Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. 21, 2012, pp. 933–960. Copyright ©TÜBİTAK
doi:10.3906/yer-1102-8 First published online 25 April 2011

# Late Cretaceous–Eocene Geological Evolution of the Pontides Based on New Stratigraphic and Palaeontologic Data Between the Black Sea Coast and Bursa (NW Turkey)

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*Received 17 February 2011; revised typescript receipt 04 April 2011; accepted 25 April 2011*

**Abstract:** The Late Cretaceous–Eocene geological evolution of northwest Turkey between the Black Sea and Bursa was studied through detailed biostratigraphic characterization of eleven stratigraphic sections. The Upper Cretaceous sequence in the region starts with a major marine transgression and lies unconformably on a basement of Palaeozoic and Triassic rocks in the north (İstanbul-type basement) and on metamorphic rocks and Jurassic sedimentary rocks in the south (Sakarya-type basement). Four megasequences have been differentiated in the Late Cretaceous–Eocene interval. The first one, of Turonian to Late Campanian age, is represented by volcanic and volcanoclastic rocks in the north along the Black Sea coast, and by siliciclastic turbidites and intercalated calcarenites in the south, corresponding to magmatic arc basin and fore-arc basin, respectively. A major ridge along the present southern margin of the Kocaeli Peninsula separated these two realms. In the Late Campanian, volcanism and clastic sedimentation gave way to the widespread deposition of the pelagic limestone and marl of the Akveren Formation; only in the extreme south near Bursa are the pelagic micrites of the Akveren Formation replaced by calciturbidites and siliciclastic turbidites. The age of the Akveren Formation ranges from Late Campanian to Late Palaeocene. The third megasequence is a thick flysch wedge of Early Eocene age, which extends from north of Bursa to the Black Sea coast. The base of the Lower Eocene flysch is marked by a major unconformity. The flysch wedge marks the collision between the Pontides and the Anatolide-Tauride Block. The fourth megasequence is a thick volcanic and volcaniclastic series of late Early to Middle Eocene age, which extends from north of Bursa to the northern margin of the Armutlu Peninsula. The coherent Upper Cretaceous–Eocene stratigraphy, the laterally traceable facies belts, absence of ophiolitic slices and high pressure metamorphic rocks in the Upper Cretaceous–Tertiary series in the region between the Black Sea and Bursa indicate pre-Santonian juxtaposition of the İstanbul and Sakarya zones.

**Key Words:** Cretaceous, Palaeocene, Eocene, Pontides, Turkey, foraminifera

## Yeni Stratigrafik ve Paleontolojik Veriler Işığında Pontidler'in Karadeniz Sahil Şeridi ile Bursa Arasındaki Geç Kretase–Eosen Jeolojik Evrimi

**Özet:** Karadeniz ile Bursa arasındaki bölgenin Geç Kretase–Eosen dönemindeki evrimi onbir stratigrafik kesitin ölçülmesi ve ayrıntılı biyostratigrafik belgelenmesi ile çalışılmıştır. Bölgede Üst Kretase istifi denizel bir transgresyon ile başlar ve kuzeyde Paleozoyik ve Triyas yaşta sedimenter kayalar (İstanbul-tipi temel), güneyde ise metamorfik kayalar ve Jura kireçtaşları üzerinde (Sakarya-tipi temel) uyumsuzlukla yer alır. Geç Kretase–Eosen zaman aralığında dört megaistif ayrılmıştır. Turoniyen–Geç Kampaniyen yaşlı birinci istif kuzey kesimlerde volkanik ve volkanoklastik kayalar, güneyde ise silisiklastik türbiditler ve kalsitürbiditlerden oluşur. Bu istifler sırası ile magmatik yay havzası ve yay-önü havza istiflerine karşılık gelir. Kocaeli Yarımadası'nın güney kesimlerinde yeralan bir yükselim alanı bu iki farklı Kretase istifini ayırır. Geç Kampaniyen'de volkanizma ve klastik çökelim yerini pelajik kireçtaşı ve marl çökelimine bırakır. Geç Kampaniyen'den Geç Paleosen'e kadar çok geniş bir alanda Akveren Formasyonu'nun pelajik mikritleri çökelmiştir; sadece en güneyde Bursa çevresinde mikritler yanal olarak kalsitürbidit ve silisiklastik türbiditlere geçer. Üçüncü megaistif Bursa'dan kuzeye Karadeniz kıyısına kadar uzanan Erken Eosen yaşında kalın bir fliş kamasıdır. Tabanı önemli bir uyumsuzluk düzeyine karşılık gelen Alt Eosen flişi, Pontidler ile Anatolid-Torid Bloku'nun çarpışması sonucu retro-

önülke havzasında çökelmiştir. Dördüncü megaistif ise Bursa'dan Armutlu Yarımadası kuzey kenarına kadar uzanan geç Erken–Orta Eosen yaşlı volkanik ve volkanoklastik kayalardır. Karadeniz kıyısından Bursa'ya kadar uzanan alandaki düzenli Üst Kretase–Eosen istiflerinin varlığı, yanal olarak izlenebilen fasiyes kuşakları, bölgede Geç Kretase–Eosen yaşta ofiyolit dilimleri veya yüksek basınç metamorfitlerinin bulunmaması, İstanbul ile Sakarya zonlarının Santoniyen öncesi bir araya geldiklerini göstermektedir.

**Anahtar Sözcükler:** Kretase, Paleosen, Eosen, Pontidler, Türkiye, foraminifer

## Introduction

The Late Cretaceous–Eocene period represents the paroxysm of the Alpide Orogeny in Anatolia. Ophiolite obduction and the collision between the Pontides and the Anatolide-Tauride Block occurred in this period, and resulted in regional deformation and various types of regional metamorphism in the Anatolide-Tauride Block (e.g., Şengör & Yılmaz 1981; Okay & Tüysüz 1999). In this study the Late Cretaceous–Eocene evolution of northwest Turkey along a 100-km-long transect from the Black Sea coast in the north, to Bursa in the south is studied through detailed lithostratigraphic and biostratigraphic characterization of sedimantary units (Figure 1). Regions farther south, close to the İzmir-Ankara suture, are devoid of Cretaceous–Eocene sedimentary rocks, probably as a result of uplift and erosion, and areas south of the İzmir-Ankara suture have undergone regional metamorphism in the Late Cretaceous–Eocene period (Okay & Tüysüz 1999).

The sedimentary succession between the Black Sea and Bursa, consisting of both shallow- and deep-marine strata with a rich association of stratigraphically important foraminiferal taxa, permit us to establish a high-resolution time-space relationship of Upper Cretaceous–Eocene sedimentary units in northwest Turkey. The gathered data are used in the interpretation of the geological evolution of the region during this interval. The region studied covers two tectonostratigraphic terranes, the İstanbul and Sakarya zones, separated by the Intra-Pontide suture. There are widely diverging views on the age and significance of the Intra-Pontide suture (e.g., Yiğitbaş *et al.* 1999; Okay & Tüysüz 1999; Elmas & Yiğitbaş 2001, 2005; Robertson & Ustaömer 2004). The results of the study also provide clues on the age of this enigmatic suture.

The strands of the North Anatolian Fault, a post-Oligocene right-lateral strike-slip fault, divide the region into three parts: the Kocaeli Peninsula north of the main strand of the North Anatolian Fault, the Armutlu Peninsula bounded by the strands of the North Anatolian Fault and the area between İznik Lake and Bursa (Figure 1). The Cretaceous–Eocene stratigraphy in these regions is described and discussed below. The locations of the measured sections are shown in Figure 1 and their geographic coordinates are given in Table 1.

Our palaeontological results are based on the detailed study of larger benthic foraminifera (LBF) and planktonic foraminifera in Upper Cretaceous–Eocene series and we here only present the main palaeontological findings and their zonal significance. In larger foraminifera our results mostly depend on the study on the radial ('orbitoidal') foraminiferal groups, such as orbitoids in the Upper Cretaceous and orthophragmines in the Late Palaeocene and Early Eocene. The larger benthic foraminifera in the studied sections are represented by orbitoidal foraminifera and siderolitids in the Upper Cretaceous, orthophragmines (commonly known as discocyclinids), nummulitids (*Nummulites*, *Assilina* and *Operculina*) and alveolinids (very poorly) in the Upper Palaeocene–Lower Eocene shallow-marine strata, and by planktonic foraminifera in the Upper Cretaceous–Lower Eocene deep-marine beds.

The species and subspecies definition and stratigraphy of Thanetian–Ypresian orthophragmines (genera *Discocyclina*, *Nemkovella*, *Orbitoclypeus* and *Asterocyclina*) follow Less (1998), Less *et al*. (2007) and Özcan *et al.* (2007). We adopt the shallow benthic zones (SBZ) of Serra-Kiel *et al.* (1998) for the biostratigraphy of Palaeocene–Eocene shallow-marine units on the time scale based on Gradstein *et al*. (2004). Correlation of orthophragminid biozones with late Palaeocene and Eocene planktonic foraminifera, calcareous nannoplankton and shallow benthic biozones (SBZ) follows Figure 5 of Özcan

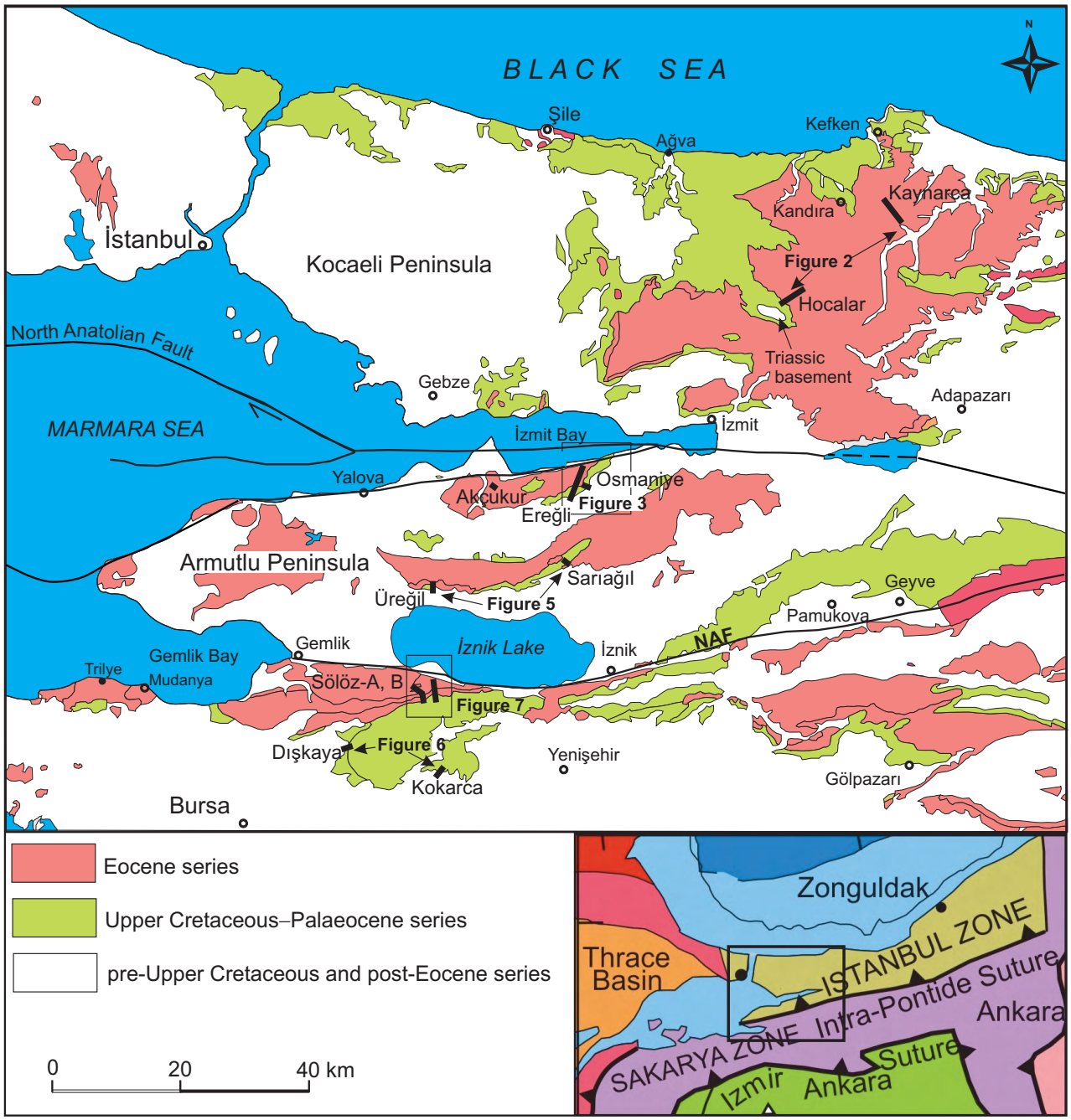


**Figure 1.** The Cretaceous, Palaeocene and Eocene outcrops in northwest Turkey (compiled from Türkecan & Yurtsever 2002; Konak 2002). The locations of the measured sections are shown. The inset shows the tectonic map of the Eastern Mediterranean modified from Okay & Tüysüz (1999). NAF– North Anatolian Fault.

*et al.* (2010). The classifications of Robaszynski *et al.* (1984), Caron (1985) and Premoli Silva & Verga (2004) are employed here for Maastrichtian planktonic foraminifera, whereas the Palaeocene–Eocene planktonic foraminifera are classified according to Berggren & Norris (1997) and Olsson *et al.* (1999).

