

Oligocene vegetation and climate characteristics in north-west Turkey: data from the south-western part of the Thrace Basin

Funda AKGÜN^{1*}, Mehmet Serkan AKKİRAZ², Səriye Duygu ÜÇBAŞ², Mustafa BOZCU³,
Sevinç KAPAN YEŞİLYURT³, Ayşe BOZCU³

¹Geological Engineering Department, Dokuz Eylül University, Buca, İzmir, Turkey

²Geological Engineering Department, Dumlupınar University, Kütahya, Turkey

³Geological Engineering Department, Çanakkale Onsekiz Mart University, Çanakkale, Turkey

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Abstract: In this paper we present the first palynomorph and mollusc assemblages from the sediments in three different sections. From east to west, these are the Şevketiye (northern Biga Peninsula), the Tayfur (Gelibolu Peninsula) and the Kuzu harbour (Gökçeada) (parts of the Danişmen Formation) sections in the south and south-western side of the Thrace Basin (north-west Turkey), with the aim of obtaining information about the composition and structure of vegetation and climate during the Oligocene. The stratigraphic interval extends from late Rupelian to Chattian. The Danişmen Formation in the Şevketiye section yielded a palynomorph association with abundant coastal palms (Arecaceae; Lepidocaryoidae), and mangrove pollen (*Pelliciera*). A similar assemblage from the Kuzu harbour section was also obtained, with minor contributions of mangrove elements *Nypa* and *Acrostichum aureum*, Arecaceae type palm, undifferentiated dinoflagellate cysts and microforaminiferal linings. These palynomorph assemblages, combined with the mollusc data, indicate that low-lying coastal environments prevailed. In contrast, the palynomorphs from the Tayfur section represent a non-marine environment lacking mangrove elements, palm trees, dinoflagellate cysts and microforaminiferal linings. The diversity of angiosperm taxa in the Tayfur palynoflora, which form the bulk of the assemblage, indicates terrestrial vegetation. Quantitative palaeoclimate analyses are based on the Coexistence Approach method, and yield over 22 °C at the coast as indicated by mangrove elements and palms in the Şevketiye and Kuzu harbour palynofloras. For the Tayfur palynoflora, mean annual temperature ranged between 16.5 and 21.3 °C. This indicates a climate cooling, corresponding to the transition from Rupelian to Chattian, and resulted in the pollen changes from mangrove bearing coastal deposits to more inland vegetation.

Key Words: Oligocene, mangrove, palaeoecology, Thrace basin, north-west Turkey

1. Introduction

In Turkey, the Eocene vegetation is mainly represented by mangrove-forming plants such as *Nypa*, *Pelliciera* and *Avicennia*, and the presence of some biostratigraphic marker species, such as *Triatriopollenites excelsus*, *Plicatopollis lunatus*, *P. hungaricus*, *Milfordia hungaricus*, *Kopekipollenites transdanubicus*, *Subtriporopollenites anulatus* and *Striasyncolpites zwocardi* (Akgün 2002; Akgün *et al.* 2002; Akkiraz *et al.* 2006, 2008). During the Oligocene, in addition to mangrove pollen, new pollen types such as *Alnus* (morpho-species *Polyvestibulopollenites verus*), *Carya* (morpho-species *Subtriporopollenites simplex*), *Calamus* (morpho-species *Dicolpopollis kockelii*), Elaeagnaceae (morpho-species *Boehlensipollis hohli*) and Hipophae (morpho-species *Slowakipollis hippophaeoides*) appeared (Akkiraz & Akgün 2005; İslamoğlu *et al.* 2010; Kayseri 2009; Akkiraz *et al.* 2011). In contrast most Eocene species disappeared in the Oligocene.

* Correspondence: funda.akgun@deu.edu.tr

This study is focused on the Oligocene Thrace Basin, situated between the Tethyan and Paratethyan realms (Rögl 1998; İslamoğlu *et al.* 2010). From Palaeocene to Middle Eocene times, much of the marine Thrace Basin was filled with thick olistostrome complexes (Özcan *et al.* 2010). According to Görür and Okay (1996), the Thrace Basin developed as a fore-arc basin during the Middle Eocene and Oligocene. During the Early Oligocene the closure of seaways between the Eastern Paratethys and Mediterranean is marked in Thrace by the deposition of dark shales with fish remains (Rögl 1998) (Figure 1). During the middle Oligocene the Paratethys returned to open marine conditions (Rögl 1999) (Figure 1). Up to the end of Rupelian the Thrace Basin was still part of the Tethys Sea. The regression started during the late Oligocene (mammal zone MP 26) (Bozukov *et al.* 2009; İslamoğlu *et al.* 2010). With regression, marine coastal swamps should



Figure 1. Palaeogeographic scheme of the Tethys and Paratethys area in the Early Oligocene with ocean and land distribution and seaways (from Rögl 1999). The location of the studied area is marked by a rectangle.

be succeeded by freshwater swamp, as recorded by Bozukov *et al.* (2009) from south-western Bulgaria.

Also, numerous palaeontological studies have been carried out on the Cenozoic units of the Thrace Basin (e.g., Nakoman 1968; Akyol 1971; Ediger *et al.* 1990; Elsik *et al.* 1990; Batı 1996; Sakınç *et al.* 1999; İslamoğlu *et al.* 2010; Özcan *et al.* 2010; Less *et al.* 2011). Previous records indicated that the lignite-bearing deposits in the Thrace Basin are of Late Oligocene age, based on palynomorphs (Ediger *et al.* 1990; Elsik *et al.* 1990; Batı 1996) whereas a recent study has suggested that these lignite-bearing units were deposited between the late Rupelian and Chattian, based on mollusc fauna and palynomorphs (İslamoğlu *et al.* 2010). The occurrences of some of the taxa recovered here are helpful in determining the age of these lignite-bearing sediments. In this study, palynological markers such as *Tilioidae*, *Carya*, *Calamus*, *Platycarya*, *Alnus* and *Aglaoreidia*, combined with bivalves such *Polymesoda convexa* (Brongniart), *Cardium* sp., *Pitar* (*Paradione*) *undata* (Basterot) and *Angulus* (*Peronidia*) *nysti* (Deshayes), and gastropods such as *Pirenella plicata* (Bruguiere), *Tympanotonus margaritaceus* (Brocchi), *Natica millepunctata tigrina* (Defrance), *Ampullina crassatina* (Lamarck), *Ampullina* sp., and *Bullia* sp. indicate a late Rupelian–Chattian age. Although the presence of lignite units from the south-western side of the Thrace Basin has also been known for many years, the characteristics of the palynofloras are still unknown (Kesgin & Varol 2003). Besides, existing studies emphasising the palaeontology of the Oligocene lignite units from the northern side of the Biga Peninsula are still lacking. The current study presents the first palaeontological analysis for the Oligocene in the south-western side of the Thrace Basin and the northern side of the Biga Peninsula, using palynomorph and mollusc data from three different outcrop sections. From east to

west, these are the Şevketiye (northern Biga Peninsula), the Tayfur (Gelibolu Peninsula) and the Kuzu harbour (Gökçeada) sections (Figure 2). Palaeoenvironment and climate changes of the Oligocene sequences have been reconstructed using the palaeontological data.

1.1. Geology

The Thrace Basin is in the south-eastern part of the Balkan Peninsula and borders the Rhodope–Strandja Massif (north and west) and the Biga Peninsula to the south (Figure 2). It has been explored for many years due to its lignite-bearing sequences and potential gas occurrences. The Cenozoic sedimentary fill in the Thrace Basin is up to 9000 m thick (e.g., Kopp *et al.* 1969; Turgut *et al.* 1991; Görür & Okay 1996; Siyako & Huvaz 2007; Okay *et al.* 2010). The Oligocene and Miocene units in the south and south-western part of the Thrace Basin consist of deposits indicating shallow marine, lagoonal swamp and continental environments. However, vertical and lateral facies changes render sediment correlation difficult.

In this area, the pre-Oligocene basement consists of Palaeozoic and Mesozoic metamorphic rocks, ophiolites, igneous rocks and Eocene units consisting of conglomerates, sandstones, claystones, tuffites and reef limestones deposited in various environments, turbiditic, tidal, shallow and deep marine (e.g., Coşkun 2000; Turgut & Eseller 2000; Siyako 2003; Hoşgörmez *et al.* 2005; Okay *et al.* 2010; Less *et al.* 2011; Özcan *et al.* 2010) (Figure 3). The Middle Eocene to Early Oligocene Ceylan Formation consists of marls and claystones (Özcan *et al.* 2010; Less *et al.* 2011) (Figure 3). The Oligocene units consist of three major formations: from bottom to top these are the Mezardere, Osmançık and Danişmen Formations. The Mezardere Formation conformably overlies the Ceylan Formation, and consists of shale, tuffites and sandstones deposited in a delta front (Kesgin & Varol 2003; Gürgey *et*

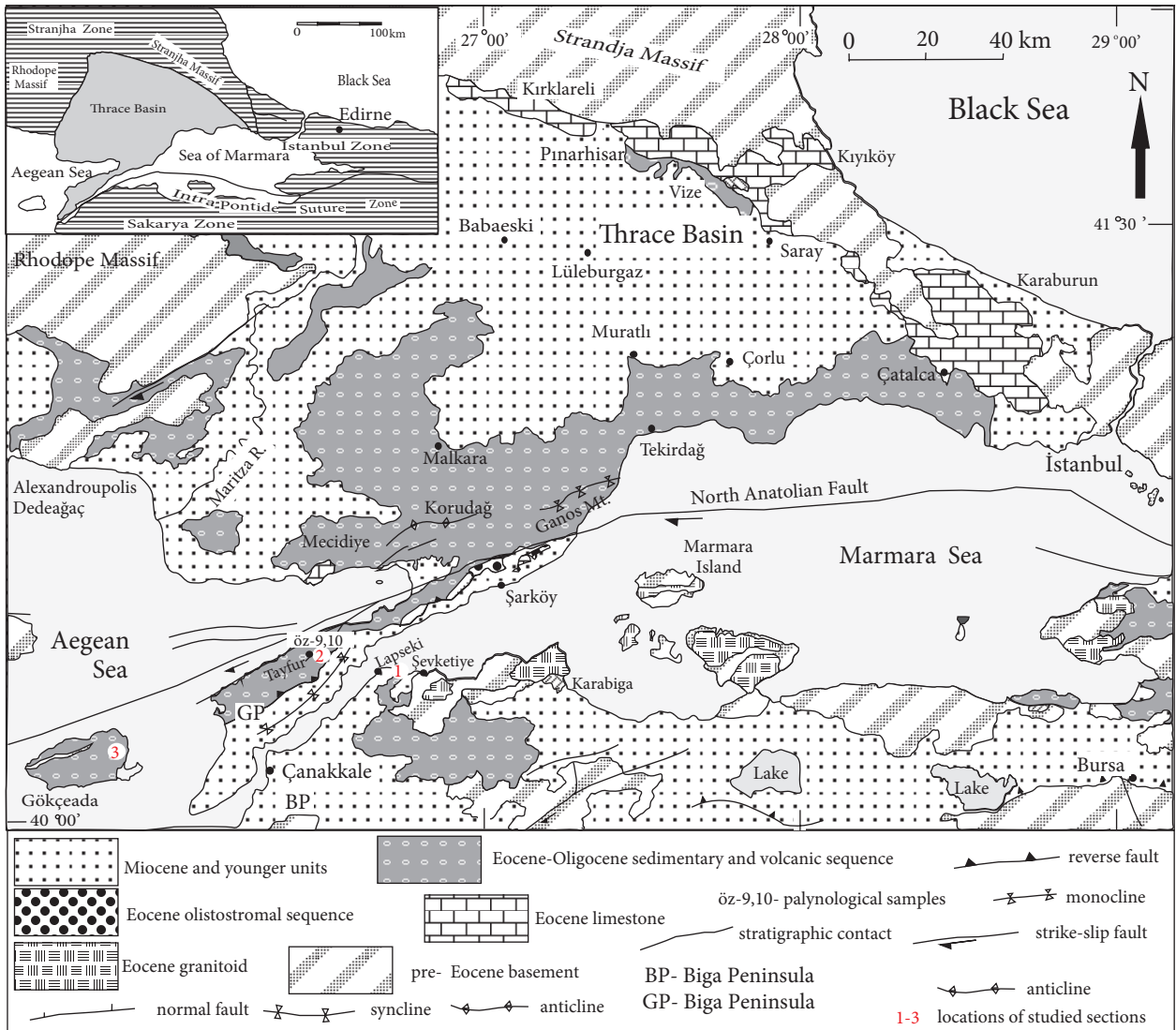


Figure 2. Simplified geological map of the Marmara and Thrace region (modified from Okay *et al.* 2010).

al. 2005). The Osmancık Formation accumulated in a delta front and rests conformably on the Mezardere Formation. The Danişmen Formation, consisting of a delta complex, lagoonal and/or lacustrine environments, conformably overlies the Osmancık Formation. Miocene–Pliocene fluvial, lacustrine and volcanic units rest unconformably on pre-Oligocene units (Figure 3). In this study palynomorph assemblages were obtained from samples taken from lignites and fine-grained sediments of the Danişmen Formation.

