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Basement Types, Lower Eocene Series, Upper Eocene Olistostromes and the Initiation of the Southern Thrace Basin, NW Turkey

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Abstract: The Eocene sequence of the southern Thrace Basin unconformably overlies two types of basement: (1) Slate, limestone and phyllite crop out in small inliers under the Upper Eocene conglomerates and limestones in the Mecidiye region, north of Saros Bay. These low-grade metamorphic rocks form the eastern extension of the Circum-Rhodope Belt of Greece. (2) In the Şarköy region south of the Ganos Fault, tectonically elevated basement consisting of serpentinite, metadiabase and Upper Cretaceous blueschists is unconformably overlain by the upper Bartonian to lower Priabonian shallow marine limestones of the Soğucak Formation. In some places erosional remnants of an upper Ypresian transgressive sequence (the newly discovered Dişbudak series) underlie the Soğucak Limestones. This Dişbudak series starts with sandstone and conglomerate and passes up into sandy limestone, marl and shale. Hydrocarbon exploration wells south of the Ganos Fault have also encountered an ophiolitic mélange basement under the Dişbudak series and/or under the Soğucak Formation. The Ganos Fault forms the boundary between the two basement types.

The Soğucak Limestone is overlain by an Upper Eocene to Early Oligocene flysch sequence with olistostromes. The clasts in the flysch include the Soğucak Limestone, Cretaceous and Palaeocene pelagic limestone, serpentinite, basalt, gabbro, greywacke, quartz-diorite and greenschist. They range in size from sand grains to olistoliths up to one kilometre across. Composite olistoliths consist of pelagic limestone or basalt overlain by the Upper Eocene limestone. The Upper Eocene mass flows were probably formed in an extensional setting and were derived from the south from the flanks of large normal faults related to the opening of the southern Thrace Basin.

The Dişbudak series is absent along the observed basement-Eocene contacts, which implies that the main transgression leading to the development of the southern Thrace Basin started in the late Bartonian.

Key Words: Thrace Basin, Circum-Rhodope belt, olistostrome, mass flows, ophiolitic mélange

Güney Trakya Havzasında Temel Tipleri, Alt Eosen Serisi, Üst Eosen Olistostromları ve Havza Oluşumu

Özet: Güney Trakya Havzası'nın Eosen ile başlayan sedimenter istifi iki farklı temel üzerinde yer alır: (1) Saros Körfezi'nin kuzeyinde Üst Eosen konglomera ve kireçtaşları, sleyt, koyu renkli kireçtaşı ve fillitten oluşan metamorfik bir temel üzerinde bulunur. Bu metamorfik kayalar, Yunanistan'daki Rodop Çevresi Kuşağı'nın doğuya doğru olan devamını teşkil eder. (2) Ganos Fayı güneyinde Şarköy çevresinde ise serpantinit, metadiyabaz ve mavişistlerden oluşan bir temel tektonik dilimi üzerinde uyumsuzlukla geç Bartoniyen–erken Priaboniyen yaşlı sığ denizel Soğucak Formasyonu kireçtaşları yer alır. Mürefte kuzeyinde Soğucak kireçtaşları altında geç İpreziyen yaşlı transgressif bir seri (Dişbudak serisi) haritalanmıştır. Kumtaşları ile başlayan Dişbudak serisi üste doğru kumlu kireçtaşı ve marnlara geçer. Ganos Fayı güneyinde açılmış olan petrol arama kuyuları da Soğucak kireçtaşı veya Dişbudak serisi altında ofiyolitik bir temel kesmiştir. Kuzey Anadolu Fayı'nın Trakya'daki kolunu temsil eden Ganos Fayı bu iki farklı temel arasındaki sınırı oluşturur.

Soğucak Formasyonu kireçtaşları üzerinde içinde olistostromlar bulunduran Geç Eosen yaşlı bir fliş yer alır. Fliş istifi içindeki çakıl ve bloklar Soğucak Formasyonu'na ait sığ denizel kireçtaşı, Kretase ve Paleosen pelajik kireçtaşı, serpantinit, bazalt, gabro, grovak, kuvars-diyorit ve yeşilşistten yapılmıştır. Birleşik olistolitler, altta pelajik kireçtaşı veya bazalt ve onu uyumsuzlukla örten Üst Eosen kireçtaşlarından oluşur. Geç Eosen yaşındaki kütle akıntıları genişlemeli bir tektonik ortamda, güneye bakan büyük normal fayların yamaçlarından kaynaklanmıştır.