**Table 1.** Locations of the measured sections and samples.

| Sections | UTM Coordinates (°) | |
|---|---|---|
| Kaynarca | 0269862, 4548455 | 0269900, 4548300 |
| | Sample 8 | 0269900, 4548300 |
| Hocalar | 0749129, 4537463 | 0749131, 4537649 |
| | 0723562, 4503190 | 0725984, 4508709 |
| | Sample 4 | 0723502, 4503898 |
| Ereğli | Sample 19 | 0723531, 4504647 |
| | Sample 21 | 0723377, 4504419 |
| | Sample 29 | 0724954, 4506149 |
| Osmaniye | 0728079, 4505450 | 0726892, 4505482 |
| | Sample 8 | 0726422, 4505781 |
| Akçukur | 0711330, 4503709 | 0711500, 4503550 |
| | Sample 14 | 0711330, 4503709 |
| Sarıağıl | 0725635, 4493634 | 0725288, 4494483 |
| | 0706450, 4488750 | 0706560, 4489480 |
| | Sample 2 | 0705883, 4488877 |
| Üreğil | Sample 6 | 0706138, 4488979 |
| | Sample 9 | 0706382, 4489076 |
| | Sample 15a | 0706602, 4489680 |
| | 0705440, 4470933 | 0703726, 4474604 |
| | Sample 14 | 0705108, 4473029 |
| Sölöz A | Sample 19 | 0705093, 4473060 |
| | Sample 22b | 0704743, 4473549 |
| | Sample 25 | 0704914, 4474048 |
| | 0704340, 4471390 | 0702611, 4473502 |
| Sölöz B | Sample 3 | 0704160, 4472245 |
| | Sample 6 | 0702611, 4473502 |
| | 0691000, 4461169 | 0691233, 4461346 |
| Dışkaya | Sample 2 | 0691000, 4461169 |
| | Sample 3 | 0691115, 4461189 |
| Kokarca | 0695368, 4458572 | 0695468, 4458701 |
| | Sample 6 | 0695368, 4458701 |

## Kocaeli Peninsula

The Upper Cretaceous–Eocene stratigraphy in the Kocaeli Peninsula is relatively well known (e.g., Erguvanlı 1949; Altınlı 1968; Altınlı *et al.* 1970; Dizer & Meriç 1981; Tansel 1989; Özer *et al.* 1990; Gedik *et al.* 2005a, b). In the north along the Black Sea coast, the Upper Cretaceous begins with a volcanic-volcanogenic series, the Yemişliçay Group, which lies unconformably over the Triassic and older sedimentary rocks. The Yemişliçay Group consists of basaltic and andesitic tuffs, agglomerates, lava flows, volcanogenic sandstones and shales with a thickness of over 500 metres. Gedik *et al.* (2005a) described a Late Santonian–Campanian fauna of planktonic foraminifera and nannofossils from the volcanogenic series. The Yemişliçay Group is overlain by 50 to 80 m of pelagic limestones of the Akveren Formation. The age of the Akveren Formation in the northern part of the Kocaeli Peninsula is Late Campanian to Middle Palaeocene (Selandian) (Gedik *et al.* 2005a). Around Şile the Akveren Formation passes up into the 5–350 m thick shales and marls of the Late Palaeocene (Thanetian)–Early Eocene (Ilerdian) Atbaşı Formation (Gedik *et al.* 2005b). The Atbaşı Formation is overlain by a turbiditic sequence of sandstone, shale and marl with olistostrome horizons. The blocks in the olistostromes are predominantly limestones of the Akveren Formation (Baykal & Önalan 1979; Gedik *et al.* 2005b). The larger foraminifera, dominated by orthophragmines in the matrix of the olistostrome, have been assigned to orthophragminid zones (OZ) 3 and SBZ 7/8 (lower Ypresian). The planktonic foraminifera suggest an interval from the middle part of P6 to the top of P7 (Ilerdian–Cuisian transition= middle part of Ypresian) (Less *et al.* 2007). The olistostromal unit is unconformably overlain by shallow marine sandstone, marl and nummulitic limestone of early Lutetian age (SBZ 13, Yunuslubayır Formation, Özcan *et al.* 2007). Continuous deposition from the Campanian to Early Eocene is observed all along the southern Black Sea coast, represented by the Campanian–Maastrichtian Akveren, Palaeocene Atbaşı and Lower Eocene Kusuri formations (Görür 1997; Tüysüz 1999; Hippolyte *et al.* 2010).

The volcanic and volcaniclastic rocks of the Yemişliçay Group, widespread along the Black Sea coast, become thinner towards the south and are absent in the Kocaeli Peninsula south of 41°N, where the Upper Cretaceous section starts locally with a sequence of sandstone, pebbly sandstone and conglomerate with clasts derived from the Palaeozoic rocks (Gedik *et al.* 2005c). This Teksen Formation lies with an angular unconformity over the Palaeozoic and Triassic series (Baykal 1943; Gedik *et al.* 2005c); its age is constrained to the Santonian–Campanian interval. However, in many localities the Teksen Formation is also absent and the Upper Cretaceous

sequence starts with the Akveren Formation. The Hocalar section measured in the Kocaeli Peninsula is located in one such area, where the Triassic conglomerate and sandstone are directly overlain by the Akveren Formation with no intervening Teksen and Yemişliçay formations (Gedik *et al*. 2005c).

*Akveren and Çaycuma Formations*

The Hocalar section is 110-m-thick and encompasses both the Akveren and the overlying Çaycuma formations (Figure 2). The Akveren Formation has a minimum thickness of 60 m and consists of white, light grey, medium- to thickly-bedded pelagic limestones rich in planktonic foraminifera. In the upper parts of the section there are intercalations of brown, coarse-grained turbiditic sandstone beds with benthic foraminifera. Three pelagic limestone samples from the lower part of the section (samples 1, 3 and 4, Figure 2) contain planktonic foraminifera of Middle–Late Maastrichtian age: *Abathomphalus intermedius* (Bolli), *Contusotruncana contusa* (Gandolfi), *C.* cf. *fornicata* (Plummer), *C. walfishensis* (Todd) (Plate 1, A-d), *Gansserina gansseri* (Bolli) (Plate 1, A-j), *Globotruncana arca* (Cushman) (Plate 1, A-f), *G. esnehensis* Nakkady, *G. insignis* Gandolfi, *G. linneiana* (d'Orbigny), *G. orientalis* El-Naggar, *Globotruncanita conica* (White) (Plate 1, A-a), *Gt. stuarti* (de Lapparent) (Plate 1, A-b), *Gt.* cf. *stuartiformis* (Dalbiez) (Plate 1, A-i), *Globotruncanella havanensis* (Voorwijk) (Plate 1, A-m), *Pseudotextularia elegans* (Rzehak), *P. intermedia* de Klasz, *Racemiguembelina fructicosa* (Egger) (Plate 1, A-h), *Heterohelix* sp. and *Planoglobulina* sp. (Plate 1, A-g).

Samples ca. 15 m below the upper contact of the Akveren Formation (samples 8 and 9) contain Middle–Late Palaeocene (late Selandian–Thanetian) planktonic foraminifera: *Globanomalina chapmani* (Parr), *G. pseudomenardii* (Bolli) (Plate 1, B-f), *Igorina pusilla* (Bolli), *I. albeari* (Cushman) (Plate 1, B-e), *I. tadjikistanensis* (Bykova), *Morozovella acuta* (Toulmin), *M. angulata* (White), *M. apanthesma* (Loeblich and Tappan), *M. occlusa* (Loeblich and Tappan), *M. velascoensis* (Cushman), *M. subbotinae* (Morozova) (Plate 1, B-ı), *Parasubbotina pseudobulloides* (Plummer), *Subbotina hornibrooki* (Brönnimann), *S. triloculinoides* (Plummer) and *S. velascoensis* (Cushman). The gap encompassing the late Thanetian and early Ypresian between these levels and the overlying Çaycuma Formation may be due to the condensed nature of the sediments or more likely because of a disconformity at the base of the Çaycuma Formation.

In the Hocalar section the Akveren Formation is overlain, probably unconformably, by a 50-m-thick package of yellowish, medium- to thickly-bedded fine to coarse sandstone and siltstone intercalations with larger foraminifera locally in rock-forming abundance. This foraminifera-dominated shallow-marine succession is ascribed to the Çaycuma Formation. Samples from the coarse sandstone beds close to the base (11 and 13) and from the top of the section (sample 16) contain the following benthic foraminiferal taxa: *Discocyclina archiaci archiaci* (Schlumberger) (Plate 2m), *D. fortisi* (d'Archiac) *simferopolensis* Less, *D. augustae* van der Weijden cf. *sourbetensis* Less (Plate 2n), *D. dispansa* (Sowerby), *Nemkovella strophiolata* (Gümbel) ex. interc. *strophiolata-fermonti* Less, *N. bodrakensis* Less, *Orbitoclypeus munieri* cf. *munieri* (Schlumberger), *O.douvillei douvillei* (Schlumberger). *Asterocyclina stellata* (d'Archiac) *adourensis* Less. Sample 13 contains *Nummulites burdigalensis* de la Harpe, *N. partschi* de la Harpe and *Assilina placentula* (Deshayes), characteristic for SBZ 10, while in sample 16, *Nummulites distans* Deshayes and *A. cuvillieri* Schaub marking SBZ 11 have been identified. This assemblage is accompanied by a rich association of molluscs. The above foraminiferal assemblage is referred to SBZ 10 and 11 (lower and middle part of the Cuisian). This shallow-marine package which has a limited lateral extent (see also the Kaynarca section below) is probably unconformable over the deep-marine Palaeocene beds.

The Kaynarca section is located 15 km northeast of the Hocalar section. It includes only the Çaycuma Formation, which here has a minimum thickness of 75 metres. The section starts with yellowish siltstones with intercalations of coarse sandstone beds and continues upward with a shale-siltstone intercalation (Figure 2). A sample from the basal siltstone beds (1a) contains Lower Eocene planktonic foraminifera *Acarinina primitiva* (Finlay) and smaller benthic foraminifera; the siltstone and sandstone beds in the shales also contain larger benthic foraminifera.

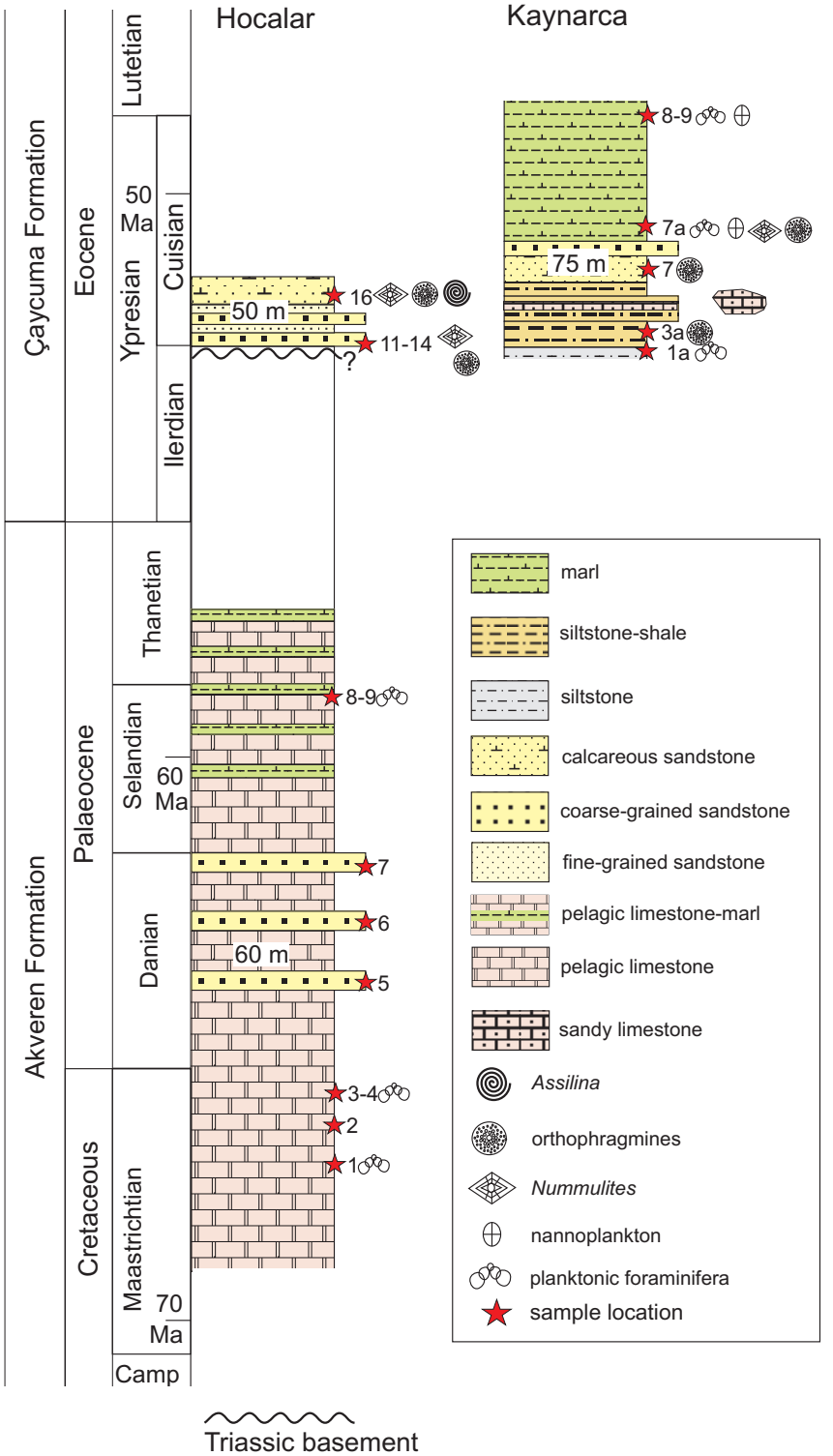


**Figure 2.** The stratigraphy of the Upper Cretaceous–Eocene sequence in the Hocalar and Kaynarca sections from the Kocaeli Peninsula. The sections are time-scaled with the stratigraphic time scale from Gradstein *et al.* (2004). For the location of the sections see Figure 1.

A composite assemblage for samples 3a, 7 and 7a include *Discocyclina archiaci archiaci* (Schlumberger) (Plate 2l), *D. fortisi fortisi* (d'Archiac) (Plate 2i), *D. augustae* Weijden *sourbetensis* Less, *D. weijdeni* Less, *D. trabayensis* Neumann, *Nemkovella evae* Less (Plate 2x), *N. strophiolata* (Gümbel) *fermonti* Less (Plate 2w), *Orbitoclypeus douvillei* (Schlumberger) *yesilyurtensis* Özcan (Plate 2r), *O. multiplicatus* (Gümbel) cf. *kastamonuensis* Less and Özcan, *O. munieri* (Schlumberger), *O. furcatus* (Rutimeyer), *Asterocyclina stella* (Gümbel), *Nummulites rotularius* Deshayes, *N. irregularic* Deshayes and *Assilina plana* Schaub. This assemblage is referred to SBZ 10 (lower part of the Upper Ypresian) and correlated with the foraminiferal assemblage identified in the Hocalar section. We suggest that the studied part of the marine record suggests a major shallowing phase during the early Cuisian, which is recognised on a regional scale in central and northwest Anatolia.