On the northern side of the Biga Peninsula (here called the Şevketiye section), coastal deposits of the Danişmen Formation are only exposed in a road cut between eastern Lapseki and Şevketiye (Coordinates: 40°23'46"N, 26°50'31"E and 65 m a.s.l.) (Figure 2). The strata show a transgressive succession, and consist mainly of clastic

deposits, starting with nodular conglomerates at the base and continuing upward into fine-grained deposits including lignites and volcanoclastic sediments with high sulphur content, indicating a highly acidic environment. The commonest components of the conglomerates consist mainly of volcanic lapilli. At this locality, there is also a syn-sedimentary fault (Figure 4). A claystone–siltstone alternation with a rich gastropod and bivalve fauna occurs in the hanging wall as well (Figure 4).

On the Gelibolu Peninsula (in the Tayfur section), the lignite-bearing Danişmen Formation crops out on the south-eastern side of the village of Tayfur, north-west of Cumali village (Coordinates: 40°21'10"N, 26°30'53"E and 72 m a.s.l.) (Figure 2). The deposits exposed generally consist of well-bedded and fine-grained clastics such as sandstone, claystone and siltstone alternations containing

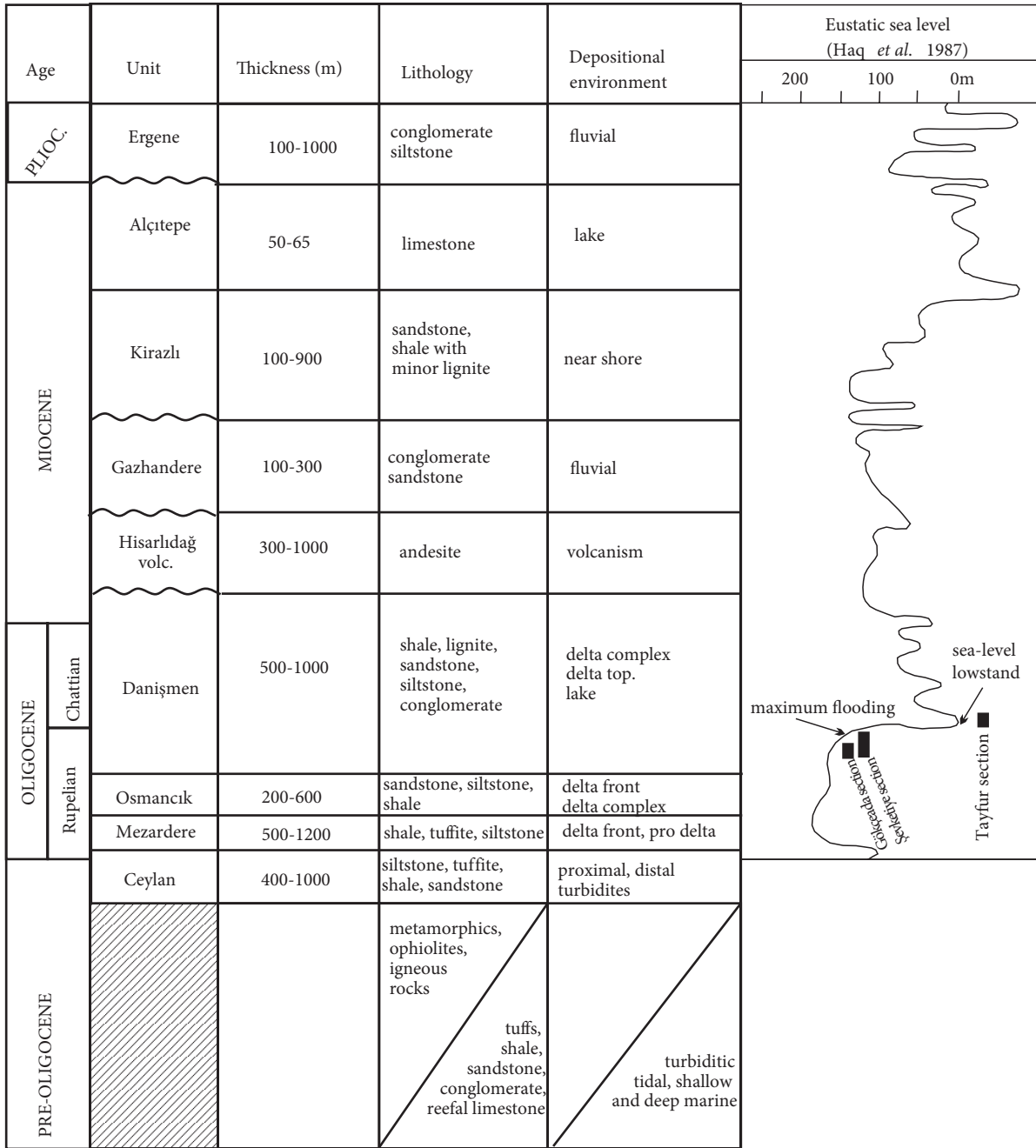


Figure 3. Generalised stratigraphic column of the Thrace Basin (modified from Kesgin & Varol 2003; Hoşgörmez & Yalçın 2005; Kürgey et al. 2005; Huvaz et al. 2007).

thin lignite beds, deposited in a continental environment (Figure 5).

At Gökçeada (in the Kuzu harbour section), the Oligocene deposits accumulated in a coastal environment and crop out on the south-eastern side of Kuzu harbour (Coordinates: 40°13'08"N, 25°57'21"E and 64 m a.s.l.), and consist mainly of conglomerates, sandstones, mudstones, lignites, mudstone with bivalves and gastropods. In some

places, iron rich sandstones contain concretions (Figures 2 & 6).

The coastal deposits of the Şevketiye and Kuzur Harbour sections correlate well since both have similar lithologies and fossil content. The high similarity in composition suggests that the two floras may be of similar Rupelian age (Figure 3). The terrestrial deposits of the Tayfur section accumulated during the subsequent

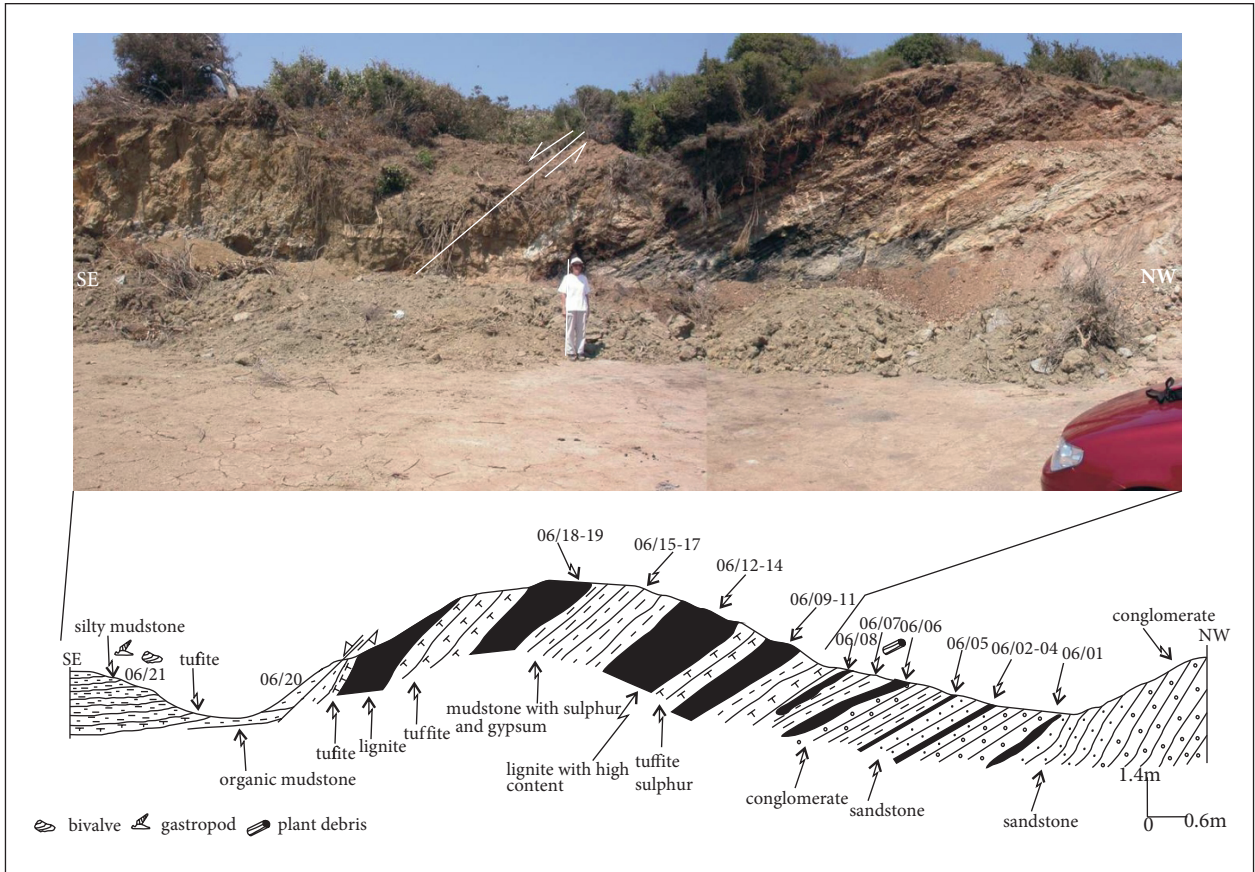


Figure 4. Small scale geological cross-section showing the sample numbers and lithological properties of the Danişmen Formation in the Şevketiye area.

regression during the beginning of the Chattian (Haq *et al.* 1987; Abreu & Anderson 1998). This was also confirmed by İslamoğlu *et al.* (2010) based on the palynoflora and mollusc fauna of the Tozaklı and Prinççeşme freshwater sediments. This regression after the end of Rupelian may have coincided with a climate cooling, as indicated from surrounding areas (Utescher *et al.* 2007; Bozukov *et al.* 2009).

