

# Palynostratigraphy of Rupelian sediments in the Mus Basin, Eastern Anatolia, Turkey

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**ABSTRACT:** Biostratigraphically important dinoflagellate, acritarch, and pollen events calibrated by planktonic foraminifers and calcareous nannoplankton are here documented for the first time in the Rupelian sediments of the Mus Basin, Eastern Anatolia. The LAD of *Ascostomocystis potane* in coincidence with the FAD of *Globorotalia opima opima* in the “late” Rupelian, the FAD of *Wetzeliella gochtii* in the “middle” Rupelian, the LAD of *Wetzeliella gochtii* in the “latest” Rupelian, and the FADs of Compositae (tubuliflorae type), *Monoporopollenites gramineoides* and Umbelliferae at the base of Rupelian should be of particular importance for regional correlations.

In addition to the Rupelian acritarch *Ascostomocystis potane*, diverse dinoflagellate cysts such as *Achilodinium biformoides*, *Wetzeliella gochtii*, *Membranophoridium aspinatum*, *Distatodinium biffii*, *Enneadocysta pectiniformis complex*, *Deflandrea* spp., *Glaphyrocysta* group, and terrestrial palynomorphs including Compositae (tubuliflorae type), *Slowakipollenites hipophaeoides*, *Mediocolpopollis compactus*, *Monoporopollenites gramineoides*, Umbelliferae, *Periporopollenites multiporatus*, *Ephedripites* sp., *Cicatricosisporites* sp., *Lusatisporites perinatus*, *Cingulatisporites* spp. and *Saxosporis* sp. comprise the main palynological elements of the Rupelian deposits.

Combined information from all three disciplines (terrestrial/marine palynomorphs and sedimentary organic matter, nannoplankton, and foraminifers) suggests that Rupelian sedimentation in the studied sections was characterized by an initial fresh water phase and continued with deposition in shallow to deep marine environments. Although the marine Eocene-Oligocene transition has not been observed in the studied sections, the presence of transitional marine Upper Eocene and Lower Oligocene successions in the northern regions (Cat, SW of Erzurum) as documented by Sancay (2005) suggests that the boundary between the Upper Eocene and Lower Oligocene sediments could have been conformable in some localities of the Mus Basin. However, this argument still needs to be tested where the appropriate lithologies, with recoverable microfossils, are present in the transitional interval in the basin.

## INTRODUCTION

Eastern Anatolian subbasins, Tertiary in age, are bordered by the Pontides on the north, Southeast Anatolian Suture Zone on the south, and Karliova Triple Junction of the North Anatolian and South Anatolian faults on the west (Allen 1969; Arpat and Saroglu 1972; Sengor 1979). The subbasins extend towards Georgia, Armenia and Iran to the East (text-fig. 1). Eastern Anatolia occupies the northwestern part of the Turkey-Iran Plateau (Sengor and Kidd 1979), and consists of the western part of the Hınıs-Mus-Van basins bounded geologically by the northern part of Bitlis-Zagros Suture Zone and the eastern part of the North Anatolian Fault zone. The basins are Mesozoic-Cenozoic in age, intermontane in nature and were formed under the influence of North Anatolian Fault.

Eastern Anatolian sedimentary basins share important geological properties with the South Caspian Basin in terms of hydrocarbon potential. For this reason, intensive field and drilling activities have been carried out in the Oligocene-Lower Miocene sediments in Eastern Anatolia during the last two decades. Potential source rocks, which are correlative with the “Maykopian” primary hydrocarbon source rocks in the South Caspian region (e.g. Gürgey 2001), are documented in the Oligocene-Lower Miocene strata of Eastern Anatolia by Tekin (2002). She indicated that these source rocks are mostly characterized by content of Type II kerogen, deposited under lagoonal, remnant sea, and lacustrine conditions and having fair to excellent regional production potential. On the other hand, despite the petroleum potential of the Eastern Anatolian sediments as documented by source rock at depth as well as by oil seeps, the paleontology of the region has not been studied ade-

quately, and no biostratigraphic framework has yet been established.

A very thick and extensively distributed succession of Oligocene sediments has been identified as a result of the field and drilling activities in Eastern Anatolia, but some uncertainties about their ages and depositional environment still exist. Since bio-litho-chronostratigraphic units have not been identified adequately for this package, they have been described as Oligocene and even Lower Miocene in the earlier palynomorph studies carried out by Turkish Petroleum Corporation (TPAO) and General Directorate of Mineral Research and Exploration (MTA) workers in Eastern Anatolia (Sancay 2005 and references therein). The nature of the Rupelian deposits in the Eastern Anatolia was not well established in these studies and their existence remained questionable. Therefore, even though there is no observed unconformity in the field, the Eocene-Oligocene transition was interpreted as a hiatus based on the supposed absence of Rupelian sediments.

This study aims to establish a bio-chronostratigraphic framework and to document stratigraphic distribution of palynomorphs of Rupelian successions in the Mus Basin (Eastern Anatolia). The Keleresdere and Ebulbahar measured stratigraphic sections (text-figs. 2 and 3) have been analysed and stratigraphically important palynological assemblages have been identified. Palynomorphs in the samples have been correlated with the worldwide biozonations of marine dinoflagellate cysts, acritarchs, planktonic foraminifers and calcareous nannoplankton of the same latitudes to determine bio-chronostratigraphic units and depositional environment of Rupelian sediments.

TABLE 1  
Distribution of the fossil-bearing samples.

Number of Samples	Keleresdere Section	Ebulbahar Section
Palynology	48	41
Calcareous Nannoplankton	48	41
Foraminiferal Micropaleontology	24	28
<b>TOTAL</b>	<b>120</b>	<b>110</b>

## MATERIAL AND METHODS

Ebulbahar and Keleresdere sections, located in the northeastern part of the Mus Basin, have been measured and sampled for biostratigraphical analysis. The GPS readings of the Ebulbahar section are N 4301639-4308671, E 37736000-37739930 (text-fig. 2), and of the Keleresdere section are N 4291397-4300308, E 37749993-37756684 (text-fig. 3). The two studied sections are composed mainly of clastic lithologies (shale, marl, silty marl, sandstone, siltstone, claystone, and conglomerate) interfingering with limestones. Palynological and nannopaleontological slides and washed samples for micropaleontological analysis have been prepared for siliciclastic lithologies, whereas limestones have been studied only in thin sections.

Relative abundances of the fossils have been calculated semiquantitatively and following terms have been used: Super-abundant (S): more than 100 specimens; Abundant (A): between 20-100 specimens; Common (C): between 6-20 specimens; Rare (R): between 2-6 specimens; Present (P): only 1 specimen.

Digital images of the palynomorphs (plates 1-12), nannoplankton, and foraminifers were made by Leica DC200 digital camera system. Fossil distribution charts (biostratigraphic correlation diagram) and lithostratigraphic log were drawn using StrataBugs and Corel Draw software respectively.

A total of 272 samples have been combined from the outcrops (text-figs. 2 and 3) but only 230 of them were productive and used in biostratigraphical analysis. Table 1 illustrates the distribution of the productive samples in three disciplines. All analysed material have been stored in the Palynology Laboratory Archive of the Turkish Petroleum Corporation Research Center, Ankara.

## PREVIOUS BIOSTRATIGRAPHICAL STUDIES IN EASTERN ANATOLIA

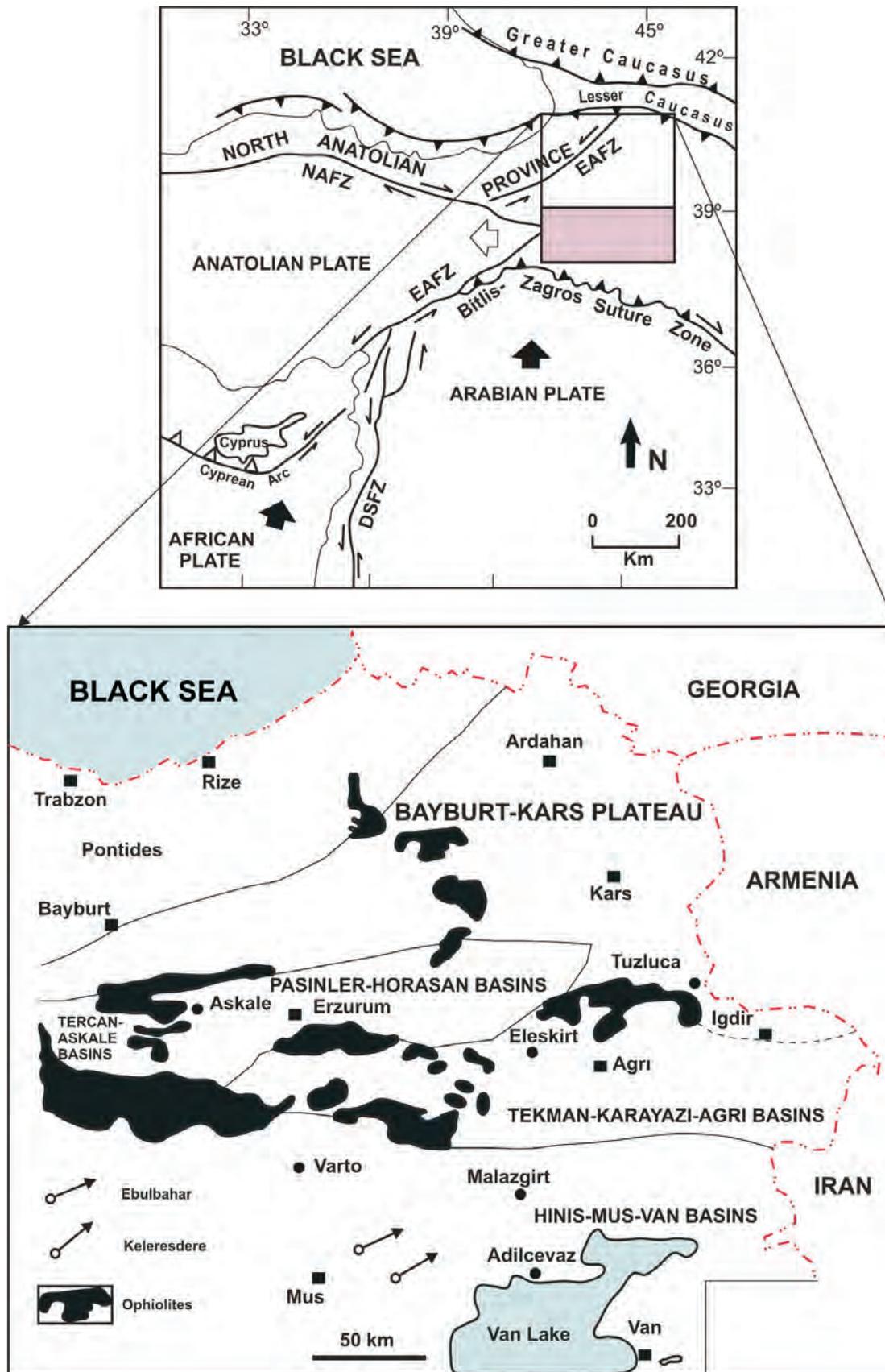
Most of the palynological studies in Eastern Anatolian Tertiary basins have been carried out by Turkish Petroleum palynologists under the scope of hydrocarbon exploration in the region, where entirely Oligocene successions have generally been interpreted as mostly Early Miocene and rarely as ?Late Oligocene in age (Sancay 2005 and references therein). Two major factors might have been responsible for the erroneous interpretation that Rupelian sediments are absent in Eastern Anatolia. First, earlier studies in Neogene palynostratigraphy and palynomorph biozonations in the western and central part of Turkey by Benda (1971a, b); Benda et al. (1977) and Benda et al. (1979), as well as other studies (Akgun et al. 1986; Akgun and Akyol 1987, 1992; Ediger et al. 1990; Bati 1996) suggested that Compositae (tubuliflorae type) only occurred for the first time at the beginning of the Miocene in Turkey. These palynological studies were mainly based on terrestrial

palynomorphs because of the restricted marine conditions that dominated the depositional environments during the Oligocene in most of Western Anatolia. Therefore, the first appearance of Compositae (tubuliflorae type) in the Oligocene sediments of Eastern Anatolia were interpreted as an indicator of beds no older than the ?latest Oligocene and the earliest Miocene. Second, Oligocene sediments are generally shallow marine in character in Eastern Anatolia, and are therefore very poor in planktonic foraminifers and calcareous nannofossils. Thus, those few that have been found could be interpreted as reworked because they contradicted the palynological data. As a result, Rupelian has been interpreted as the time of nondeposition or erosion in the Eastern Anatolia.

On the other hand, as far as the benthic foraminifers are concerned, biostratigraphical and paleontological studies in Eastern Anatolia have mentioned the presence of Rupelian sediments. One of the most detailed micropaleontological studies was carried out recently by Sirel (2003) in the Keleresdere and Norkagakdere sections of the Mus Basin, who found that the Middle Eocene in the Norkagakdere section is unconformably overlain by a Rupelian and Chattian succession, as identified by shallow-water Oligocene benthic foraminifera. This author suggested that SB 21, 22 zones (Rupelian-Lower Chattian) were represented by the interval from the first occurrence of *Austrotrillina striata* to the last occurrence of *Nummulites fichteli* and *Nummulites vascus*. SB 23 zone (Upper Chattian), on the other hand, was represented by *Miogypsinoides complanatus*, *Eulepidina*, *Nephrolepidina* and *Sriroclypeus* in Keleresdere section.

