sample No: 72, 91, 93; Kelereşdere section, Sample No: 92)
9. *Polysphaeridium zoharyi* (Ebulbahar section, Sample No: 93)
10–12. *Spiniferites mirabilis* (Ebulbahar section, Sample No: 93)
13–15. *Criboperidinium tenuitabulatum* (Ebulbahar section, Sample No: 91, 93)

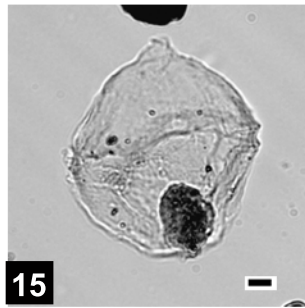
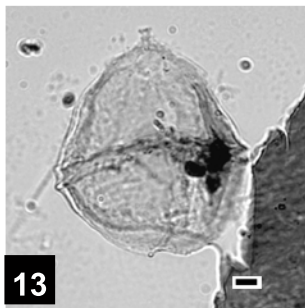
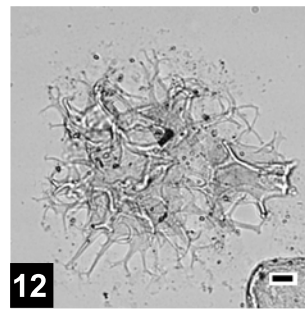
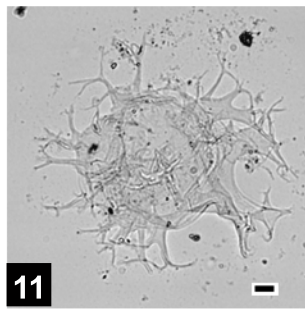
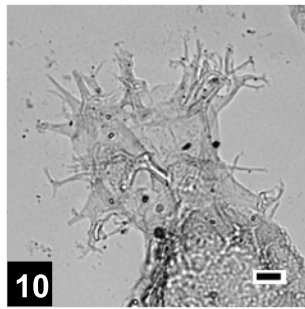
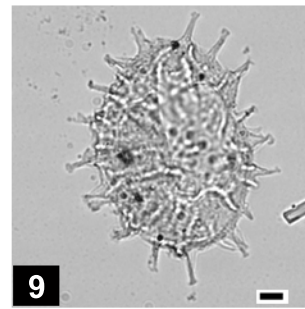
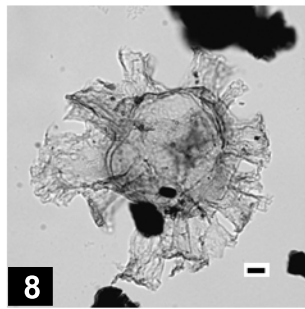
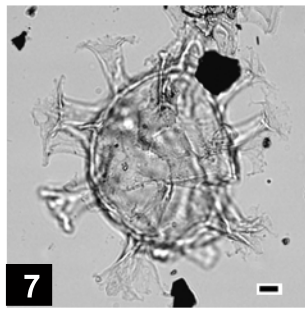
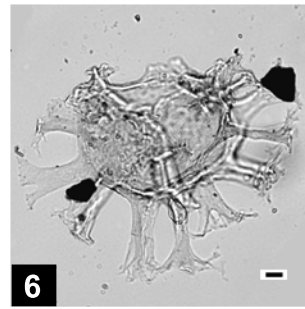
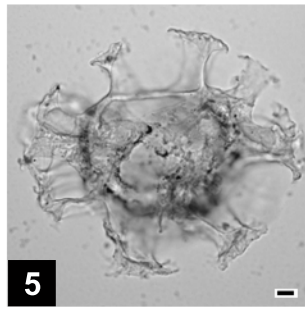
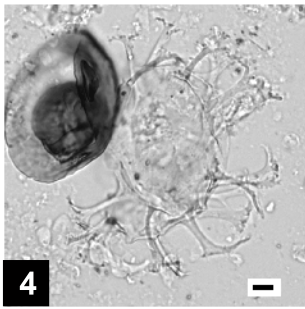
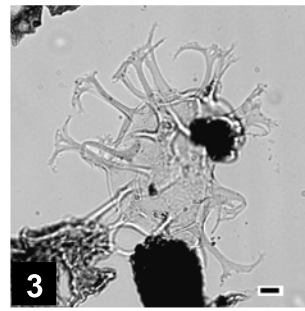
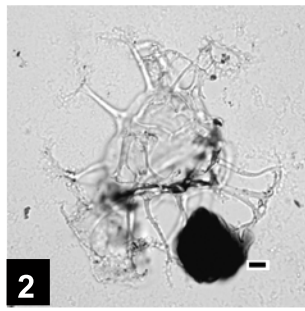
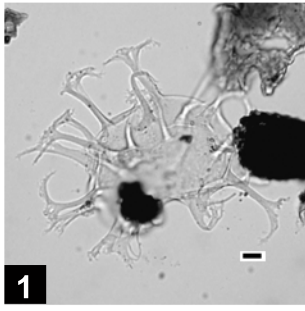


PLATE 5

- 1–5. *Thalassiphora pelagica* (Ebulbahar section, Sample No: 70, 72, 93, 116; Kelereşdere section, Sample No: 92)
6, 7, 9, 10. *Deflandrea* sp. (Ebulbahar section, Sample No: 66, 70, 72)
8. *Deflandrea phosphoritica* (Ebulbahar section, Sample No: 72)
11–13. *Tuberculodinium vancampoae* (Ebulbahar section, Sample No: 70, 72)
14. *Distatodinium* sp. (Kelereşdere section, Sample No: 92)
15. *Distatodinium biffii* (Kelereşdere section, Sample No: 92)