1.2. Modern climate and cegetation

Turkey is located between latitudes 36 and 42°N and longitudes 26 and 45°E, between the temperate and subtropical regions. The location of the mountain ranges that run parallel to the coasts and the variety of geographical formations resulted in various climates and ecosystems. An important part of the country is under the influence of Mediterranean climate, which is warm and humid (arid in summers) (Csa in the Köppen–Geiger classification system: Peel *et al.* 2007). The Thrace Region experiences a hybrid climate between the Mediterranean and Black Sea climates. The Black Sea coast has a mild oceanic climate. According to Mudie *et al.* (2002), the

northern Marmara Sea and Black Sea coasts have a mild climate with an average temperature of 14 °C, and annual precipitation of 700–2400 mm. The northern side of the Thrace Basin is also influenced by the Balkan continental climate (Sırdaş & Şen 2003). The western parts of the Biga and Gelibolu peninsulas have a Mediterranean climate, with an average temperature of 15 °C and annual rainfall of 737 mm (Erginal *et al.* 2008; Kantarcı 2011). The main vegetation types are characterised by Mesic euxinian-type forest and Eu-Mediterranean woodland (Roberts & Wright 1993). Mesic euxinian-type forest, common along the Black Sea coast and in the Thrace Basin, consists of *Fagus orientalis*, *Fagus sylvatica*, *Carpinus betula*, *Carpinus orientalis*, and deciduous plants *Quercus petraea*, *Quercus robur* and *Quercus cerris*. *Pinus*, *Abies*, *Fraxinus*, *Alnus glutinosa*, *Populus tremula*, *Acer campestre*, *Ulmus* spp. and *Rhododendron ponticum* are also present (Roberts & Wright 1993). Mesic euxinian-type forest is widespread along the southern coasts of the Marmara Sea, Gelibolu peninsula and Gökçeada, and contains evergreen oaks (*Quercus ilex*, *Quercus coccifera*, and *Quercus infectoria*), *Pinus halapensis* and *Pinus brutia*, *Pistacia lentiscus*, *Olea oleaster*, *Arbutus*

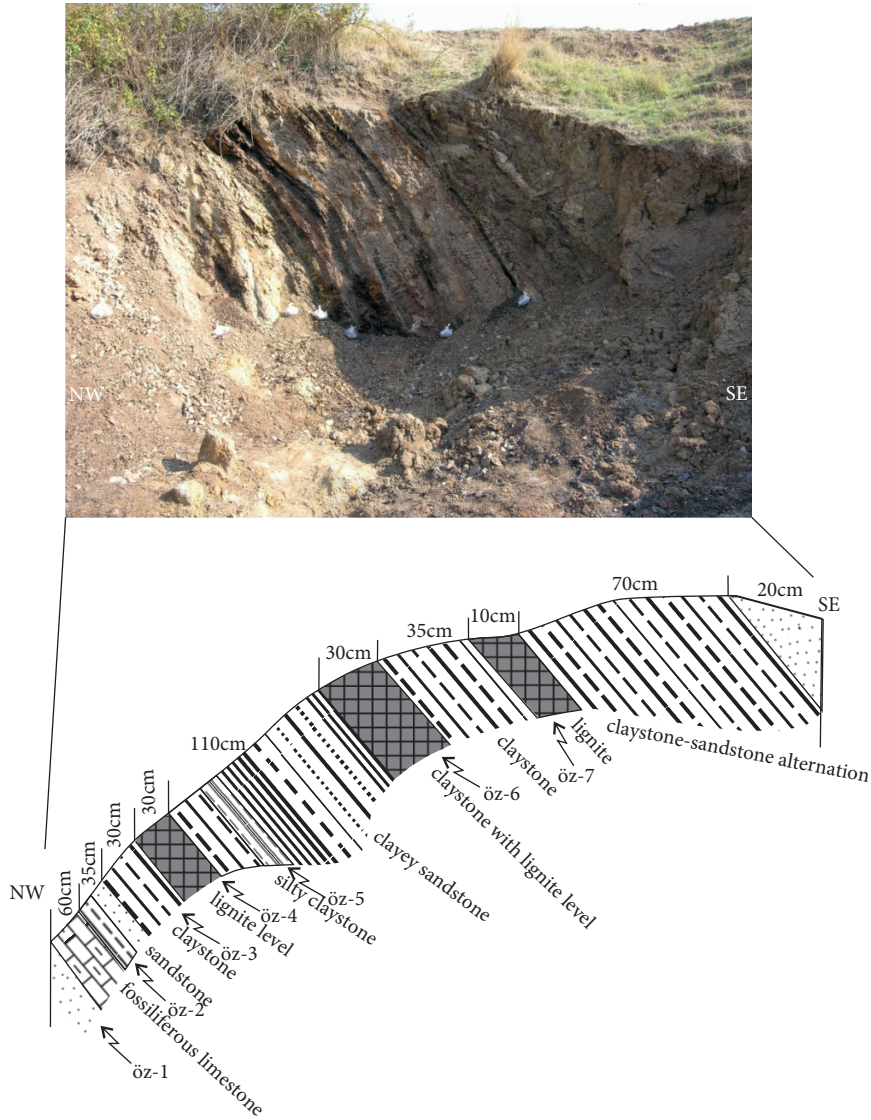


Figure 5. Small scale geological cross-section showing the sample numbers and lithological properties of the Danişmen Formation in the Tayfur area.

andrachne and *Ceratonia siliqua*. The herbaceous steppe vegetation in the area today is considered to be a secondary association (Yarcı 2000; Kavgacı *et al.* 2010)

2. Materials and methods

In total, 21 palynological samples were collected from the Şevketiye section (Figure 4), 7 from the Tayfur section (Figure 5), and 19 from the Kuzu harbour section (Figure 6). Two samples (öz-9 and öz-10) were also collected near the Tayfur section corresponding to upper levels of the sequence (Figure 2). Most of the samples yielded rare pollen grains. Only 9 samples from the Şevketiye section (Figure 7a), 7 from the Tayfur section (Figures 2 & 7b) and 12 from the Kuzu harbour section were productive (Figure 8).

For palynological studies, 10 g of each sample were treated with HCl-HF-Acetolysis using standard procedures. The organic residue was sieved through an 8 µm mesh screen and 1–4 slides per sample of the >8 µm fraction were prepared for transmitted light microscopy. Pollen counts were carried out at a magnification of ×400 using an Olympus microscope. Sporomorph contents of the samples are shown in detailed palynological analytical diagrams (Figures 7 & 8). Selected sporomorphs were photographed using an Olympus BX51 microscope and Dewinter Caliper Pro 4.1 camera (Plates 1–3). Also, selected molluscs were photographed (Plate 4). TILIA software was used to calculate the pollen and spore records, and TILIAGRAPH was used to plot the pollen diagrams (Grimm 1994).

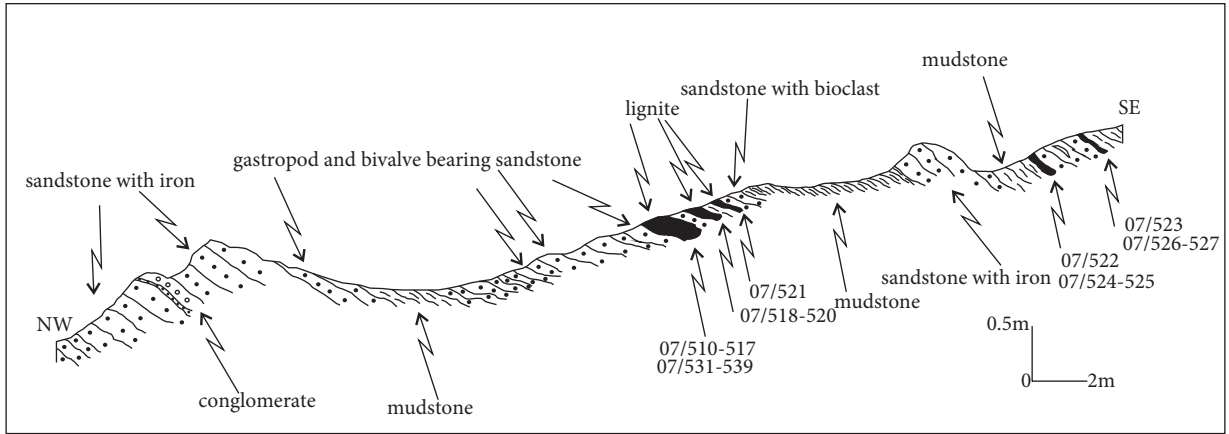


Figure 6. Small scale geological cross-section showing the sample numbers and lithological properties of the Danişmen Formation in Gökçeada (Kuzu harbour).

To study the palaeoclimatological evolution during the Oligocene the Coexistence Approach (Mosbrugger & Utescher 1997) was used. The method is described in detail in the latter references. The Coexistence Approach follows the nearest living relative (NLR) concept. The distribution of plant species depends strongly on climatic conditions. The climatic tolerance of fossil plants is considered to be close to their NLRs. Climatic tolerances for all NLRs known for a fossil flora are used to define for a given climate parameter the range in which the fossil flora existed. In the current study the following palaeoclimate parameters were reconstructed: mean annual temperature (MAT), cold month mean temperature (CMT), warm month mean temperature (WMT), mean annual precipitation (MAP), precipitation in the warmest month (WMP), precipitation in the driest month (LMP), and precipitation in the wettest month (HMP).

3. Results

3.1. Şevketiye pollen flora

The Şevketiye palynoflora includes 44 palynomorphs, consisting of angiosperms (62%), gymnosperms (14%) and pteridophytes (24%). The angiosperms are represented by 28 pollen taxa which are assigned to 24 families. The gymnosperms are made up of 5 pollen taxa assigned to 3 families. Of 10 types of spores, 7 are assigned to 6 families and 1 to the class Filicopsida (spore grains of *Laevigatosporites haardti*). *Stephanocolporites* sp. and *Plicapollis pseudoexcelsus* of unknown botanical affinity were recorded as single grains. Also, undifferentiated dinoflagellate cysts and microforaminiferal linings were recorded. Based on quantitative changes in major sporomorphs, the pollen diagram has been divided into three pollen phases (= local pollen zones), which are confirmed by CONISS clustering via TILIA 2.0 (Figure 7a).

3.1.1. Ş-I (2.95–5.00 m of the cross section; sample numbers 06/02-06)

This zone contains high percentages of the fern spores Filicopsida (range 20.2% to 35.1%), *Lycopodium* (range 0% to 7.2%) and *Lygodium* (range 14.8% to 23.2%). Lower percentages were recorded of Cyatheaceae (range 0% to 4.8%), deciduous broad-leaved forest element *Castanea* (range 0% to 9.7%) and Lepidocaryoidae (range 0% to 13.8%). Fagaceae, a palm tree *Phoenix*, broad-leaved elements *Carpinus*, Symplocaceae and Corylaceae are scarcer (Figure 7a).

3.1.2. Ş-II (5.00–8.15 m of the cross section; sample numbers 06/08-17)

This zone is characterised by abundant spores of Osmundaceae (range 5.1% to 20%), *Lygodium* (range 9.8% to 25.2%) and *Selaginella* (range 0% to 14.8%). Filicopsida show a decreasing trend from Ş-I to Ş-II. Also, higher percentages were recorded of the evergreen broad-leaved plant *Engelhardia* (range 2.2% to 14.8%), palms *Arecipites* (range 0% to 8.7%) and Lepidocaryoidae (5.1% to 20%), deciduous *Castanea* (range 5% to 31.2%), and evergreen to deciduous *Quercus* (range 0% to 14.8%). Broad-leaved Myrtaceae occur sporadically. Evergreen broad-leaved element Myricaceae, which is totally absent in other zones, also appears in this zone, but is scarce (Figure 7a).

3.1.3. Ş-III (8.15–13.10 m of the cross section; sample numbers 06/18-20)

This zone includes high percentages of the mangrove element *Pelliciera* (range 29.8% to 63.7%) which is missing in the Ş-I and Ş-II zones. The curve of *Lygodium* reaches a peak of 37.08% at 8.90 m (sample 06/18). The mangrove element *Nypa* and undifferentiated dinoflagellate cysts, which were not found in Ş-I and Ş-II, are present but scarcer in this zone as well. The hydrophilous tree *Nyssa*, broad-leaved elements of Anacardiaceae and Simaroubaceae and *Celtis* appear in minor percentages.