Dişbudak serisinin, temel-Eosen dokanakları boyunca genellikle gözlenmemesi, Güney Trakya Havzası'nın oluşumuna yol açan ana transgresyonun geç Bartoniyen'de meydana geldiğine işaret etmektedir

Anahtar Sözcükler: Trakya Havzası, Rodop Çevresi Kuşağı, olistostrom, kütle akıntısı, ofiyolitik melanj

Introduction

The Thrace Basin is an Eocene–Oligocene siliciclastic depocentre whose sedimentary fill reaches up to 9000 metres in thickness (e.g., Kopp *et al.* 1969; Turgut *et al.* 1991; Görür & Okay 1996; Siyako & Huvaz 2007). In the northeast and northwest the basin sediments rest stratigraphically on the metamorphic rocks of the Strandja and Rhodope massifs, respectively (Figure 1). The southern boundary of the Thrace Basin is less well defined, with Eocene sedimentary and volcanic rocks extending southward into the Biga Peninsula, where they unconformably overlie the metamorphic rocks of the Sakarya Zone (Sirel & Acar 1982; Siyako *et al.* 1989). In the south the North Anatolian Fault cuts and deforms the sedimentary rocks of the Thrace Basin. Small outcrops of ophiolitic rocks in this region have been interpreted as marking the Intra-Pontide suture between the Sakarya Zone and the Strandja-Rhodope massifs (Şengör & Yılmaz 1981; Okay & Tüysüz 1999; Beccaletto *et al.* 2005).

Here we present data on the tectonic setting of these ophiolitic rocks and the nature of the basement of the Thrace Basin both north and south of the North Anatolian Fault. We also describe an erosional remnant of a Lower Eocene series and an Upper Eocene–Lower Oligocene olistostromal sequence with ophiolitic clasts and large blocks of Eocene (Bartonian and Priabonian) limestone around Şarköy, and discuss the significance of the basement type and Eocene olistostromes in terms of the origin of the Thrace Basin, its development during the Eocene, and the evolution of the Intra-Pontide suture. The detailed descriptions of Eocene benthic foraminifera identified both in the shallow-marine units transgressive over the ophiolitic lithologies, and in the blocks of the olistostromal sequence are presented in Özcan *et al.* (2010).

Geological Setting

The Thrace Basin is commonly subdivided into three parts (e.g., Doust & Arıkan 1974; Turgut *et al.* 1991) (Figure 1). (1) In the northeast along the Strandja Massif there is a shelf region characterized by shallow-marine Eocene limestones, which pass southwestward into deeper marine limestones, marls and turbidites. (2) In the basin centre, located along a SE–NW axis from Marmara Ereğlisi to Babaeski, most of the Eocene–Oligocene sequence consists of siliciclastic rocks, ca. 9000 metres thick, as shown by seismic sections and hydrocarbon exploration wells (e.g., Turgut *et al.* 1991; Siyako & Huvaz 2007). (3) The Eocene shallow-marine limestones in the south around Şarköy and Mecidiye are regarded as forming the southern shelf of the basin. This part of the basin is transected by a segment of the North Anatolian Fault, the Ganos Fault (e.g., Şengör 1979; Okay *et al.* 1999; Janssen *et al.* 2009). South of the Ganos Fault there are ophiolitic rocks, which are regarded either as basement outcrops (Şentürk *et al.* 1998a, b) or as olistoliths in the Eocene flysch (Saner 1985). North of the Ganos Fault, the only basement outcrop in the Thrace Basin is a small locality on the northern coast of the Saros Bay near Mecidiye (Figure 1). Although