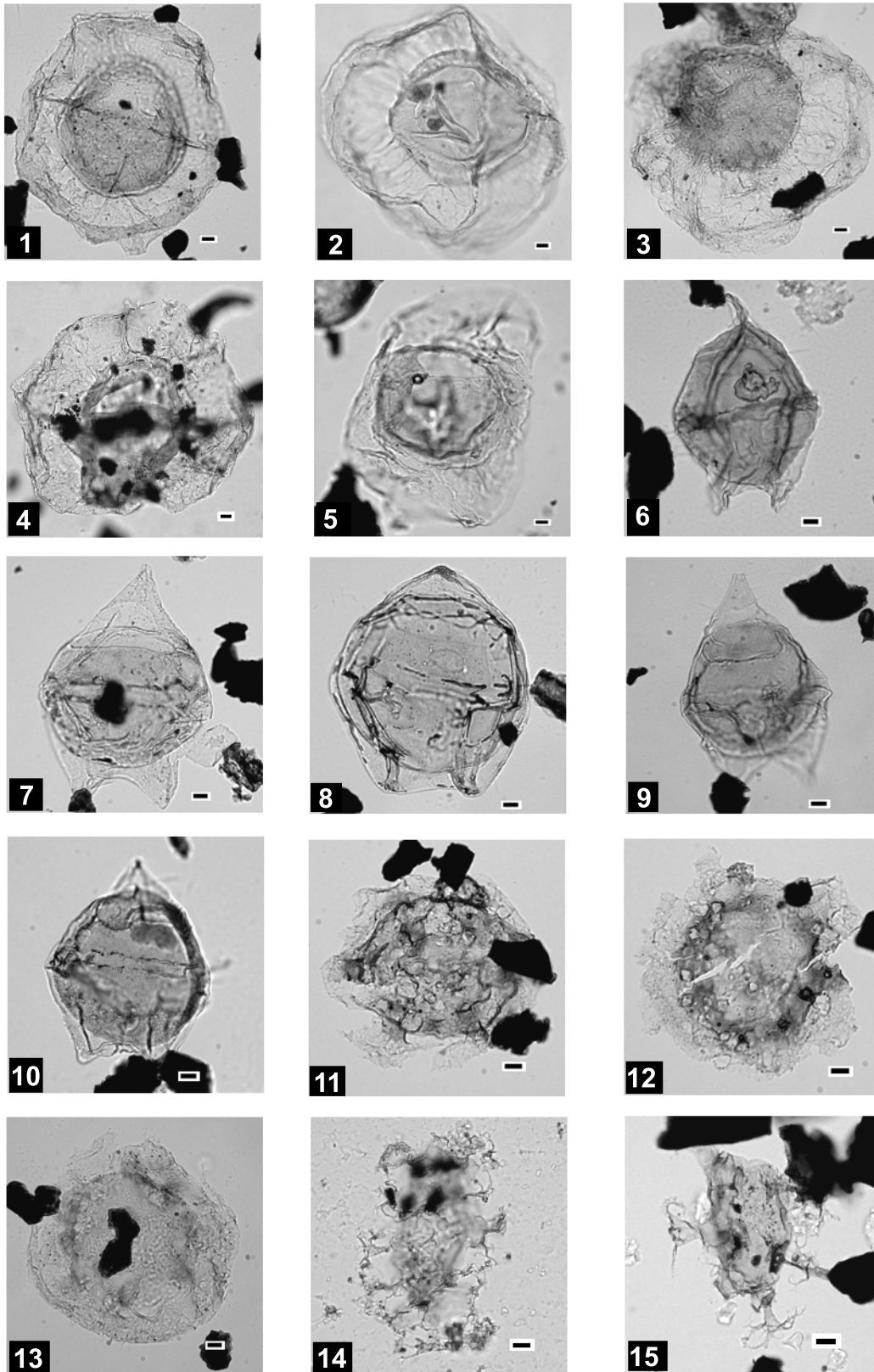


PLATE 6

1. *Wetzeliella gochtii* (Ebulbahar section, Sample No: 70)
- 2-3, 5. *Wetzeliella* sp. (Ebulbahar section, Sample No: 70, 72)
7. *Wetzeliella symmetrica* (Ebulbahar section, Sample No: 70)
- 4, 6. *Wetzeliella articulata* (Ebulbahar section, Sample No: 70)
8. *Polysphaeridium zoharyi* (Ebulbahar section, Sample No: 93)
9. *Reticulosphaera actinocoronata* (Ebulbahar section, Sample No: 116)
10. *Operculodinium microtriainum* (Ebulbahar section, Sample No: 93)
- 11-12. *Riculacysta perforata* (Ebulbahar section, Sample No: 93)
- 13-15. *Operculodinium* sp. (Ebulbahar section, Sample No: 93, 116)

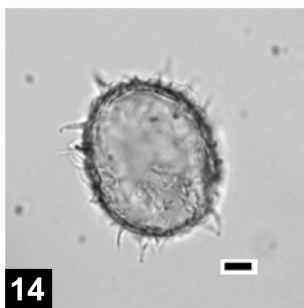
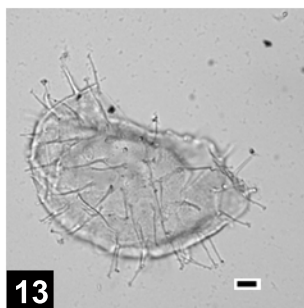
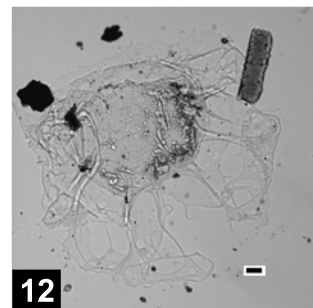
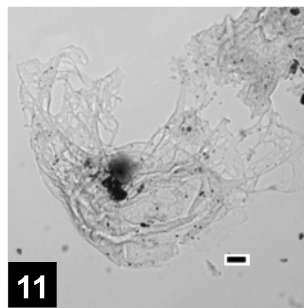
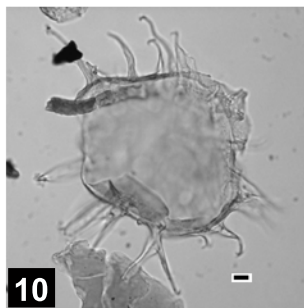
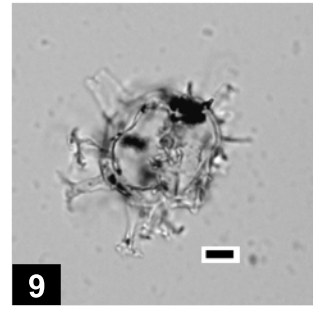
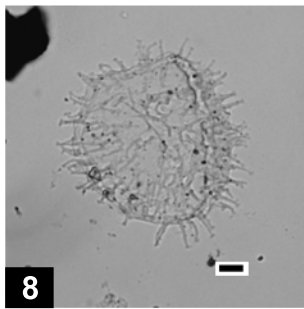
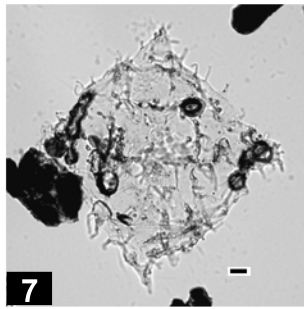
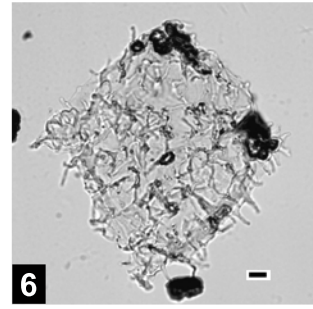
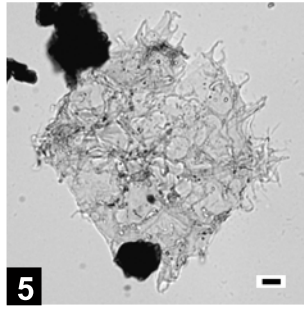
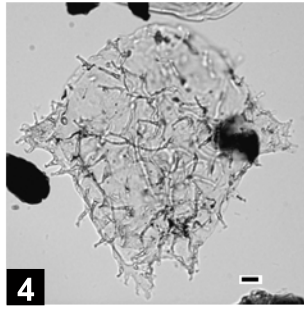
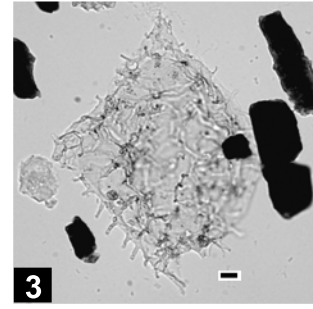
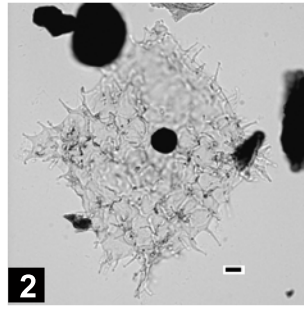
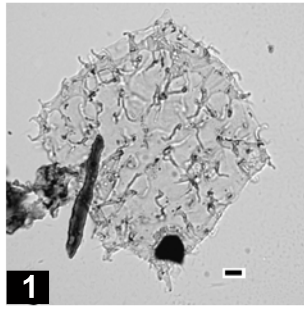


PLATE 7

- 1–3. *Fibrocysta* sp. (high, mid, and low focus) (Ebulbahar section, Sample No: 70)
4. *Selenopemphix nephroides* (Ebulbahar section, Sample No: 70)
5. *Cordosphaeridium minimum* (Ebulbahar section, Sample No: 111)
6. *Hystriocholpoma rigaudiae* (Ebulbahar section, Sample No: 112)
- 7–8. *Polysphaeridium zoharyi* (Ebulbahar section, Sample No: 93, 111)
9. *Homotryblium oceanicum* (Ebulbahar section, Sample No: 93)
- 10–12. *Pentadinium* sp. (Ebulbahar section, Sample No: 72, 116)
13. *Heteraulacacysta* sp. (Ebulbahar section, Sample No: 92)
- 14–15. unidentified chorate fragment (Ebulbahar section, Sample No: 70)