The Ahirdag section, lying north of the Kahramanmaras, Keleresdere and Norkagakdere sections in the northeastern part of Mus, was measured and analyzed by Sirel (2003), who identified shallow water, large benthic foraminifer taxa of Bartonian, Priabonian, and Oligocene age. Lutetian and Miocene sediments are also present, but were out of scope of his study. The Ahirdag section seems to be comparable with Keleresdere section in that Middle to Upper Eocene, Oligocene, and Oligocene-Miocene sediments (shallow benthic foraminiferal zonation of SB17-SB24) are exposed in both areas. The main difference between the two sections is the dominance of limestone in the Ahirdag section whereas the Keleresdere section is mainly composed of clastic lithologies interfingering with limestone beds. According to Sirel (2003), in the Ahirdag section Upper Eocene sediments unconformably overlie the ophiolitic melange, and essentially continuous sedimentation without any depositional break took place until the Early Miocene.

*Nummulites fichteli* and *Nummulites vascus* together with *Globorotalia opima opima* have been also identified in the Mus-2 well which is located in the northwestern part of the studied sections drilled by TPAO, and which were interpreted as Oligocene in age. Those intervals might correspond to SB 21, 22 zones of Sirel (2003) and might be represented by reefal limestones that are interpreted as Rupelian-Early Chattian in age and comparable to the P-Rp1 and P-Rp2 dinoflagellate and acritarch biozonations documented in this study. Even though Lower Miocene sediments crop out in the Keleresdere section, they were not included in any of the sections studied in Mus or Kahramanmaras areas by Sirel (2003). Therefore, he did not have a chance to compare foraminiferal assemblages of Oligocene-Miocene boundary transition in the sequences exposed in these basins.



TEXT-FIGURE 1  
 Location map of the Eastern Anatolia subbasins, Ebulbahar and Kelerepdere measured stratigraphic sections. (NAFZ: North Anatolian Fault Zone, EAFZ: East Anatolian Fault Zone, DSFZ: Dead Sea Fault Zone, (modified Sancay et al. 2006).

Another study of the Keleresdere section worth mentioning is the doctoral thesis published by Sakinc (1982), in which he distinguished five biozones in Oligocene and Lower Miocene sediments based on large foraminifera (Nummulitidae, Lepidocyclinidae, Miogypsinidae). These zones were Lower Oligocene (Lattorfian) *Nummulites vascus-Nummulites intermedius* biozone; middle Oligocene (Rupelian) *Nummulites intermedius-Lepidocyclina dilatata* biozone; upper Oligocene (Chattian) *Lepidocyclina tournoueri-Pararotalia lithothamnica lithothamnica* biozone; lower Miocene (Aquitanian) *Operculina ammonoides-Miogypsinoides complanatus* biozone; and lower Miocene (Burdigalian) *Miogypsinoides dehaartii-Lepidocyclina (Eu) Lepidina gigas* biozone. However, even though Sakinc (1982) identified a benthic foraminiferal assemblage for the Rupelian sediments in Mus Basin, his age assignments remained questionable since he did not calibrate his data with any other fossil groups.

Oligocene biostratigraphy of Eastern Anatolia obviously needs multidisciplinary studies to establish a biostratigraphic framework. The first attempt was Sancay et al. (2006), regarding the dinoflagellate, acritarch, planktonic foraminifer, and calcareous nannoplankton events occurred at the Oligocene-Miocene transition in the Mus Basin. However, Rupelian sediments were not treated in this paper.

#### DINO CYST ZONATION OF THE MEDITERRANEAN AREA

Several biostratigraphical studies based on dinocysts have been carried out in different regions of the Mediterranean and Western Europe, beginning in the early 1980's (e.g. Powell 1986a and b; Biffi and Manum 1988; Heilmann-Clausen and Costa 1989; Köthe 1990; Brinkhuis et al. (1992); Zevenboom et al. (1994); Stover and Hardenbol 1994; Zevenboom (1995). More recently dinocyst biozonation of the Early Oligocene in particular has been established by Brinkhuis and Biffi (1993), Brinkhuis (1994), and Wilpshaar et al. (1996) with selected palynomorph events calibrated by magnetostratigraphical data.

Following his previous work in 1986a, Powell (1986b) made an approach to the stratigraphic occurrences (LADs) of some selected Oligo-Miocene taxa in the Mediterranean region including *Chiropteridium* spp., *Wetzeliella* spp., *Glaphyrocysta* spp., *Homotryblium plectilum*, *Cordosphaeridium gracile* *Thalassiphora pelagica*, *Chiropteridium mespilanum*, *Homotryblium floripes*, *Distatodinium craterum* recorded in Upper Oligocene while *Cordosphaeridium cantharellus* and *Bipolaribucina paradoxa* last occurred in Lower Miocene sediments in the Piedmont Basin.

Later, Biffi and Manum (1988) investigated four sections from the Marche Region (Central Italy) and distinguished seven dinoflagellate zones in the upper Eocene-lower Oligocene sediments. Since Biffi and Manum (1988) referred to several previously undescribed and stratigraphically important taxa, it is not easy to correlate their assemblages with Powell (1986a and b).

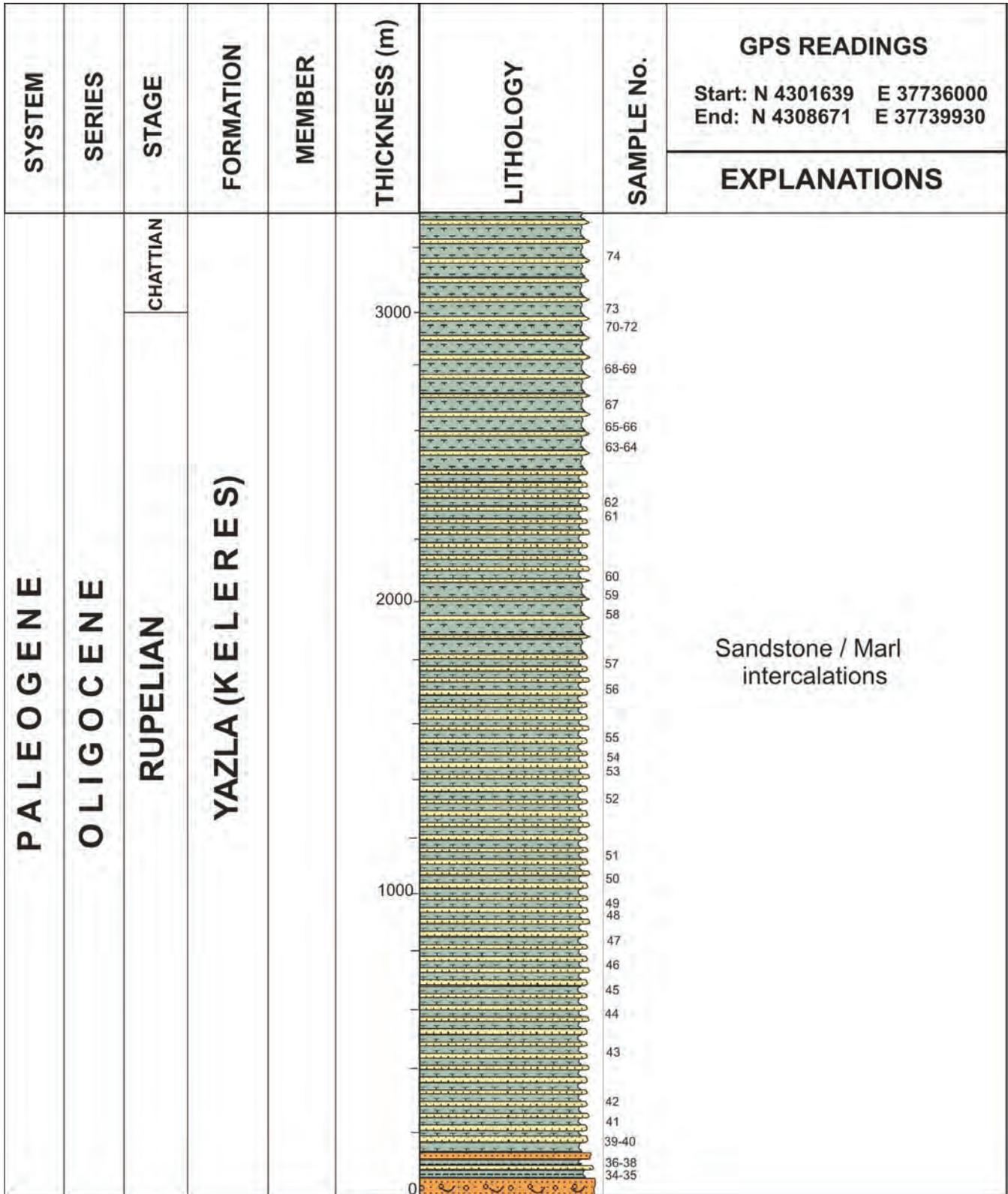
Heilmann-Clausen and Costa (1989) investigated the 20m-thick upper Oligocene?-lower Miocene sediments from the Wunsterheide research well (NW Germany) and assigned an early Oligocene age to the stratigraphically lower two samples corresponding to D14 or D15 of Costa and Manum (1988), citing the presence of *Pentadinium laticinctum-imaginatum*. However, *Rhombodinium draco* was also identified in those two samples, which would reflect a Rupelian age. A third sample of

Heilmann-Clausen and Costa (1989) includes *Wetzeliella gochtii*, corresponding to D15 zone of Costa and Manum (1988), indicating early Chattian age.

Köthe (1990) studied the Paleogene dinocysts of northwest Germany and reported an assemblage which can be comparable with D15 of Costa and Manum (1988). The overall assemblage is characterized by the common occurrences of *Homotryblium plectilum*, *Membranophoridium aspinatum* (especially common in the lower part and becoming rare in the upper part), rare occurrences of *Chiropteridium* and absence of *Deflandrea phosphoritica*, all of which indicates a Late Oligocene age.

One of the most detailed studies in the Mediterranean region was carried out by Brinkhuis et al. (1992), who developed a high resolution dinoflagellate cyst stratigraphy in which they documented dinoflagellate assemblages in the Oligocene-Miocene transition of Northwest and Central Italy. They correlated their dinoflagellate cyst zonations with planktonic foraminifers, calcareous nannoplankton and also with magnetostratigraphy, in defining two zones and four subzones in the uppermost Oligocene-lowermost Miocene sediments in the Marche Basin and one zone and two subzones in the lower Miocene sediments in the Piedmont Basin. The criteria that were used to correlate sections in the Piedmont Basin included the FADs of *Hystrichosphaeropsis* cf. *obscura*, *Distatodinium apennicum*, *Ectosphaeropsis burdigaliensis*, *Caligodinium pycnum* and *Hystrichokolpoma pusilla*, as well as total ranges of *Distatodinium biffii* and *Saturnodinium perforatum*. For the Marche Basin, they used FADs of *Hystrichosphaeropsis* cf. *obscura*, *Distatodinium apennicum*, *Ectosphaeropsis burdigaliensis*, *Caligodinium pycnum* and LADs of *Homotryblium* sp., cf. *Homotryblium oceanicum*, *Impagidinium dispertitum*, *Impagidinium brevisulcatum*, and *Hystrichokolpoma pusilla*. In general, they claimed that typical Paleogene dinoflagellate cysts such as *Wetzeliella*, *Glaphyrocysta*, *Areoligera*, *Deflandrea*, and *Chiropteridium* gradually disappeared in the interval from upper Oligocene to lower Miocene, and were never found in high abundance above the Oligocene-Miocene boundary. Similarly, Dybkjaer (2004) assigned a Late Oligocene age for her sequence A in Jylland, Denmark based on the presence of *Deflandrea phosphoritica* and the absence of the Early Oligocene species such as *Wetzeliella gochtii*.

Brinkhuis and Biffi (1993) and Brinkhuis (1994) studied the Eocene-Oligocene transition in Italy and documented the Upper Eocene to lower Oligocene dinoflagellate cyst zonation for the central Mediterranean. They distinguished 8 dinoflagellate biozones based on 20 dinoflagellate events (text-fig. 5). They reported *Melitasphaeridium pseudorecurvatum* (Mps), *Schematophora speciosa* (Ssp), and *Cordosphaeridium funiculatum* (Cfu) interval zones in the Upper Eocene in stratigraphical order. The Eocene-Oligocene boundary was placed in *Achomospaera alciornu* (Aal) Interval zone. In the Lower Oligocene, they distinguished *Glaphyrocysta semitecta* (Gse), *Areosphaeridium diktyoplokus* (Adi), *Reticulosphaera actinocoronata* (Rac), and *Corrudinium incompositum* (Cin) interval zones occurred in the Lower Oligocene. According to Brinkhuis and Biffi (1993), *Wetzeliella gochtii* occurred for the first time in their *Reticulosphaera actinocoronata* (Rac) Interval Zone interpreted as earliest Early Oligocene age in Italy. However, Pross (2001) suggested that the LAD of wetzelioid dinoflagellate cysts including *Wetzeliella symetrica* and *Wetzeliella gochtii* reflects strong diachronism in that younger LADs occurred in the Northwest European Tertiary Basin whereas older



TEXT-FIGURE 2  
Ebulbahar measured stratigraphic section and sample locations.