The Kaynarca section ends with light grey, massive marls. Sample 7a from the base of the marls, which contains transported larger foraminifera, was also studied for planktonic foraminifera and nannoplanktons. The planktonic foraminifera are characteristic of the *Morozovella aragonensis* Zone (late Early Eocene): *Acarinina pentacamerata* Subbotina, *A. primitiva* (Finlay), *Morozovella aragonensis* (Nuttall), *M. caucasica* (Glaessner), M. subbotinae (Morozova), *Globigerina inaequispira* Subbotina and *Globigerina* sp. The nannoplankton fauna in the same sample is characteristic of NP 12 (middle Early Eocene): *Discolithina plana* (Bramlette et Sullivan), *Helicosphaera* cf. *lophota* (Bramlette et Sullivan), *H. seminulum* Bramlette et Sullivan, *Zygrhablithus bijugatus* (Deflandre), *Coccolithus pelagicus* (Wallich), *Cyclococcolithus formosus* Kamptner, *Chiasmolithus expansus* (Bramlette et Sullivan), *Discoaster multiradiatus* Bramlette et Riedel, *D. lodoensis* Bramlette et Riedel, *D. binudosus* Martini, *D. barbadiensis* Tan, *D. deflandrei* Bramlette et Riedel and *Sphenolithus radians* Deflandre. Two samples from the marls at the top of the Kaynarca section (8 and 9, Figure 2) contain planktonic foraminifera also characteristic of the *Morozovella aragonensis* Zone and a calcareous nannoplankton assemblage represented by *Helicosphaera lophota* (Bramlette et Sullivan), *Zygrhablithus bijugatus* (Deflandre), *Coccolithus pelagicus* (Wallich), *Cyclococcolithus formosus* Kamptner, *Cyclicargolithus floridanus* (Roth et Hay), *Chiasmolithus grandis* (Bramlette et Riedel), *C.* cf. *solitus* (Bramlette et Sullivan), *Reticulofenestra* aff. *bisecta* (Hay et al.), *R. hillae* Bukry et Percival, *Discoaster deflandrei* Bramlette et Riedel, *D. barbadiensis* Tan, *D. lodoensis* Bramlette et Riedel, *Braarudosphaera bigelowi* (Gran et Braarud), *Sphenolithus radians* Deflandre. The nannoplankton assemblage could be assigned to the NP 14 Zone according the ranges of *Discoaster lodoensis* (NP 12-14) and *Helicosphaera lophota* (from NP 14). This suggests that these levels correspond to the Ypresian–Lutetian transition.

Data from the Hocalar and Kaynarca sections from the Kocaeli Peninsula indicate that the Akveren Formation ranges from middle Maastrichtian to Late Palaeocene in age, as also shown by previous studies (e.g., Dizer & Meriç 1981; Tansel 1989; Özer *et al.*1990). The unconformable passage from quiet carbonate deposition to the Cuisian (late Early Eocene) flysch of the Çaycuma Formation is constrained to the late Thanetian–Ilerdian interval.

**Armutlu Peninsula**

Compared to the Kocaeli Peninsula, the Cretaceous stratigraphy of the Armutlu Peninsula is more complex and less well understood. Akartuna (1968) described clastic and carbonate rocks of Campanian–Maastrichtian age from the Armutlu Peninsula. Bargu & Sakınç (1989/1990) differentiated a basal Campanian–Maastrichtian sequence of conglomerate, sandstone and siltstone (Oluklu Formation), 400–500 m thick, overlain by 600-m-thick Maastrichtian limestones. A very thick series of Maastrichtian olistostromes has been described from the eastern part of the Armutlu Peninsula (Erendil *et al.* 1991). The Palaeocene has been reported either as a limestone (Bargu & Sakınç 1989/1990) or as a flysch sequence (Akartuna 1968; Erendil *et al.* 1991). According to Akartuna (1968) and Erendil *et al.* (1991) the Palaeocene flysch continues into the Eocene but includes tuffaceous horizons.

Five sections have been measured in the Armutlu Peninsula; three in the north (Ereğli, Osmaniye and Akçukur) and two in the south (Sarıağıl and Üreğil)

(Figure 1). The common features of these sections are a highly heterogeneous basal clastic sequence of Campanian age called the Osmaniye Formation, which is overlain by Campanian to Palaeocene carbonates of the Akveren Formation. The Akveren Formation passes in the south to the turbidites of the Üreğil Formation. As in the Kocaeli Peninsula, the Lower Eocene has developed in clastic facies. These formations will be described below, based on the measured sections.

*Osmaniye Formation*

The Osmaniye Formation is a deep-water clastic unit over 430 metres thick and of Campanian age. It forms the base of the Cretaceous sequence in the Armutlu Peninsula and unconformably overlies a metamorphic basement (Bargu & Sakınç 1989/1990), but in the measured sections the contacts between the Osmaniye Formation and the underlying metamorphic rocks are faulted (Figure 3). The bulk of this unit consists of conglomerate, sandstone and siltstone with lesser intercalations of calciturbidite and marl (Figure 4a). The conglomerates represent debris flows and may reach several hundred metres in thickness.

In the Ereğli section the Osmaniye Formation is represented mainly by siltstones and sandstones 200 m thick. The upper parts of the clastics include calciturbidite, marl and sandy limestone intercalations (Figure 5). Larger benthic foraminifera in the calciturbidites include *Lepidorbitoides* sp., *Praesiderolites* sp. (Plate 2a) and *Pseudosiderolites* sp. (samples 4 and 7), and indicate a Campanian age. A marl sample from a similar stratigraphic level (5) comprises Upper Campanian–Maastrichtian planktonic foraminifera: *Globotruncana linneiana* (d'Orbigny), *Kuglerina rotundata* (Brönnimann and Brown), *Hedbergella* sp., *Heterohelix* sp. and *Rugoglobigerina* sp. The Osmaniye Formation in the Ereğli section ends with conglomerates with well-rounded and poorly-sorted purple and green sandstone clasts, 1–50 cm across.

In the Osmaniye section, the Osmaniye Formation is 430 m thick and consists mainly of conglomerates with well-rounded, poorly-sorted clasts of grey, reddish, or green sandstone in a sandy matrix (Figure 5). The conglomerate horizons are separated by siltstone beds. In the upper part of the Osmaniye Formation the conglomerates pass up into sandstones and marls. In the Üreğil section the Osmaniye Formation starts with dark grey, massive pebbly sandstones and passes up into a sandstone-siltstone-shale intercalation (Figure 6). Larger benthic foraminifera from the pebbly sandstones indicate a Campanian age: *Lepidorbitoides campaniensis* van Gorsel, *Orbitoides* sp. and *O.* cf. *media* (sample 2; Figure 6). In the Sarıağıl section, the Osmaniye Formation is 135 m thick and is mainly represented by conglomerates with shale interbeds, which pass up into medium- to thickly-bedded coarse-grained sandstones with flute casts. Campanian benthic foraminifera *Praesiderolites* sp. have been found in the matrix of the conglomerates (sample 3).

Data from the four stratigraphic sections from the Armutlu Peninsula indicate that the Osmaniye Formation is a sequence of Campanian debris flows and proximal siliciclastic flysch with intercalations of calciturbidite and marl over 430 m thick. Greber (1996) described a similar Campanian–Maastrichtian debris flow unit with large blocks of Santonian pelagic limestones from southeast of Adapazarı, where it also lies on metamorphic rocks.

*Akveren Formation*

The Akveren Formation in the Armutlu Peninsula is 270 m thick and consists of pelagic limestones, which conformably overlie the clastic rocks of the Osmaniye Formation. In the southern part of the Armutlu Peninsula in the Üreğil and Sarıağıl sections the age equivalent strata are represented by calciturbidites and intercalated clastic rocks and have been described as part of the Üreğil Formation.

In the Ereğli section the Akveren Formation is 200 m thick and consists of pale green, light grey pelagic limestones, which rest on the conglomerates of the Osmaniye Formation. Transported larger benthic foraminifera of Campanian age (*Lepidorbitoides* sp., *Praesiderolites* sp. and *Pseudosiderolites* sp.) are found in the lower part of the Akveren Formation (sample 12, Figure 5). Higher in the section pelagic limestones include Maastrichtian planktonic foraminifera represented by *Gansserina gansseri*

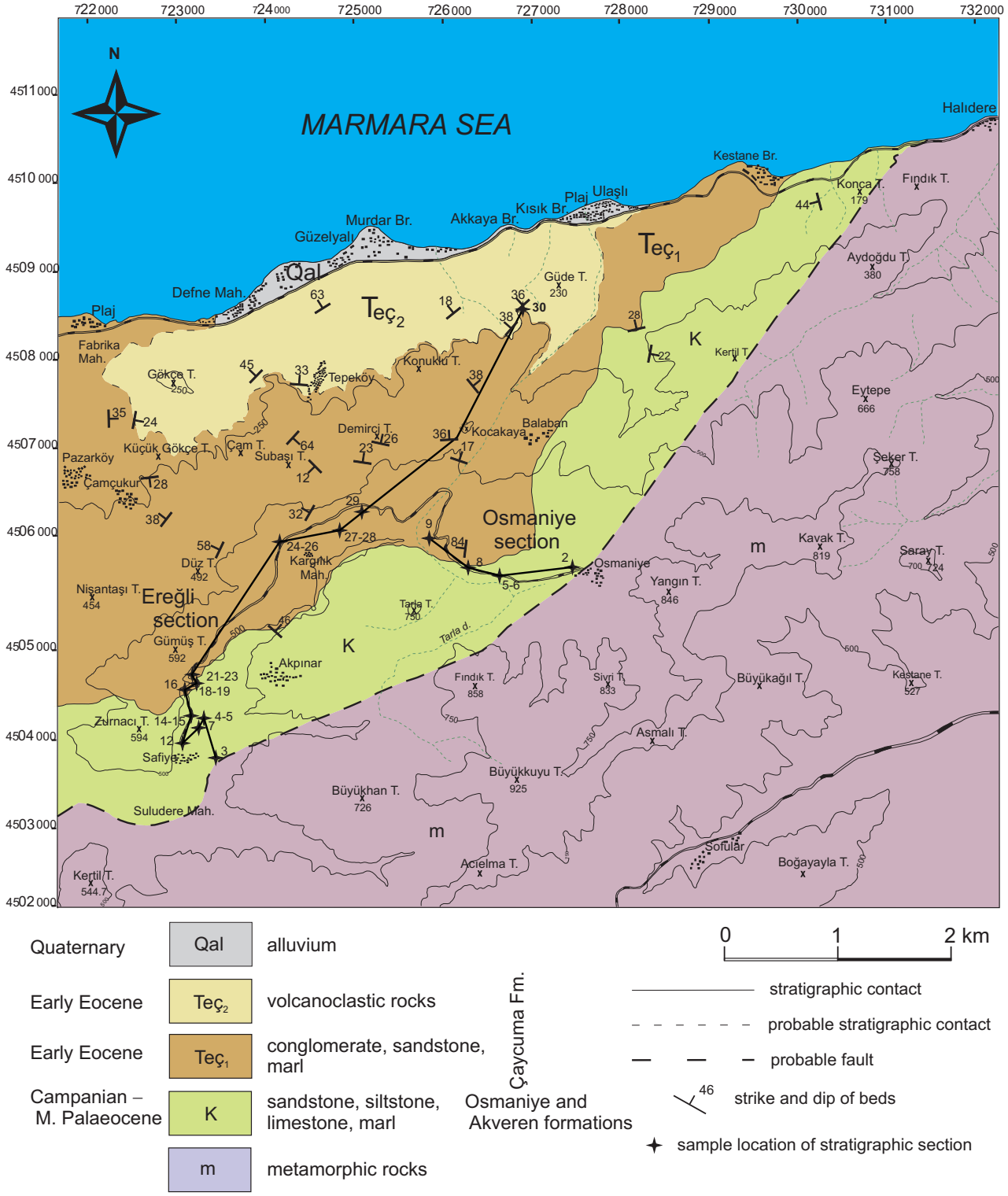


**Figure 3.** Geological map of the region south of İzmit Bay showing the locations of the Ereğli and Osmaniye sections. For the location of the map see Figure 1.

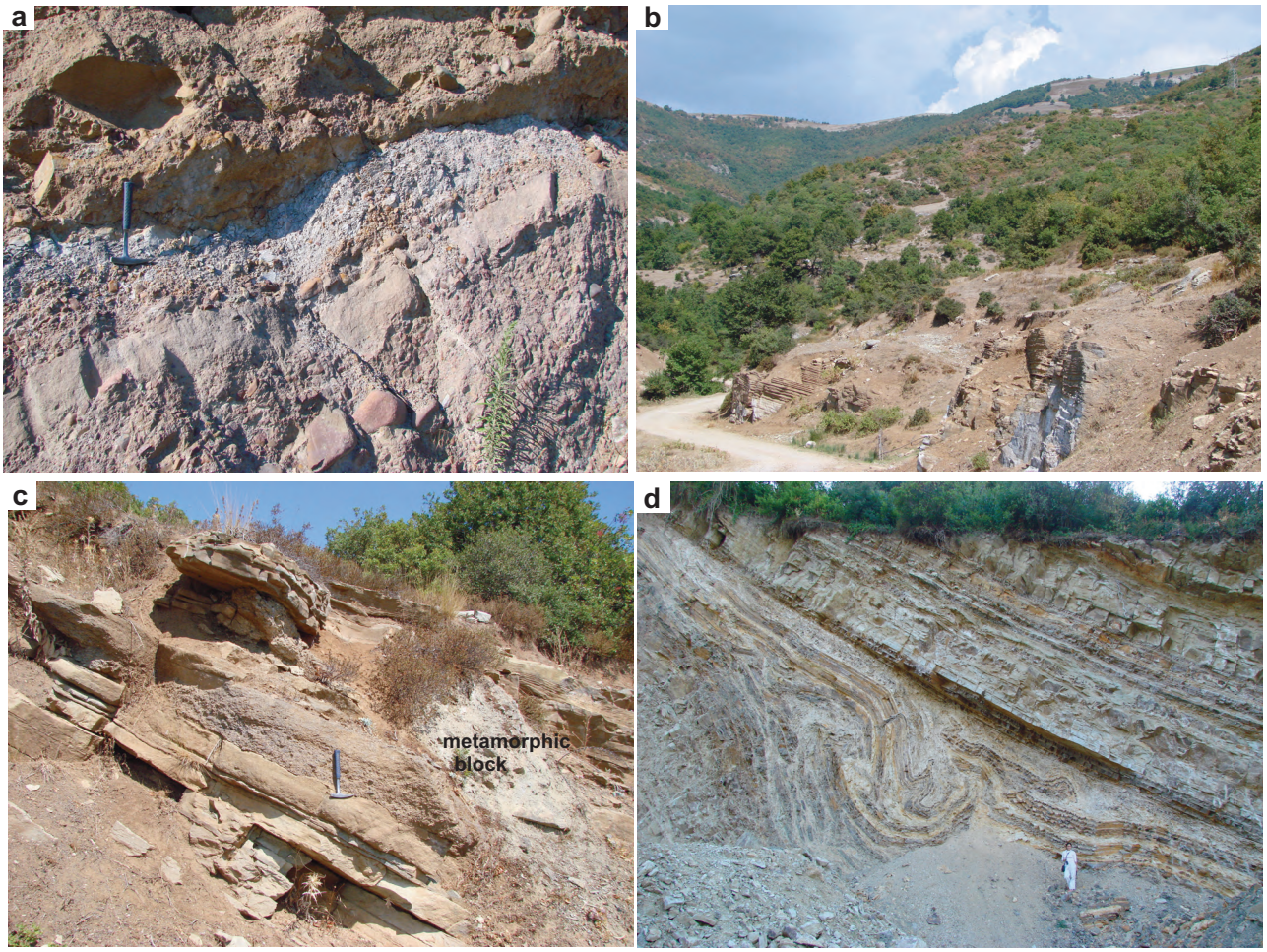


**Figure 4.** **(a)** Sandstone and conglomerates of the Osmaniye Formation. **(b)** Calciturbidites of the Üreğil Formation from the Üreğil section north of İznik Lake. The top of the crest in the back is made up of Cuisian–Lutetian volcanic rocks. **(c)** Sandstone, conglomerate, calciturbidites of the Üreğil Formation with a large metamorphic block, north of the İznik lake. **(d)** Slump in the Eocene sequence in the Ereğli section, north of the Armutlu Peninsula, Karamürsel.