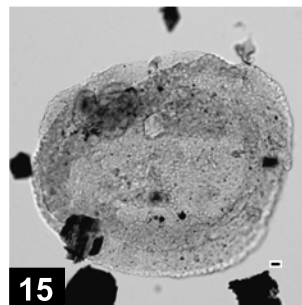
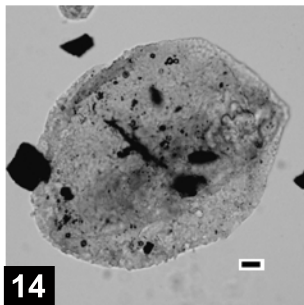
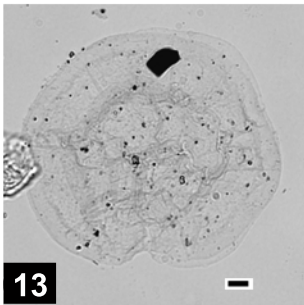
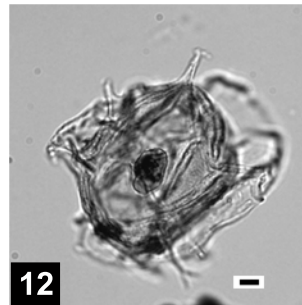
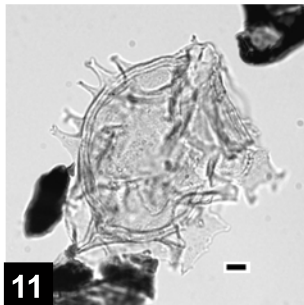
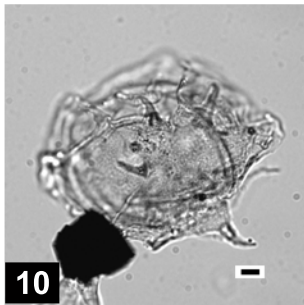
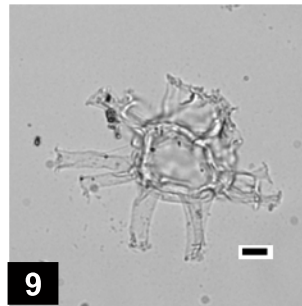
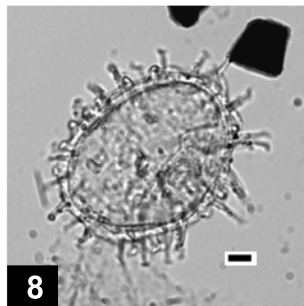
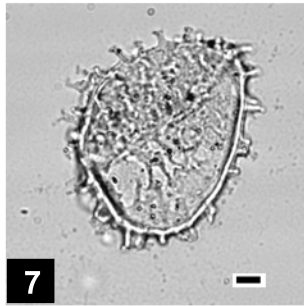
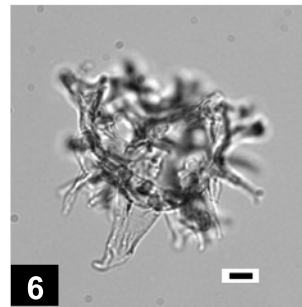
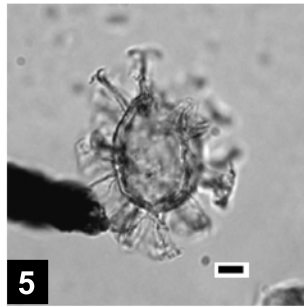
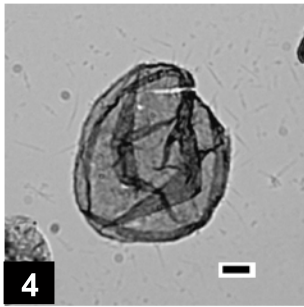
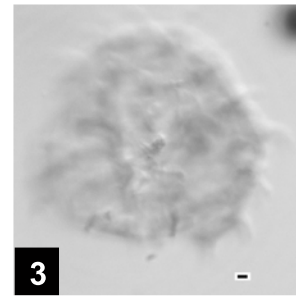
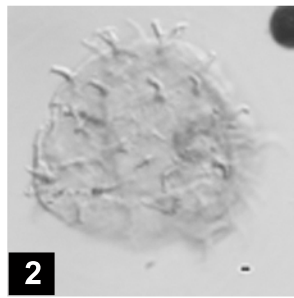
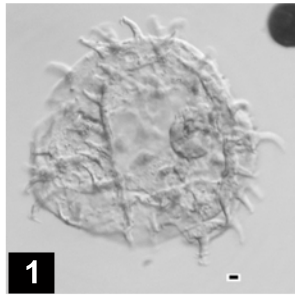


PLATE 8

- 1–2. *Lingulodinium machaerophorum* (Ebulbahar section, Sample No: 112)
3–10, 12, 13. *Chiropteridium galea* (Ebulbahar section, Sample No: 91, 92, 93; Kelereşdere section, Sample No: 115)
11. *Chiropteridium lobospinosum* (Ebulbahar section, Sample No: 93)
14. Chitinous foraminiferal linings (Kelereşdere section, Sample No: 92)
15. *Botryococcus braunii* (Ebulbahar section, Sample No: 77)

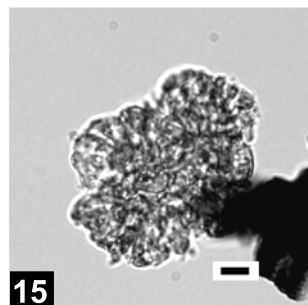
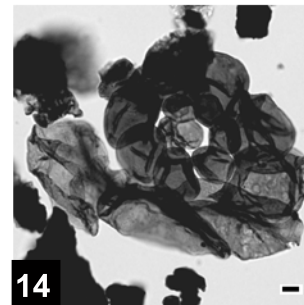
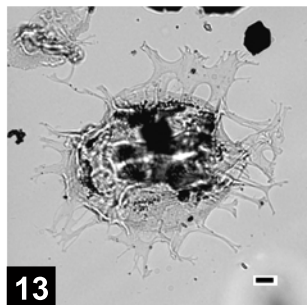
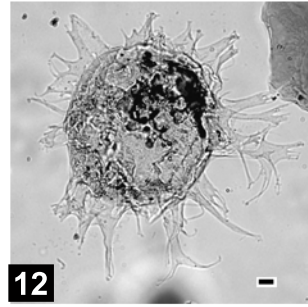
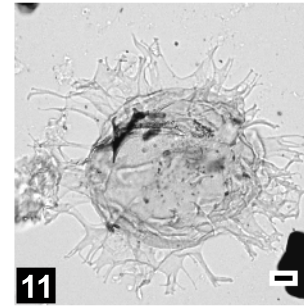
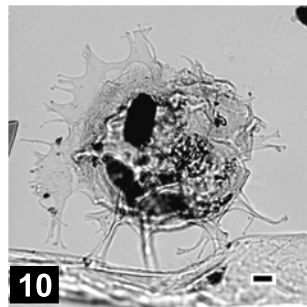
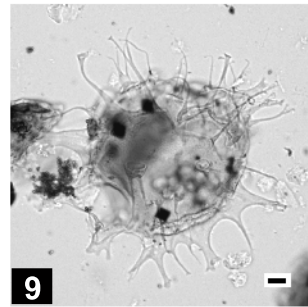
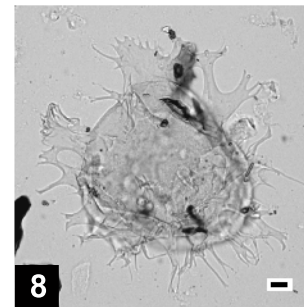
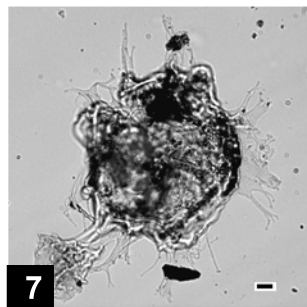
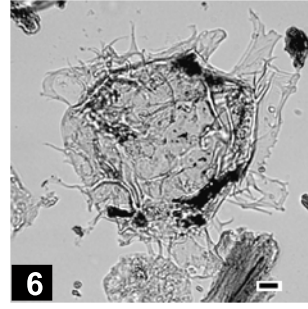
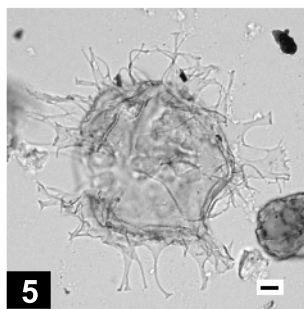
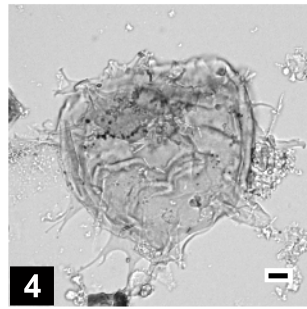
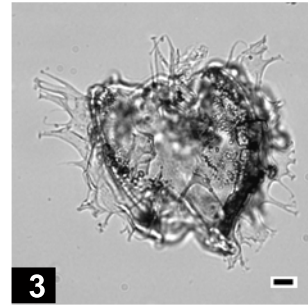
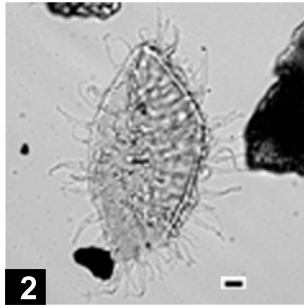
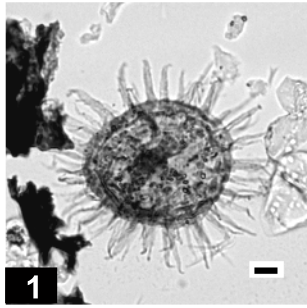