LADs occurred in the southern part of the Europe due to the seaway connection between the Tethys and Northwest European Basin. Pross (2001) indicated a 4.5 Ma of time difference for *Wetzelialla symetrica* and 3.6 Ma of time difference for *Wetzelialla gochtii* in different regions of Europe. *Wetzelialla gochtii* recorded in the “middle” part of Rupelian for the first time in this study in the Eastern Anatolia. Therefore, relatively younger FAD of *Wetzelialla gochtii* recorded in the Eastern Anatolia, in the most eastern part of the Mediterranean, than Italy (central Mediterranean) for this taxon.

Stover and Hardenbol (1994) studied the Boom Composite Section (Belgium), and documented 37 dinoflagellate and acritarch taxa. According to Stover and Hardenbol (1994), *Achillodinium biformiodes*, *Areosphaeridium pectiniforme*, *Cordosphaeridium inodes*, *Cordosphaeridium gracile*, *Cordosphaeridium minimum*, *Membranophoridium aspinatum*, *Spiniferites pseudofurcatus*, *Spiniferites ramosus*, *Systematophora placantha*, *Thalassiphora pelagica*, *Deflandrea phosphoritica* complex, *Wetzelialla symetrica* complex, *Cordosphaeridium fibrospinosum*, *Homotryblium tenuispinosum*, *Wetzelialla articulata* and *Fibrocysta axialis* have their tops in Rupelian whereas *Reticulosphaera actinocoronata* and *Wetzelialla gochtii* show their first occurrences in Rupelian. Stover and Hardenbol (1994) suggested that an acritarch called *Ascostocystis potane* is restricted to the Rupelian.

Zevenboom (1995) studied the Upper Oligocene-Lower Miocene sediments of the Lemme Section, Italy and defined the dinoflagellate biostratigraphy and paleoenvironment. The (Dbi) Interval zone of Zevenboom (1995) was defined as the interval between the FAD of *Distatodinium biffii* and the base of the youngest acme of *Deflandrea* spp., dated as Late Oligocene to latest Oligocene. The (Ebu) Interval zone of Zevenboom (1995) was defined as the interval between the base of the youngest acme of *Deflandrea* spp. and the FAD of *Membranilarnacia? picenam*, dated as latest Late Oligocene to Early Miocene in age. Zevenboom (1996) also investigated the Late Oligocene-Early Miocene dinoflagellate cysts from the Lemme-Carrosi section, northwest Italy, but unlike the previous studies he here used other microfossils as well as magnetostratigraphy and geochemistry to calibrate his dinocyst biozones.

Another study worth mentioning is that of Wilpshaar et al. (1996), who added two new Oligocene dinoflagellate cyst zones (Hpu; *Hystrichokolpoma pusillum*, and Clo; *Chiropteridium lobospinosum* interval zones) to the already established biozonations of Brinkhuis and Biffii (1993) and Brinkhuis (1994) for Rupelian (text-fig. 5). Wilpshaar et al. (1996) reported that the first occurrence of *Distatodinium biffii*, the last occurrence of *Areosphaeridium pectiniforme*, and the lowest acme of *Chiropteridium* spp. all occur at the base of the Chattian, and that the LAD of *Enneadocysta pectiniformis* is well below the FAD of *Distatodinium biffii* in the central Mediterranean. Even though the FAD of *Membranilarnacia? picana* occurs below the FAD of *Distatodinium biffii* in the North Sea, it is much higher than the FAD of *Distatodinium biffii* in the Mediterranean. They concluded that even though some correlation problems still exist because of migration effects, low resolution, and poor calibrations, some dinoflagellate cyst events such as the LADs of *Areosphaeridium dictyoplopus*, *Glaphrocysta semitecta*, *Corrudinium incompositum*, *Areosphaeridium pectiniforme*, *Distatodinium biffii*, and *Wetzelialla* spp., and the FADs of *Areoligera semicurculata*, *Wetzelialla gochtii*,

*Hystrichokolpoma pusillum*, *Chiropteridium lobospinosum*, and *Ectosphaeropsis burdigalensis* can be used for regional correlations throughout Europe.

Torricelli and Biffi (2001) studied the palynostratigraphy of the Oligocene-Lower Miocene Numidian Flysch in five different sections from the northern part of Tunisia. They reported that the dinoflagellate cyst zonation scheme proposed by Wilpshaar et al. (1996) for the central Mediterranean area can be successfully identified in their samples. We find that most of the stratigraphically important dinoflagellate events identified by Torricelli and Biffi (2001) are also recorded in the Eastern Anatolian Oligocene-Miocene sediments. For instance, both FAD and LAD of *Wetzelialla gochtii*, FAD of *Tuberculodinium vancampoe*, and LAD of *Achillodinium biformiodes*, which occur in the Rupelian in their study, are also identified in the EO1 to EO3 zones to which Rupelian age has been assigned in this study. Therefore, the age assignments suggested by Torricelli and Biffi (2001) and Sancay (2005) and Sancay et al. (2006) for the same dinoflagellate events are quite consistent. According to Torricelli and Biffi (2001), the FAD of *Tuberculodinium vancampoe* and the LAD of *Wetzelialla gochtii* can be used as confirmatory events for the detection of Rac and Clo zones (Early Oligocene) of Brinkhuis and Biffi (1993) for the southern part of the Mediterranean. They have also reported that the FAD of *Membranilarnacia? picana*, LAD of *Chiropteridium lobospinosum* and *Hystrichokolpoma pusillum* occur in the Early Miocene in their study. These events have also been seen in the Eastern Anatolia in EM2 to EM5 zones of Sancay (2005) and Sancay et al. (2006), with an Early Miocene age as reported by Torricelli and Biffi (2001) from Tunisia. The acme of *Chiropteridium lobospinosum* is also reported in the Late Oligocene both in Eastern Anatolia and in the study carried out by Torricelli and Biffi (2001).

In addition to these works in the Mediterranean region, Van Simaëys (2004) and Van Simaëys et al. (2005) have recently investigated the typical Rupelian and Chattian sediments in the North Sea region. They reported that, because of the latitudinal differences, the FAD of *Wetzelialla gochtii* and *Wetzelialla symetrica* occurred at 32.8 Ma, latest Rupelian in age and related to NP21/NP22 transition. The highest occurrences of *Achillodinium biformiodes* are identified at the base of the Chattian followed by the *Deflandrea* spp. acme. The FAD of *Membranilarnacia? picana* and *Ectosphaeropsis burdigalensis* occur at the top of the Chattian in the North Sea, earlier than the Mediterranean where the first occurrences are the Early Miocene (e.g. Brinkhuis et al. 1992; Zevenboom et al. 1994). According to Van Simaëys (2004) and Van Simaëys et al. (2004), *Distatodinium biffii* is not an exclusively Chattian species as it was reported by Wilpshaar et al. (1996) in the central Mediterranean basins because it shows its first occurrence in the upper Rupelian in the North Sea.

## BIOZONATION

### *Palynomorph zones*

Palynomorphs from the Ebulbahar and Keleresdere stratigraphic sections can be correlated with the worldwide biozonations of marine dinoflagellate cysts and acritarchs using first and last occurrences (FAD: first occurrence, LAD: last occurrence), planktonic foraminifers (Berggren et al. 1995) and calcareous nannoplankton (Martini 1971) from the same latitudes as in the samples. Two palynomorph biozones are defined





CHRONOSTRATIGRAPHY					STRATIGRAPHIC OCCURRENCES OF SELECTED TAXA		Biozonations of Dinoflagellate Cyts			
Ma (Bergreen et al. 1995) SYSTEM	SERIES		STAGES	PLANKTON ZONES (Bergreen et al. 1995)	NANNOPLANKTON ZONES (Martini 1971)		This Study	Brinkhuis et al. (1992) Brinkhuis and Biffi (1993) Zevenboom et al. (1994) Zevenboom (1995) Wilpshaar et al. (1996)		
28.50	PALEOGENE	OLIGOCENE	LOWER	Rupelian	P21	a	NP24	▼ <i>Wetzelietta gochtii</i> ▼ <i>Ascostomocystis potane</i>	EO1 of Sancay et al. (2006)	Clo
					P20		NP23	▲ <i>Distatodinium biffi</i> ▲ <i>Wetzelietta gochtii</i>	P-Rp2	
33.70	EOCENE	UPPER	Priabonian	P18			NP22	▲ <i>Ascostomocystis potane</i> and <i>Spiniferites mirabilis</i> ▲ <i>Achillodinium biformoides</i> ▲ <i>Glaphyrocysta</i> -group	P-Rp1	Hpu
							NP21			Cin
							NP19-NP20	Unsuitable Lithologies	LE1 of Sancay (2005)	Rac Adl Gsp Apt Cfu Ssp Mps

TEXT-FIGURE 5

Bio-chronostratigraphic chart and the stratigraphic occurrences of selected taxa (PF: planktonic foraminifer; BF: benthic foraminifer; NP: Calcareous Nannoplankton; D: dinoflagellate; A: Acritarch; P: pollen; ; peak occurrences).

Equivalent Planktonic Foraminiferal Zones: uppermost part of P19-P20

Equivalent Nannoplankton Zone: upper part of NP-23 and lowermost part of NP-24

Samples: 63-66 in the Ebulbahar Section and 90-92 in the Keleresdere Section.

This zone is defined by the interval between the FAD of *Wetzelietta gochtii* and the LAD of *Ascostomocystis potane* (text-fig. 5). *Distatodinium biffii* first occurs within this zone. This zone is overlain by EO3 (*Distatodinium biffii* Interval Zone) of Sancay et al. (2006) which is identified as the interval between LAD of *Ascostomocystis potane* and the LAD of *Wetzelietta gochtii*. According to Sancay et al. (2006) this zone is latest Rupelian in age and corresponding to planktonic foraminiferal zone P21a and lower to middle parts of nannofossil zone NP-24. As it has been indicated by Pross (2001), the LAD of *Wetzelietta gochtii* was diachronous (changes up to 3.6 Ma in the late Rupelian and the early Chattian) in the Northwest European localities and reflects relatively earlier LADs in the southernmost regions. This diachronic trend was explained by paleoceanographic changes between the Northwestern European Tertiary Basin and Tethys (Pross 2001). Therefore, as far as the location of the Mus Basin is considered in the most eastern Mediterranean region, younger LAD of *Wetzelietta gochtii* in the latest Rupelian might also be related to paleoceanographic changes from south to north.

### Nannofossil zones

Two major stratigraphically important nannofossil events are recorded in the studied sections. These are the FAD of *Sphenolithus distentus* and the FADs of *Helicosphaera recta* and *Sphenolithus ciperoensis*. According to Berggren et al. (1995), the former occurred between 31.5 to 33.1 Ma in nannoplankton zone NP23 of Martini (1971) whereas the latter events mark the base of nannoplankton zone NP24 of Martini (1971), at 29.9 Ma. Based on these events, the following biozones have been established in the Mus Basin sections:.

#### N-Rp1. *Sphenolithus predistentus* Interval Zone

Assigned age: early Early Oligocene (early Rupelian).

Samples: 34-55 in the Ebulbahar Section and 164-86 in the Keleresdere Section.

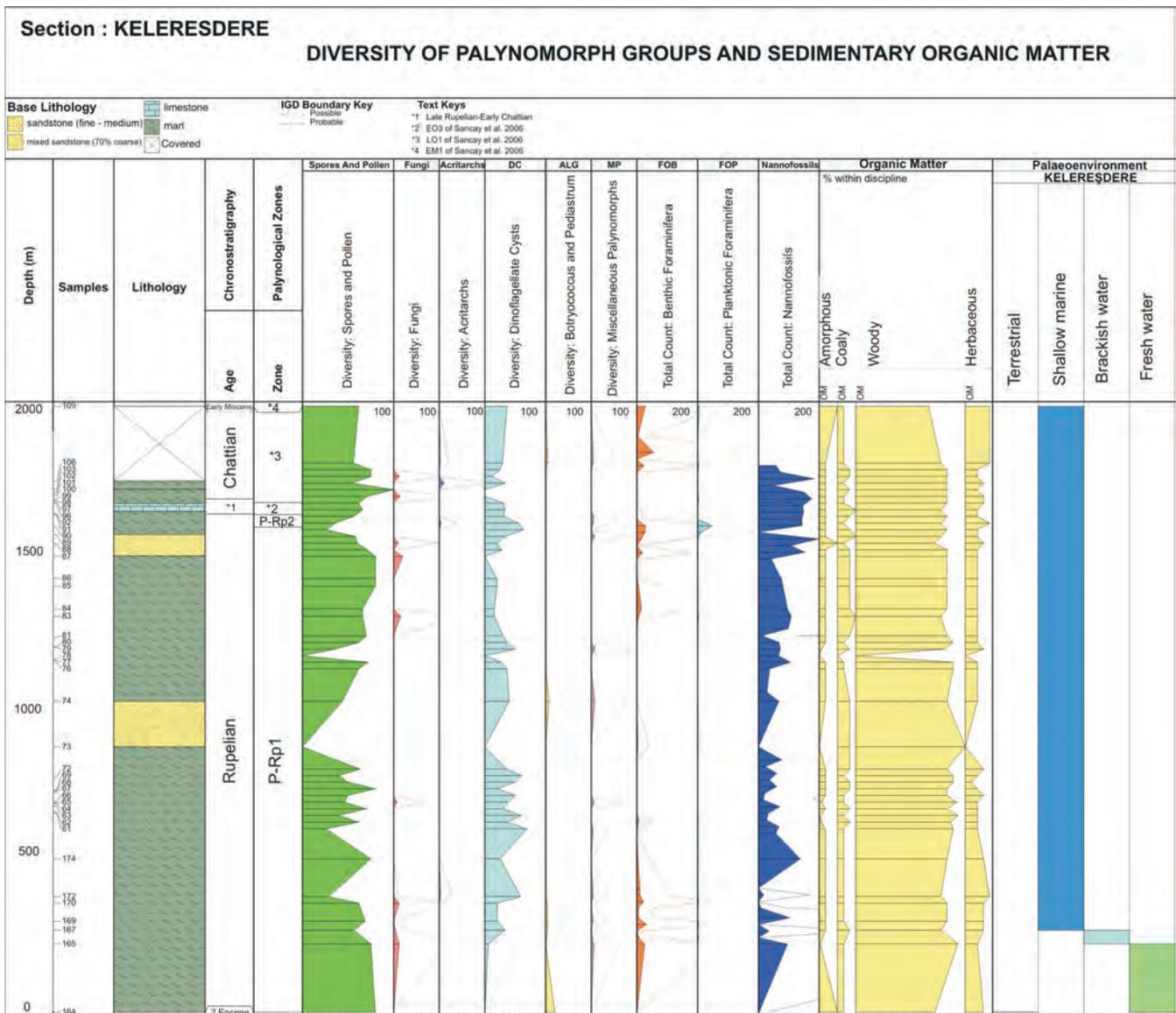
The top of the zone is defined by the FAD of *Sphenolithus distentus* but the base of the zone can not be defined properly due to the unsuitable depositional environment. This zone corresponds to planktonic foraminiferal zone P18 and the lower part of P19.