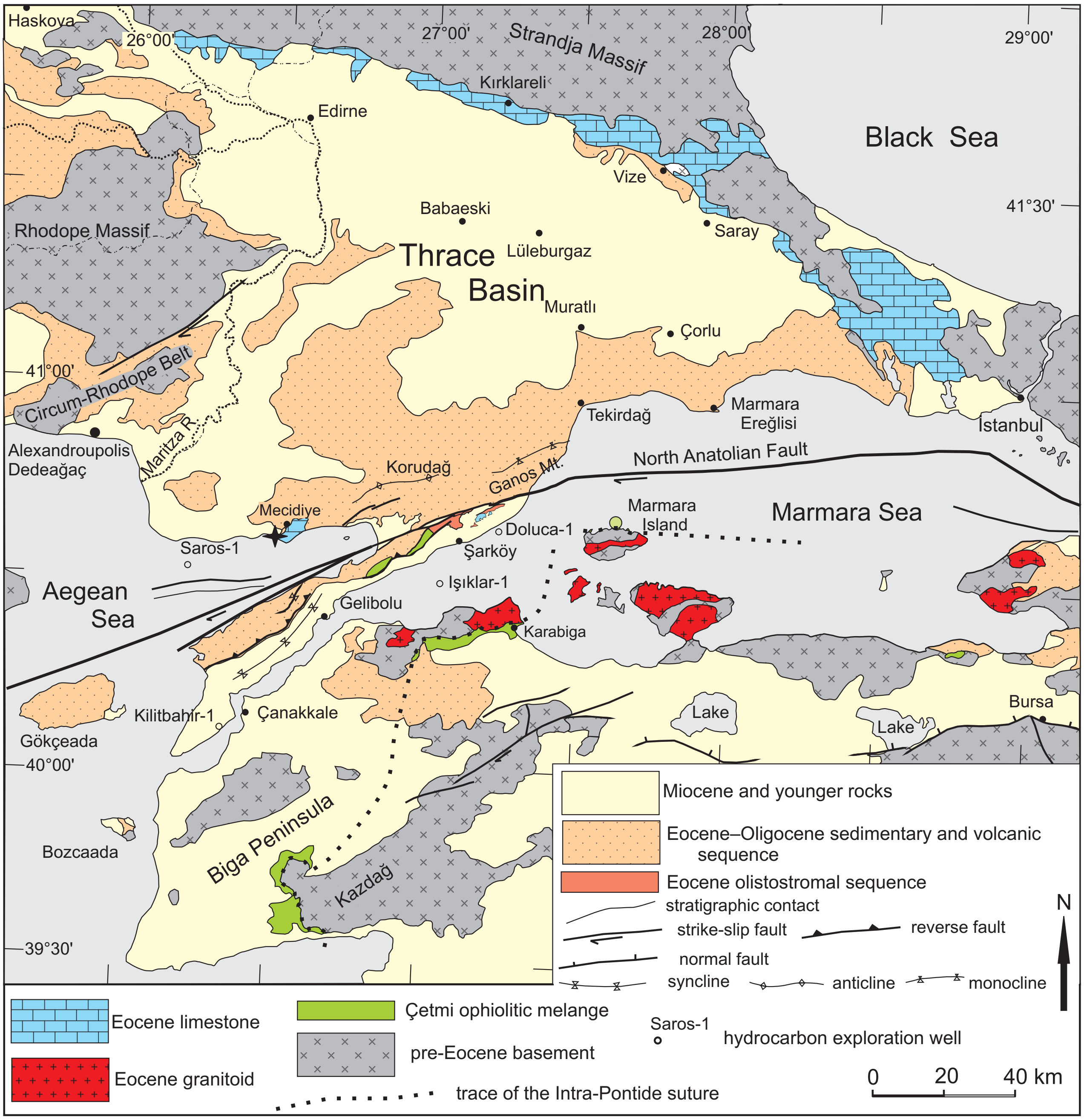

Figure 1. Tectonic map of the Marmara and Thrace region (compiled from Türkecan & Yurtsever 2002; Konak 2002) showing the Eocene–Oligocene outcrops, the Upper Cretaceous ophiolitic mélange and the pre-Eocene basement. The star north of Saros Bay marks the location of the metamorphic basement. The very small mélange outcrops north of Marmara Island are shown exaggerated by a green circle. Mt– mountain.

this locality has been known for some time (Saner 1985; Sümengen & Terlemez 1991; Şentürk *et al.* 1998a; Tüysüz *et al.* 1998), no detailed geological map or description of the basement rocks are available.