PLATE 9

- 1–9. Compositae (tubuliflorae-type) (Ebulbahar section, Sample No: 66, 74, 77, 92; Kelereşdere section, Sample No: 92,96, 109, 115)
10–11. Compositae (liguliflorae-type) (Kelereşdere section, Sample No: 159)
13. Compositae-type pollen (Ebulbahar section, Sample No: 78)
13–14. Umbelliferae (Ebulbahar section, Sample No: 66, 70; Kelereşdere section, Sample No: 109, 118)
15. *Monoporopollenites gramineoides* (Kelereşdere section, Sample No: 106)

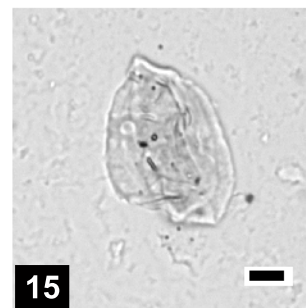
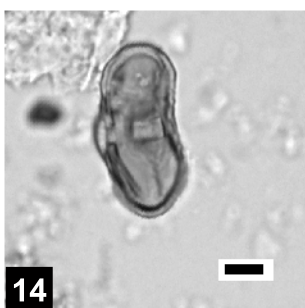
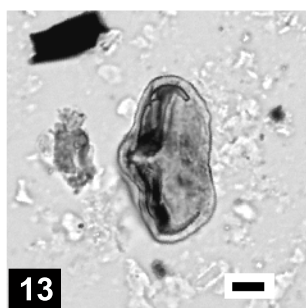
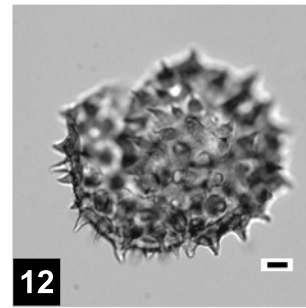
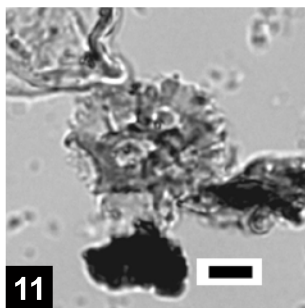
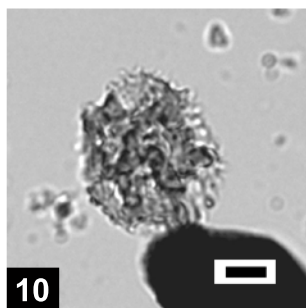
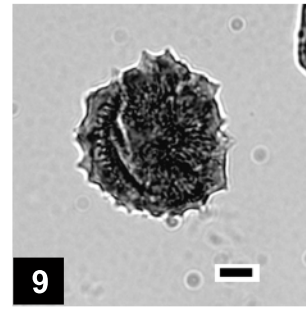
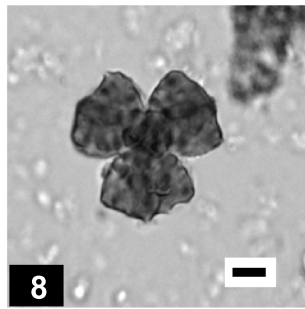
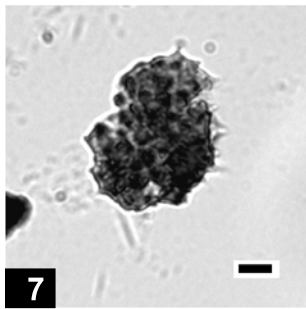
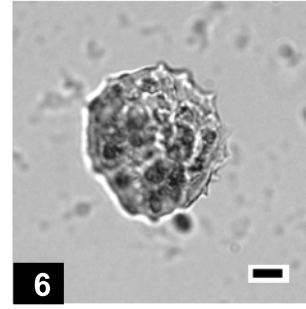
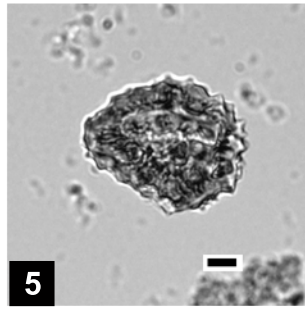
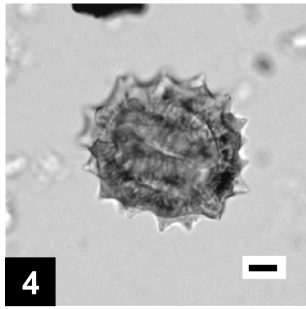
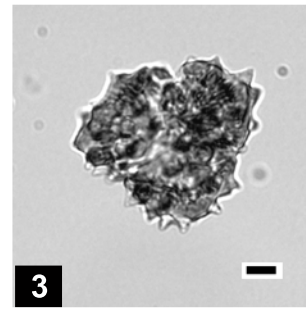
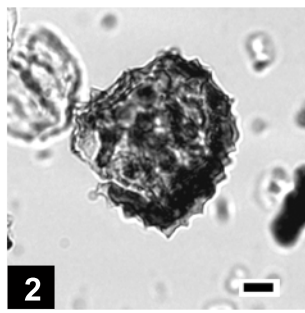
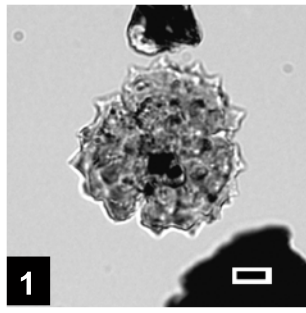


PLATE 10

- 1–3. *Slowakipollenites hipophæeoides* (Ebulbahar section, Sample No: 70; Kelereşdere section, Sample No: 106)
- 4–5. *Mediocolpopollis compactus* (Kelereşdere section, Sample No: 92, 106)
6. *Dicolpopollis kalewensis* (Ebulbahar section, Sample No: 70)
7. *Verucatosporites favus* (Ebulbahar section, Sample No: 82)
8. *Subtriporopollenites simplex* (Kelereşdere section, Sample No: 109)
9. *Polyporopollenites undulosus* (Kelereşdere section, Sample No: 109, 118)
10. *Periporopollenites multiporatus* (Ebulbahar section, Sample No: 74)
11. *Polyvestibulopollenites verus* (Kelereşdere section, Sample No: 106)
12. *Lusatisporites perinatus* (Kelereşdere section, Sample No: 92)
13. *Saxosporis* sp. (Ebulbahar section, Sample No: 116)
14. *Cicatricosisporites* sp. (Ebulbahar section, Sample No: 70)
15. *Echinatisporis* sp. (Ebulbahar section, Sample No: 86)