(Bolli), *Globotruncana arca* (Cushman), *G. orientalis* El-Naggar, *Globotruncanita stuarti* (d'Lapparent), *Gt. stuartiformis* (Dalbiez), *Kuglerina rotundata* (Brönnimann) (Plate 1, A-l), *Globotruncanita* sp., *Contusotruncana* sp., *Globotruncanella petaloidea* (Gandolfi), *Planoglobulina acervulinoides* Egger, *Racemiguembelina fructicosa* (Egger), *Heterohelix* sp., *Pseudoguembelina* sp., *Globigerinelloides* sp. and *Rugoglobigerina* sp. (samples 14 and 15, Figure 5). The upper part of the limestone sequence contains Lower Palaeocene (Danian) foraminifera: *Eoglobigerina edita* (Subbotina) (Plate 1, B-a), *Eoglobigerina eobulloides* (Morozova) (Plate 1, B-b), *Globanomalina compressa* (Plummer), *Parasubbotina pseudobulloides* (Plummer), *Praemurica inconstans* (Subbotina) (Plate 1, B-c), *P. taurica* (Morozova) (Plate 1, B-d), and *Subbotina triloculinoides* (Plummer) (sample 16), and a sample from the uppermost part of the limestone sequence (18) has Middle–Late Palaeocene (late Selandian–Thanetian) foraminifera: *Globanomalina ehrenbergi* (Bolli), *G. pseudomenardii* (Bolli), *Morozovella acuta* (Toulmin), *M. angulata* (White) (Plate 1, B-g), *M. apanthesma* (Loeblich and Tappan), *M. occlusa* (Loeblich and Tappan), *M. pasionensis* (Bermudez), *Igorina albeari* (Cushman and Bermudez), *I pusilla* (Bolli), *I. tadjikistanensis* (Bykova), *Parasubbotina pseudobulloides* (Plummer), *Subbotina triangularis* (White), and *S. triloculinoides* (Plummer).

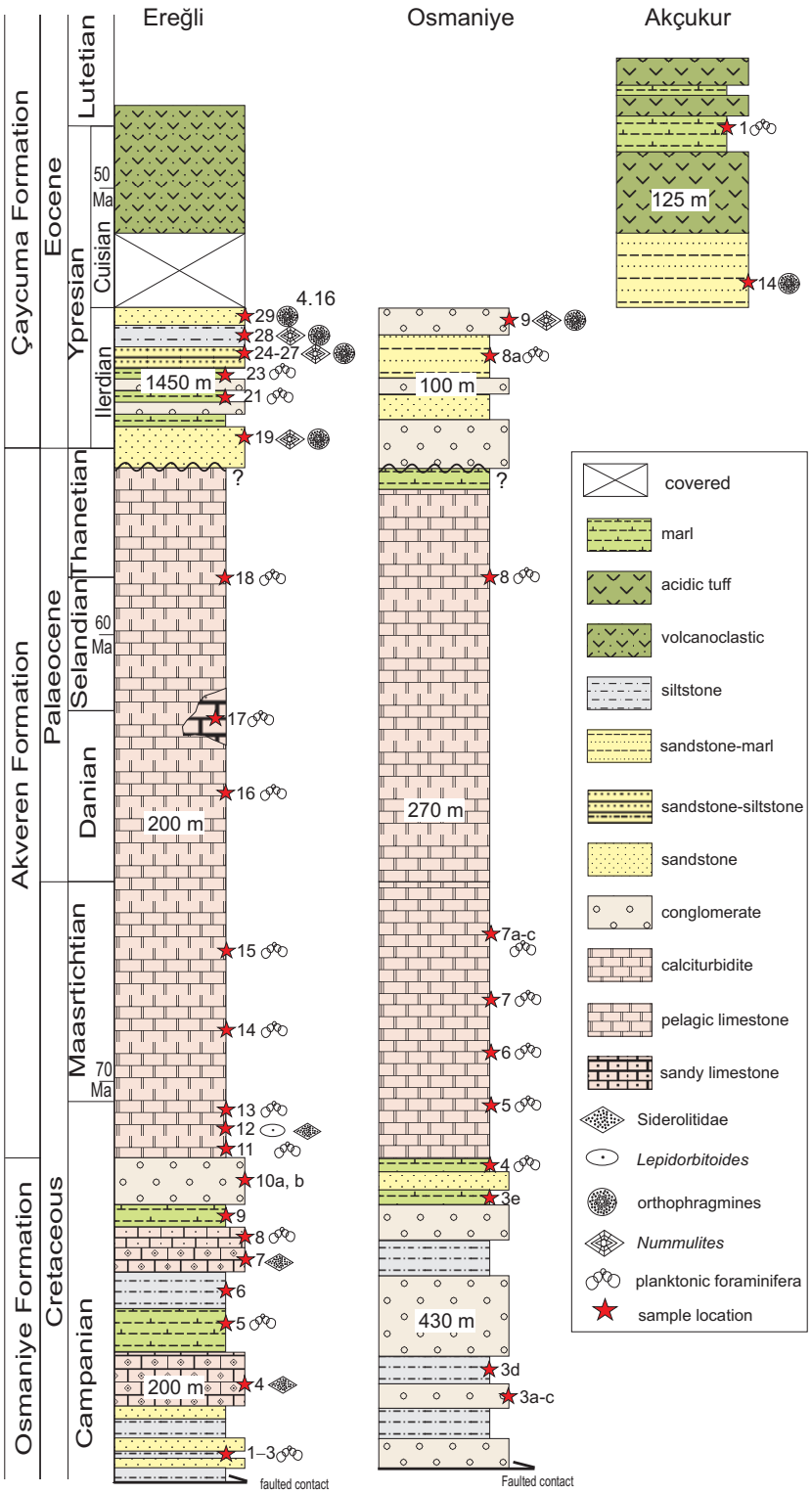


**Figure 5.** The stratigraphy of the Upper Cretaceous–Eocene sequence in the Ereğli, Osmaniye and Akçukur sections from the Armutlu Peninsula. The sections are time-scaled with the stratigraphic time scale from Gradstein *et al.* (2004). For the location of the sections see Figure 1.

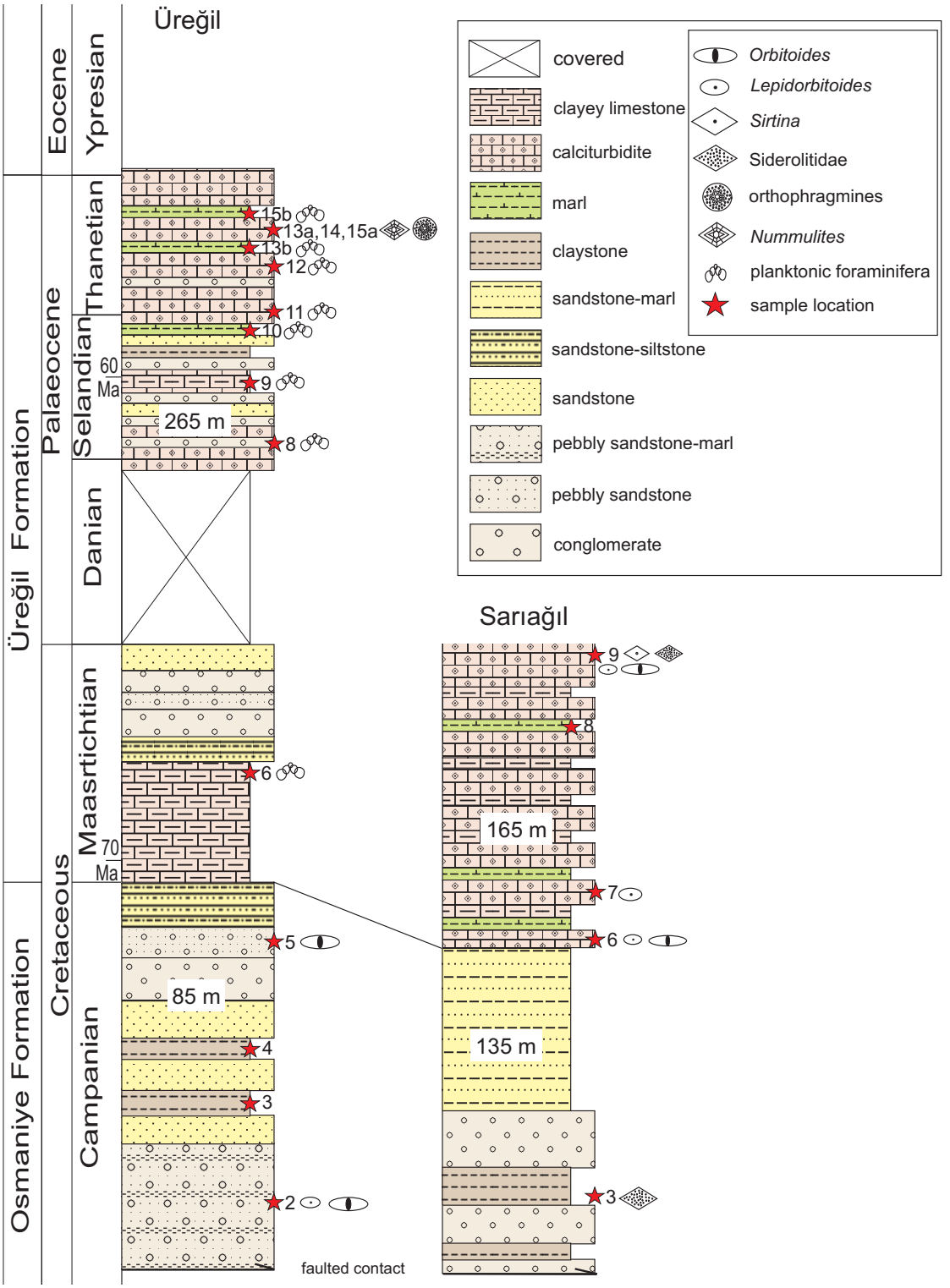


**Figure 6.** The stratigraphy of the Upper Cretaceous–Eocene sequence in the Üreğil and Sarıağıl sections from the southern part of the Armutlu Peninsula. The sections are time-scaled with the stratigraphic time scale from Gradstein *et al.* (2004). For the location of the sections see Figure 1.

In the Osmaniye section pelagic limestones of the Akveren Formation, also ca. 270 m thick, conformably overlie the marls and sandstones of the Osmaniye Formation. A sample from the base of the Akveren Formation (sample 5, Figure 5) contains planktonic foraminifera characteristic for the Upper Campanian–Maastrichtian: *Contusotruncana fornicata* (Plummer), *Globotruncana arca* (Cushman), *G. orientalis* El-Naggar, *Globotruncanita stuarti* (d'Lapparent), *Globotruncanella pschadae* (Keller) (Plate 1, A-n), *Rugoglobigerina rugosa* (Plummer), *Pseudotextularia elegans* (Rzehak), *Globotruncanella* sp., *Rugoglobigerina* sp., *Heterohelix* sp., *Racemiguembelina* sp. and *Heterohelix* sp. The top of the Akveren Formation in the Osmaniye section is dated as Middle–Late Palaeocene (late Selandian–Thanetian) based on the planktonic foraminiferal assemblage of *Acarinina pseudotopilensis* Subbotina, *A. strabocella* (Loeblich and Tappan), *Globanomalina ehrenbergi* (Bolli), *G. pseudomenardii* (Bolli), *G. chapmani* (Parr), *Igorina tadjikistanensis* (Bykova), *Morozovella acuta* (Toulmin), *M. angulata* (White), *M. apanthesma* (Loeblich and Tappan), *M. conicotruncata* (Subbotina), *M. occlusa* (Loeblich and Tappan) (Plate 1, B-h), *M. velascoensis* (Cushman) (Plate 1, B-o), *Parasubbotina pseudobulloides* (Plummer) (Plate 1, B-j), *Subbotina triangularis* (White), and *S. triloculinoides* (Plummer) (Plate 1, B-n) (sample 8, Figure 5).

The Ereğli and Osmaniye sections indicate that the Akveren Formation in the Armutlu Peninsula is 270 m thick and consists of Late Campanian to Middle–Late Palaeocene pelagic limestones.

### *Üreğil Formation*

The Late Campanian–Palaeocene interval in the Kocaeli Peninsula and in the northern parts of the Armutlu Peninsula is represented by the pelagic limestones and marls of the Akveren Formation. In contrast, this interval in the southern part of the Armutlu Peninsula is characterized by mixed clastic-carbonate deposition. This sequence, which is lithologically different from the Akveren Formation, is named the Üreğil Formation, the type section of which is the Üreğil section between Karamürsel and İznik Lake (Figure 6).