#### N-Rp2. *Sphenolithus distentus* Interval Zone

Assigned age: Early Oligocene (Rupelian).

Samples 55-63 in the Ebulbahar Section and 86-90 in the Keleresdere Section).





TEXT-FIGURE 7  
 Diversity of fossil groups sedimentary organic matter in the Keleresdere measured stratigraphic section.

Defined by the interval between the FAD of *Sphenolithus distentus* to the LAD of *Sphenolithus predistentus*. This zone corresponds to the upper part of planktonic foraminiferal zone P19.

**N-Rp-Ch1. *Helicosphaera recta* Interval Zone**

Assigned age: Early Oligocene (Rupelian) to Late Oligocene (Chattian).

Samples 63-78 in the Ebulbahar Section and 91-108 in the Keleresdere Section.

This zone is characterized by the presence of *Helicosphaera recta* and *Sphenolithus ciperoensis* and the absence of *Sphenolithus predistentus*. It corresponds to the range from upper part of P19 to P22.

**Planktonic foraminiferal zone**

**M-Rp2 *Globigerina selli* Interval Zone**

Assigned age: Early Oligocene (Rupelian)

Samples 52-66 in the Ebulbahar Section and 84-92 in the Keleresdere Section.

This zone is defined by the interval between the FAD of *Globigerina selli* and the FAD of *Globorotalia opima opima*, and correlates to planktonic foraminiferal zone P20. This zone is conformably overlain by the ELO1 zone (*Globorotalia opima opima* Range Zone) of Sancay (2005) and Sancay et al. (2006), defined by the complete range of *Globorotalia opima opima*, which is late Rupelian-early Chattian in age and corresponds to planktonic foraminiferal zone P21.

Terrestrial palynomorphs are abundant in all biozones and include Compositae (tubuliflorae type), *Cicatricosisporites* sp.,

*Periporopollenites multiporatus*, *Monoporopollenites gramineoides*, *Slowakipollenites hipophæeoides*, *Mediocolpopollis compactus*, and *Ephedripites* sp. Specimens reworked from Eocene (*Echinatisporis* sp.) and Cretaceous (*Muderongia tetracantha* and *Discorsia nanna*) have also been seen in some of the samples.

#### PALEOENVIRONMENT

As far as the depositional environment is concerned, information from palynomorphs, benthic and planktonic foraminifera, nannofossils, and sedimentary organic matter suggests that Oligocene sediments were deposited under fresh water, transitional (brackish water), and shallow marine to near shore conditions, related to fluctuation of sea level in Mus Basin (Figures 6 and 7). Relatively deep marine deposition at the beginning of the Late Eocene was replaced by shallowing-upward deposition towards the end of the Late Eocene. Rupelian deposition started under fresh water conditions and then continued in brackish water to shallow marine environments related to changes in sea level followed by shoaling-upward deposition during the Late Oligocene.

#### DISCUSSION AND CONCLUSIONS

Biostratigraphically important dinoflagellate/acritarch events calibrated by planktonic foraminifers and calcareous nannoplankton are documented for the first time in Rupelian sediments in the Mus Basin, Eastern Anatolia (see text-figs. 8 and 9 for fossil distribution and abundances). As given in detail in the section on biozonation, FADs and LADs of some selected dinoflagellates, acritarchs and pollen are important to establish a regional biostratigraphic framework. The LAD of *Ascostomocystis potane*, coincident with the FAD of *Globorotalia opima opima* in the "upper" Rupelian, FAD of *Wetzeliella gochtii* in the "middle" Rupelian, LAD of *Wetzeliella gochtii* in the "uppermost" Rupelian, and FADs of Compositae (tubuliflorae type), *Monoporopollenites gramineoides* and Umbelliferae at the base of Rupelian have particular significance for regional correlations.

Acritarchs identified as *Ascostomocystis potane* (Plate 8, Figures 1-20) have been collected for the first time in Turkey at the bottom of the Keleres Formation in the Keleresdere section. According to Stover and Hardenbol (1994), its first occurrence is near the base of the Rupelian and the last occurrence is at the top of middle Rupelian, in the calcareous nannoplankton zone NP23 of Martini (1971). This taxon shows an even higher range in Turkey, however, extending to the base of NP24 in the upper Rupelian sediments of Eastern Anatolia.

Even though most of the palynological studies (Benda 1971a, b; Benda et al. 1977; Benda et al. 1979; Akgun et al. 1986; Akgun and Akyol 1987, 1992; Ediger et al. 1990; Bati 1996) carried out in western and central part of the Turkey suggested that Compositae occurred for the first time at the beginning of the Miocene in Turkey, palynostratigraphic analysis of the Eastern Anatolia shows that Compositae (tubuliflorae type) flourished earlier in Eastern Anatolia, where Late Oligocene occurrences of Compositae pollen are noted in company reports by the senior author of this paper. Recently, Sancay et al. (2006) have reported that Compositae (tubuliflorae type) can be traced back to Chattian and even to Rupelian in Eastern Anatolia in their multidisciplinary study on the basis of world-wide defined dinoflagellate, planktonic foraminifer, and calcareous nannoplankton biozonations. This argument is also quite comparable with the results of Sirel (2003), who found that SB21-22 shal-

low benthic foraminiferal zones, Rupelian-early Chattian in age, have been identified at the same levels with the earliest Compositae (tubuliflorae type) in the Eastern Anatolia. Again, Compositae (tubuliflorae type) pollen are clearly recorded together with Rupelian dinoflagellate cysts and acritarchs in P-Rp1 and P-Rp2 biozones in this study. Therefore, it can be concluded that Compositae (tubuliflorae type) in Eastern Anatolia can be traced back to the base of Rupelian. Climate might be the main driving factor on the earlier occurrences of Compositae (tubuliflorae type) in this region. Tropical and subtropical elements such as *Tilia*, *Alnus*, *Carya* etc. are recorded fairly abundantly in Cenozoic sediments of Northwestern and Western Anatolia (Bati 1996; Akkiraz 2000) but only in very low proportions (0.5-1%) in the Oligocene sediments of Eastern Anatolia. Therefore, relatively cooler conditions, which would favor development of Compositae (tubuliflorae type), might be considered earlier in Eastern Anatolia than in Western Anatolia during the Oligocene. Moreover, supplementary results have been indicated from the paleoclimatological reconstructions by coexistence approach technique (Climsat) of the two regions. According to Akgun et al. (2004), in the Oligocene of Western Anatolia the mean annual temperatures (MAT) ranges were between 17.2 to 20.8 °C and the mean temperatures of the coldest month (CMT) were between 9.6 to 13.3 °C in Oligocene. Climstat software results of the Oligocene sediments of Eastern Anatolia suggest relatively cooler conditions, with mean annual temperatures between 15.6 to 21.3 °C and the mean temperatures of the coldest month (CMT) between 5.0 to 13.3 °C (Sancay 2005; Sancay et al. 2006).

In contrast to the earlier interpretations on the general stratigraphic settings of Eastern Anatolia, the presence of Rupelian successions may suggest that the transition between the Upper Eocene and Lower Oligocene sediments could have been conformable in some regions. Although a marine Eocene-Oligocene transition has not been observed in the studied sections, presence of transitional marine Upper Eocene and Lower Oligocene successions in the northern regions (SW of Erzurum) documented by Sancay (2005) may suggest that the boundary between the Upper Eocene and Lower Oligocene sediments was conformable in some localities of the Mus Basin.

Combined information from all three disciplines (terrestrial/marine palynomorphs, nannoplankton and foraminifers) suggests that Rupelian was a time of deposition rather than erosion, during which sedimentation started in fresh water environments and continued with shallow marine conditions in the Keleresdere section, and with shallow to deep marine environments in the Ebulbahar, varying under the influence of sea level fluctuations.

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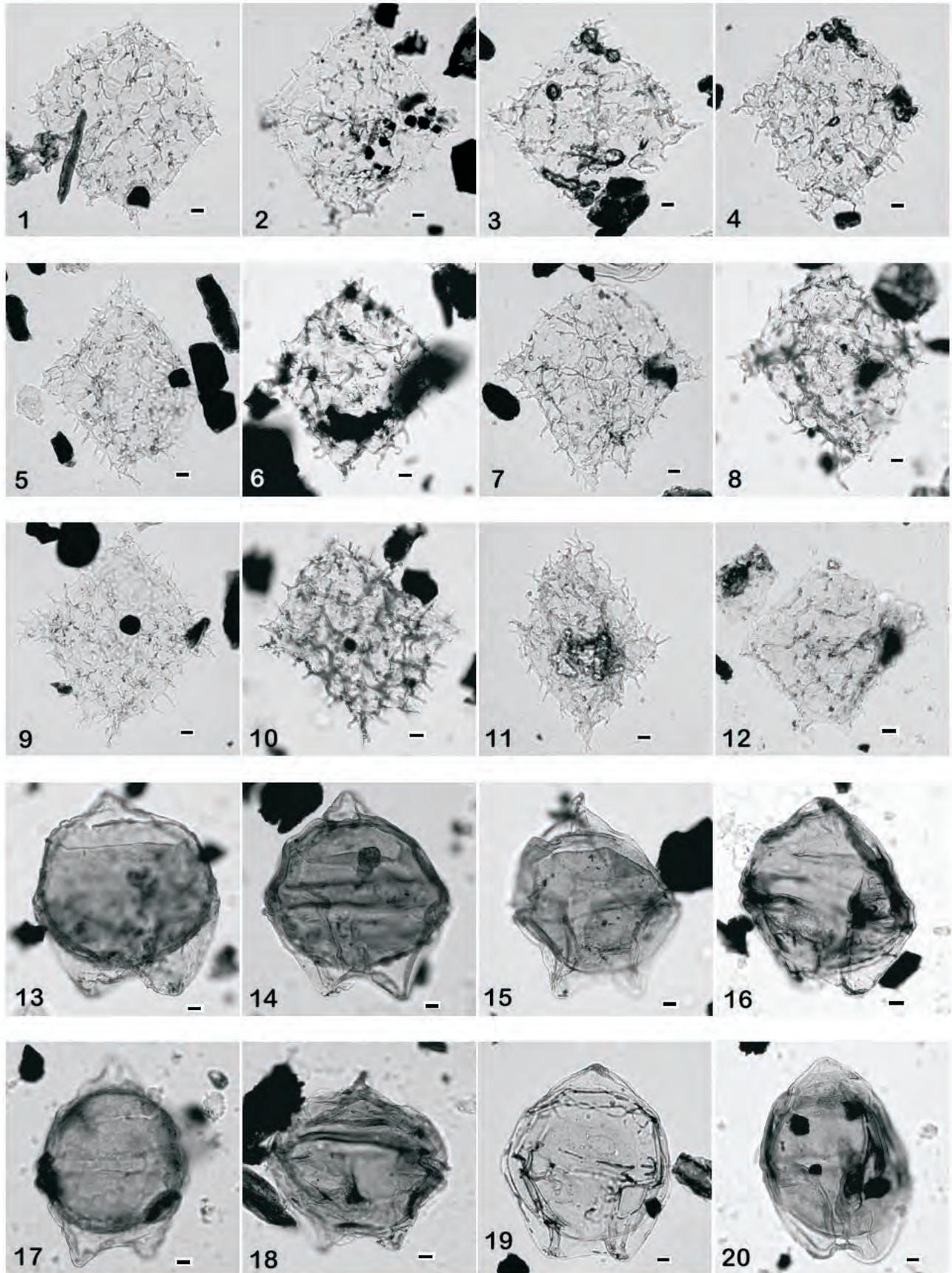
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## PLATE 1

- |         |                                       |       |   |
|---------|---------------------------------------|-------|---|
| 1, 2,7  | <i>Wetzeliella gochtii</i>            | 13    | <i>Deflandrea</i> sp.                     |
| 3,5,6,  | <i>Wetzeliella</i> sp.                | 14-18 | <i>Deflandrea phosphoritica</i>           |
| 8-10,12 |                                       | 19    | <i>Deflandrea</i> cf. <i>leptodermata</i> |
| 4       | <i>Wetzeliella</i> cf. <i>gochtii</i> | 20    | <i>Deflandrea leptodermata</i>            |
| 11      | <i>Wetzeliella</i> cf. <i>ovalis</i>  |       |   |