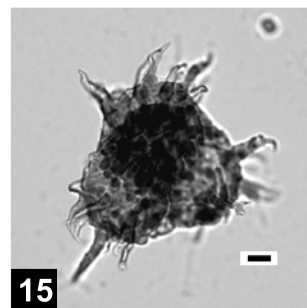
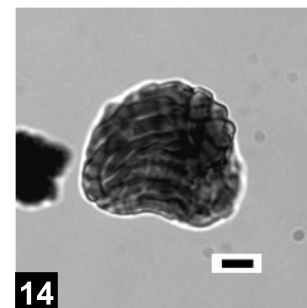
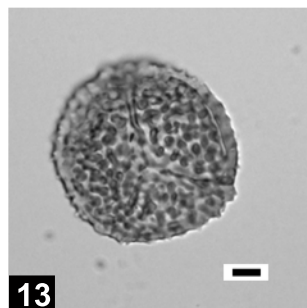
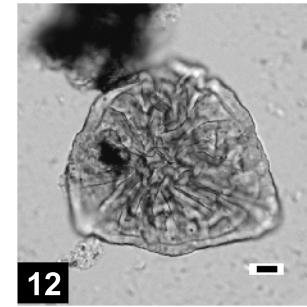
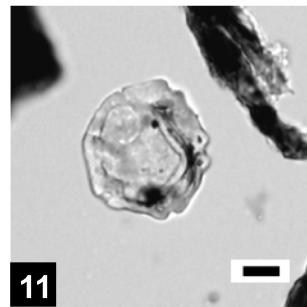
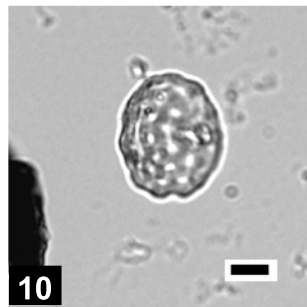
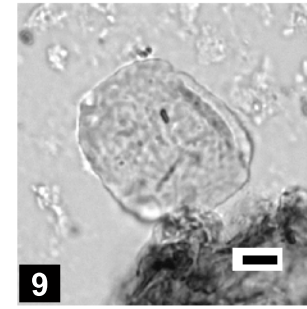
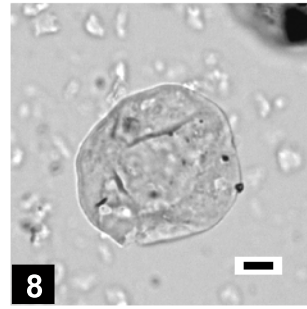
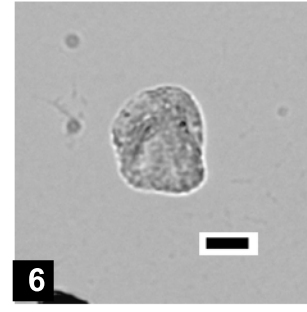
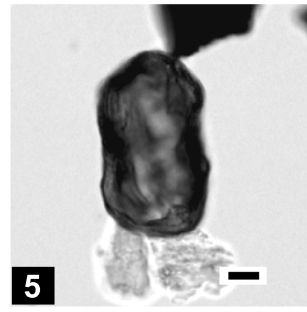
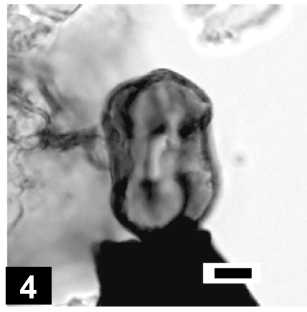
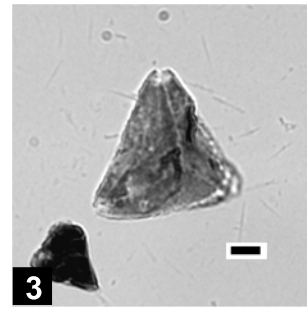
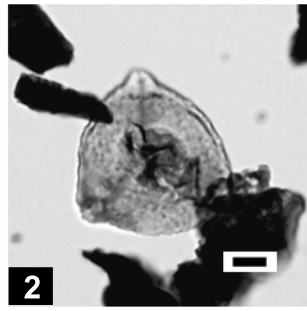
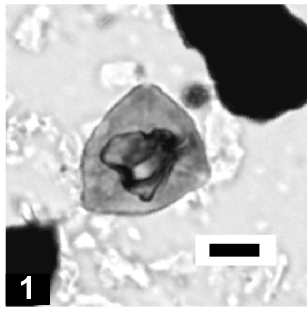


PLATE 11

- 1a-c. *Globorotalia opima opima* (Kelereşdere section, Sample No: 74)
2a-c. *Globigerina* cf. *ciperoensis ciperoensis* (Kelereşdere section, Sample No: 99)
3a-c. *Globorotalia obesa* (Kelereşdere section, Sample No: 115)
4a-c. *Globigerina praebulloides*. (Kelereşdere section, Sample No: 115)
5a-c. *Globigerina venezuelana* sp. (Kelereşdere section, Sample No: 115)

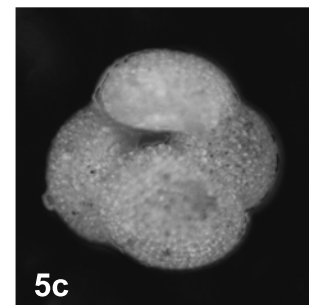
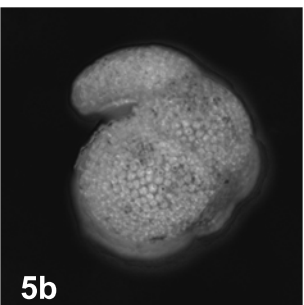
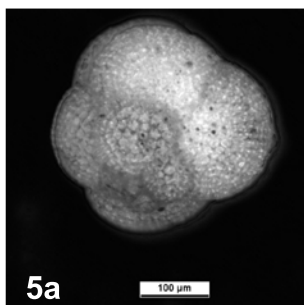
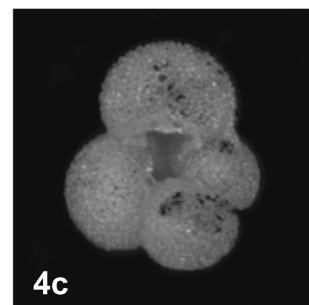
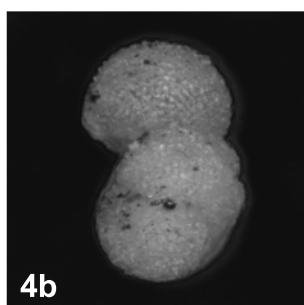
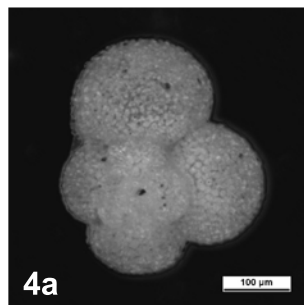
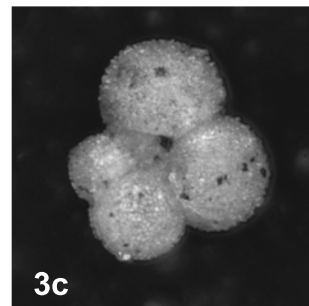
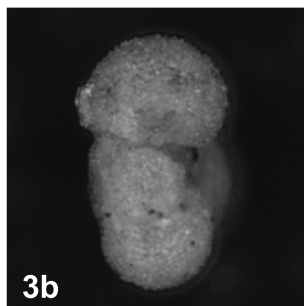
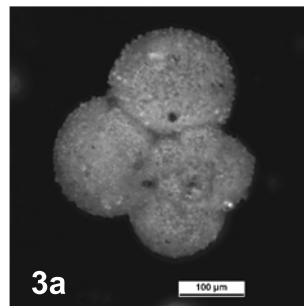
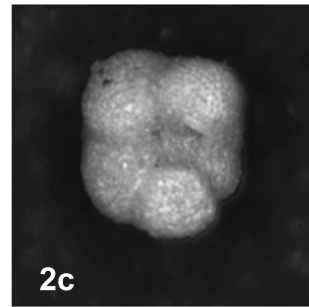
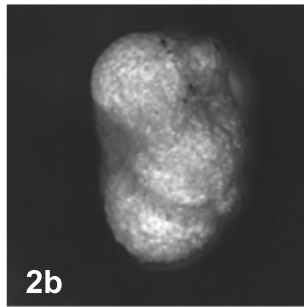
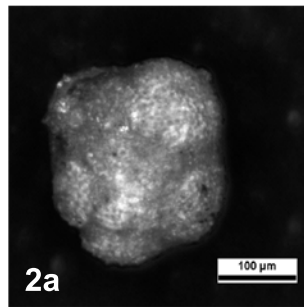
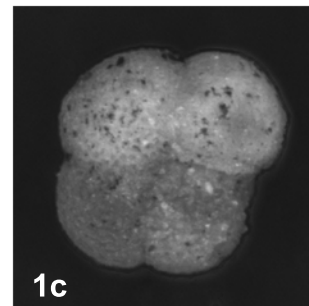
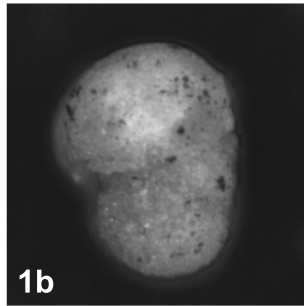
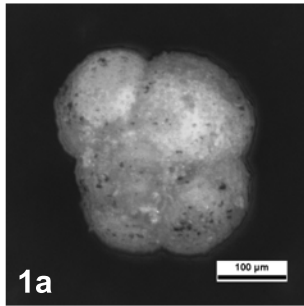


PLATE 12

- 1a-c. *Globigerinoides primordius* (Kelereşdere section, Sample No: 113)
2a-c. *Catapsydrax dissimilis* (Ebulbahar section, Sample No: 93)
3a-c. *Globigerina binaiensis* (Ebulbahar section, Sample No: 93)
4a-c. *Globigerinoides trilobus sacculifer* (Ebulbahar section, Sample No: 94)
5a-c. *Globigerinoides* gr. *trilobus* (Ebulbahar section, Sample No: 94)