In the Üreğil section the Üreğil Formation starts with grey, massive clayey limestones with a fauna of Middle–Upper Maastrichtian planktonic foraminifera: *Contusotruncana contusa* (Cushman) (Plate 1, A-e), *C. patelliformis* (Gandolfi), *C. walfishensis* (Todd), *Gansserina gansseri* (Bolli), *Globotruncana esnehensis* (Nakkady), *G. rosetta* (Carsey), *Globotruncanita conica* (White), *Gt. stuarti* (de Lapparent), *Pseudotextullaria elegans* (Rzehak), and *Racemiguembelina fructicosa* (Egger), *Heterohelix* sp. and *Pseudoguembelina* sp. (sample 6; Figure 6). The clayey limestone is overlain by an intercalation of sandstone, siltstone and conglomerate, which pass up into thinly- to thickly-bedded, locally laminated and graded calciturbidites (Figure 4b, c). A sample from the calciturbidites (sample 8, Figure 6) comprises planktonic foraminifera of Middle–Late Palaeocene (Selandian–Thanetian) age: *Globanomalina compressa* (Plummer), *G. ehrenbergi* (Bolli), *Morozovella angulata*, *Parasubbotina pseudobulloides* (Plummer) and *Subbotina triloculinoides* (Plummer). The same sample also includes transported Upper Maastrichtian foraminifera: *Abathomphalus mayaroensis* (Bolli) (Plate 1, A-k), *Globotruncana arca* (Cushman), *Globotruncanita stuarti* (de Lapparent), *Planoglobulina* sp., *Globotruncanella* sp. and *Racemiguembelina* sp. The next 90 metres of the section consists of an intercalation of calciturbidite, conglomerate, marl and clayey limestone. Several samples from this interval contain pelagic foraminifera of Middle–Late Palaeocene (Selandian–Thanetian) age: *Globanomalina chapmani* (Parr), *G. ehrenbergi* (Bolli), *Igorina* sp., *Morozovella* spp., *Parasubbotina pseudobulloides* (Plummer), *Igorina* sp., *Subbotina* sp., *Morozovella* sp. and transported Maastrichtian foraminifera (samples 9, 10 and 11). The upper parts of the Üreğil Formation consist mainly of calciturbidites with rare intercalations of marl. This part of the section is Late Palaeocene (Thanetian) in age as shown by the planktonic foraminifera fauna from sample 12: *Globanomalina* sp., *Igorina tadjikistanensis* (Bykova), *Morozovella apanthesma* (Loeblich and Tappan), *M. occlusa* (Loeblich and Tappan), *M. velascoensis* (Cushman), *Subbotina* spp. and *S. triangularis* (White). The Thanetian age of this part of the section is also shown by the larger benthic foraminifera from sample 15a: *Discocyclina seunesi* Douville *beloslavensis* Less &

Özcan (Plate 2g-h), and from the pelagic fauna in the marl interbeds: *Acarinina mckannai* (White), *A. nitida* (Martin), *A.* cf. *pseudotopilensis* Subbotina, *A. soldadoensis* (Brönnimann), *A. wilcoxensis* (Cushman and Ponton), *Globanomalina pseudomenardii* (Bolli), *G. chapmani* (Parr), *Igorina albeari* (Cushman and Bermudez), *Morozovella acuta* (Toulmin), *M. apanthesma* (Loeblich and Tappan), *M. occlusa* (Loeblich and Tappan), *M. simulatilis* (Schwager), *M. velascoensis* (Cushman), *Subbotina velascoensis* (Cushman) (Plate 1, B-m) and *S. triangularis* (White), (samples 13b and 15b, Figure 6).

In the Sarıağıl section the Üreğil Formation has a minimum thickness of 165 m and consists predominantly of light grey, thickly-bedded calciturbidites, which are intercalated with grey, medium-bedded clayey limestone and marl. The basal parts of the calciturbidites in the Sarıağıl section contain large benthic foraminifera of Campanian age: *L. bisambergensis* (Jaeger) (Plate 2d), *Lepidorbitoides bisambergensis* Jaeger *asymmetrica* Özcan ve Özkan-Altıner (Plate 2c), *L. campaniensis* van Gorsel (Plate 2b) and *Orbitoides media* d'Archiac- *megaloformis* Papp & Küpper (Plate 2e-f) (samples 6 and 7, Figure 6). Sample 9 from the top part of the calciturbidites contains Maastrichtian benthic foraminifera: *Siderolites calcitrapoides* Lamarck, *Sirtina orbitoidiformis* Brönnimann & Wirtz, *Lepidorbitoides* sp. and *Orbitoides* sp.

*Çaycuma Formation*

The Çaycuma formation in the Armutlu Peninsula consists of sandstone, conglomerate and shale (Figure 4d) over 1000 m thick. It is mainly defined from the northern part of the Armutlu Peninsula. In the Ereğli and Osmaniye sections the Çaycuma Formation lies with a probable unconformity over the Middle–Upper Palaeocene limestones of the Akveren Formation (Figure 5).

In the Ereğli section conglomerates near the base contain the following larger foraminiferal assemblage: *Nemkovella evae* Less, *Orbitoclypeus munieri* (Schlumberger) *ponticus* Less & Özcan (Plate 2v), *O. multiplicatus* (Gümbel) ex. interc. *multiplicatus-haymanaensis* Özcan, Sirel, Özkan-Altıner and Çolakoğlu, *O. schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine) (Plate 2s), *O. bayani* (Münier-Chalmas), *Nummulites* spp. and *Assilina* sp. (sample 19, Figure 5). This assemblage is referred to OZ 3 and SBZ 7/8 (early Ypresian= middle part of the Ilerdian). When compared to the Hocalar and Kaynarca sections in the Kocaeli Peninsula, this shallow-marine package suggests an earlier phase of transgression in the Armutlu Peninsula. Marl beds between the conglomerates comprise Late Palaeocene–Early Eocene planktonic foraminifera represented by *Globanomalina pseudomenardii* (Bolli), *Morozovella* sp. and *Subbotina* sp. (samples 21 and 23). The conglomerate-marl intercalation is overlain by interbedded siltstones and sandstones with abundant *Discocyclina archiaci* (Schlumberger) *staroseliensis* Less (Plate 2k), *D. pseudoaugustae* Portnaya (Plate 2p), *Nemkovella evae* Less, *Orbitoclypeus douvillei douvillei* (Schlumberger) (plate 2q), *O. schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine) (Plate 2t), *O. multiplicatus* (Gümbel), *Asterocyclina stella* (Gümbel) (Plate 2y), *Nummulites* spp. and *Assilina* sp. This assemblage is referred to OZ 4 and SBZ 8/9 (early Ypresian= upper part of the Ilerdian) (samples 24, 25, 26, 28 and 29, Figure 5). In the Osmaniye section the Çaycuma Formation is represented by thickly-bedded conglomerates with sandstone clasts 1 to 20 cm across, intercalated with coarse sandstones.

The Çaycuma Formation in the Ereğli section is overlain by a thick sequence of medium- to thickly-bedded andesitic volcaniclastic rocks. These volcaniclastic rocks have been studied along the Akçukur section between Karamürsel and İznik Lake. The volcaniclastic rocks are represented mainly by acidic to andesitic tuffs and lesser amounts of agglomerates with rare sandstone and marl intercalations. A sandstone sample from the base of the Akçukur section (sample 14, Figure 5) contains the following larger benthic foraminifera: *Discocyclina archiaci archiaci* (Schlumberger), *D. fortisi fortisi* (d'Archiac) and *Orbitoclypeus douvillei douvillei* (Schlumberger). This assemblage is referred to OZ 5/6 or SBZ 10 (lower part of upper Ypresian= lower part of Cuisian). Another sample from the marl horizon between the tuff beds (sample 1) comprises the following late Ypresian–early Lutetian planktonic foraminifera: *Acarinina* cf. *broedermanni* (Cushman and Bermudez), *A. bullbrooki* (Bolli) (Plate 1, B-l), *A.*

cf. *nitida* (Martin), *A.* cf. *pentacamerata* (Subbotina) (Plate 1, B-k), *A.* cf. *wilcoxensis* (Cushman and Ponton), *Morozovella aragonensis* (Nuttall) (Plate 1, B-p), *M. caucasica* (Glaessner) and *Subbotina* spp.

The data from the Ereğli, Osmaniye and Akçukur sections in the Armutlu Peninsula indicate that the Çaycuma Formation in the region consists of sandstone, siltstone and conglomerate, more than 1 km thick and with an Ilerdian age (early Ypresian). The acidic to intermediate volcanism in the Armutlu Peninsula starts in the middle Ypresian, which is compatible with isotopic ages (52–47 Ma) obtained from the volcanic rocks in the Armutlu Peninsula (Kürkcüoğlu *et al.* 2008).

## The Region Between the İznik Lake and Bursa

This region constitutes the western end of a major Jurassic–Cretaceous basin, named the Central Sakarya Basin (Altınlı 1975). The Mesozoic stratigraphy in the Central Sakarya Basin is relatively well studied (e.g., Altınlı 1975; Saner 1978a, b, 1980; Altıner *et al.* 1991). It starts with a Liassic sandstone-conglomerate sequence (Bayırköy Formation), which unconformably overlies a heterogeneous basement of Carboniferous granites, metamorphic rocks and the Karakaya Complex. The Bayırköy Formation is disconformably overlain by Upper Jurassic–Lower Cretaceous (Callovian–Hauterivian) limestones (Bilecik Group) (Altıner *et al.* 1991). The first clastic deposition starts in the Albian and the limestone sequence passes up into siliciclastic turbidites with horizons of pelagic limestone (e.g., İ.Ö. Yılmaz 2008). The basin shallows in the Palaeocene and the flysch deposition gives way to deposition of red beds (Saner 1980).

### *The Upper Cretaceous Series*

In the western margin of the Middle Sakarya Basin between İznik Lake and Bursa, the Jurassic and Lower Cretaceous series are mostly eroded and the Upper Cretaceous sequence lies unconformably over Jurassic limestones or the Triassic Karakaya Complex (e.g., Saner 1978a; Bargu 1982). The Upper Cretaceous sequence consists of flysch, called the Gölpazarı Group, with several horizons of pelagic limestone. The pelagic limestones are commonly present at the base of the Gölpazarı Group, and are differentiated as the Vezirhan Formation (Eroskay 1965; Saner 1978a).

Four sections have been measured in the Upper Cretaceous series between the İznik Lake and Bursa (Figure 1). The 35-m-thick Dışkaya section starts with a breccia of poorly sorted, angular blocks of the Upper Jurassic limestone, 0.5 to 10 cm across, in a pelagic micritic matrix (Figure 7). The carbonate breccias are overlain by pink, grey, thin- to medium-bedded pelagic limestones with radiolaria and planktonic foraminifera. A sample 30 metres above the breccias (sample 2) contains a characteristic foraminiferal assemblage for the Middle Turonian: *Dicarinella algeriana* (Caron), *D. canaliculata* (Reuss), *Helvetoglobotruncana helvetica* (Bolli), *Heterohelix globulosa* (Ehrenberg), *Marginotruncana coronata* (Bolli), *M. pseudolinneiana* Pessagno, *M. renzi* (Gandolfi), *M. sigali* (Reichel), *M.* cf. *marginata* (Reuss), and *M.* cf. *sinuosa* Porthault. Sample 3, collected five metres above sample 2, contains a Coniacian–Santonian fauna of *Dicarinella concavata* (Brotzen), *D.* cf. *asymetrica* (Sigal), *Marginotruncana coronata* (Bolli), *M. pseudolinneiana* Pessagno, *Muricohedbergella delrionsis* (Carsey), *Heterohelix moremani* (Cushman), *Pseudotextularia nuttali* (Voorwijk), and *Sigalia* sp.

The Kokarca section also starts with Upper Cretaceous debris flows with Jurassic limestone clasts. These are overlain by sandstones, which pass up into a 25-m-thick sequence of pelagic limestone with calciturbidite and chert intercalations. Samples from the pelagic limestones (samples 2 to 4, Figure 7) contain a Coniacian fauna of *Dicarinella concavata* (Brotzen), *D. primitiva* (Dalbiez), *Marginotruncana coronata* (Bolli), *M. marginata* (Reuss), *M. pseudolinneiana* Pessagno (Plate 1, A-o), *M. renzi* (Gandolfi), *Muricohedbergella flandrini* (Porthault), *Pseudotextularia nuttali* (Voorwijk), *Pithonella ovalis* Banner and *Macroglobigerinelloides* sp. The planktonic foraminifera from sample 6 from the top of the measured section is characteristic of the Coniacian–Santonian: *Dicarinella concavata* (Brotzen) (Plate 1, A-c), *Marginotruncana coronata* (Bolli), *M. marginata* (Reuss), *M. pseudolinneiana*

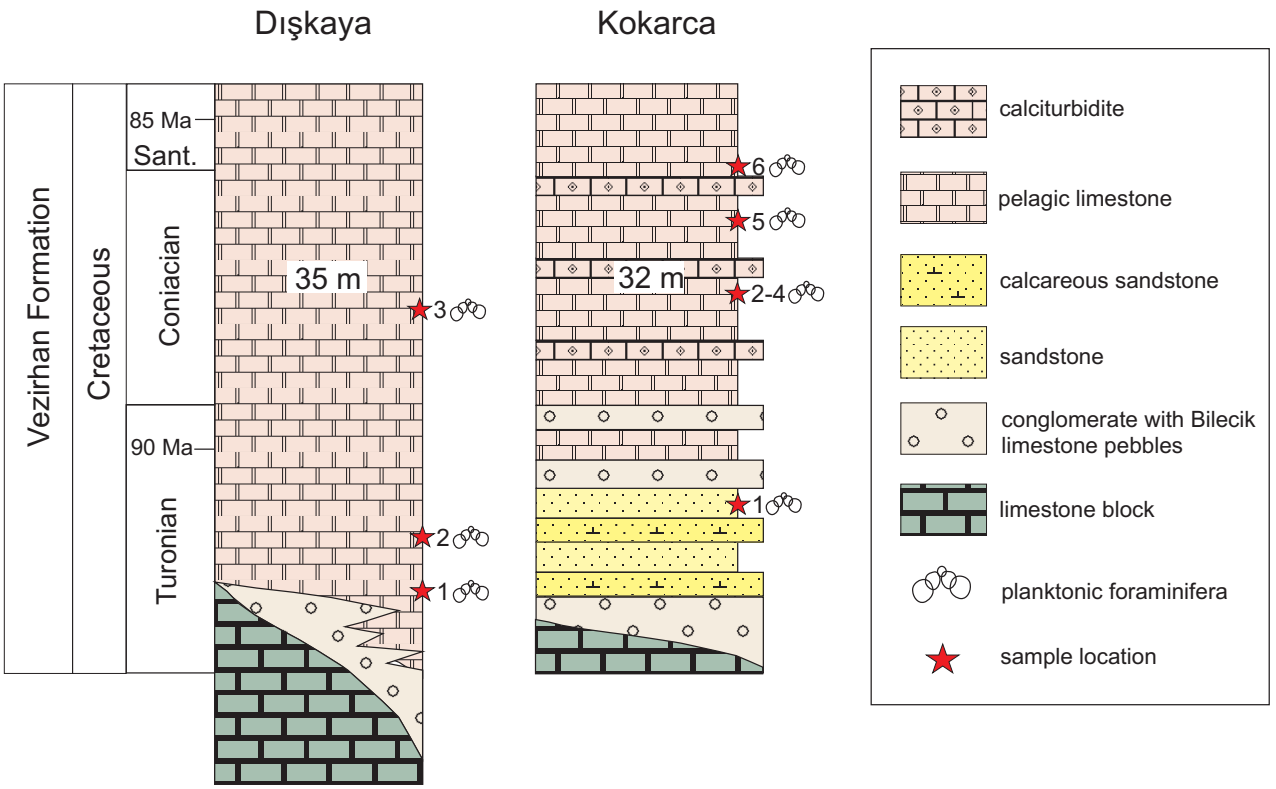


**Figure 7.** The stratigraphy of the Upper Cretaceous sequence in the Kokarca and Dışkaya sections from north of Bursa Peninsula. The sections are time-scaled with the stratigraphic time scale from Gradstein *et al.* (2004). For the location of the sections see Figure 1.