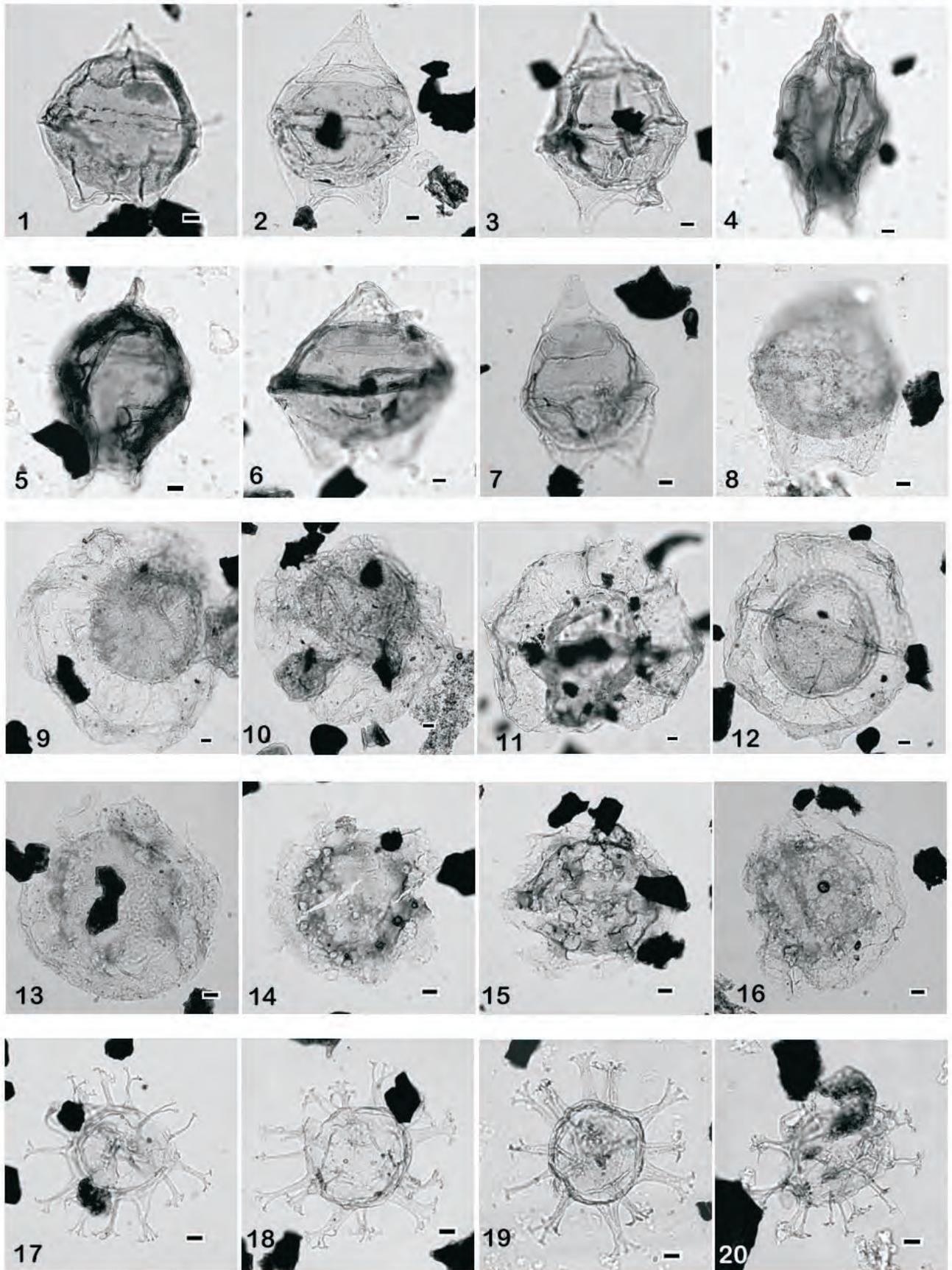


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**PLATE 2**  
(see page 267)

- |  |   |
|--|---|
| 1 <i>Deflandrea phosphoritica</i>            | 9-12 <i>Thalassiphora pelagica</i>      |
| 2-7 <i>Deflandrea</i> sp.                    | 13-16 <i>Tuberculodinium vancampoae</i> |
| 8 <i>Deflandrea</i> cf. <i>heterophlycta</i> | 17-20 <i>Homotryblum plectilum</i>      |

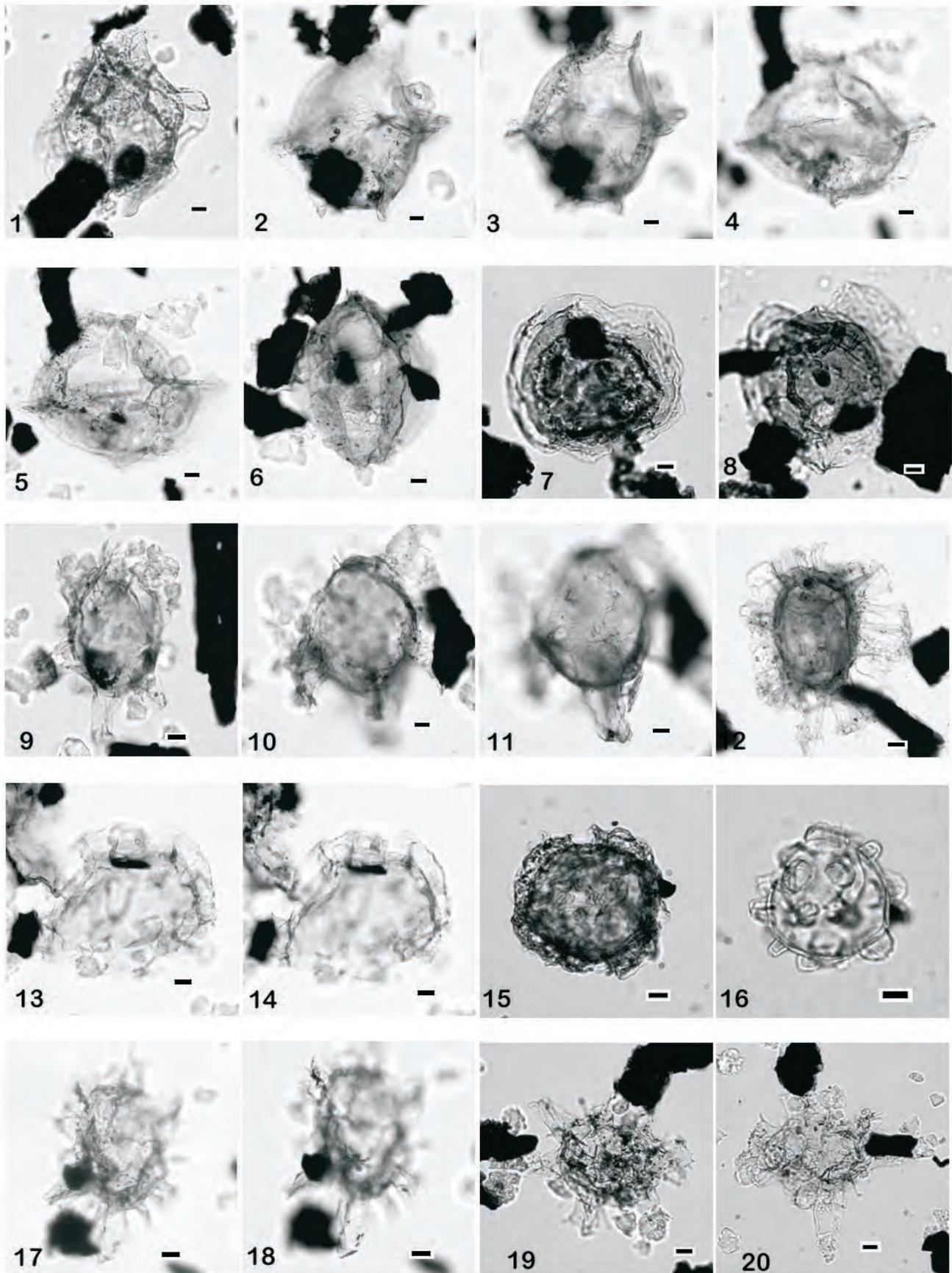


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### PLATE 3

- |  |  |
|--|--|
| 1-6 <i>Pentadinium</i> sp.               | 16 <i>Hystrichokolpoma pusillum</i>        |
| 7-8 <i>Pentadinium imaginatum</i>        | 17-18,20 <i>Hystrichokolpoma rigaudiae</i> |
| 9-12 <i>Achillodinium biformoides</i>    | 19 <i>Hystrichokolpoma</i> sp.             |
| 13-15 <i>Membranophoridium aspinatum</i> |  |

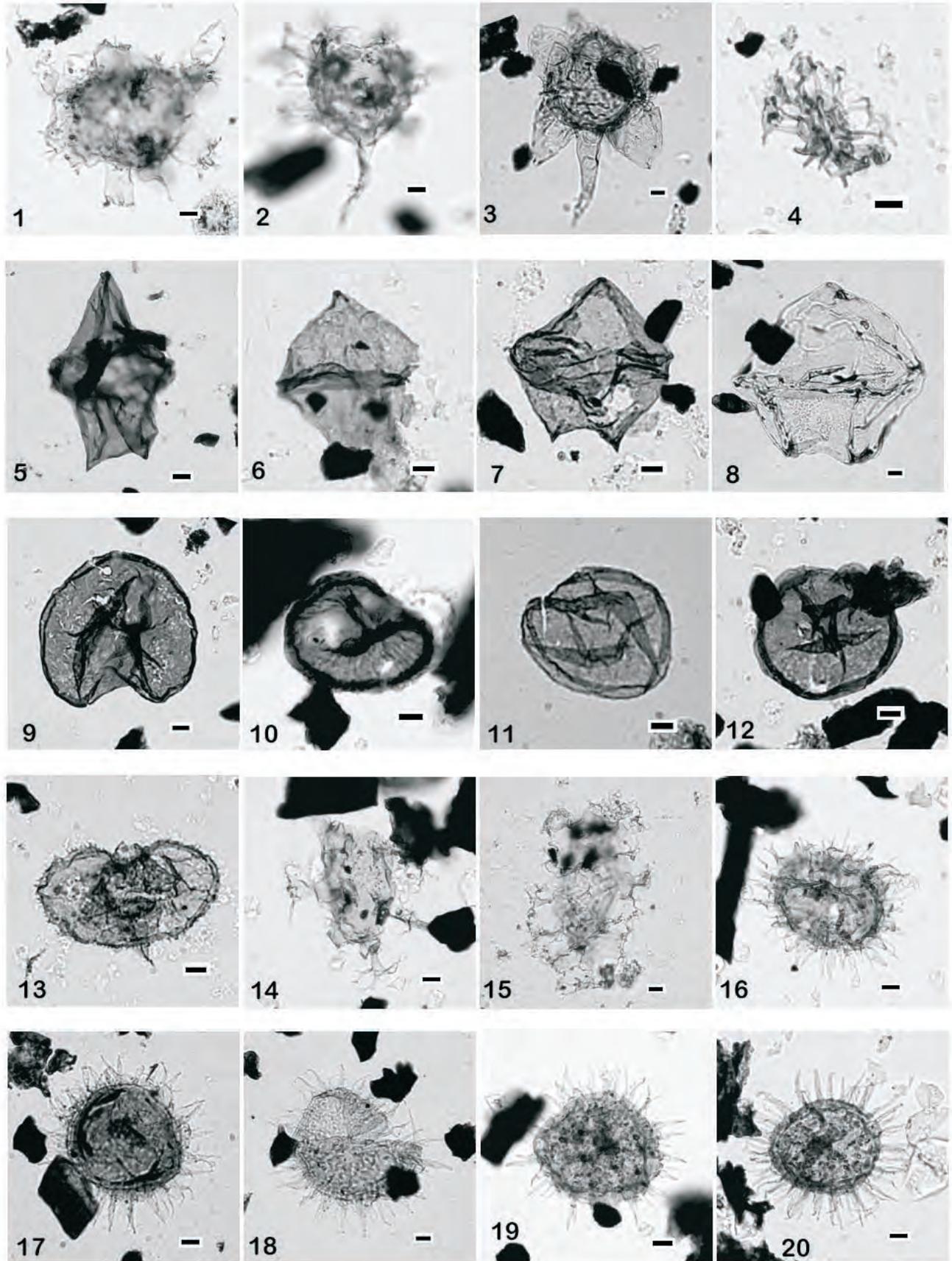


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- Manuscript received March 19, 2007  
Manuscript accepted July 15, 2007

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#### PLATE 4

- |     |   |       |                                     |
|-----|---|-------|-------------------------------------|
| 1   | <i>Hystrichokolpoma</i> sp.             | 9-12  | <i>Selenopemphix nephroides</i>     |
| 2-3 | <i>Hystrichokolpoma cinctum</i>         | 13    | <i>Selenopemphix</i> sp.            |
| 4   | <i>Reticulatosphaera actinocoronata</i> | 14    | <i>Distatodinium biffii</i>         |
| 5-7 | <i>Lejeunecysta</i> sp.                 | 15    | <i>Distatodinium ellipticum</i>     |
| 8   | cf. <i>Lejeunecysta</i> sp.             | 16-20 | <i>Lingulodinium machaerophorum</i> |