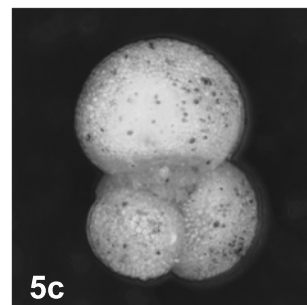
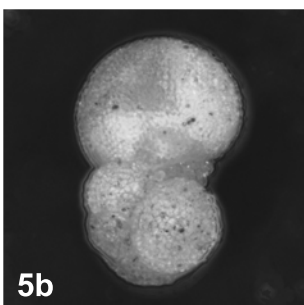
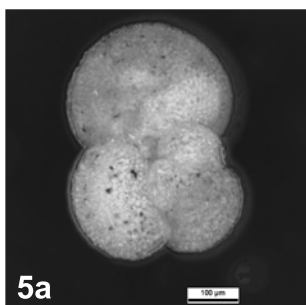
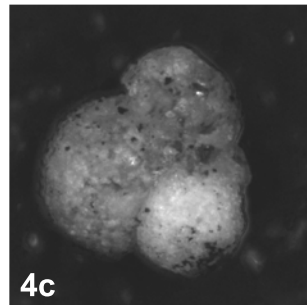
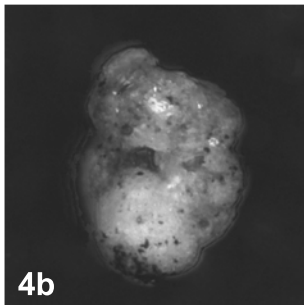
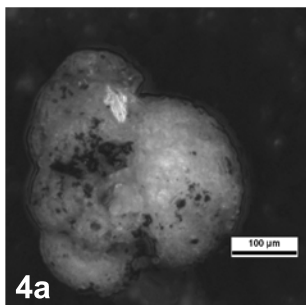
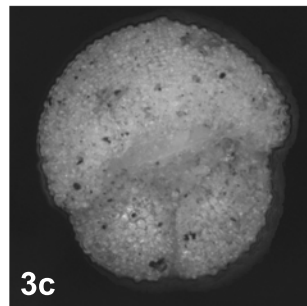
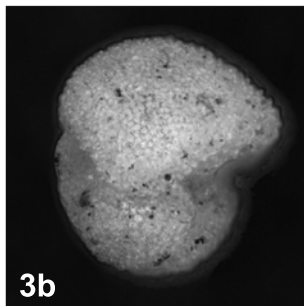
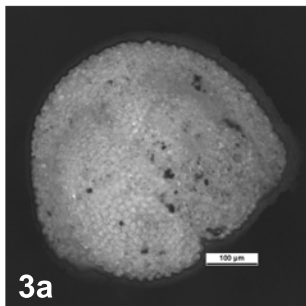
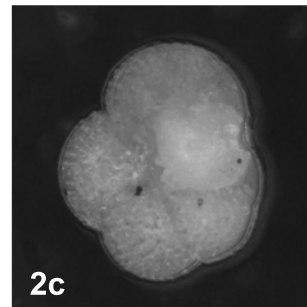
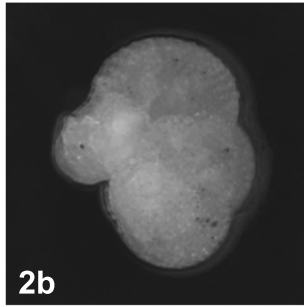
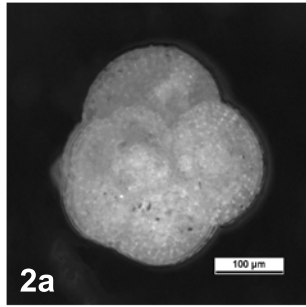
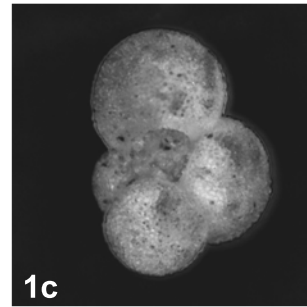
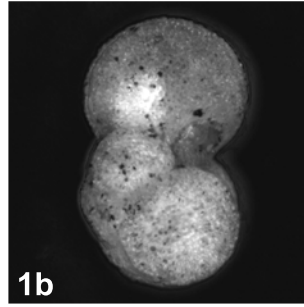
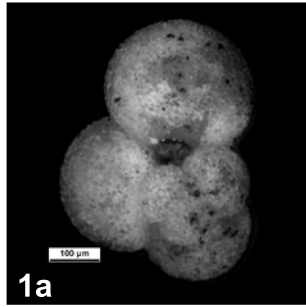


PLATE 13

- 1, 2. *Miogypsinooides* cf. *bantamensis* (Ebulbahar section, Sample No: 96)
3. *Miogypsinooides bantamensis* (Ebulbahar section, Sample No: 96)
4. *Miogypsinooides bantamensis* (Ebulbahar section, Sample No: 99)
5. *Miogypsinooides* cf. *dehaarti* (Ebulbahar section, Sample No: 119)
6. *Miogypsina* sp. (Ebulbahar section, Sample No: 119)
7. *Miogypsinooides grandipustulosa* (Ebulbahar section, Sample No: 102)
8. *Heterostegina* sp. (Ebulbahar section, Sample No: 97)
- 9, 10. *Eulepidina* sp. (Ebulbahar section, Sample No: 119)
11. *Nephrolepidina* sp. (Ebulbahar section, Sample No: 100)
12. *Nephrolepidina* cf. *tournoyeri* (Ebulbahar section, Sample No: 97)
13. *Miolepidocyclina* sp. (Ebulbahar section, Sample No: 119)
14. *Spiroclypeus* sp. (Ebulbahar section, Sample No: 104)
15. *Lepidocyclina gigas* (Ebulbahar section, Sample No: 119)
16. *Praeorbulina* cf. *sicana* (Ebulbahar section, Sample No: 127)
- 17, 18. *Praeorbulina transitoria* (Ebulbahar section, Sample No: 129)
- 19–21. *Praeorbulina* gr. *glomerosa* (Ebulbahar section, Sample No: 129)