Pessagno, *M. sinuosa* (Porthault), *M. schneegansi* (Sigal), *M.* cf. *renzi* (Gandolfi), *Muricohedbergella flandrini* (Porthault), *Macroglobigerinelloides* spp. and *Muricohedbergella* spp.

An Upper Cretaceous series also crops out at the base of the Sölöz A and B sections (Figure 8), where it consists of a turbiditic sequence of sandstone, siltstone and conglomerate with horizons of pelagic limestone. The conglomerates in the sequence include poorly sorted clasts of Jurassic limestone, spilite and sandstone. A sample from the pelagic limestones contains a planktonic foraminiferal assemblage of Coniacian–Santonian age: *Dicarinella concavata* (Brotzen), *Dicarinella primitiva* (Dalbiez), *Marginotruncana coronata* (Bolli), *M. pseudolinneiana* Pessagno and *Heterohelix* sp.

The data from the Dışkaya, Kokarca, Sölöz-A and B sections indicate that the Late Cretaceous transgression in the region started in the Turonian, and continued into the Coniacian–Santonian. The rest of the Upper Cretaceous sequence is missing, most probably due to erosion in the Early Eocene.

*Eocene Series*

South of İznik Lake the Eocene sequence unconformably overlies the Upper Cretaceous series. The Palaeocene is missing but is present farther east and north of İznik Lake, where it is represented by shallow marine limestones of Early to Middle Palaeocene age (Bargu 1982; Genç 1986; Bargu & Sakınç 1989/1990; Örçen 1992). The Eocene series south of İznik Lake consists of a thick and heterogeneous series of conglomerate, sandstone, limestone and volcanic rocks of Early to Middle Eocene age. It has been studied in detail by Genç (1986), who divided it into a number of formations. We studied the Eocene series along two sections (Figure 8) and largely followed the nomenclature of Genç (1986).

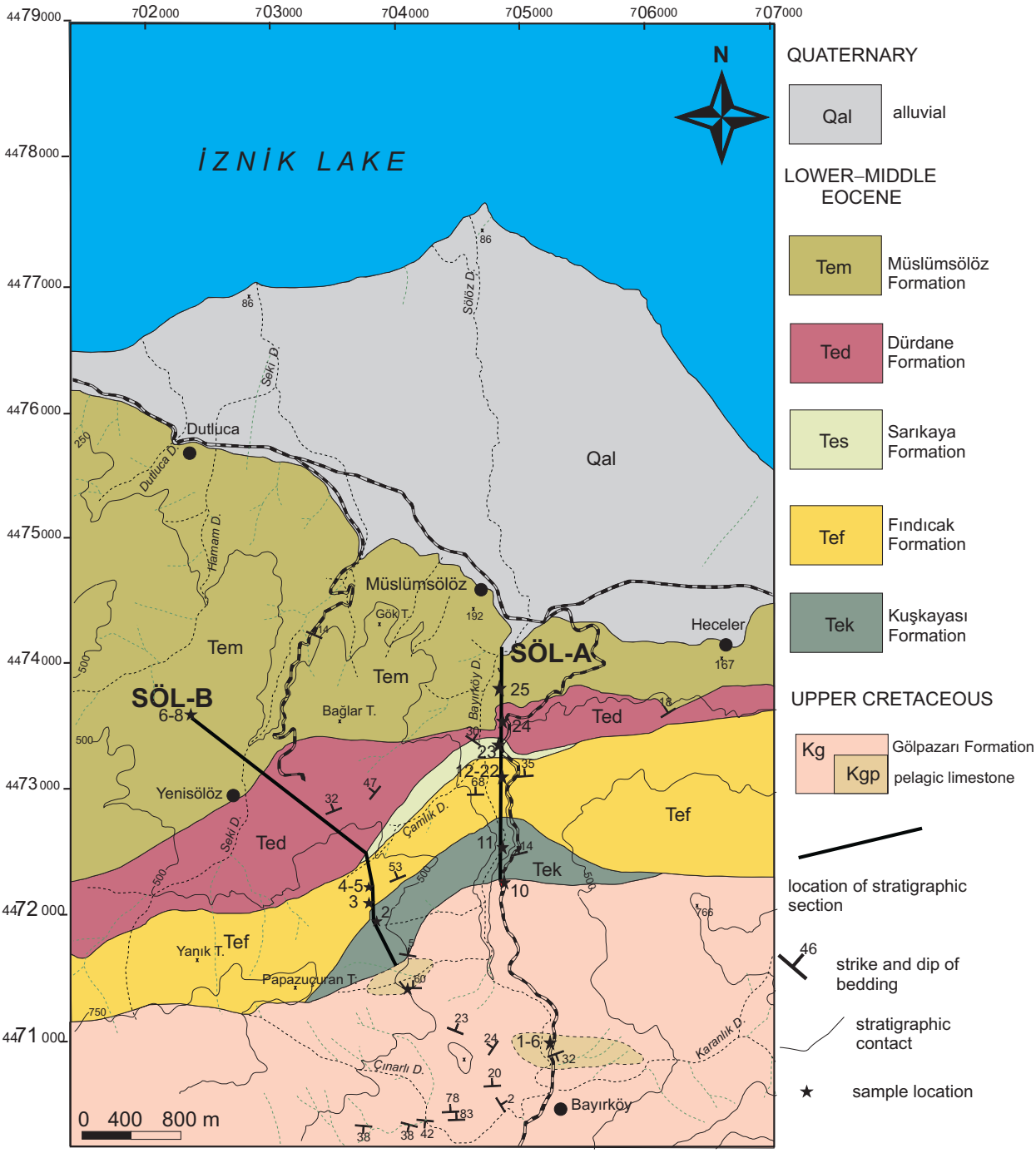


**Figure 8.** Geological map of the region south of İznik Lake showing the location of the Sölöz-A and Sölöz-B sections. For the location of the map see Figure 1 (modified from Genç 1986).

The base of the Eocene series south of İznik Lake is marked by a thick sequence of terrigeneous conglomerates, called the Kuşkayası Formation (Genç 1986). The conglomerates are thickly bedded to massive with poorly sorted, medium- to well-rounded clasts 1 to 50 cm across, in a sandy matrix. The clasts consist of 40% pelagic limestone, 30% sandstone, 20% quartz and 5% microconglomerate.

The conglomerates show major variations in thickness along strike; in the Sölöz-A and B sections the conglomerates are 180 m, and 325 m thick, respectively, and pinch out laterally (Figure 8). They are overlain by a heterogeneous sequence of sandstone, siltstone, marl and limestone 125–175 m thick, assigned to the Fındıcak Formation. The sandstones are medium to thickly bedded and contain benthic foraminifera belonging to alveolinids, orthophragmines and nummulitids: *Alveolina cremae* Checchia-Rispoli, *A. ruetimeyeri* Hottinger, *Discocyclina archiaci* (Schlumberger), *Discocyclina archiaci archiaci* (Schlumberger), *D. augustae* Weijden, *D. dispansa* (Sowerby), *D. fortisi* (d'Archiac) *simferopolensis* Less (Plate 2j), *D. trabayensis* Neumann, *Nemkovella evae* Less, *N. strophiolata* (Gümbel) *fermonti* Less, *Orbitoclypeus douvillei douvillei* (Schlumberger), *O. munieri* (Schlumberger), *O. schopeni* (Checchia-Rispoli), *O. schopeni* (Checchia-Rispoli) *crimensis* Less (Plate 2u), *O. schopeni* (Checchia-Rispoli) *suvlukayensis* Less, and *O. varians* (Kaufmann) cf. *ankaraensis* Özcan & Less, *Nummulites* sp. and *Assilina* sp. (samples SÖL-A 12-14, 16, 17 and SÖL-B 3, Figure 9). The benthic foraminiferal assemblage in this lower part of the shallow-marine sequence is referred to OZ 5/6 or SBZ 10 (lower part of upper Ypresian= lower part of Cuisian).

The limestones of the Fındıcak Formation also contain Upper Ypresian foraminifera such as *Asterocyclina stella* (Gümbel), *Discocyclina archiaci* (Schlumberger) cf. *bartholomei* (Schlumberger), *D. dispansa* (Sowerby) *taurica* Less (Plate 2o), *D. fortisi* (d'Archiac) cf. *simferopolensis* Less, *Nemkovella evae* Less, *N. strophiolata* (Gümbel), *Orbitoclypeus douvillei* (Schlumberger), *O.schopeni* (Checchia-Rispoli), and *O. varians* (Kaufmann) *ankaraensis* Özcan & Less, *Nummulites distans* Deshayes, *N. irregularis* Deshayes and *Assilina laxispira* de la Harpe. The topmost part

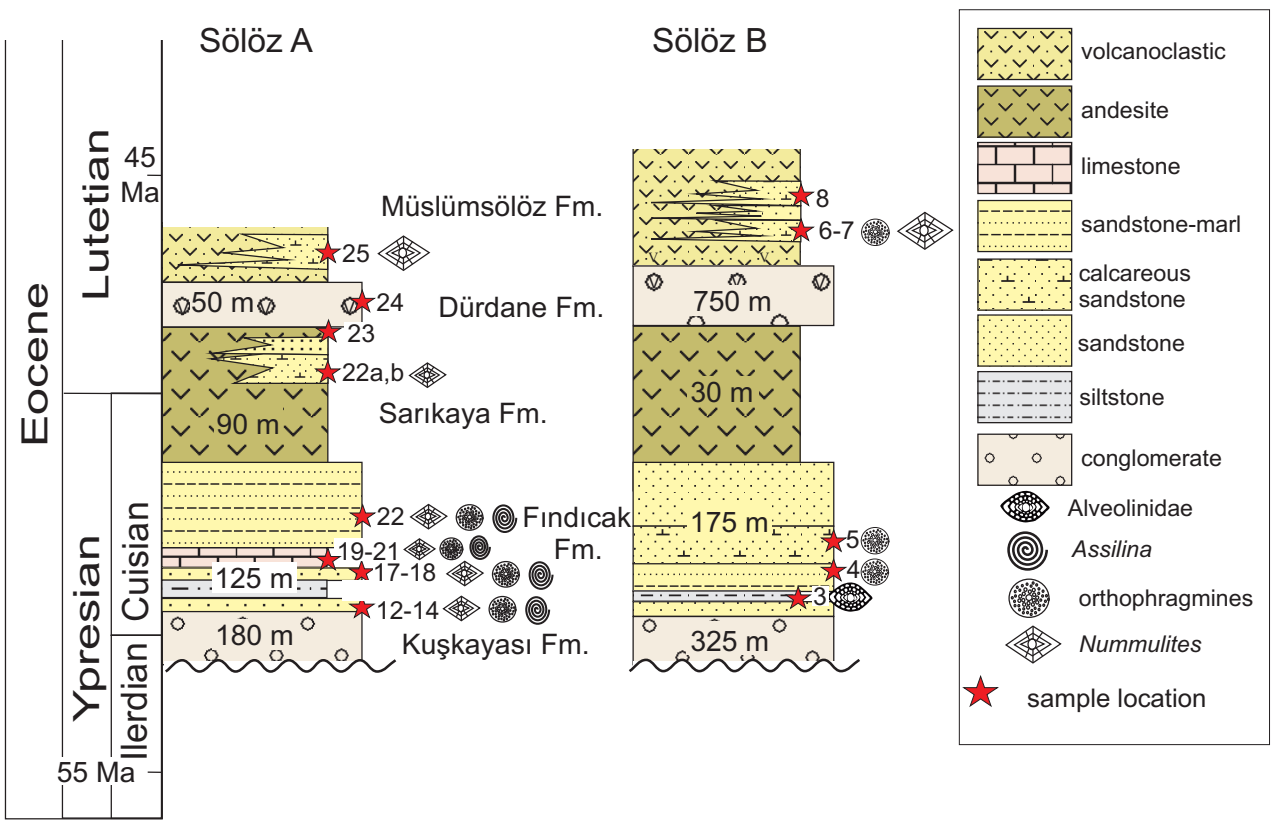


**Figure 9.** The stratigraphy of the Eocene sequence in the Sölöz-A and Sölöz-B sections south of the İznik Lake. The sections are time-scaled with the stratigraphic time scale from Gradstein *et al.* (2004). For the location of the sections see Figures 1 and 8.

of the Fındıcak Formation is of middle Cuisian age (SBZ 11), as shown by the benthic foraminifera from sample SÖL-A 22a: *Asterocyclina alticostata* (Nuttall), *A. stellata* (d'Archiac) cf. *adourensis* Less, *Discocyclina dispansa* (Sowerby) cf. *taurica* Less & Özcan, *D. trabayensis* Neumann, *Nemkovella evae* Less, *N. strophiolata* (Gümbel) cf. *fermonti* Less, *Orbitoclypeus douvillei* (Schlumberger) cf. *yesilyurtensis* Özcan, and *O. varians* (Kaufmann).