**PLATE 5**  
(see page 273)

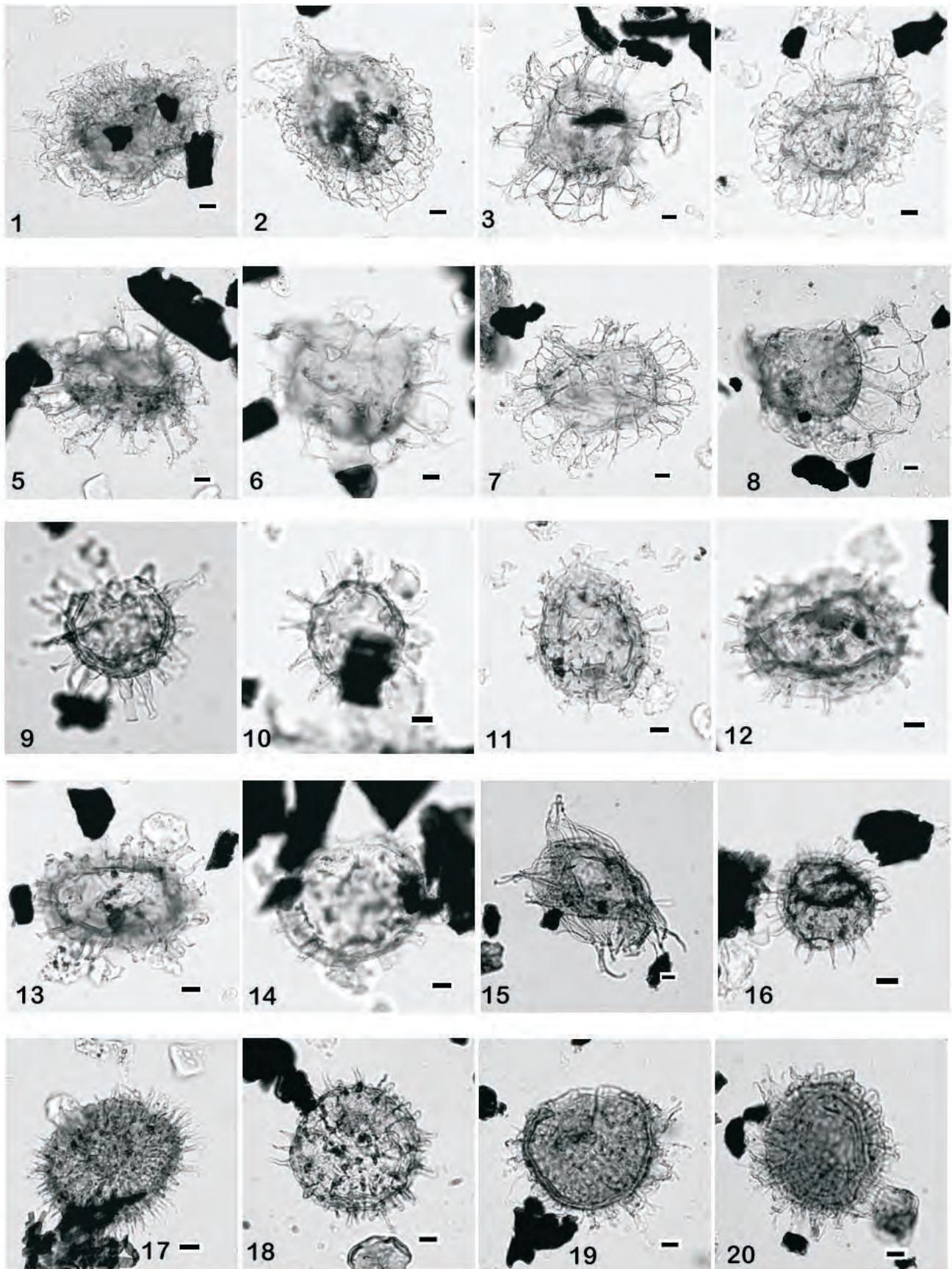
- |      |   |       |                                    |
|------|---|-------|------------------------------------|
| 1-4  | <i>Glaphyrocysta</i> group                | 11-13 | <i>Polysphaeridium zoharyi</i>     |
| 5-6  | <i>Ennaedocysta pectiniformis</i> complex | 14    | <i>Polysphaeridium</i> sp.         |
| 7    | <i>Systematophora</i> sp.                 | 15    | <i>Opeculodinium microtriainum</i> |
| 8    | Undetermined dinoflagellate               | 16-20 | <i>Opeculodinium</i> sp.           |
| 9-10 | <i>Dapsilidinium pseudocolligerum</i>     |       |                                    |
- 

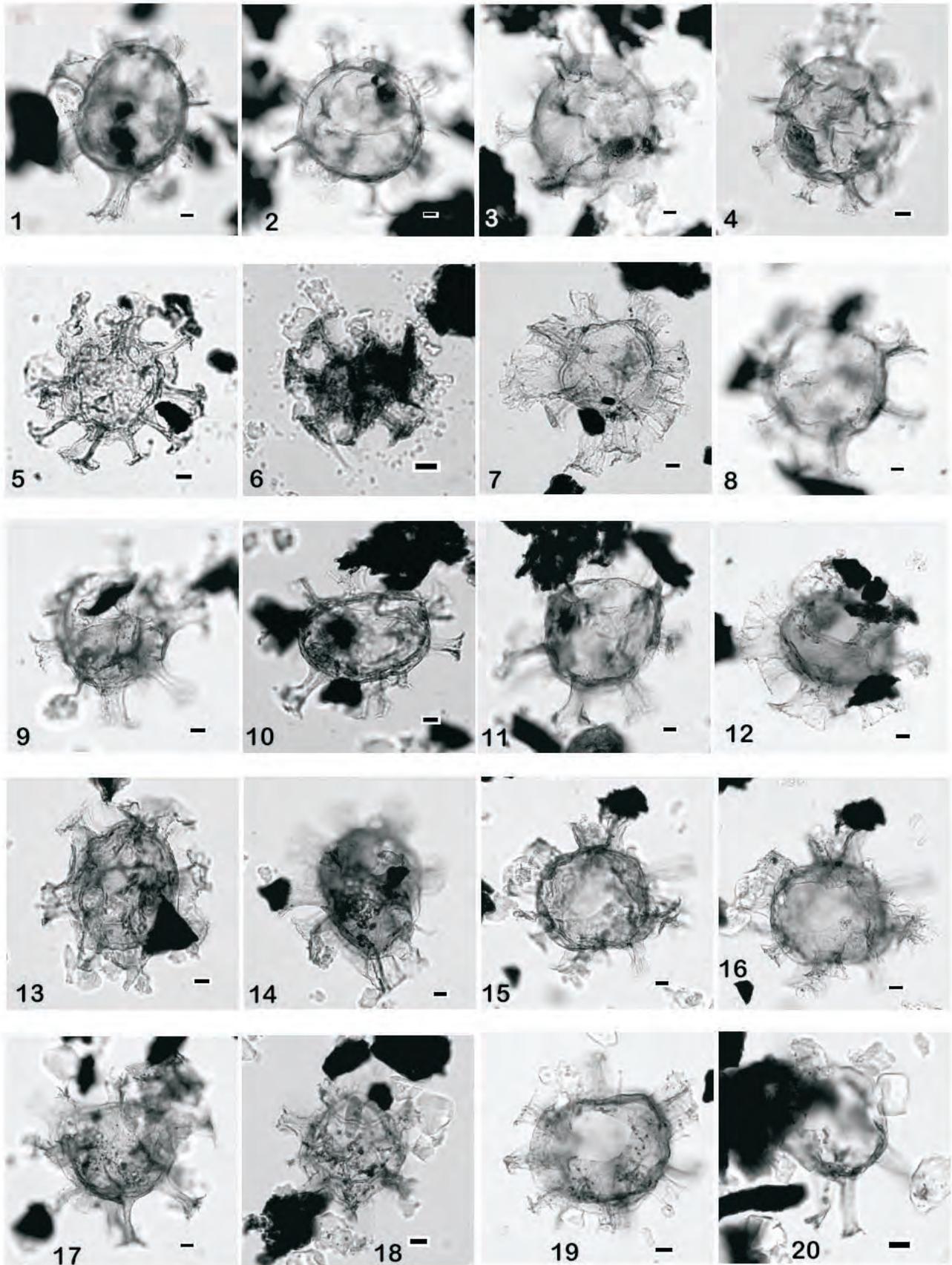
**PLATE 6**  
(see page 274)

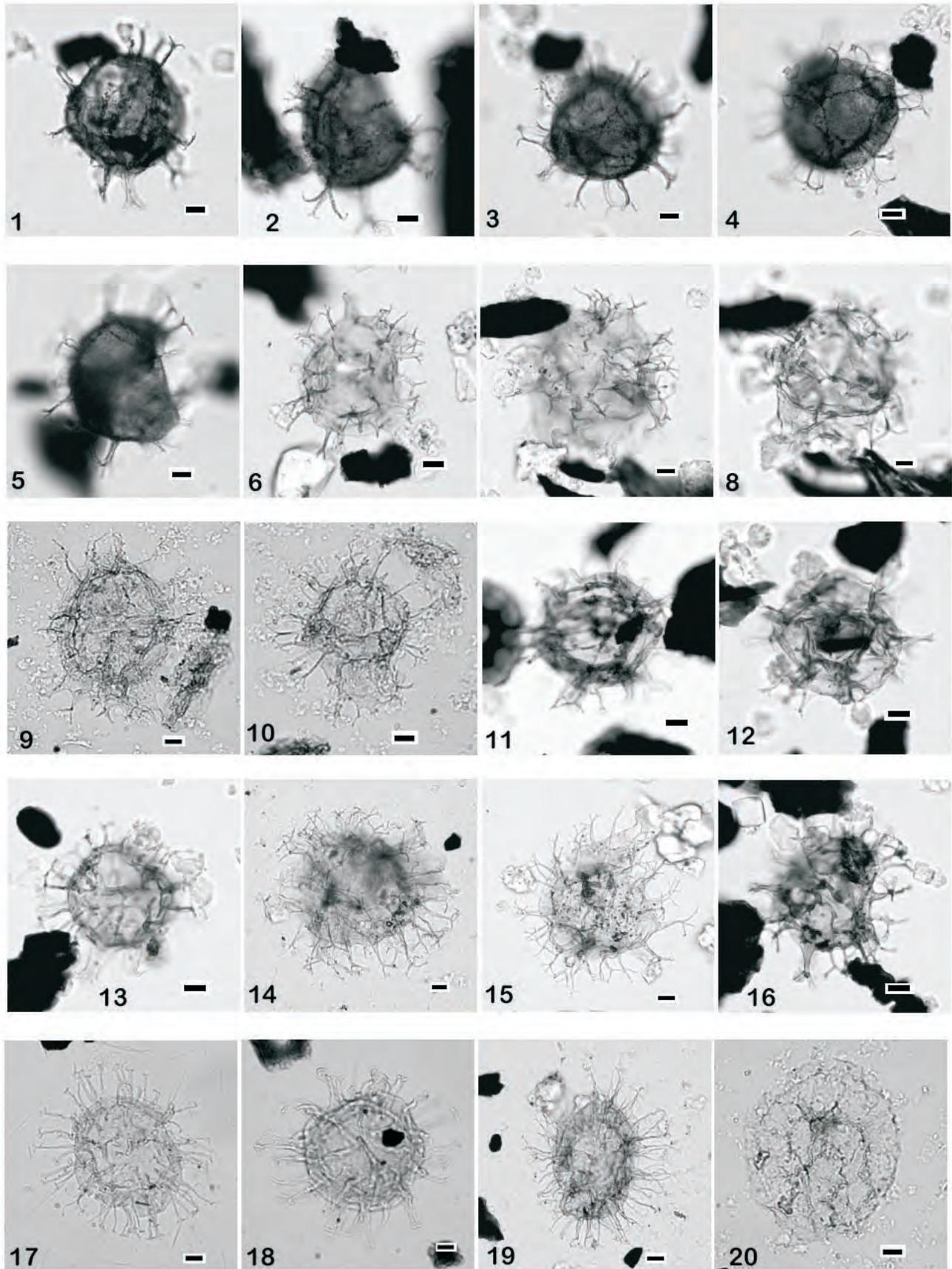
- |                       |  |    |                                  |
|-----------------------|--|----|----------------------------------|
| 1,9,11-14             | <i>Cordosphaeridium cantharellus</i>             | 7  | <i>Cordosphaeridium</i> sp.      |
| 2-5,8,10,<br>15,17,18 | <i>Cordosphaeridium fibrospinosum</i>            | 20 | cf. <i>Hystriochokolpoma</i> sp. |
| 6,16,19               | <i>Cordosphaeridium</i> cf. <i>fibrospinosum</i> |    |                                  |
- 

**PLATE 7**  
(see page 275)

- |      |                                      |       |  |
|------|--------------------------------------|-------|--|
| 1-5  | <i>Hafniasphaera</i> sp.             | 11-16 | <i>Spiniferites</i> sp.                |
| 6-8  | <i>Artemisiocysta cladodichotoma</i> | 17-19 | <i>Cleistosphaeridium placacanthum</i> |
| 9-10 | <i>Spiniferites mirabilis</i>        | 20    | <i>Heteraulacacysta</i> sp.            |







**PLATE 8**  
(see page 277)

1-19 *Ascostomocystis potane*

20 cf. *Ascostomocystis potane*

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**PLATE 9**  
(see page 278)

1 cf. *Wilsonidinium* sp.