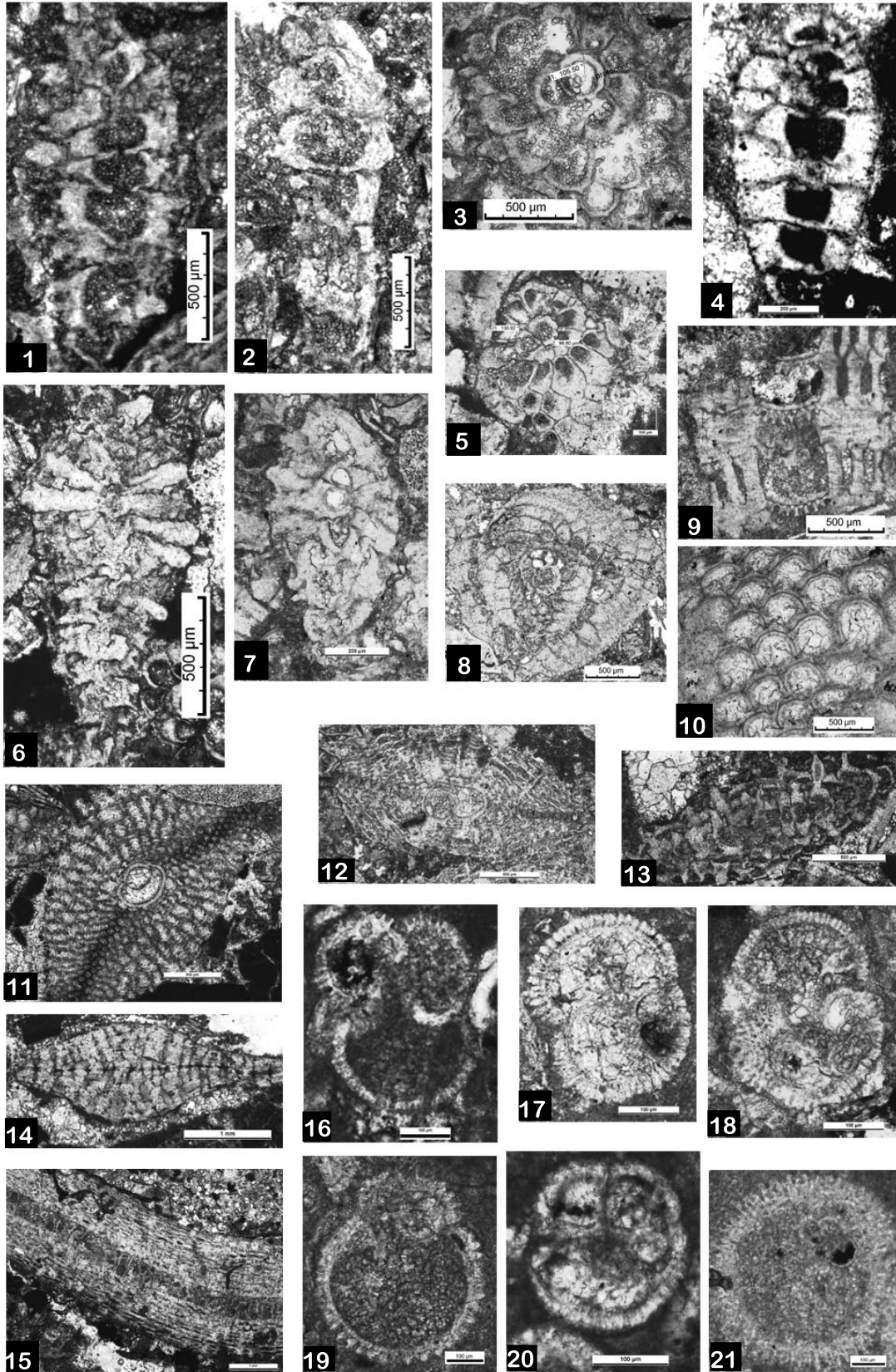


PLATE 14

1. *Spiroclypeus* sp. (Kelereşdere section, Sample No: 120)
2. *Globigerinoides* gr. *trilobus* (Kelereşdere section, Sample No: 97)
3. *Amphistegina* sp. (Kelereşdere section, Sample No: 121)
- 4, 9. *Austrotrillina howchini* (Kelereşdere section, Sample No: 121)
5. *Miogypsinoidea* sp. (Kelereşdere section, Sample No: 120)
6. *Miogypsina* sp. (Kelereşdere section, Sample No: 122)
7. *Archias* sp. (Kelereşdere section, Sample No: 123)
8. *Operculina complanata* (Kelereşdere section, Sample No: 121)
10. *Heterostegina* sp. (Kelereşdere section, Sample No: 123)
11. *Borelis* sp. (Kelereşdere section, Sample No: 123)
12. *Nephrolepidina* sp. (Kelereşdere section, Sample No: 123)
13. *Nephrolepidina* sp. (Kelereşdere section, Sample No: 122)
14. *Rotalia* sp. (Kelereşdere section, Sample No: 121)

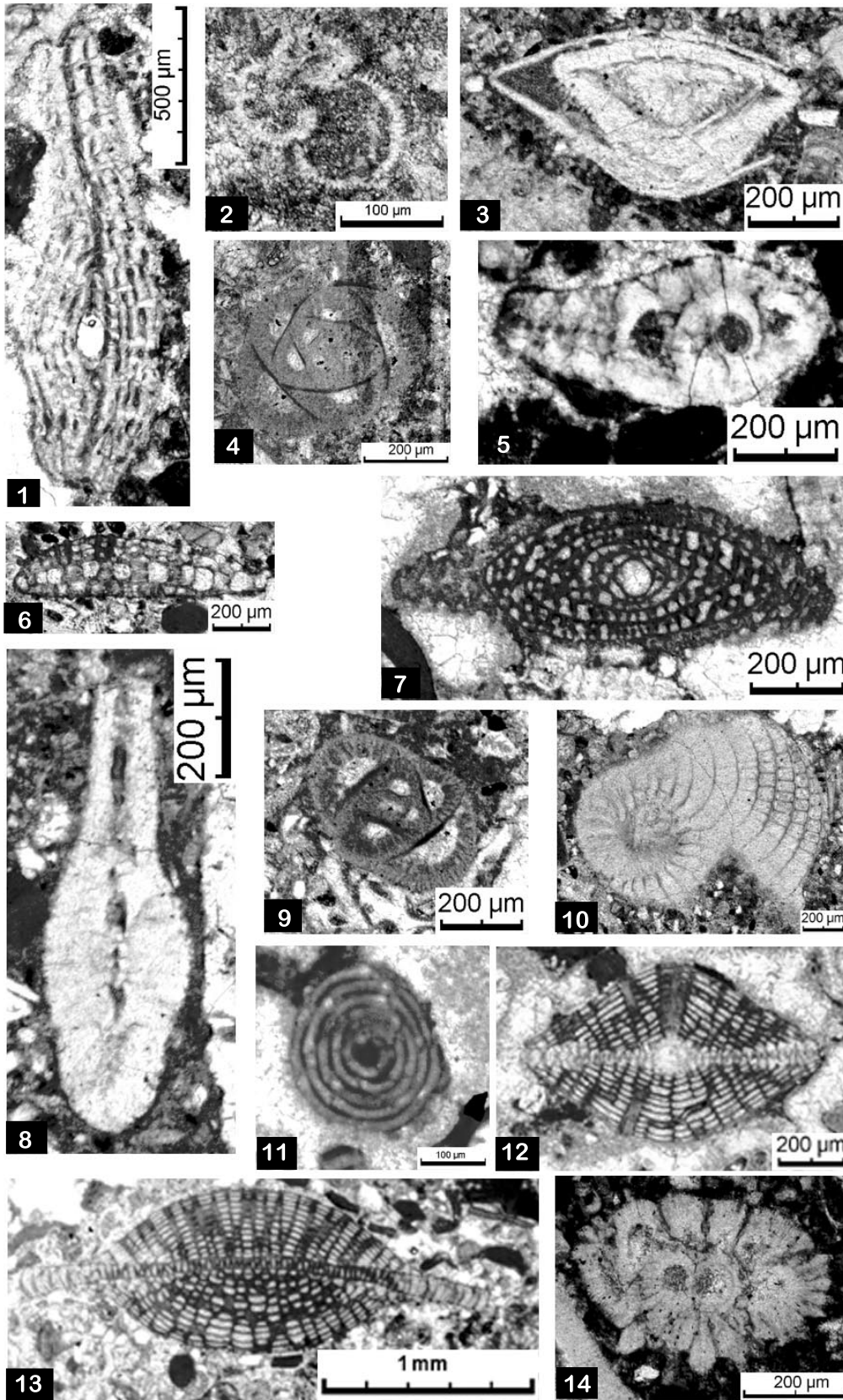


PLATE 15

1. *Sphenolithus distentus* (Ebulbahar section, Sample No: 80) under crossed polarized light (XPL)
- 2, 3. *Sphenolithus distentus* (Kelereşdere section, Sample No: 65, 86) (XPL)
4. *Sphenolithus ciperoensis* (Kelereşdere section, Sample No: 90) (XPL)
5. *Sphenolithus ciperoensis* (Kelereşdere section, Sample No: 86) XPL 0°
6. *Sphenolithus ciperoensis* (Kelereşdere section, Sample No: 86) XPL 45°
- 7–9. *Helicosphaera recta* (Kelereşdere section, Sample No: 84, 116) (XPL)
- 10, 11. *Helicosphaera obliqua* (Kelereşdere section, Sample No: 112) (XPL)
12. *Sphenolithus predistentus* (Kelereşdere section, Sample No: 77) (XPL)
13. *Cyclicarcolithus abisectus* (Ebulbahar section, Sample No: 82) (XPL)
14. *Dictyococcites bisecta* (Ebulbahar section, Sample No: 82) (XPL)
15. *Discoaster* cf. *calculosus* (Kelereşdere section, Sample No: 92 under parallel light) (PL)