The Fındıcak Formation is overlain by the andesitic lava flows of the Sarıkaya Formation 90 m thick (Figure 9). The light green, grey massive andesites are porphyritic with phenocrysts of plagioclase and hornblende. There are also sandstone beds and lenses within the andesites, which make up ca. 10% of the sequence. *Nummulites* of Early Lutetian age have been determined in these sandstone beds: *N. deshayesi* d'Archiac and Haime and *N. obesus* d'Archiac. (sample SÖL-A 22b, Figure 9). The Sarıkaya and Fındıcak formations are overlain by the thickly-bedded, massive red conglomerates of the Dürdane Formation. The clasts in the Dürdane Formation are mainly andesites, 1 to 20 cm across. Farther west between Orhangazi and Bursa, the conglomerates of the Dürdane Formation are intercalated with red, purple sandstones and siltstones and constitute a typical fluviatile series. The Dürdane Formation shows major lateral variation in thickness; in the Sölöz-B section it is 750 m thick, whereas in the Sölöz-A section one kilometre to the east, its thickness is reduced to 50 metres.

In the Sölöz-A and B sections the Dürdane Formation is overlain by the volcaniclastic rocks with sandstone beds belonging to the Müslümsölöz Formation. A thin horizon of shallow marine limestone of Lutetian age [the Kayacık Çayırı Formation of Genç (1986)] generally intervenes between the Dürdane and Müslümsölöz formations (Örçen 1992). Larger benthic foraminifera in the sandstone lenses of the Müslümsölöz Formation contain ?Early–Middle Lutetian large benthic foraminifera: *Asterocyclina alticostata* (Nuttall) cf. *cuvillieri* (Neumann), *Discocyclina dispansa* (Sowerby) cf. *hungarica* Kecskeméti, *D. spliti spliti* Butterlin et Chorowicz and *Orbitoclypeus varians* (Kaufmann) cf. *ankaraensis* Özcan and Less (sample SÖL-B 6, Figure 9) and the early Lutetian *Nummulites obesus* d'Archiac (sample SÖL-A 25).

**Upper Cretaceous–Eocene Stratigraphy, Tectonics and Paleogeography in Northwest Turkey**

The region between the Black Sea and Bursa is crossed by the North Anatolian Fault, a post-Oligocene right-lateral strike-slip fault. The cumulative offset along the North Anatolian Fault shows a decrease from east to west and is estimated to be in the order of 50 to 100 km (e.g., Şengör *et al*. 2005). The locations of the measured sections are chosen to compensate for the Late Tertiary offset along the North Anatolian Fault (Figure 1); furthermore, considering the size of the area studied, the offset along the North Anatolian Fault, probably ca. 50 km at İzmit Bay, is negligible and is not considered in the discussion on the regional correlation of the stratigraphy.

Major uplift and erosion affected northwest Turkey during the Early to middle Cretaceous. The Lower Cretaceous rocks are missing in the region between Bursa and the Black Sea, and the Upper Cretaceous sequence unconformably overlies a heterogeneous basement. Farther east in the Middle Sakarya Basin, where sedimentation is more continuous, this period of uplift and erosion corresponds to the base of the Gölpazarı Group, the thick flysch sequence of Late Cretaceous age (e.g., Saner 1978a).

In the north along the Black Sea coast the Cretaceous transgression started in the Late Santonian with the deposition of the volcaniclastic and volcanic rocks of the Yemişliçay Group (Gedik *et al*. 2005a), which form part of the Pontide Late Cretaceous magmatic arc (e.g., Şengör & Yılmaz 1981; Okay & Şahintürk 1997). The Santonian–Campanian volcanism pinches out southward and is replaced by the deposition of the clastic rocks derived from the erosion of the Palaeozoic and Triassic basement (Teksen Formation, Figure 10). A broad ridge separated the northern volcanic belt from a southern basin characterized by the deposition of coarse siliciclastic turbidites with calciturbidite and pelagic limestone horizons (Osmaniye Formation and the Gölpazarı Group). This southern basin was in a fore-arc setting and the subduction zone was probably several tens of kilometres farther south. The ridge separating the magmatic arc from the fore-arc basin, corresponding to the southern margin of the Kocaeli Peninsula, was first transgressed in the late Campanian by the Akveren Formation, which forms

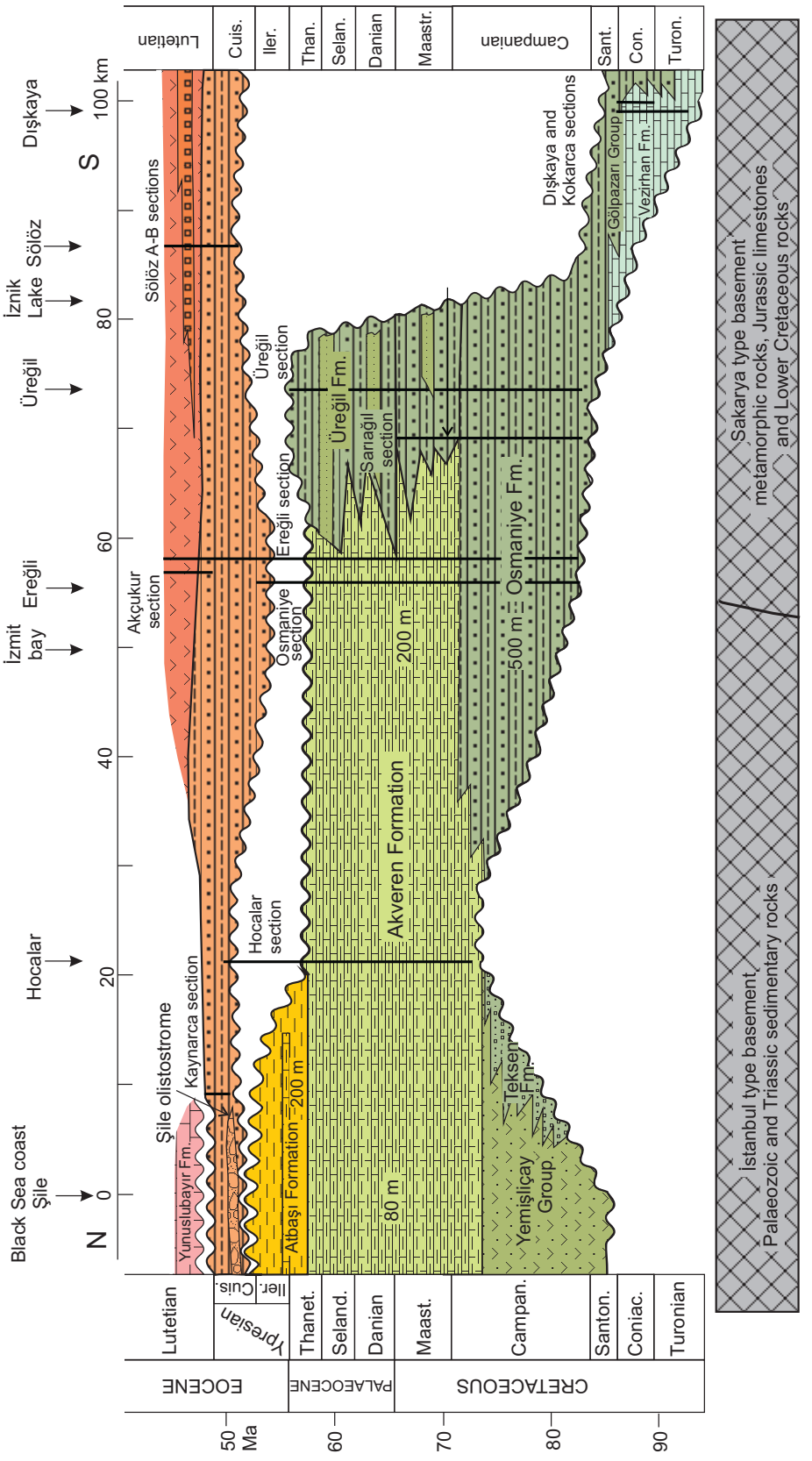


**Figure 10.** Chronostratigraphic correlation of the Upper Cretaceous–Eocene sequences from the Black Sea south to Bursa; the horizontal scale is approximate. The section is time-scaled with the stratigraphic time scale from Gradstein *et al.* (2004). The locations of the measured sections are also marked.

a relatively thin blanket of pelagic limestone and marl extending from the Black Sea 70 km south to the southern part of the Armutlu Peninsula (Figure 10). The deposition of the Akveren and Yemişliçay formations continued into the Middle–Late Palaeocene over a large area. However, south of the Armutlu Peninsula the Akveren Formation passes laterally into a sequence of siliciclastic turbidites and calciturbidites (Üreğil and Osmaniye formations and the Gölpazarı Group), which reflect the proximity of this region to the orogen.

The carbonate-rich Maastrichtian–Middle–Upper Palaeocene sequence is overlain by a thick flysch wedge of Early Eocene age (Figure 10), which formed in a retro-foreland basin (e.g., Allen & Allen 2005; Naylor & Sinclair 2008) due to the continental collision between the Pontides and the Anatolide-Tauride Block (Okay & Tüysüz 1999). Uplift preceded the deposition of the Cuisian flysch, and in many places led to the erosion of the Palaeocene and lowermost Eocene (Ilerdian) strata. In regions relatively far from the orogen, such as the Black Sea coast, the Late Palaeocene and Ilerdian is represented by marl and shale, in other regions this period is generally not recorded (Figure 10). Data from the Üreğil section indicates, however, that this is due to erosion in the latest Ilerdian–earliest Cuisian. The Lower Eocene flysch wedge (Çaycuma Formation and its equivalents) extend from north of Bursa 100 km to the Black Sea coast, where it includes olistostromes.

In the region between north of Bursa and İzmit Bay, the Lower Eocene flysch passes up into a thick volcanic and volcaniclastic series of Late Ypresian–earliest Lutetian age (52–47 Ma, Kürkçüoğlu *et al.* 2008), possibly forming part of an Early to Middle Eocene magmatic arc (e.g., Okay & Satır 2006). The north-vergent thrusting of the İstanbul Palaeozoic sequence over the Cretaceous and younger rocks along the Şile thrust occurred in the Early Eocene (Baykal 1943; Baykal & Önalan 1979). Along the Black Sea coast Lutetian shallow marine limestone and sandstone of the Yunuslubayır Formation (Baykal & Önalan 1979) lie with angular unconformity over the Lower Eocene rocks (Özcan *et al.* 2007). The Early Eocene deposition of flysch and volcanism was followed by deformation, uplift and erosion; Upper Eocene and Oligocene marine strata are not recorded in the region studied.

## Conclusions

In northwest Turkey in the region between the Black Sea and Bursa the Upper Cretaceous rocks overlie with an angular unconformity a heterogeneous basement of metamorphic rocks and Palaeozoic–Triassic sedimentary rocks. The Upper Cretaceous–Eocene biostratigraphy in this region has been studied through measured sections. Based on these sections and on the published data four major periods of deposition are differentiated (Figure 10). The Santonian–Campanian interval is represented by volcanic and volcaniclastic rocks in the north and by siliciclastic turbidites, pelagic limestones and calciturbidites in the south. These two realms were separated by a broad ridge corresponding to the southern margin of the Kocaeli Peninsula.

Deposition of pelagic limestone and marl (Akveren Formation) characterizes the Late Campanian–Late Palaeocene interval, but in the south, close to the orogen, the Akveren Formation passed into calciturbidites and siliciclastic turbidites. The third megasequence is a thick Lower Eocene flysch wedge, which extends for over 100 km from north of Bursa to the margin of the Black Sea. The base of the flysch is marked by a major unconformity, which records the erosion of Palaeocene strata over a large region. The flysch has formed in a retro-foreland basin due to the collision of the Pontides and the Anatolide-Tauride Block. The final megasequence in the region is a thick volcanic and volcaniclastic series of late Ypresian to early Lutetian age, which extends from Bursa north to the bay of İzmit.

The transsect from the Black Sea to Bursa crosses two main tectonic units of the Pontides: the İstanbul and Sakarya zones (Okay & Tüysüz 1999). The time of their juxtaposition has been controversial, with suggestions of Palaeocene–Lutetian (Şengör & Yılmaz 1981; Okay *et al.* 1994), Coniacian–Santonian (Y. Yılmaz *et al.* 1997; Elmas & Yiğitbaş 2001, 2005), Turonian (Robertson & Ustaömer 2004), pre-Senonian (Göncüoğlu & Erendil 1990) and Early Cretaceous (Akbayram *et al.* 2009). The coherent Upper Cretaceous–Eocene stratigraphy, the

laterally traceable facies belts (Figure 10), absence of ophiolitic slices and high pressure metamorphic rocks in the Upper Cretaceous–Tertiary series in the region between the Black Sea and Bursa indicate that the juxtaposition of the İstanbul and Sakarya zones occurred before the Santonian.

**Acknowledgements**

This study represents part of the PhD Thesis of the senior author supported by TÜBİTAK. We thank M. Baldi-Beke and K. Kollanyi from Budapest for the identification of calcareous nannoplankton and planktonic foraminifera in the Kaynarca section, Lucas Hottinger (Basel) for the identification of alveolinids in the Sölöz section and Gyorgy Less (Miskolc) for the identification of nummulids. Erdinç Yiğitbaş and Muzaffer Siyako are thanked for detailed and constructive reviews. Aral Okay thanks to TÜBİTAK and TÜBA for financial support.