3.2. Tayfur pollen flora

This flora comprises 46 palynomorphs belonging to 30 families. Most are angiosperms (72%). Gymnosperms (10%), pteridophytes (6%), algae (4%) and unknown affinity (8%) are present in lesser proportions. The angiosperms are represented by 36 pollen taxa, 31 of which are assigned to 22 families, while the remaining 5 are of unknown or ambiguous origin. The gymnosperms are made up of 3 genera of Pinaceae and 1 family of Cupressaceae. Pteridophytes comprise 3 spore taxa, 2 assigned to 2 families and 1 to a class. Freshwater algae are represented by *Mougeotia*, *Pediastrum* and *Botryococcus*. Based on the composition of the sporomorphs, the palynological assemblages can be divided into two zones (Figure 7b).

3.2.1. T-I (1.20–3.35 m of the cross section; sample numbers öz/03-07)

This zone contains high proportions of Filicopsida (range 12.5% to 66.80%), marsh plants Sparganiaceae (range 0% to 30.8%), hydrophilous trees *Alnus* (range 0% to 29.8%) and *Myrica* (range 0% to 9.8%), broad-leaved plants Cyrillaceae–Clethraceae (range 0% to 10.8%), Poaceae (range 1.2% to 9.95%) and *Pediastrum* (range 3.2%–13.75%). *Alnus* reaches its maximum percentage (29.8%) in sample öz/03 at 1.10 m (Figure 7b). The curve of Filicopsida peaks at 66.80% at 2.00 m (sample öz/05). *Rhus*, *Liquidambar*, *Calamus*, *Heterophanax*, Liliaceae, *Ephedra*, broad-leaved woody angiosperm *Tricolporopollenites villensis*, *Stephanocolporites* spp. and *Tricolporopollenites reticulatostratus* of unknown botanical affinity are recorded as single grains.

3.2.2. T-II (3.35–5.40 m of the cross section; sample numbers öz/09-10)

The highest percentages of *Alnus* are recorded in this zone, reaching up to 55% at 5.40 m (sample öz/10). The percentages of Filicopsida, *Sparganium*, *Myrica*, Poaceae and *Pediastrum* tend to slightly decrease. *Lygodium*, *Pinus*, Cupressaceae, *Quercus*, *Castanea* occur throughout this zone, but in minor amounts. *Osmunda*, *Liriodendron*, *Betula*, *Tricolporopollenites reticulatostratus* of unknown botanical affinity, *Stephanocolporites hexaradiatus* and *Tricolporopollenites steinensis* are rare.

3.3. Kuzu harbour pollen flora

This microflora contains 45 palynomorphs including angiosperms (70%), gymnosperms (14%), pteridophytic spores (14%) and undifferentiated dinoflagellate cysts (2%). The angiosperms are characterised by 29 pollen taxa assigned to 22 families. The gymnosperms include 6 pollen taxa assigned to 2 families: Pinaceae and Cupressaceae. The pteridophytic spores are assigned to 6 types belonging to 4 families (Figure 8). *Aglaoreidia* sp. of unknown botanical affinity and *Plicapollis pseudoexcelsus* were found as well. Based on cluster analysis, pollen percentages and

concentrations diagrams have been divided into two pollen zones with subzones (Figure 8).

3.3.1. KH-I (8.50–9.50 m in the cross section; sample numbers 08/531-538)

This zone includes high percentages of Schizaceae spores (range 0% to 65.2%), *Alnus* (range 0% to 57.5%) and the climbing rotan palm *Calamus* (morpho-species *Dicolpopollis kockelii*) (range 9.8% to 64.9%). Dennstaedtiaceae, *Histiopteris incisa*, *Picea*, Moraceae and *Salix* show low and fluctuating occurrences. Relative changes in pollen concentrations define two subzones (Figure 8).

3.3.2. KH-Ia (8.50–9.10 m of the cross section; sample numbers 08/531-534)

This subzone has high percentages of Filicopsida (range 0% to 9.8%), *Alnus* (range 0% to 57.5%) and *Calamus* (range 9.8% to 64.9%). Dennstaedtiaceae, undifferentiated Pinaceae, *Castanea* and *Salix* are scarcer. *Pinus haploxylon* type, *Picea*, Moraceae and *Ulmus* are also rare and even recorded as single grains (Figure 8).

3.3.3. KH-Ib (9.10–9.50 m of the cross section; sample numbers 08/535-538)

Percentages of Cupressaceae (range 0% to 15.01%), *Calamus* (range 29.95% to 52.5%), *Carya* (range 0% to 6.2%) and Sparganiaceae (range 0% to 7.5%) have increased, whereas the percentages of Dennstaedtiaceae, Filicopsida and *Alnus* show a slight decrease. A few *Histiopteris incisa*, *Betula* and *Nypa* are present in this subzone.

3.3.4. KH-II (9.50–14.00 m of the cross section; sample numbers 08/539, 08/519-525)

This zone includes high percentages of Schizaceae (range 16.2% to 41.3%), Filicopsida (range 2.1% to 33.25%), Sparganiaceae (range 2.1% to 15.08%) and undifferentiated dinoflagellate cysts (range 0% to 5.1%). The percentages of *Alnus* and *Calamus* show a slight decrease in this zone, whereas Schizaceae, Filicopsida and Sparganiaceae have increased.

3.4. Vegetation

Samples of the Şevketiye palynoflora contain abundant ferns, *Castanea* (morpho-species *Tricolporopollenites cingulum*), palm Lepidocaryoid palms (morpho-species *Longapertites proxopertitoides*, *L. psilatus* and *L. retipilatus*) and a mangrove association comprising pollen of *Pelliciera* (morpho-species *Psilatricolporites crassus*), *Nypa* (morpho-genus *Spinizonocolpites* sp.) and *Acrostichum aureum* (morpho-species *Deltoidospora adriennis*). However, the assemblage in the upper samples (06/18-20), corresponding to the Ş-III pollen zone, differs from samples between 06/02 and 06/17 collected from lower zones (Ş-I and Ş-II local pollen zones) in having the mangrove elements *Pelliciera* and *Nypa* pollen, a few poor preserved undifferentiated dinoflagellate cysts and microforaminiferal linings (Figure 7a). The great abundance of *Pelliciera* and scarcity of *Nypa*

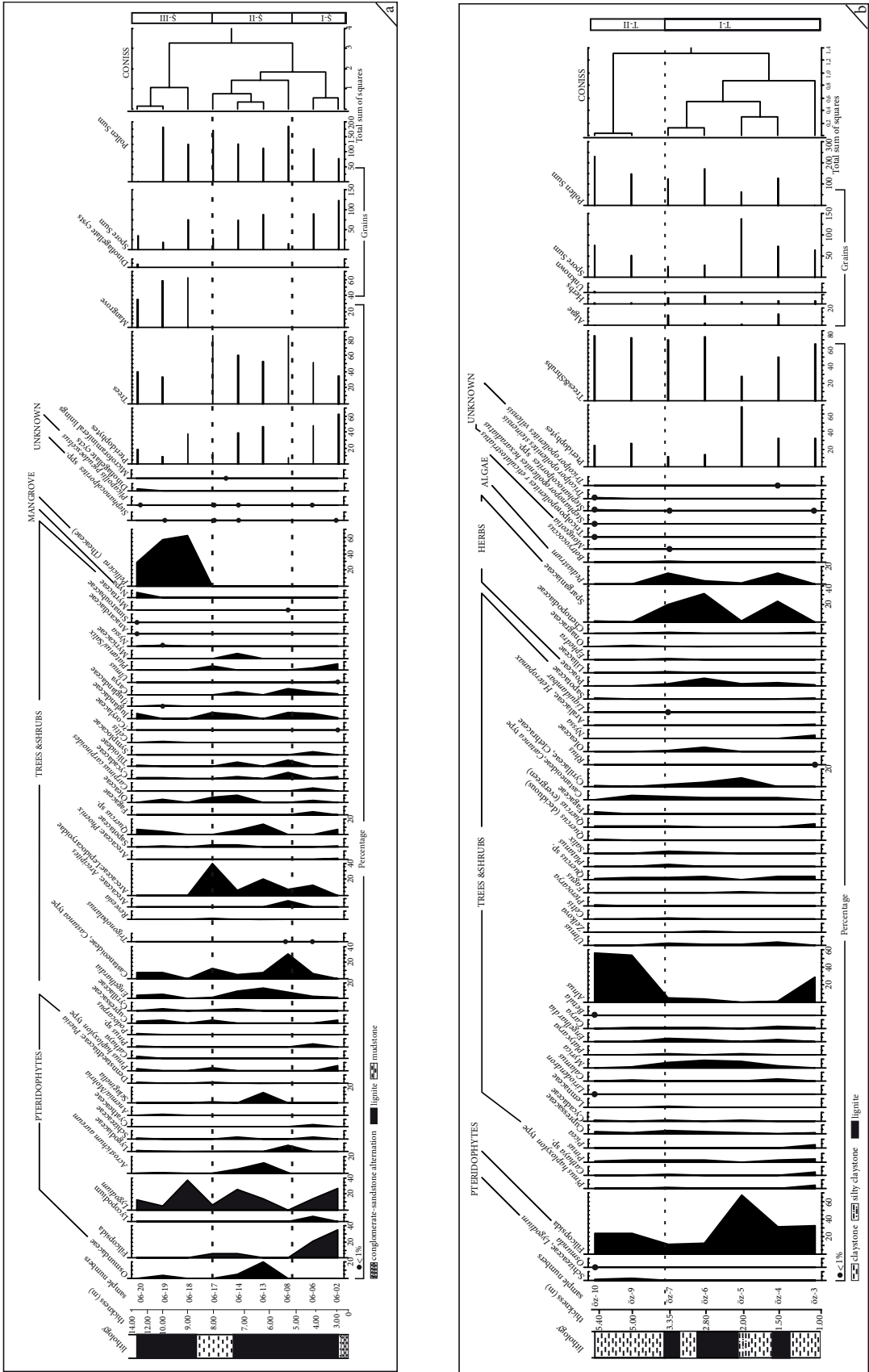


Figure 7. Simplified pollen diagram of the samples from the Şevketiye section (a), and the Tayfur section (b).