11 unidentified chorate fragment

2,9-10 *Brigantedinium* sp.

12 *Tasmanites* sp.

3-4,8 Undetermined dinoflagellate

13-14 Chitinous foraminiferal linings

5 cf. *Sumatradinium* sp.

15-16 Scolecodont

6-7 *Invertocysta* sp.

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**PLATE 10**  
(see page 279)

1 *Pityosporites microalatus*

11-13 *Slowakipollenites hipophæoides*

2 *Pityosporites libellus*

14 *Corsinipollenites oculus noctis*

3-4 *Inaperturopollenites hiatus*

15 *Normapollis* sp.

5-7 *Ephedripites* sp.

16-17 *Medicolpopollis compactus*

8 *Dicolpopollis kalewensis*

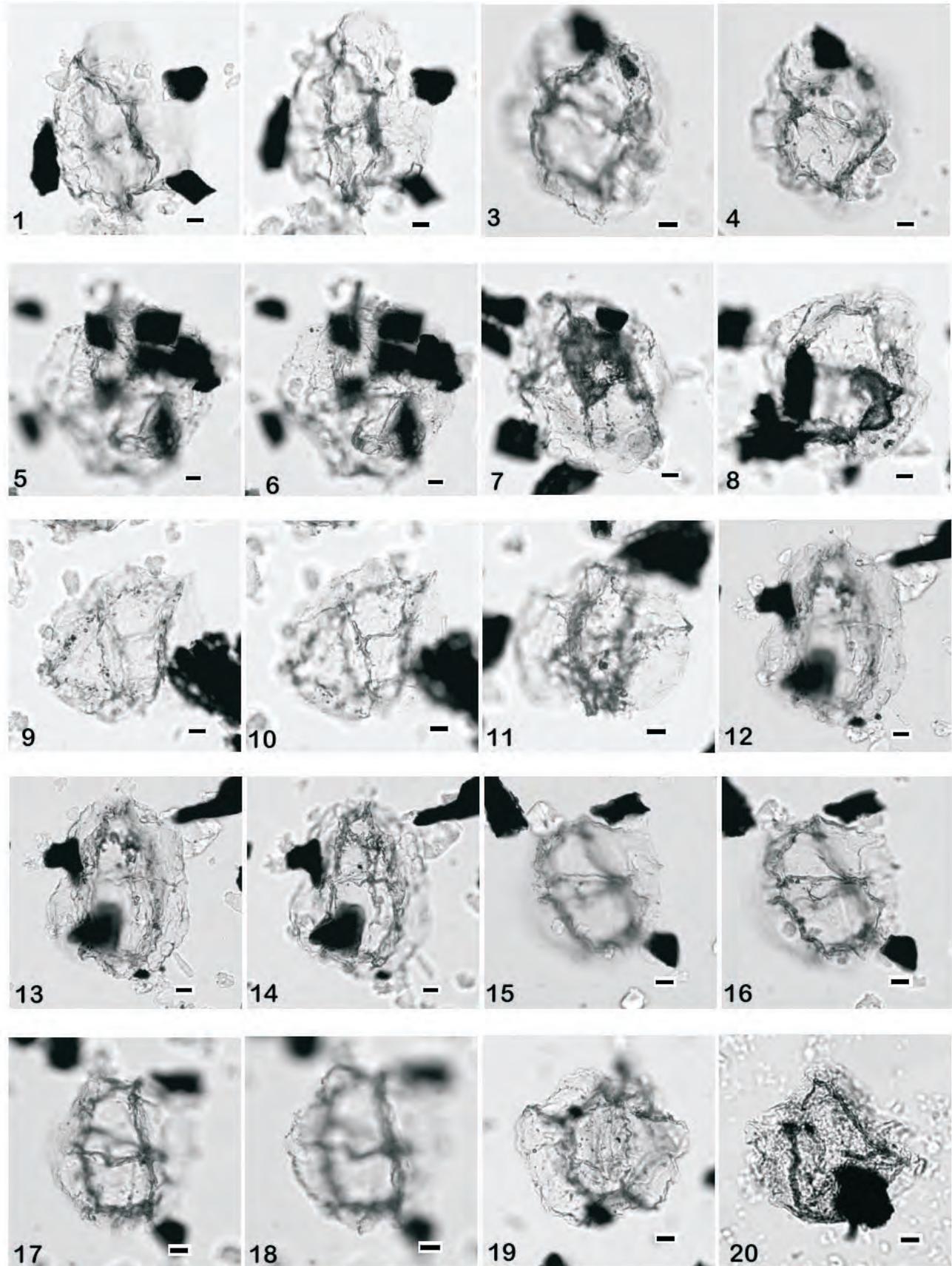
18 *Tricolporopollenites euphorii*

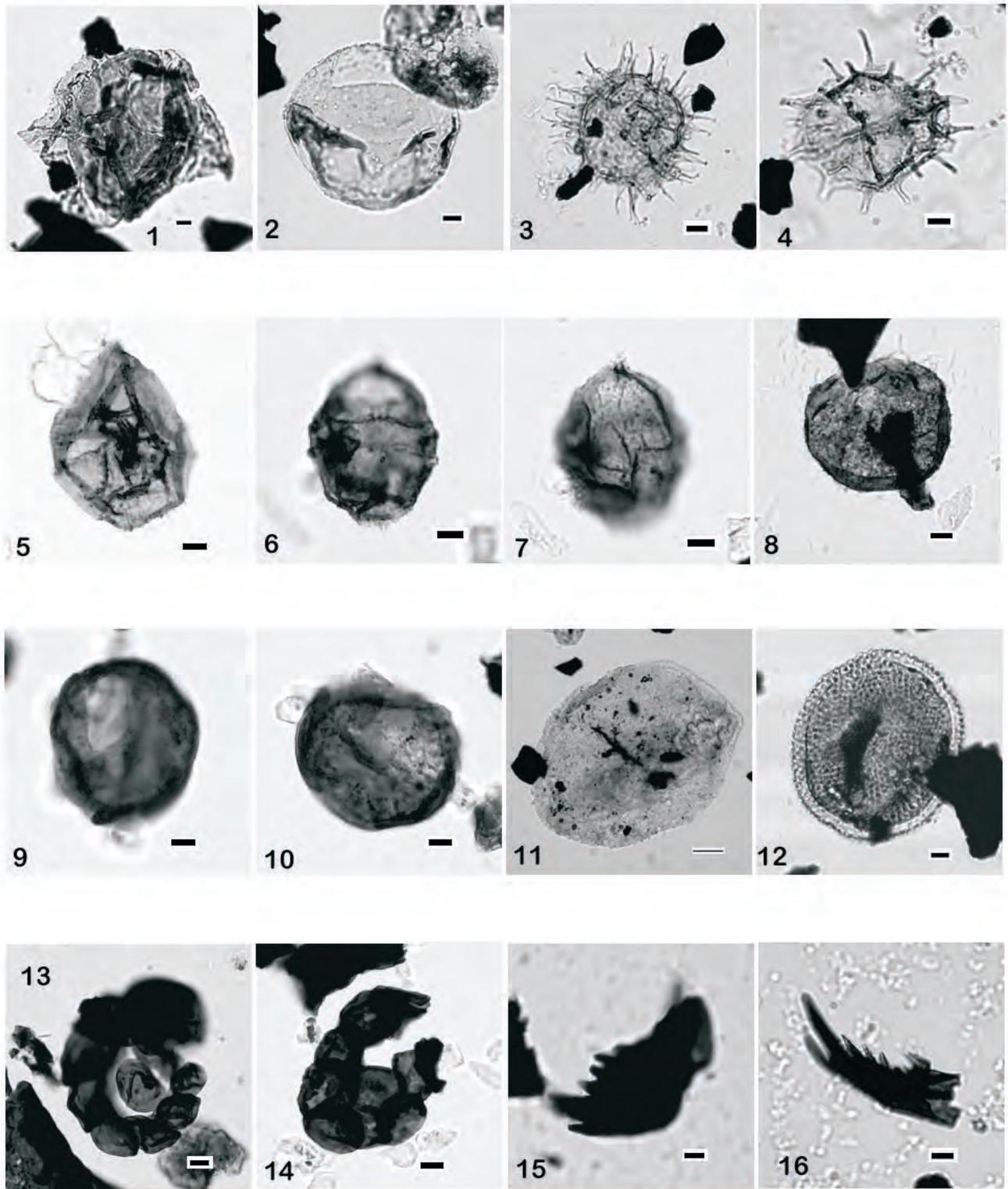
9 *Ilex* sp.

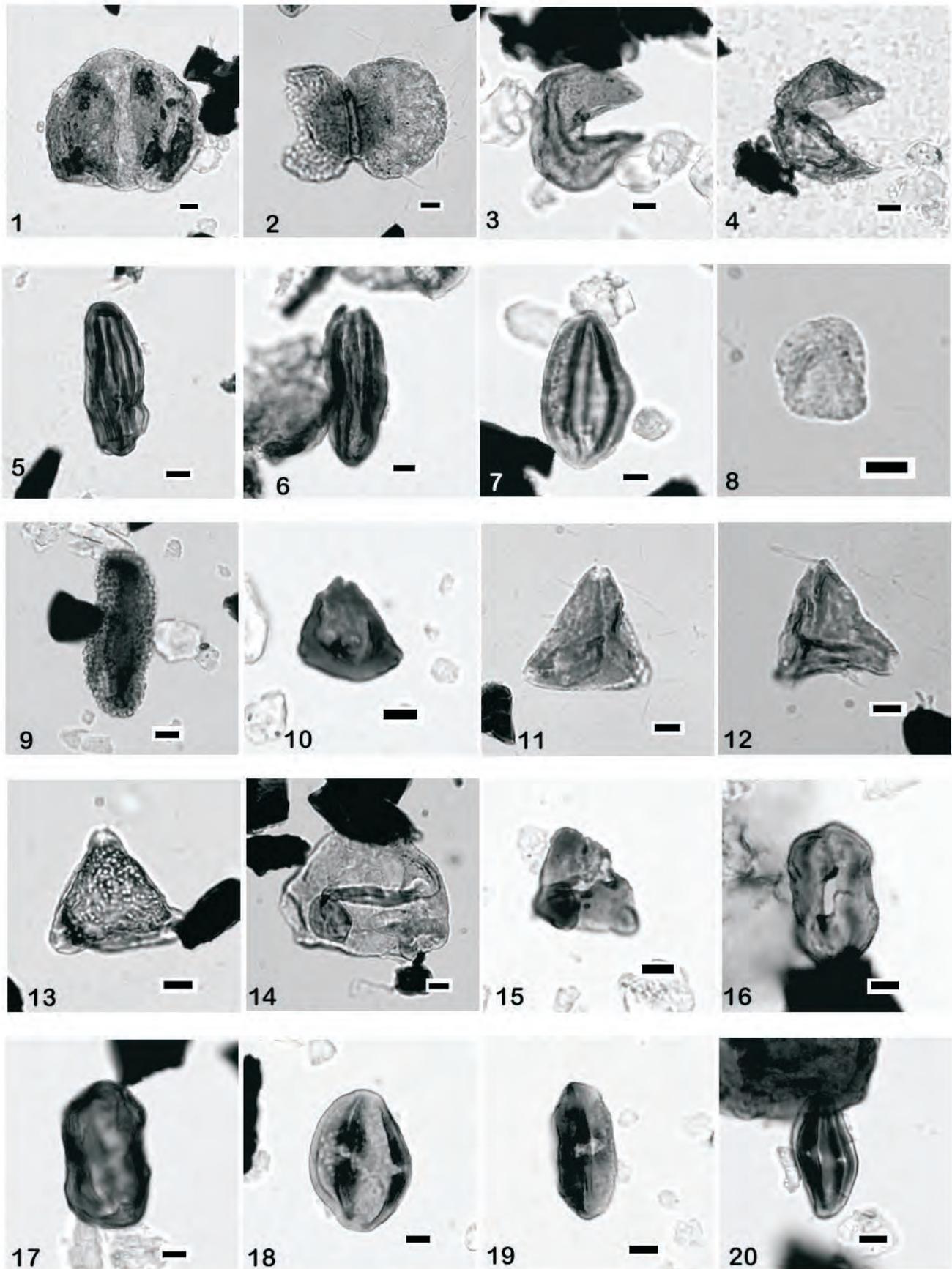
19-20 *Tricolporopollenites* sp.