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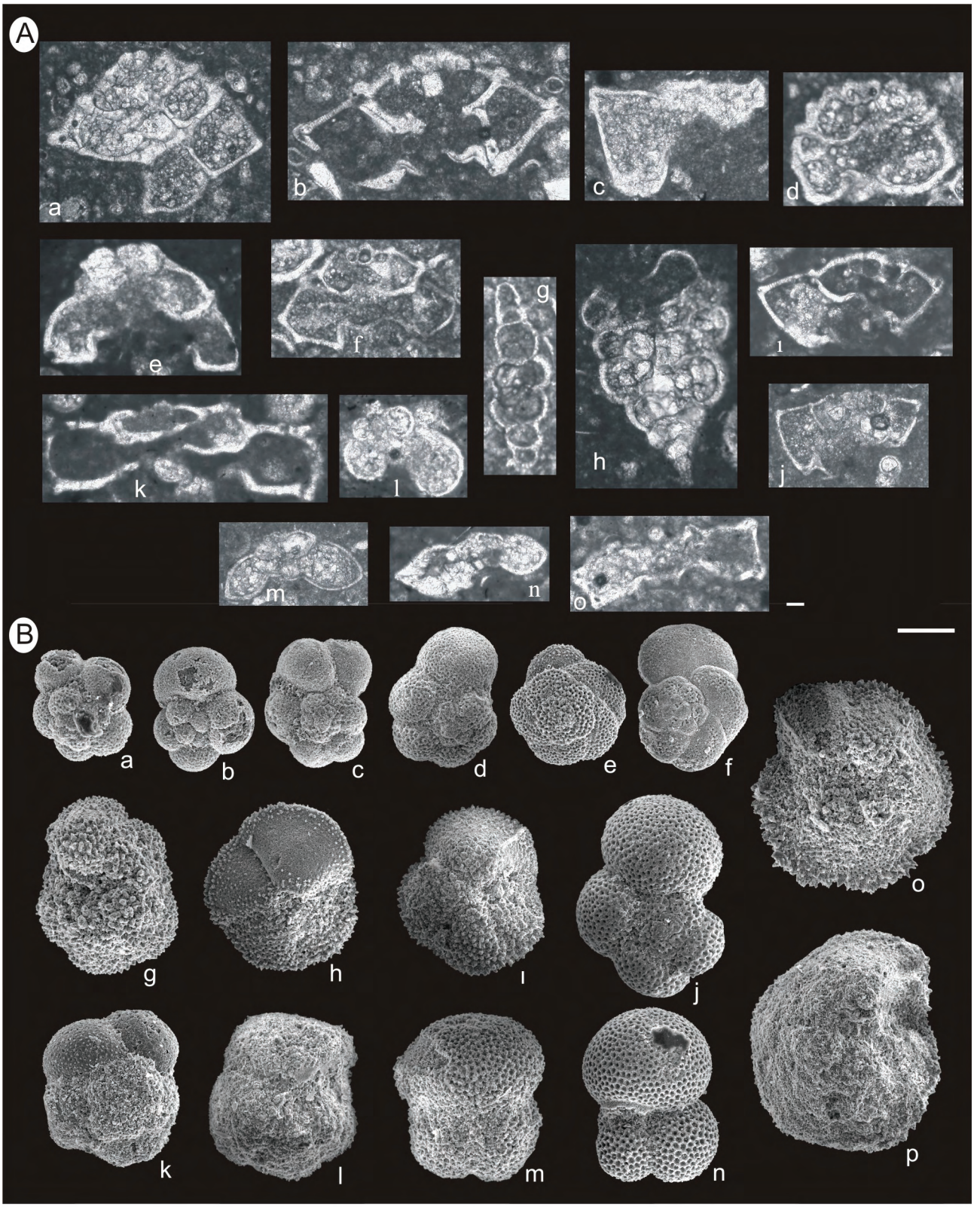
Scientific editing by Erdin Bozkurt

## PLATE 1

**(A-a)** *Globotruncanita conica* (White), sample HOC.1, Middle–Late Maastrichtian, Akveren Formation, **(A-b)** *Gt. stuarti* (de Lapparent), sample HOC.1, Middle–Late Maastrichtian, Akveren Formation, **(A-c)** *Dicarinella concavata* (Brotzen), sample KOK.6, Coniacian–Santonian, Vezirhan Formation, **(A-d)** *Contusotruncana walfishensis* (Todd), sample HOC.1, Middle–Late Maastrichtian, Akveren Formation, **(A-e)** *Contusotruncana contusa* (Cushman), sample ÜRE.6, Middle–Late Maastrichtian, Üreğil Formation, **(A-f)** *Globotruncana arca* (Cushman), sample HOC.1, Middle–Late Maastrichtian, Akveren Formation, **(A-g)** *Planoglobulina* sp., sample HOC.1, Middle–Late Maastrichtian, Akveren Formation, **(A-h**) *Racemiguembelina fructicosa* (Egger), sample HOC.4, Middle–Late Maastrichtian, Akveren Formation, **(A-ı)** *Globotruncanita* cf. *stuartiformis* (Dalbiez), sample HOC.1, Middle–Late Maastrichtian, Akveren Formation, **(A-j)** *Gansserina gansseri* (Bolli), sample HOC.1, Middle–Late Maastrichtian, Akveren Formation, **(A-k)** *Abathomphalus mayaroensis* (Bolli), sample ÜRE.8, Upper Maastrichtian, Üreğil Formation, **(A-l)** *Kuglerina rotundata* (Brönnimann), sample ERE.14, Maastrichtian, Akveren Formation, **(A-m)** *Globotruncanella havanensis* (Voorwijk), sample HOC.3, Middle–Late Maastrichtian, Akveren Formation, **(A-n)** *Globotruncanella pschadae* (Keller), sample OSM.5, Upper Campanian–Maastrichtian, Akveren Formation, **(A-o)** *Marginotruncana pseudolinneiana* Pessagno, sample KOK.3, Coniacian, Vezirhan Formation, **(B-a)** *Eoglobigerina edita* (Subbotina), spiral view, sample ERE.16, Danian, Akveren Formation, **(B-b)** *Eoglobigerina eobulloides* (Morozova), spiral view, sample ERE.16, Danian, Akveren Formation, **(B-c)** *Praemurica inconstans* (Subbotina), spiral view, sample ERE.16, Danian, Akveren Formation, **(B-d)** *Praemurica taurica* (Morozova), spiral view, sample ERE.16, Danian, Akveren Formation, **(B-e)** *Igorina albeari* (Cushman and Bermudez), spiral view, sample HOC. 9, late Selandian–Thanetian, Akveren Formation, **(B-f)** *Globanomalina pseudomenardii* (Bolli), spiral view, sample HOC.8, late Selandian-Thanetian, Akveren Formation, **(B-g)** *Morozovella angulata* (White), umbilical view, sample ERE.18, late Selandian–Thanetian, Akveren Formation, **(B-h)** *Morozovella occlusa* (Loeblich and Tapan), umbilical view, sample OSM.8, late Selandian–Thanetian, Akveren Formation, **(B-ı)** *Morozovella subbotinae* (Morozova), umbilical view, sample HOC.9, late Selandian-Thanetian, Akveren Formation, **(B-j)** *Parasubbotina pseudobulloides* (Plummer), spiral view, sample OSM.8, late Selandian–Thanetian, Akveren Formation, **(B-k)** *Acarinina pentacamerata* (Subbotina), spiral view, sample AKÇ.1, late Ypresian–early Lutetian, Çaycuma Formation, **(B-l)** *Acarinina bullbrooki* (Bolli), umbilical view, sample AKÇ.1, late Ypresian–early Lutetian, Çaycuma Formation, **(B-m)** *Subbotina velascoensis* (Cushman), umbilical view, sample ÜRE.15b, Thanetian, Üreğil Formation, **(B-n)** *Subbotina triloculinoides* (Plummer), umbilical view, sample OSM.8, late Selandian–Thanetian, Akveren Formation, **(B-o)** *Morozovella velascoensis* (Cushman), umbilical view, sample OSM.8, late Selandian–Thanetian, Akveren Formation, **(B-p)** *Morozovella aragonensis* (Nuttall), umbilical view, sample AKÇ.1, late Ypresian–early Lutetian, Çaycuma Formation (Scale bar: 100μm).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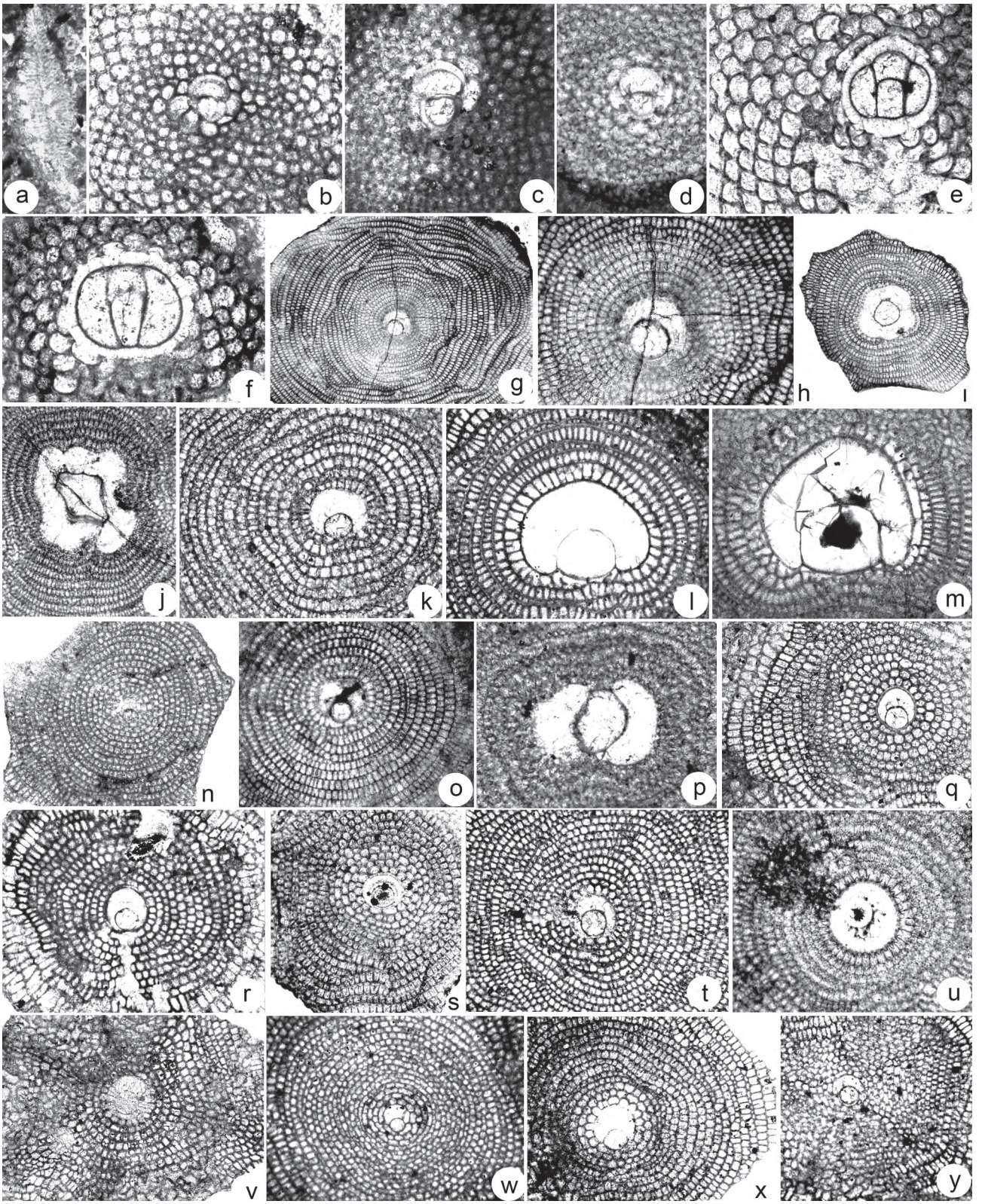
## PLATE 2

**(a)** *Praesiderolites* sp., sample ERE.4, Campanian, Osmaniye Formation, **(b)** *Lepidorbitoides campaniensis* van Gorsel, sample SAR.6, Campanian, Akveren Formation, **(c)** *L. bisambergensis* (Jaeger) *asymmetrica* Özcan and Özkan-Altıner, sample SAR.6, Campanian, Akveren Formation, **(d)** *L. bisambergensis* (Jaeger), sample SAR.7, Campanian, Akveren Formation, **(e, f)** *Orbitoides media* (d'Archiac)-*megaloformis* Papp and Küpper, sample SAR.6, Campanian, Akveren Formation, **(g, h)** *Discocyclina seunesi* Douville *beloslavensis* Less and Özcan, sample ÜRE.15, Thanetian, Üreğil Formation, **(i)** *D. fortisi fortisi* (d'Archiac), sample KAY.7, late Ypresian (Cuisian), Çaycuma Formation, **(j)** *D. fortisi* (d'Archiac) *simferopolensis* Less, sample SÖL-A.14, late Ypresian (Cuisian), Fındıcak Formation, **(k)** *D. archiaci* (Schlumberger) *staroseliensis* Less, sample ERE.26, early Ypresian (Ilerdian), Çaycuma Formation, **(l, m)** *D. archiaci archiaci* (Schlumberger), (l) sample KAY.3a and (m) sample HOC.16, late Ypresian (Cuisian), Çaycuma Formation, **(n)** *D. augustae* van der Weijden cf. *sourbetensis* Less, sample HOC.16, late Ypresian, Çaycuma Formation, **(o)** *D. dispansa* (Sowerby) *taurica* Less, sample SÖL-A.21, late Ypresian (Cuisian), Fındıcak Formation, **(p)** *D. pseudoaugustae* Portnaya, sample ERE.29, early Ypresian (Ilerdian), Çaycuma Formation, **(q)** *Orbitoclypeus douvillei douvillei* (Schlumberger), sample ERE.25, early Ypresian (Ilerdian), Çaycuma Formation, **(r)** *O. douvillei* (Schlumberger) *yesilyurtensis* Özcan, sample KAY.3a, late Ypresian (Cuisian), Çaycuma Formation, **(s, t)** *O. schopeni* (Checchia-Rispoli) *neumannae* (Toumarkine), (s) sample ERE.19, (t) sample ERE.25, early Ypresian (Ilerdian), Çaycuma Formation, **(u)** *O. schopeni* (Checchia-Rispoli) *crimensis* Less, sample SÖL-A.12, late Ypresian (Cuisian), **(v)** *Orbitoclypeus munieri* (Schlumberger) *ponticus* Less and Özcan, sample ERE.19, early Ypresian (Ilerdian), Çaycuma Formation, **(w)** *Nemkovella strophiolata* (Gümbel *fermonti* Less, sample KAY.3a, late Ypresian (Cuisian), Çaycuma Formation, **(x)** *N. evae* Less, sample KAY.3a, late Ypresian (Cuisian), Çaycuma Formation, **(y)** *Asterocyclina stella* (Gümbel), sample ERE.28, early Ypresian (Ilerdian), Çaycuma Formation All equatorial sections except for figure 2a which is tangential section: b–f, h, k–m, o–y x36; a, g, ı–j, n x16.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