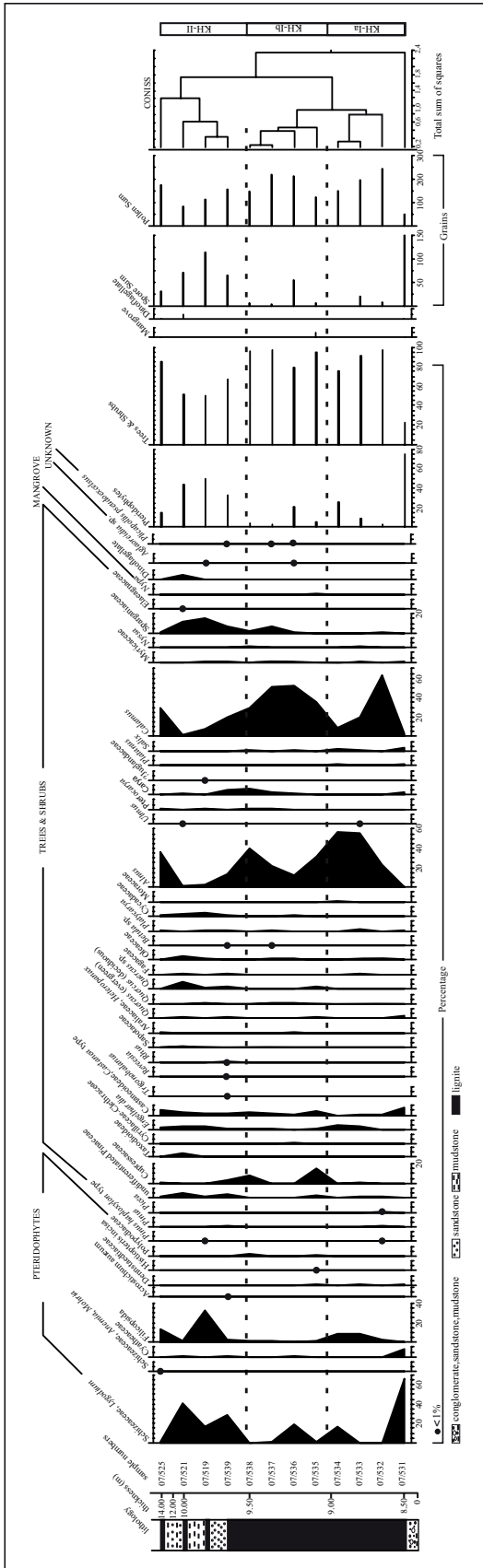


Figure 8. Simplified pollen diagram of the samples from the Kuzu harbour section.

in Ş-III suggest that the sediments certainly accumulated in a coastal swamp into which pteridophytic spores and angiosperms were transported by river channels. The high percentages of mangrove elements indicate a transgression that could be related to a rising sea level during the Rupelian. Minor amounts of dinoflagellate cysts also occur in the same phase as mangrove elements. The pollen of *Avicennia*, which was reported from the Pullukçu section at northern Malkara, on the southwestern side of the Thrace Basin, is another reliable indicator of a mangrove environment (İslamoğlu et al. 2010) (Figure 2). Except for *Lygodium*, other ferns, such as Osmundaceae, Lygodiaceae and *Selaginella*, are common in the Ş-I and Ş-II zones, potentially indicating a low sea level stand. In this phase, the coastal pollen assemblage was also dominated by palms such as Arecaceae (Lepidocaryoidae, *Arecipites*, *Calamus* and *Phoenix*) which may have lived in both coastal swamps and inland forest. The fern *Acrostichum aureum* was the most widespread species among the associated flora on more elevated sites and around dry and less saline settings within the mangrove. *Anemia/Mohria*, Schizaceae ferns growing on the coastal plain, are rare in the Ş-III zone. Their fluctuations in abundance indicate small-scale palaeoenvironmental changes in the coastal area. The proportion of conifers in the pollen spectra is negligible. The occurrence of mangrove, palm/fern swamps, dinoflagellate cysts and microforaminiferal linings in some samples certainly suggests proximity to the palaeo-shoreline. The sediments at the top of the sequence (after the mangrove phase) are greenish grey organic and silty mudstones with marine mollusc shells and fragments which include *Polymesoda convexa* (Brongniart), *Cardium* sp., *Pitar* (*Paradione*) *undata* (Basterot) and *Angulus* (*Peronidia*) *nysti* (Deshayes), and gastropods such as *Pirenella plicata* (Bruguere), *Tympanotonus margaritaceus* (Brocchi), *Natica millepunctata tigrina* Defrance, *Ampullina crassatina* (Lamarck), *Ampulina* sp., and *Bullia* sp. (Plate 4). *Polymesoda convexa* (Brongniart) existed in a shallow littoral and sandy environment, indicating low salinity conditions ranging from 3% to 10%. It can also survive in a swamp environment. Today the genus *Polymesoda* lives in water temperatures between 18 and 32 °C in mangrove swamps (Morton 1983). *Angulus* sp. settled in the muddy lagoons (İslamoğlu et al. 2010) as well. As a result it was possible to reconstruct a theoretical succession of plant communities along the coast. In the regressional phase, ferns in the Ş-I and Ş-II zones colonised coastal swamp and lowland marshes, while forests dominated the inland areas. Later, in the transgressional phase corresponding to the Ş-III zone, mangrove vegetation consisting of *Nypa* palms and *Pelliciera* trees developed along the coastline. Inland from this coastal fringe were mostly mangrove swamps dominated by palms, containing respectively

both *Acrostichum aureum* and other ferns, or palms such as Arecaceae-*Phoenix*, Arecaceae-Lepidocaryoidae and Arecaceae-*Arecipites*. A distinct increase in the abundance of gastropods and bivalves through the upper part of the section has been interpreted as reflecting a maximum flooding surface (Figures 3 & 4).

Lignite-bearing deposits of the Tayfur section accumulated in a freshwater environment, as indicated by the majority of freshwater algae *Pediastrum* and the hydrophilous plant *Sparganium* (morpho-species *Sparganiapollenites neogenicus*) in the T-I zone. In contrast, coastal palms, mangrove trees, marine dinoflagellate cysts and microforaminiferal linings disappeared here and the assemblage mainly contains pollen grains of inland vegetation. This should be related to global regression during the late Rupelian and early Chattian that affected vegetation cover (Figure 3). This was also confirmed by previous work in surrounding areas (Bozukov et al. 2009; İslamoğlu et al. 2010). The understorey vegetation was made up of different kinds of ferns. Increasing percentages of hydrophilous tree alder (*Alnus*) occur from zone T-I to T-II, where flooded settings proliferated. The scarcity of coniferous pollen indicates that they might have lived outside the depositional area, probably indicating a distant mountain range. Mesophytic forest elements *Quercus*, *Fagus*, *Carya*, *Ulmus*, *Betula*, *Zelkova*, *Engelhardia*, etc. are recorded in low quantity in the pollen spectra. The climbing rotan palm *Calamus* (liana or vine), which has mainly wide ecological amplitude, may have lived further inland. Currently, *Calamus* grows on the riparian margins of peat swamps in tropical and subtropical regions (Frederiksen 1985; Bande & Prakash 1986). Herbaceous plants such as Poaceae, Liliaceae, *Ephedra* and Chenopodiaceae are also minor components of the assemblage.

As in the Şevketiye palynological assemblage, the deposits of the Kuzu harbour section accumulated in a coastal environment, indicated by coastal plants such as *Nypa*, *Acrostichum aureum*, *Anemia/Mohria* (morpho-species *Cicatricosisporites dorogensis*) and *Calamus* type palms and marine dinoflagellate cysts in the KH-II zone. The other mangrove element, *Pelliciera*, which is the main mangrove forming tree of the Şevketiye palynological assemblage, is absent here. Minor occurrences of *Nypa* and dinoflagellate cysts in some samples suggest a brackish and/or shallow marine depositional environment. The pollen of the KH-Ia and KH-Ib subzones indicate a regressional phase since they contain high percentages of *Alnus* related to flooded settings. The percentage of *Calamus*, probably living in inland areas, is also high. Its ratio decreases through the upper part of the section. Also the KH-II zone of the Kuzu harbour section can be correlated with the Ş-III zone of the Şevketiye section, since both of them include mangrove elements and dinoflagellate cysts. The

sediments of the Kuzu harbour section accumulated in marine environments further offshore, indicating a more transgressive facies as represented by high numbers of marine dinoflagellate cysts. Mollusc fauna is represented by abundant *Polymesoda convexa* (Brongniart) and scarce *Pitar* sp., indicating a coastal environment. Both marine palynomorphs and macrofauna clearly indicate a shallow water coastal environment of deposition.

In summary, palynological analysis reveals that, during the Early Oligocene, low lying coastal environments of the Şevketiye and Kuzu harbour were dominated by mangroves consisting of *Nypa* and *Pelliciera*. The coastal environment is further indicated by the scarcer back-mangrove element *Acrostichum aureum*, undifferentiated dinoflagellate cysts, microforaminiferal linings and macrofauna as well. The dispersion of mangrove elements in our outcrops (Şevketiye and Kuzu harbour) clearly indicates that the shoreline was to the north-east in the Early Oligocene, and moved towards the south-west at the onset of the Late Oligocene. As a result, the deposits of the Tayfur section accumulated in a sea-level low stand condition, probably in a freshwater environment, corresponding to a sea-level fall at the Early–Late Oligocene transition (Figure 3). This result can be linked to the global eustatic sea-level changes of Haq *et al.* (1987) and Abreu & Anderson (1998) who indicated a regression at the end of the Rupelian. Mangroves totally disappeared from the Tayfur area.

3.5. Palaeoclimate

Eleven groups, megathermic, mega-mesothermic, mesothermic, microthermic, dinoflagellate cysts, herbs, freshwater algae, evergreen *Quercus*, mangrove, Cupressaceae, Pinaceae, and one unknown group are recognised in the assemblages (Figure 9).

In the Şevketiye palynoflora, apart from the abundance of spores from a palm Lepidocaryoidae and mangrove element *Pelliciera*, pollen spectra show that mega-mesothermic (*Castanea* and *Engelhardia*) and mesothermic (Oleaceae, *Carya*, Tiliaceae etc.) also occur, but in comparatively minor proportions of all local pollen zones. Mega-mesothermic elements are common in the Ş-I and Ş-II zones, and decrease in the Ş-III zone. However, mangroves become prolific in the Ş-III zone (Figure 9a). The presence of mangroves suggests that warm climate conditions existed during deposition of the Danişmen Formation in Şevketiye. *Nypa*, especially, cannot survive in temperatures less than 20 °C (Fechner 1988). Arecaceae palms (Lepidocaryoidae and *Phoenix*) and *Anemia/Mohria* are mainly abundant in tropical areas. The megathermic Simaroubaceae and *Trigonobalanus* are scarce in the Ş-I zone. Also the palaeoclimate data, using the coexistence approach for 7 samples from the Şevketiye section, are indicated in Figure 10a. Here the exclusion of the lepidocaryoid palm, indicating an outlier with higher climate requirements, leads to an interval of 21.7 to 23.9

°C, determined by *Nypa* and *Nyssa*, for the MAT, but intervals between 17.2 and 20.8 °C, determined by *Reevesia* and *Tilia*, also occur (Figure 10a). Similarly the CMT is between 15.2 and 16.7 °C, delimited by *Nypa* and *Castanea*. But a number of samples indicate lower temperatures and a second coexistence interval 7.7–13.3 °C based on Arecaceae and *Carya*, may appear (Figure 10a). Possibly, these two coexistence intervals for the MAT and CMT are relevant to palaeogeographic relief, permitting the growth of different plant communities under discrete climate conditions. The first coexistence interval indicates coastal vegetation. The others imply more inland vegetation. Calculation of the WMT yields an interval from 27.5 to 27.9 °C, delimited by Cycadaceae and *Nyssa*. The MAP is thought to lie between 1215 and 1355 mm, based on the presence of *Nypa* and *Carpinus betulus carol* as the nearest living relative of *Carpinuspollenites carpinoides*. *Engelhardia* and *Carpinus betulus carol* indicate that the coexistence interval for the HMP is 204–265 mm (Figure 10a). But a range between 322 and 346 mm (*Nypa* and *Nyssa*) is also indicated. The range of the LMP is determined as 16 to 24 mm, according to *Podocarpus* and *Celtis*. For the WMP, the coexistence approach yields an interval between 118 and 163 mm, determined by *Reevesia* and *Carya*.