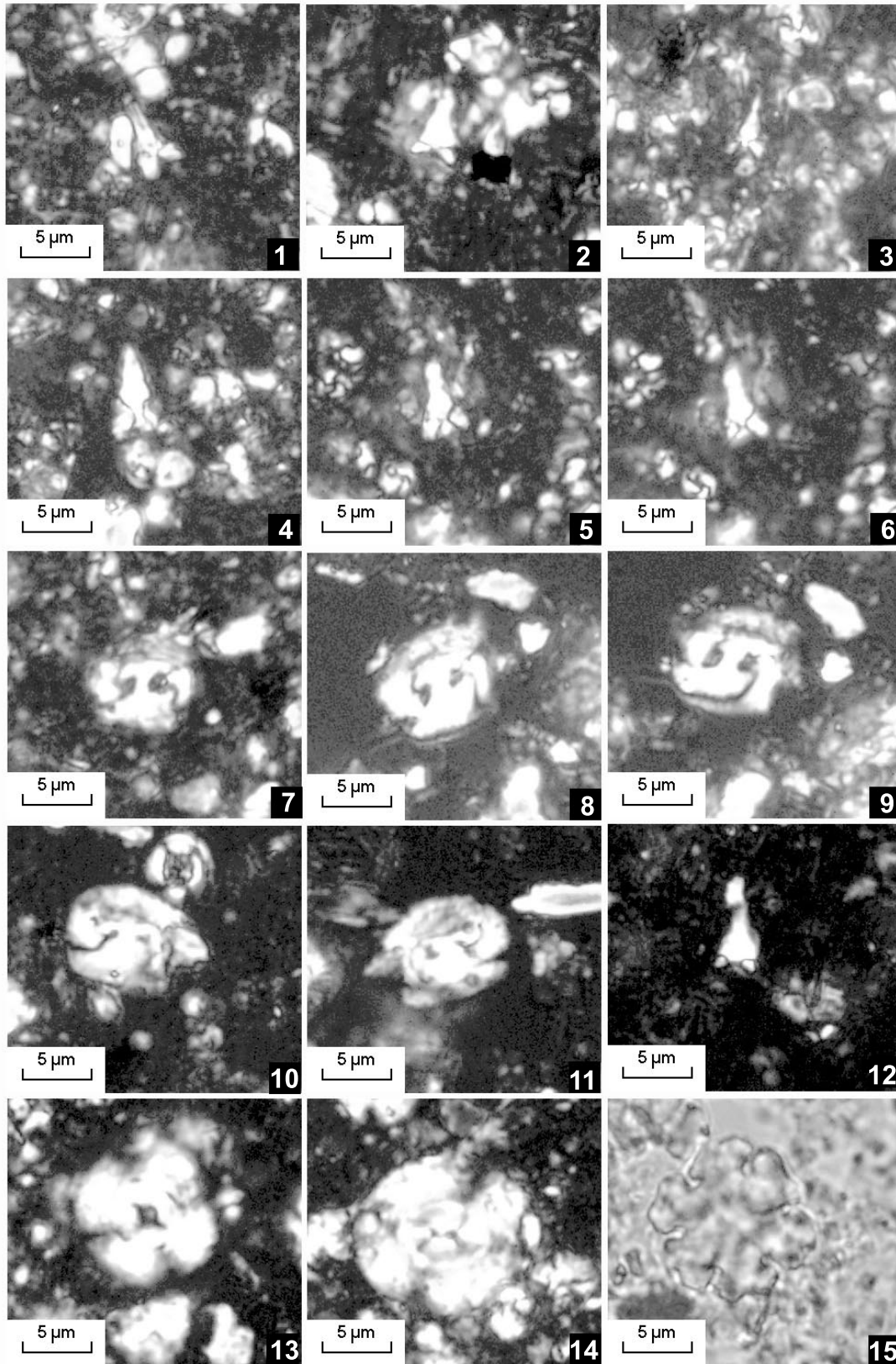


PLATE 16

1. *Watznaueria barnesae* (Kelereşdere section, Sample No: 66) (XPL)
2. *Eiffellithus turriseiffelli* (Kelereşdere section, Sample No: 84) (XPL)
3. *Eiffellithus eximius* (Kelereşdere section, Sample No: 85) (XPL)
4. *Quadrum gothicum* (Ebulbahar section Sample No: 167) (XPL)
5. *Ceratolithoides kamptneri* (Kelereşdere section, Sample No: 88) (XPL)
6. *Calculites ovalis* (Kelereşdere section, Sample No: 91) (XPL)
7. *Microrhabdulus decoratus* (Kelereşdere section, Sample No: 88) (XPL)
8. *Fasciculithus tympaniformis* (Kelereşdere section, Sample No: 76) (XPL)
9. *Discoaster multiradiatus* (Kelereşdere section, Sample No: 116) (PL)
10. *Sphenolithus radians* (Kelereşdere section, Sample No: 83) (XPL)
11. *Zygrhablithus bijugatus* (Kelereşdere section, Sample No: 72) (XPL)
12. *Tribrachiatus orthostylus* (Kelereşdere section, Sample No: 102) (PL)
13. *Discoaster lodoensis* (Kelereşdere section, Sample No: 82) (PL)
14. *Discoaster* cf. *tanii* (Kelereşdere section, Sample No: 84) (PL)
15. *Discoaster barbadiensis* (Kelereşdere section, Sample No: 86) (PL)

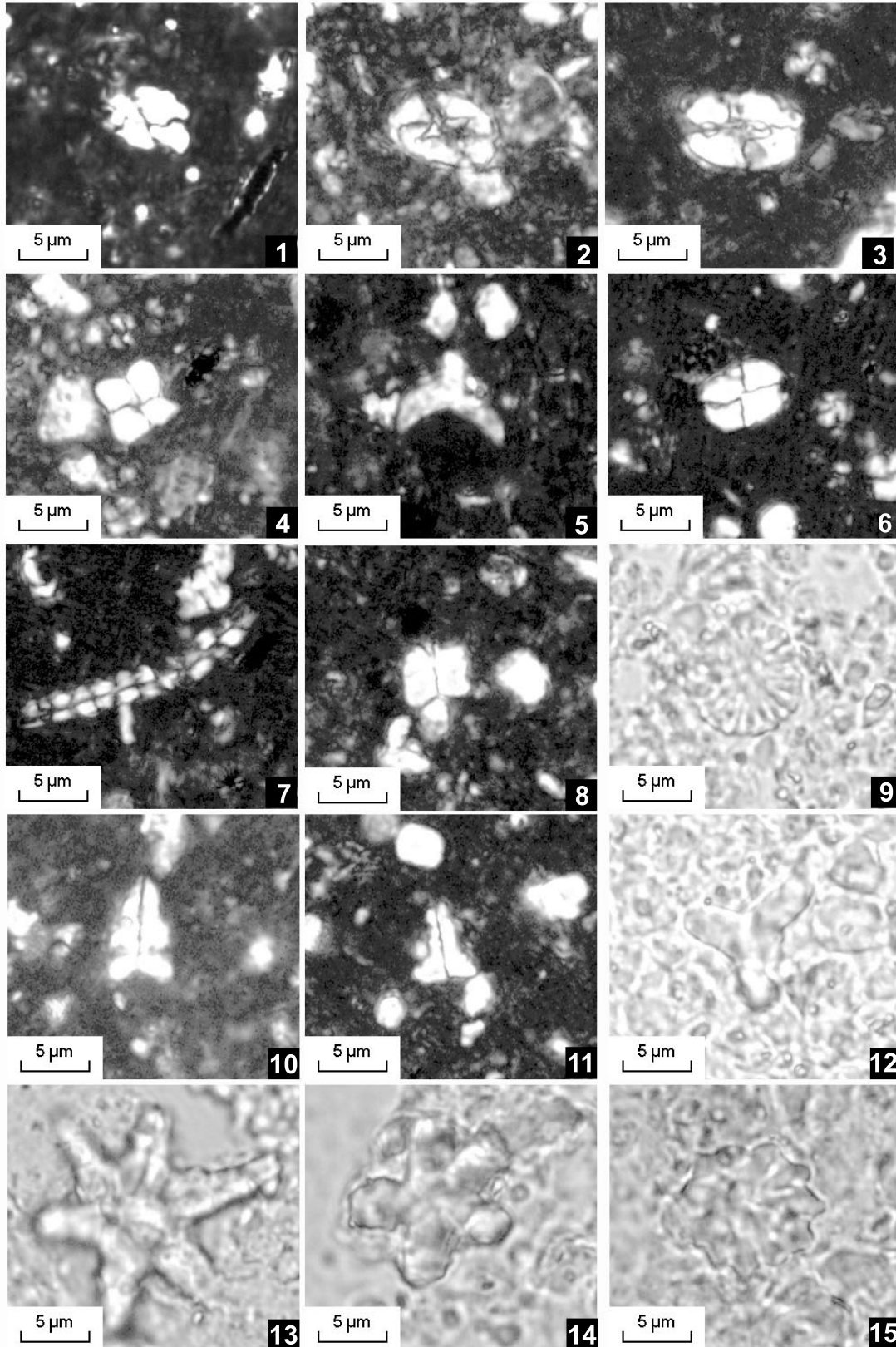


PLATE 17

- 1–3. *Helicosphaera compacta* (Kelereşdere section, Sample No: 83, 89, 91) (XPL)
- 4–5. *Helicosphaera euphratis* (Kelereşdere section, Sample No: 88) (XPL)
6. *Helicosphaera euphratis* (Ebulbahar section, Sample No: 120) (XPL)
- 7–8. *Braarudosphaera bigelowii* (Kelereşdere section, Sample No: 92) (XPL)
9. *Sphenolithus moriformis* (Kelereşdere section, Sample No: 71) (XPL)
10. *Cyclicargolithus abisectus* (Kelereşdere section, Sample No: 90) (XPL)
11. *Coccolithus pelagicus* (Kelereşdere section, Sample No: 71) (XPL)
12. *Coccolithus pelagicus* (Kelereşdere section, Sample No: 84) (PL)
- 13–15. *Discoaster deflandrei* (Kelereşdere section, Sample No: 82, 86) (PL)