10 *Triatriopollenites* cf. *excelsus*

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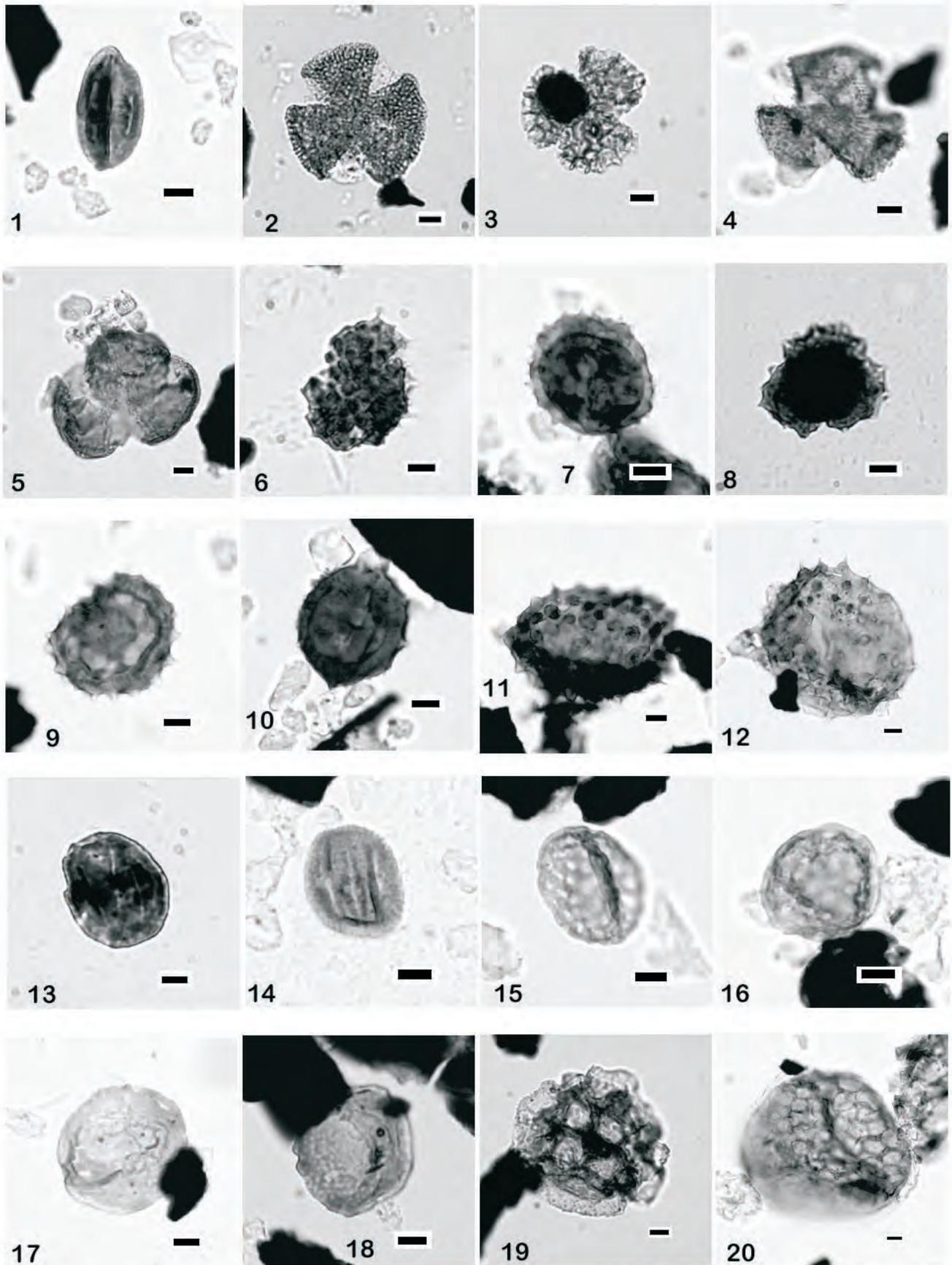
**PLATE 11**  
(see page 281)

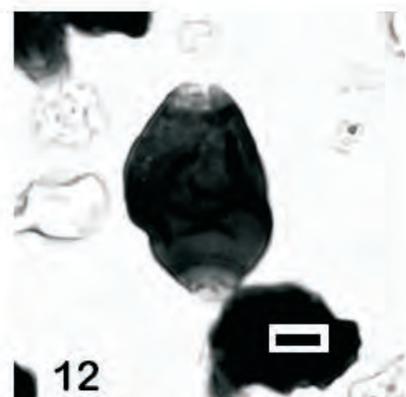
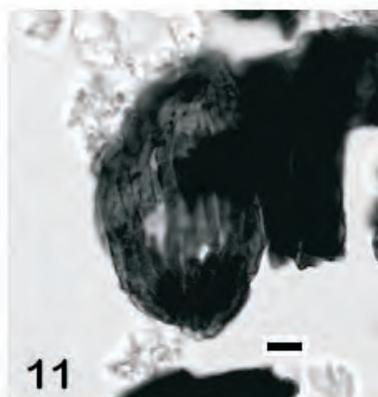
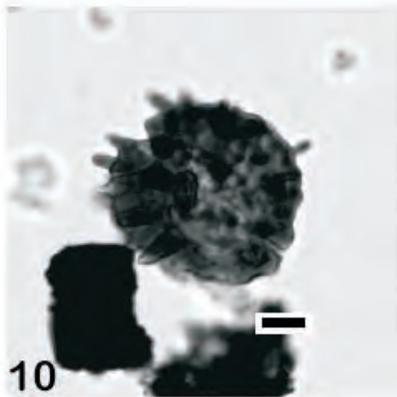
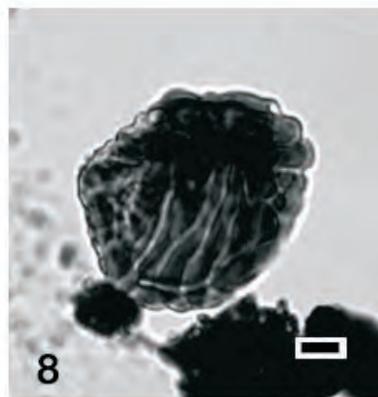
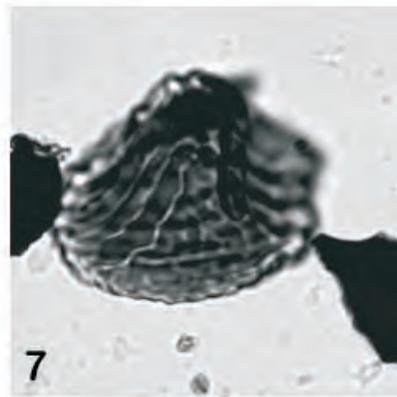
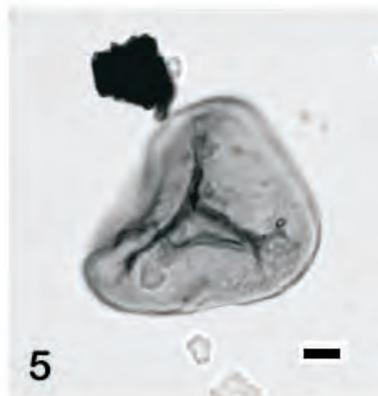
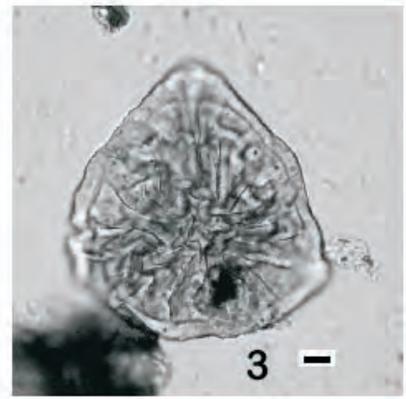
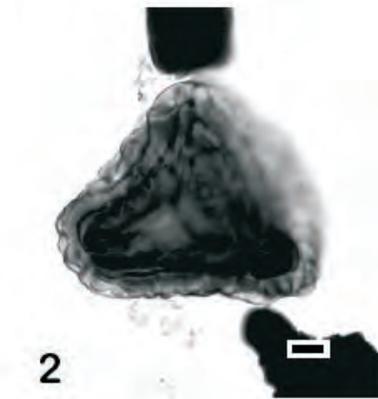
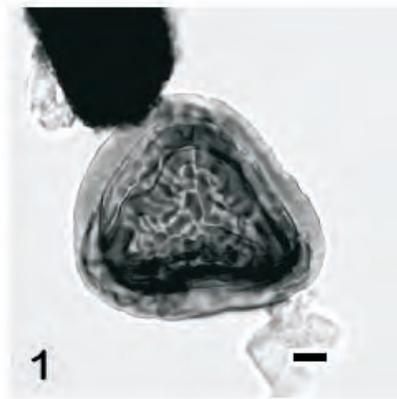
- |       |                                  |       |  |
|-------|----------------------------------|-------|--|
| 1     | <i>Tricolporopollenites</i> sp.1 | 13-14 | <i>Tetracolporopollenites</i> sp.      |
| 2     | <i>Tricolporopollenites</i> sp.2 | 15-16 | <i>Periporopollenites multiporatus</i> |
| 3     | <i>Tricolporopollenites</i> sp.3 | 17-18 | <i>Polyporopollenites undulosus</i>    |
| 4-5   | <i>Tricolporopollenites</i> sp.4 | 19    | <i>Polyadopollenites</i> sp.           |
| 6-10  | Compositae (tubuliflorae-type)   | 20    | <i>Reticulatisporites</i> sp.          |
| 11-12 | Compositae-type pollen           |       |  |

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**PLATE 12**  
(see page 282)

- |     |                                    |     |                                |
|-----|------------------------------------|-----|--------------------------------|
| 1-2 | <i>Cingulatisporites</i> sp.       | 7-9 | <i>Cicatricosisporites</i> sp. |
| 3-4 | <i>Lusatisporites perinatus</i>    | 10  | <i>Echinatisporis</i> sp.      |
| 5   | <i>Leiotriletes microadriennis</i> | 11  | <i>Appendicisporites</i> sp.   |
| 6   | <i>Saxosporis</i> sp.              | 12  | <i>Dyadosporonites</i> sp.     |





## APPENDIX 1

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

- Achillodinium bififormoides* (Eisenack 1954) emend. EATON 1976  
*Artemisiocysta cladodichotoma* BENEDEK 1972  
*Ascostomocystis potane* DRUGG and LOEBLICH JR. 1967  
*Brigantedinium* sp.  
*Cleistosphaeridium placacanthum* (Deflandre and Cookson 1955)  
 DAVEY et al. 1969. – EATON et al. 2001 includes  
*Systematophora ancyrea*  
*Cordosphaeridium cantharellus* (Brosius 1963) GOCHT 1969  
*Cordosphaeridium fibrospinum* DAVEY and WILLIAMS 1966  
*Cordosphaeridium inodes* (Klumpp 1953) EISENACK 1963;  
 emend. MORGENROTH 1968; emend. SARJEANT 1981;  
 species complex includes form transitional to *C.*  
*fibrospinum*.  
*Cordosphaeridium minimum* (Morgenroth 1966) BENEDEK 1972  
*Cyclopsiella lusatica* (Kruttsch 1970) STRAUSS and LUND 1992  
*Dapsilidinium* sp.  
*Dapsilidinium pseudocolligerum* (Stover 1977) BUJAK et al. 1980  
*Deflandrea leptodermata* COOKSON and EISENACK 1965  
*Deflandrea heterophlycta* COOKSON and EISENACK 1955  
*Deflandrea phosphoritica* EISENACK 1938  
*Deflandrea* sp.  
*Deflandrea spinulosa* COOKSON and EISENACK 1965  
*Distatodinium biffii* BRINKHUIS et al. 1992  
*Distatodinium ellipticum* COOKSON 1965 EATON, 1976  
*Enneadocysta pectiniformis* complex (Gerlach 1961) emend.  
 STOVER and WILLIAMS 1995 (probably includes *E.*  
*arcuatum* and *E. multicornutum*)  
 Glaphyrocysta group  
*Hafniasphaera* sp.  
*Heteraulacacysta* sp.  
*Homotryblium plectilum* DRUGG and LOEBLICH JR. 1967  
*Homotryblium tenuispinosum* DAWAY and WILLIAMS 1966  
*Hystrichokolpoma cinctum* KLUMPP 1953  
*Hystrichokolpoma* spp.  
*Hystrichokolpoma pusillum* BIFFI and MANUM 1988  
*Hystrichokolpoma rigaudiae* DEFLANDRE and COOKSON  
 1955  
*Hystrichokolpoma* sp.  
*Invertocysta* sp.  
*Lejeunecysta* sp.  
*Lingulodinium machaerophorum* (Deflandre and Cookson 1955)  
 WALL 1967  
*Membranophoridium aspinatum* GERLACH 1961  
*Opeculodinium microtriainum* (Klumpp 1953) ISLAM 1983  
*Opeculodinium* spp.  
*Pentadinium imaginatum* (Benedek 1972) STOVER and  
 HARDENBOL 1994  
*Pentadinium laticinctum* GERLACH 1961 subsp. *laticinctum*  
*Pentadinium* sp.  
*Polysphaeridium* sp.  
*Polysphaeridium zoharyi* (Rossignol 1962) BUJAK et al. 1980  
*Reticulatosphaera actinocoronata* (Benedek 1972) emend.  
 BUJAK and MATSUOKA 1986  
*Riculacysta perforata* STOVER 1977  
*Selenopemphix nephroides* BENEDEK 1972  
*Selenopemphix* sp.  
*Spiniferites mirabilis* (Rossignol 1964) Sarjeant 1970  
*Spiniferites pseudofurcatus* (Klump 1953) SARJEANT 1970  
*Spiniferites* sp.  
*Sumatradinium* sp.  
*Systematophora* sp.  
*Thalassiphora pelagica* (Eisenack 1954) EISENACK and  
 GOCHT 1960; emend. BENEDEK and GOCHT 1981  
*Tuberculodinium vancampoeae* (Rossignol 1962) WALL 1967  
*Wetzeliella gochtii* COSTA and DOWNIE 1976  
*Wetzeliella* cf. *ovalis* EISENACK 1954  
*Wetzeliella symmetrica* WEILER 1956  
*Wilsonidinium* sp.  
 undetermined dinoflagellate  
 miscellaneous unidentified chorate fragments