In the Tayfur palynoflora, mega-mesothermic elements such as *Myrica*, Cyrillaceae–Cletraceae and *Castanea* rarely occur in the T-I and T-II zones (Figure 9b). The mesothermic element *Alnus* was abundant both in the lower part (sample öz-03) and upper part (samples öz-9/10). Other mesothermic elements, such as *Betula*, *Ulmus*, *Zelkova*, *Celtis*, *Platanus*, *Salix*, *Pterocarya*, deciduous *Quercus*, *Rhus*, *Nyssa*, *Liquidambar* and Oleaceae, rarely occur in the T-I and T-II zones. Herbs show pointed peaks of 40%–50% in the T-I zone, whereas they rapidly decreased in T-II zone (Figure 9b). Their presence may point to dry conditions as shown by previous works on Miocene deposits of Europe (Ivanov *et al.* 2002, 2007; Jimenez Moreno *et al.* 2008). Similarly, a higher proportion of freshwater algae, *Pediastrum*, occurs in the T-I zone, but decreases in the T-II zone. The microthermic element *Picea* appears in the lower part of the T-I zone. The palaeoclimate parameters were determined for 6 samples from the Tayfur section, in which similar coexistence intervals resulted from each sample, and no indication of climate changes is evident from T-I to T-II (Figure 10b). Calculating the MAT leads to an interval of 16.5 to 21.3 °C, based on the Cycadaceae and *Liquidambar*. The CMT indicates wider coexistence intervals between 5.5 and 13.3 °C, delimited by Cycadaceae and *Liriodendron* and the WMT coexistence interval is 27.3–27.9 °C based on Cycadaceae and *Nyssa* (Figure 10b). The interval for the MAP is rather broad and ranges from 887 to 1623 mm, determined by Cycadaceae and *Liquidambar*. The HMP was calculated by the coexistence

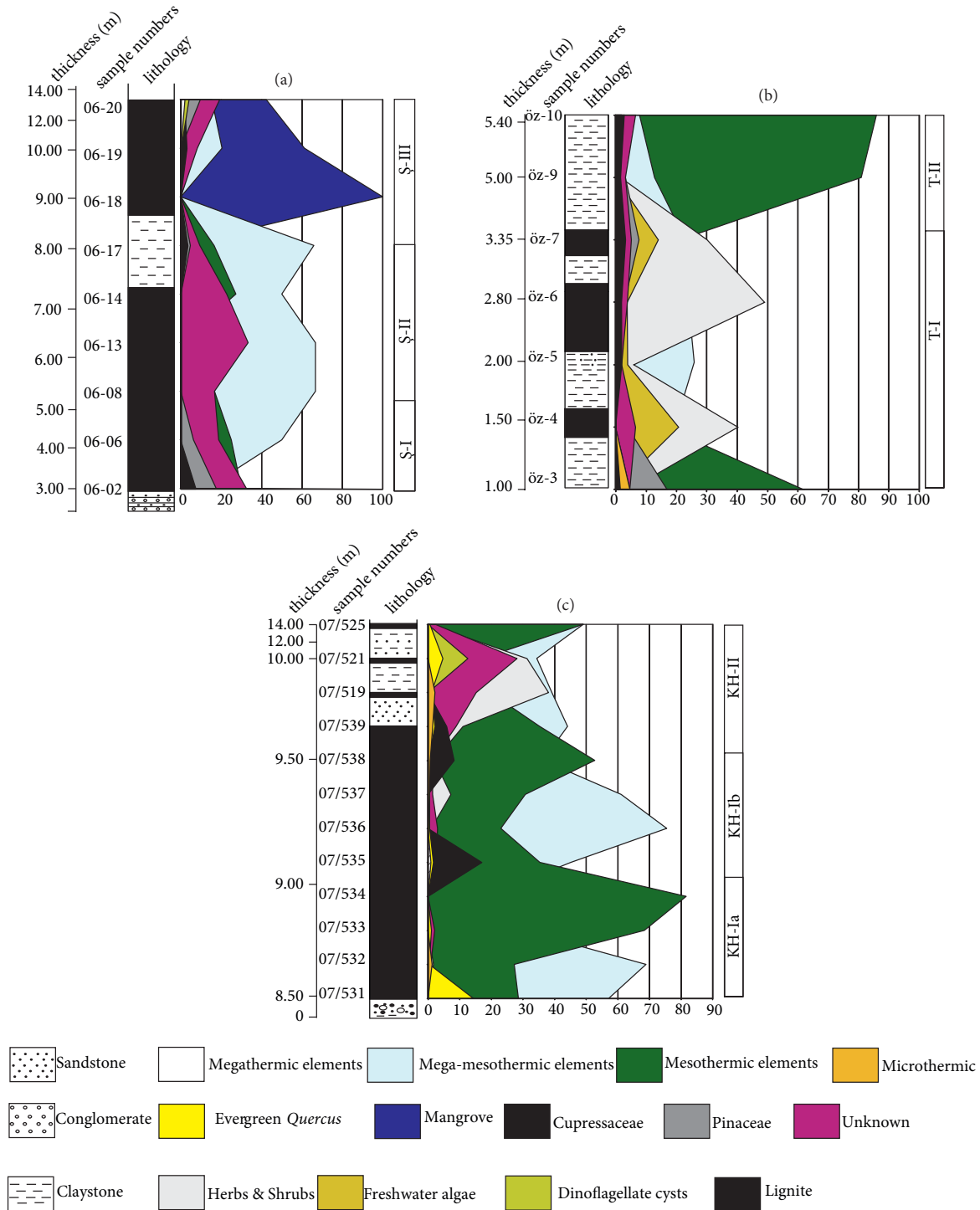
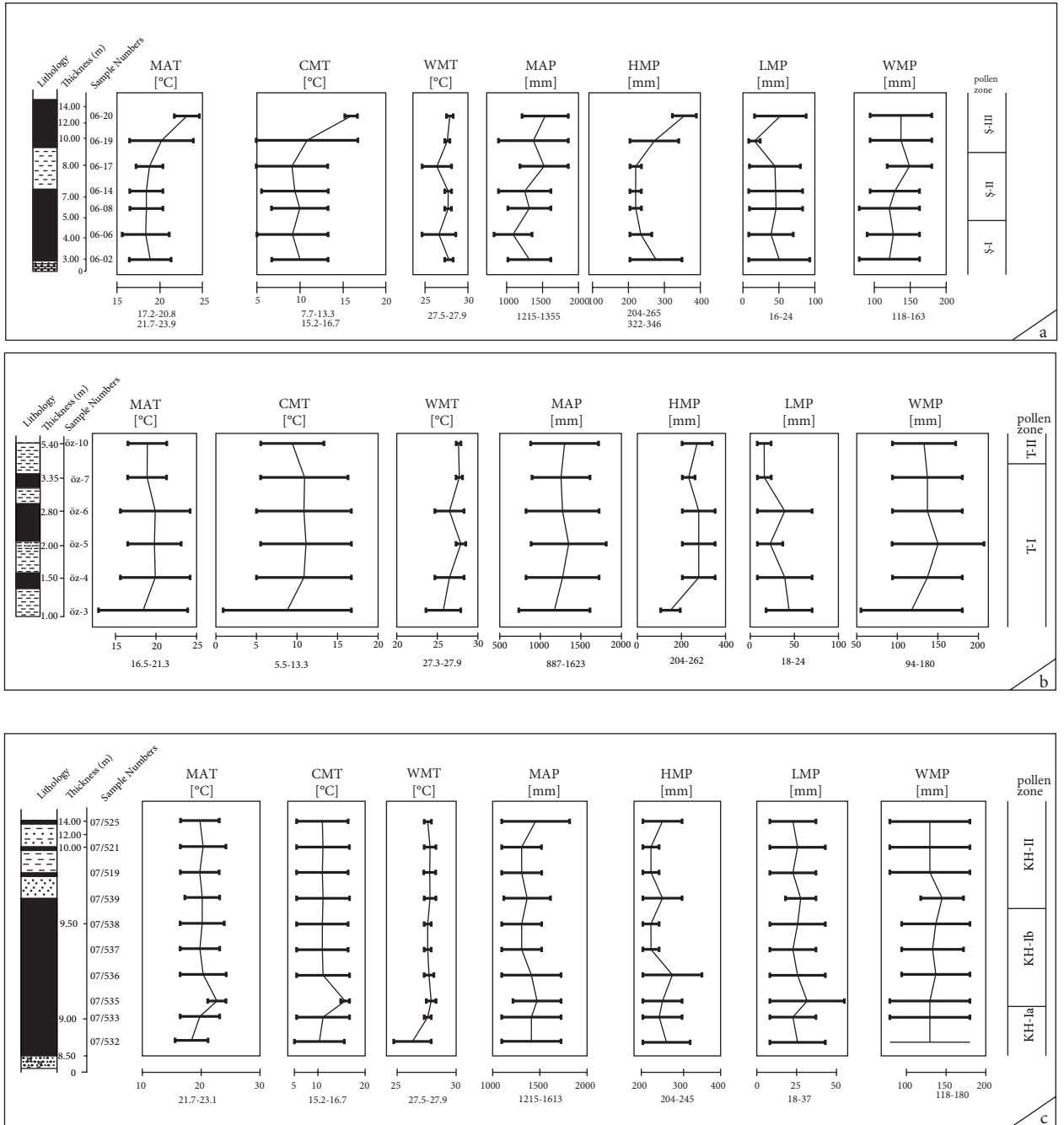


Figure 9. Synthetic pollen diagrams. Pollen taxa have been grouped on the basis of ecological criteria (according to Suc 1984, Jimenez-Moreno *et al.* 2005): Megathermic element (tropical): Simaroubaceae, *Trigonobalanus*; Mega-mesothermic elements (subtropical): *Engelhardia*, *Platycarya*, *Myrica*, Araliaceae (*Heteropanax*), *Calamus*, Sapotaceae, *Castanea-Castanopsis*, *Liriodendron*, Cyrillaceae-Clethraceae, *Reevesia*, Arecaceae (*Phoenix*, *Lepidocaryoidae*), Myrtaceae, Symplocaceae and Elaeagnaceae; Mesothermic elements (warm temperate): deciduous *Quercus*, *Carya*, *Pterocarya*, Oleaceae, *Carpinus*, Corylaceae, *Liquidambar*, *Zelkova*, *Ulmus*, Tiliaceae, Moraceae, *Celtis*, *Alnus*, *Salix*, *Platanus*, *Nyssa* and *Fagus*; Microthermic element (cool): *Picea*; Pinaceae: *Pinus haploxylon* type, *Pinus diploxylon* type and *Podocarpus*; Cupressaceae; Herbs/shrubs: Onagraceae, Liliaceae Poaceae, Chenopodiaceae, *Ephedra* and *Sparganium*; Freshwater Algae: *Pediastrum* and *Botryococcus*; Mangrove: *Nypa*, *Pelliciera* and *Acrostichum aureum*; Evergreen *Quercus*; Unknown; Lemnaceae, *Quercus* sp., Cycadaceae, Fagaceae and Juglandaceae.



approach to have an interval of 204–262 mm, delimited by *Engelhardia* and *Ephedra*. The interval for the LMP is 18–24 mm, with the borders of this range determined by *Rhus* and *Celtis*. For the WMP, the coexistence approach yields a range of 94–180 mm, based on *Cyrillaceae*–*Clethraceae* and *Quercus*.

In the Kuzu harbour palynological assemblage, the mega-mesothermic *Calamus* and mesothermic *Alnus* are very abundant in the KH-Ia and Ib subzones, but decrease slightly in the KH-II zone (Figure 9c). Other mega-mesothermic elements such as *Araliaceae*, *Cyrillaceae*–*Clethraceae*, *Reveesia*, *Sapotaceae*, *Myrica*, *Engelhardia*,

Castanea and Elaeagnaceae, and mesothermic elements like *Betula*, *Ulmus*, *Salix*, *Pterocarya*, *Carya*, deciduous *Quercus*, *Rhus*, *Nyssa* and Moraceae were rare. The microthermic element *Picea* appears sporadically at the end of the KH-Ib zone and proliferates in the KH-II zone. The herbaceous Sparganiaceae also proliferated in the KH-II zone. The palaeoclimate data obtained from 10 samples from the Kuzu harbour section using the coexistence approach are indicated in Figure 10c. The coexistence intervals for all palaeoclimate parameters are similar for each sample. Using the combined samples, the values obtained are 21.7 to 23.1 °C (lower boundary: *Nypa*; upper boundary: *Platycarya*) for MAT, 15.2 to 16.7 °C (lower boundary: *Nypa*; upper boundary: *Castanea*) for CMT, 27.5–27.9 °C (lower boundary: *Nypa*; upper boundary: *Nyssa*) for WMT, 1215–1613 mm (lower boundary: *Nypa*; upper boundary: *Rhus*) for MAP, 204–245 mm (lower boundary: *Engelhardia*; upper boundary: Taxodiaceae) for HMP, 18–37 mm (lower boundary: *Rhus*; upper boundary: *Platycarya*) for LMP, and 118–180 mm (lower boundary: *Reevesia*; upper boundary: *Quercus*) for WMP (Figure 10c).

After interpreting the pollen flora, the presence of mangrove elements (*Nypa*, *Pelliciera* and *Acrostichum aureum*) as well as palms and climbing fern spores during the Early Oligocene indicates that a warm-subtropical climate prevailed during sediment deposition in the Şevketiye and Kuzur harbour sections, with MAT between 21.7 and 23.9 °C which probably represents the climate of the coastal environment. In contrast, due to the mosaic-like character of the palaeovegetation, the second coexistence interval, 17.2–20.8 °C, represents more inland environments. Also, the winter temperatures (CMT) from both sections indicate values between 15.2 and 16.7 °C, implying almost tropical conditions in the coastal environment. According to Mosbrugger *et al.* (2005), the Cenozoic cooling may be best indicated by variations in the CMT rather than other climate parameters. Utescher *et al.* (2007) reported similar results for the Early Oligocene in Serbia: e.g. for the Bogovina flora annual temperatures almost reached 20 °C, with summer temperature around 27 °C, winter temperature at 10 °C, and the mean annual precipitation from 867 to 1384 mm, values very close to our results from the Şevketiye and Kuzu harbour sections. However the climate changed to warm-temperate after the end of the Rupelian, as indicated by the Tayfur palynoflora, and this most probably is a record of global climate cooling at that time (Utescher *et al.* 2007; Bozukov *et al.* 2009). As shown in this study, cooling is also mirrored by vegetation change from the coastal environment (mixture of subtropical to temperate taxa) to the hinterland. Utescher *et al.* (2007) indicated lower temperatures from the Serbian Late Oligocene (Ravna Reka flora). These results also demonstrate a vegetation change related to sea-level

fall in the Oligocene of the south-western Thrace Basin, from marine deposits of the Şevketiye and Kuzu harbour sections to the terrestrial deposits of the Tayfur section. The regressive trend at the Early–Late Oligocene transition is contemporaneous with the slight decrease in the lower limit of annual precipitation (below 1000 mm) and mean annual temperature falling below 17 °C in the Tayfur section (Figure 10b).

3.6. Mangrove biogeography

Based on previous records and the data of the current study, present-day, Eocene and Oligocene geographic distribution of the mangrove elements *Nypa* and *Pelliciera* have been plotted on maps. For this, palynological data of Turkish Eocene–Oligocene basins and others published in peer-reviewed articles (either in international or regional journals) were considered. Mangrove assemblages were determined from various Eocene sites in Western and Southern Europe (e.g., Palamarev *et al.* 2000; Plaziat *et al.* 2001; Collinson & Hooker 2003; Utescher & Mosbrugger 2007).

Late Cretaceous and Palaeocene records of *Nypa* (*Spinizonocolpites*) are uncommon, and were reported from northern Africa and the Caribbean (Germeraad *et al.* 1968). Although *Nypa* occurred on all continents during the Eocene, at present it only occurs in the Indo-Malaysian and Australo-Malayan regions (Figure 11). It has been identified as abundant in the Early Eocene of southern Europe (Gruas-Cavagnetto 1977). In contrast, its pollen was also widespread in Eocene deposits of Turkey (Akgün 2002; Akgün *et al.* 2002; Akkiraz *et al.* 2006; Akkiraz *et al.* 2008). Its presence was proved from Lower Oligocene deposits of the Çardak–Tokça and Ören basins by Akkiraz (2000) and Kayseri (2009), respectively. However, there is no pollen record of *Nypa* from the Late Oligocene or younger deposits in Turkey.

Pollen of *Pelliciera* (*Psilatricolporites crassus*) were first recorded from Middle to ?Upper Eocene sequences of Turkey by Akgün (2002) and Akkiraz *et al.* (2006, 2008). It has also been found in Oligocene deposits of the Ören Basin (south-west Turkey) by Kayseri (2009). *Pelliciera* occurred in the Caribbean and on the Atlantic coasts of Guyana and Brazil during Eocene–Oligocene times (Rull 1998); it was also recorded from Middle–Upper Eocene sediments of the Ebro basin (north-east Spain) by Cavagnetto & Anadon (1995, 1996). Although its presence in Africa is uncertain during Eocene times, it was also reported from Cenozoic of the Guiana basin (Van Der Hammen & Wijmstra 1964), the Oligo-Miocene of Chiapas and from Lower Miocene sediments of Panama (Graham 1977). According to Graham (1995), it survived into the Quaternary of the Gulf/Caribbean region (Mexico, the Antilles, Central America, and northern part of South America). However, at present, *Pelliciera*

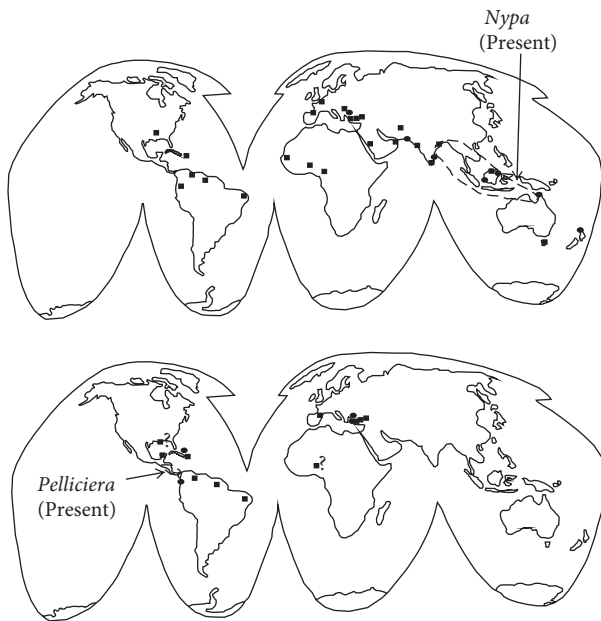


Figure 11. Present (dashed areas), Eocene (black squares) and Oligocene (black circles) geographic distributions of *Nypa* and *Pelliciera*. After Germeraad *et al.* (1968), Müller (1980, 1981), Thanikaimoni *et al.* (1984), Frederiksen (1980, 1985, 1988, 1994), Thanikaimoni (1987), Westgate & Gee (1990), Srivastava & Binda (1991), Hornibrook (1992), Cavagnetto & Anadon (1995), Graham (1995), Nickel (1996), Pole & Macphail (1996), Rull (1998, 1999), El Beialy (1998), Riegel *et al.* (1999), Plaziat *et al.* (2001), Akgün (2002), Akgün *et al.* (2002), Akkiraz (2000), Akkiraz *et al.* (2006, 2008), Kayseri (2009).

occurs only in a restricted area of northern South America (Figure 11). The present Atlantic mangrove (*Pelliciera*) and present Indo-Pacific mangrove (*Nypa*) elements have not so far been reported as fossils from the Thrace Basin. However, the mangrove *Avicennia* was reported as single grains by İslamoğlu *et al.* (2010). Its existence in Lower Oligocene deposits indicates warm Tethys waters. During

the Oligocene, the mangroves with *Pelliciera*, *Nypa* and *Avicennia* in the Thrace Basin disappeared because of changing palaeoclimate or facies change.

4. Conclusions

The results obtained by this study are as follows:

Palynology and mollusc data from early Oligocene indicate that the deposits of the Şevketiye and Kuzu harbour sections accumulated in coastal environments where mangroves prevailed. In contrast, during the Late Oligocene, the sediments of the Tayfur section were deposited in a non-marine environment where more inland vegetation was dominant.

Although coaly Oligocene units are mostly known from the northern Thrace Basin, their presence is not merely limited to the Thrace Basin, and extends to the northern side of the Biga Peninsula.

An overall sea level fall during the Early to Late Oligocene transition is indicated by change of both macrofaunal and palynological associations from a mangrove to terrestrial environment.

Although small-scale climate fluctuations during the Early Oligocene took place, evidence for mainly high temperatures come from mangroves, such as *Pelliciera*, *Nypa* and *Acrostichum aureum* and palms (mainly Arecaceae) in the Şevketiye and Kuzu harbour palynoflora. During the deposition of sediments in the Tayfur area, lower temperatures corresponding to global cooling during the Early–Late Oligocene transition are estimated.

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PLATE 1

(Şevketiye Palynoflora)

(All pnatomicrographs have their own scales)

Figures 1, 2. *Osmunda*.

Figure 3. *Lycopodium*.

Figure 4. *Acrostichum aureum*.

Figure 5. Schizaceae, *Lygodium*.

Figure 6. *Selaginella* sp.

Figure 7. Schizaceae, *Anemia/Mohria*.

Figure 8. *Pinus haploxylon* type.

Figures 9–11. Lepidocaryoidae.

Figure 12. *Plicapollis pseudoexcelsus*.

Figure 13. Tilioideae.

Figure 14. *Ulmus*.

Figure 15. Anacardiaceae.

Figure 16. *Stephanocolporites* sp.

Figure 17. Myrtaceae.

Figure 18. *Nypa*.

Figures 19, 20. *Pelliciera*.

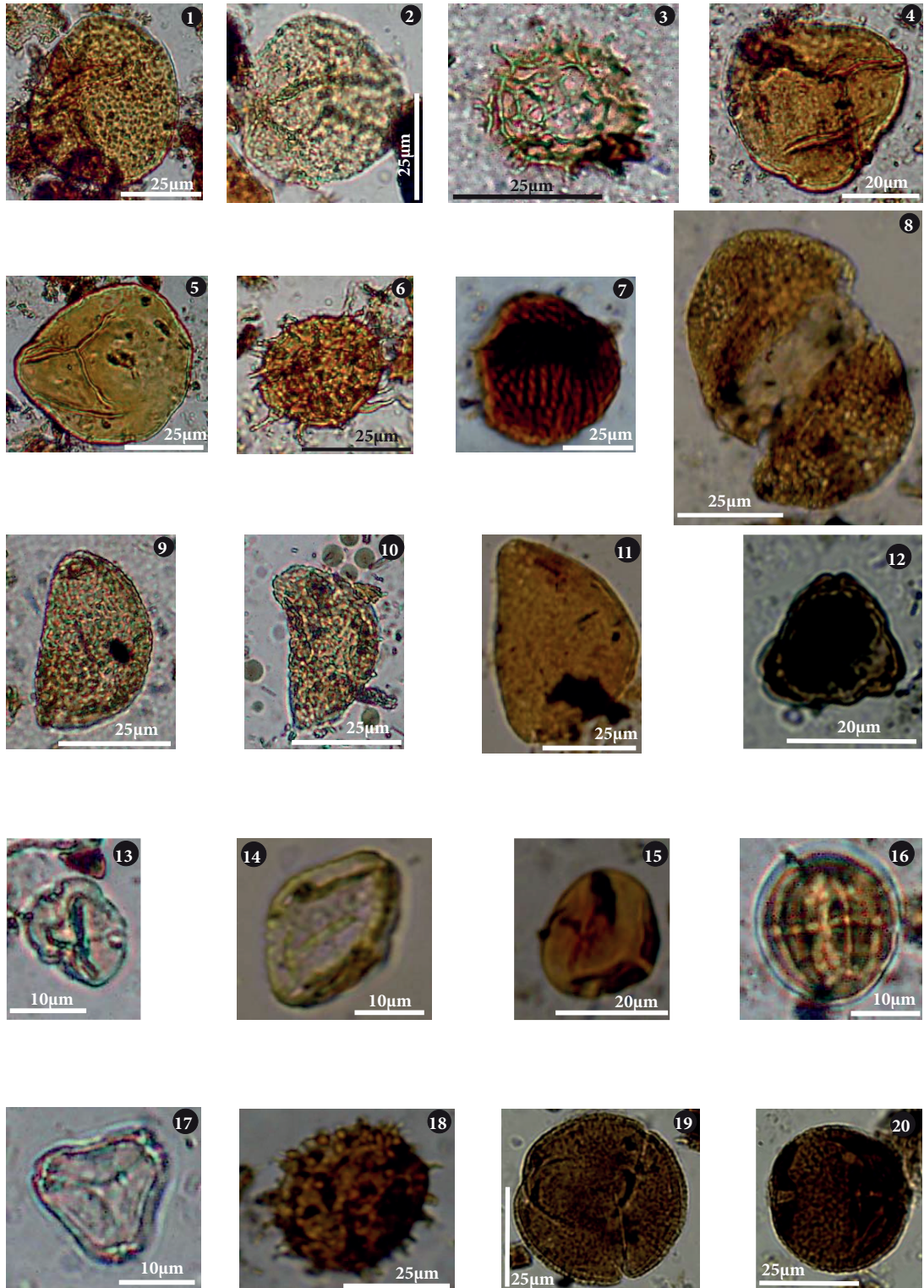


PLATE 2
(Tayfur Palynoflora)

- Figure 1. Schizaceae, *Lygodium*.
Figure 2. Filicopsida.
Figure 3. *Pinus*.
Figure 4. Cycadaceae.
Figure 5. Cupressaceae.
Figure 6. Lemnaceae.
Figure 7. Poaceae.
Figure 8. *Calamus*.
Figure 9. Sparganiaceae.
Figure 10. *Liriodendron*.
Figure 11. Myricaceae.
Figure 12. *Platycarya*.
Figure 13. *Engelhardia*.
Figure 14. *Betula*.
Figure 15. *Carya*.
Figure 16. *Alnus*.
Figure 17. *Ulmus*.
Figure 18. *Stephanoporopollenites hexaradiatus*.
Figure 19. *Pterocarya*.
Figure 20. Onagraceae.
Figure 21. *Fagus*.
Figure 22. Evergreen *Quercus*.
Figure 23. *Salix*.
Figure 24. Cyrillaceae-Clethraceae.
Figure 25. *Stephanocolporites* sp.
Figure 26. *Nyssa*.
Figure 27. Chenopodiaceae.
Figure 28. *Pediastrum*.

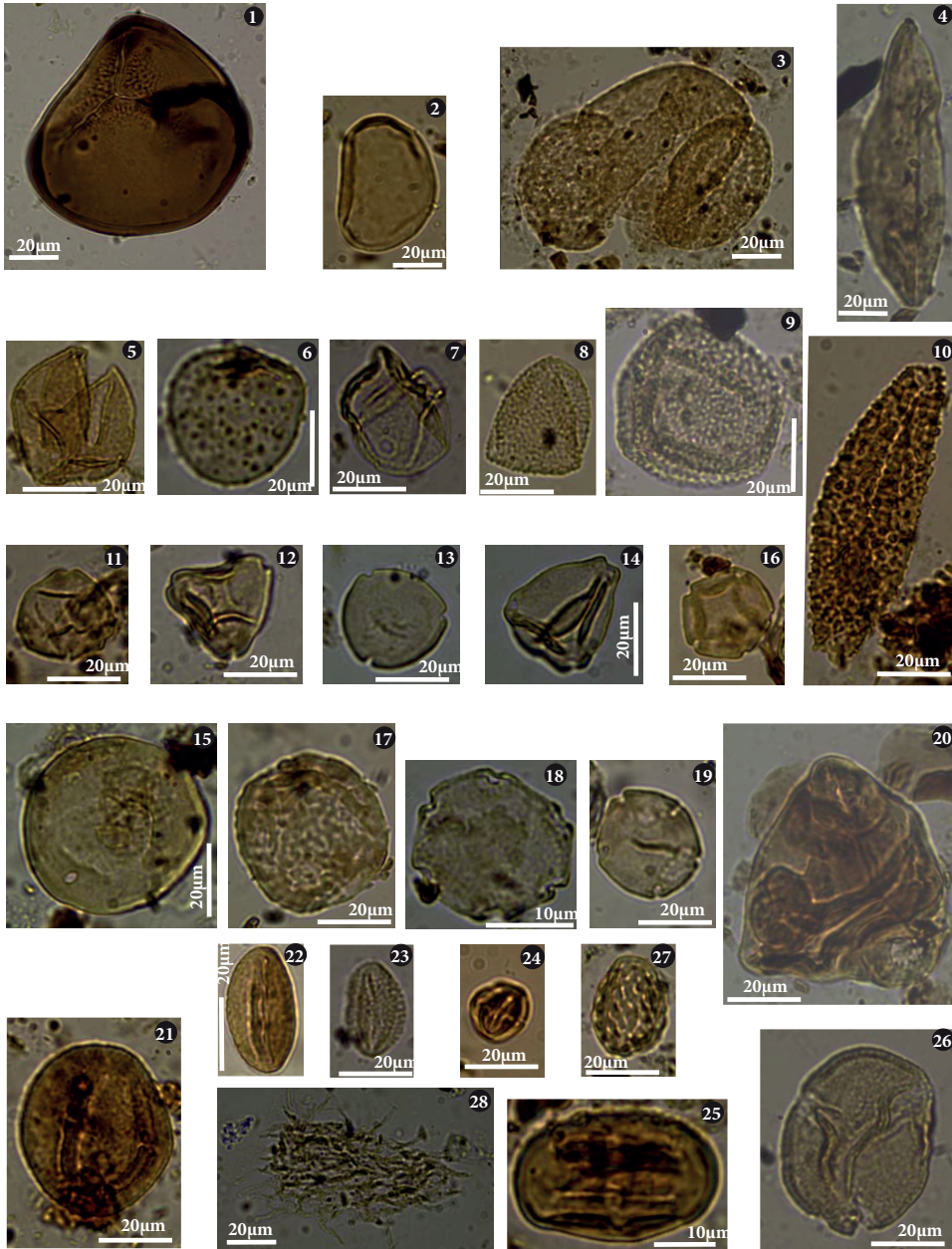


PLATE 3

(Kuzu harbour Palynoflora)

- Figure 1. *Acrostichum aureum*.
Figure 2. Schizaceae, *Lygodium*.
Figure 3. Schizaceae, *Anemia*, *Mohria*.
Figure 4. Cyatheaceae.
Figure 5. Dennstaedtiaceae.
Figure 6. Filicopsida.
Figure 7. Cupressaceae.
Figure 8. Cycadaceae.
Figure 9. *Calamus*.
Figure 10. *Nypa*.
Figure 11. *Aglaoreidia* sp.
Figure 12. *Carya*.
Figure 13. *Engelhardia*.
Figure 14. *Reveesia*.
Figure 15. *Plicapollis pseudoexcelsus*.
Figure 16. Fagaceae.
Figure 17. Deciduous *Quercus*.
Figure 18. *Trigonabalanus* sp.
Figure 19. Oleaceae.
Figures 20. Sapotaceae.
Figures 21, 22. Undifferentiated Dinoflagellate cysts.

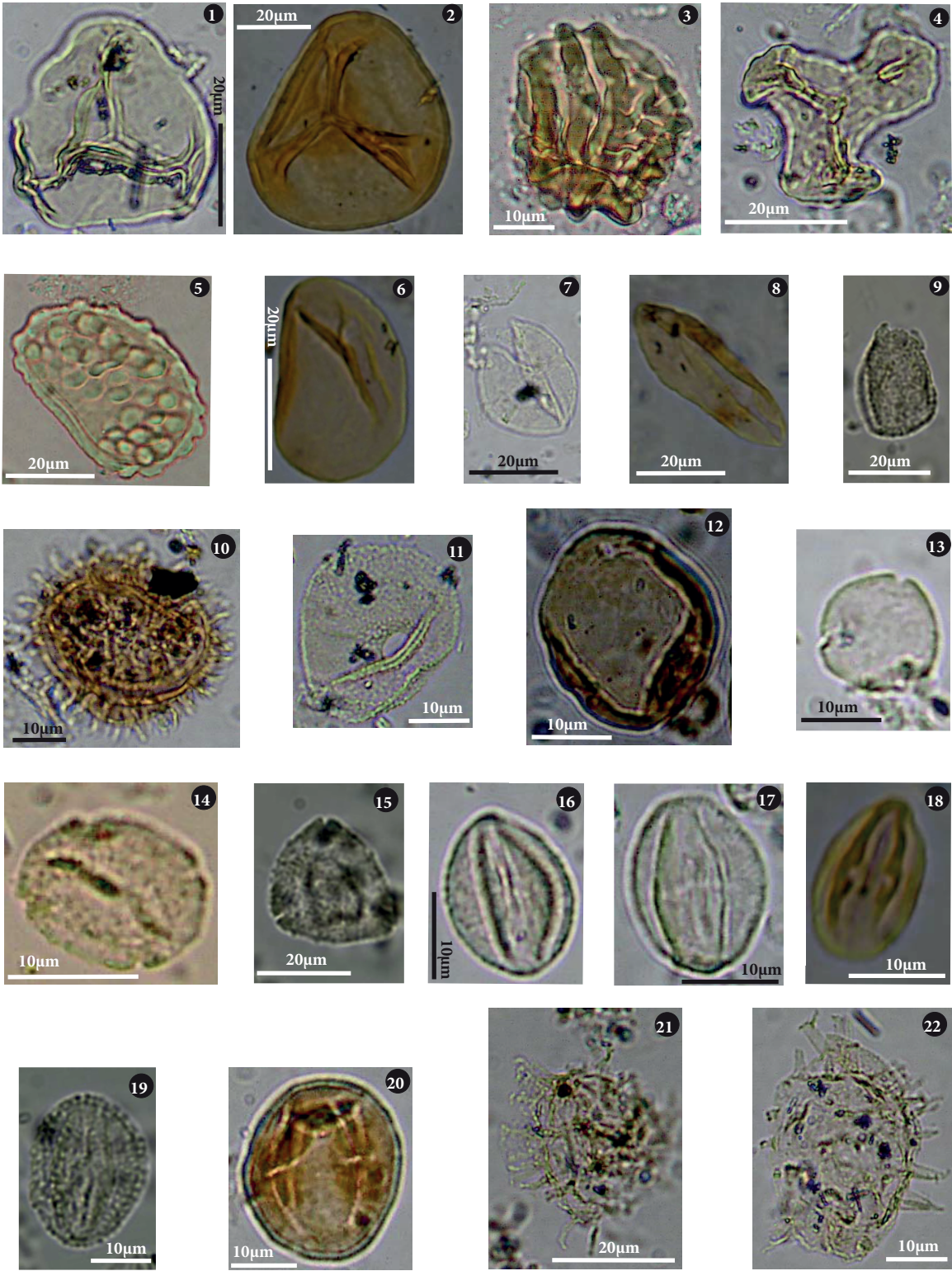


PLATE 4

(Selected mollusc photographs from the Şevketiye and Kuzu harbour sections)
(All photographs have their own scales)

Figures 1a, b. *Pirenella plicata* (Bruguiere) ×2.

Figures 2–4. *Tympanotonus margaritaceus* (Brocchi) ×2.

Figure 5a, b. *Natica millepunctata tigrina* Defrance ×2.

Figures 6a, b. *Ampullina crassatina* (Lamarck) ×1.

Figure 7. *Ampulina* sp. ×2.

Figures 8a, b. *Bullia* sp. ×2.5.

Figures 9–11. *Polymesoda convexa* (Brongniart) ×2.

Figure 12. *Cardium* (? *Trachycardium*) *egerense* Telegdi-Roth ×2.

Figure 13. *Pitar* (*Paradione*) *undata* (Basterot) ×2.

Figures 14, 15. *Angulus* (*Peronidia*) *nysti* (Deshayes) ×2.