Slates, Limestones and Phyllites – Basement North of the Ganos Fault

Low-grade metamorphic rocks crop out over a very small area along the northern coast of Saros Bay near Mecidiye (Figures 1 & 2). The metamorphic rocks

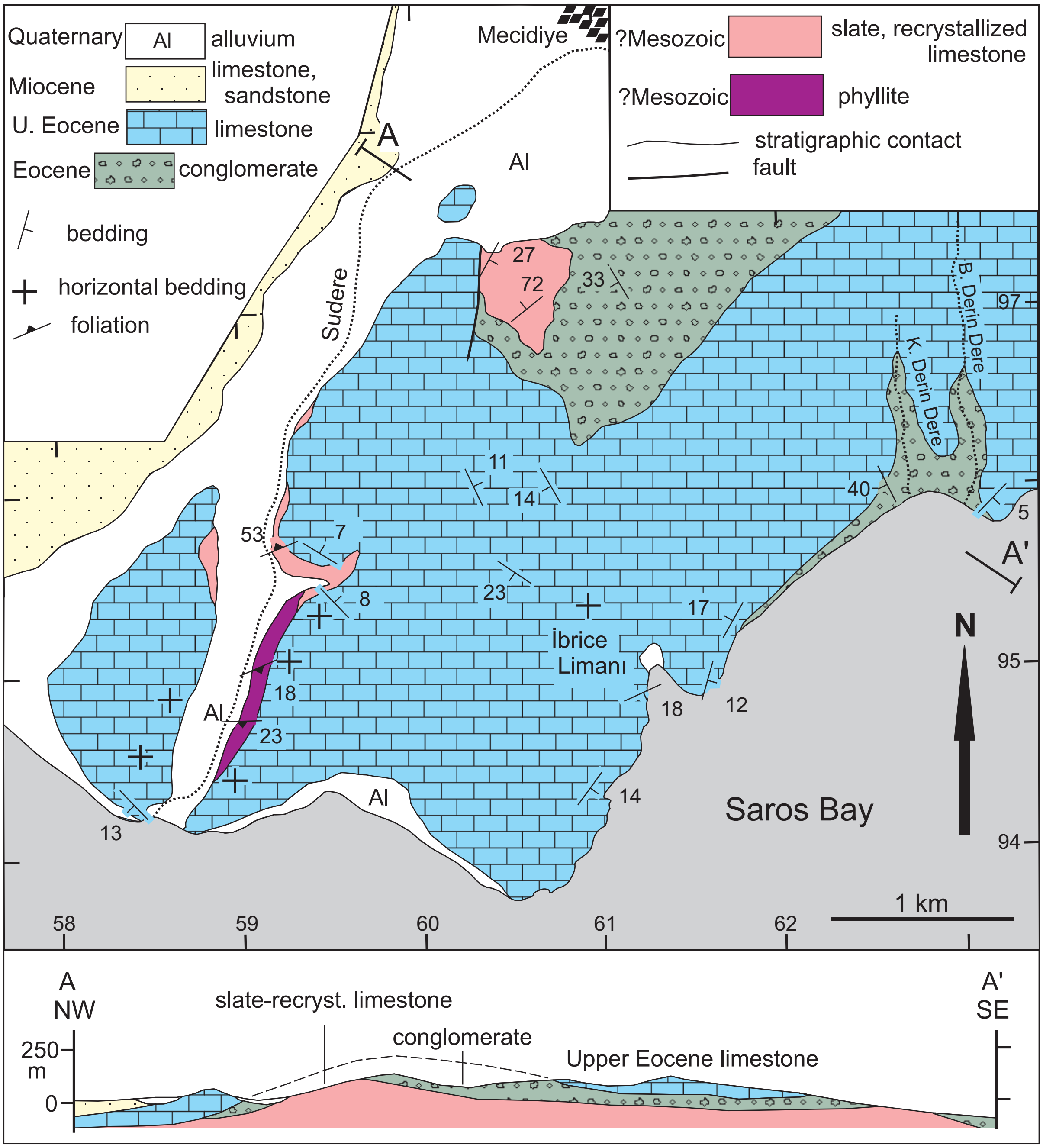

Figure 2. Geological map and cross-section of the Mecidiye area, where the basement to the Thrace Basin crops out. For location see Figure 1.

can be divided into a slate-limestone sequence and a phyllite series. The yellowish grey and grey slates make up 70% of the sequence and are intercalated with dark grey to black limestones. The limestones consist of thin-bedded micrites alternating with thin- to thick-bedded calciturbidites containing clasts up to 1 cm across. Although there is slaty cleavage, metamorphism is of very low grade; the micritic limestone and quartz grains in the calciturbidites have not recrystallized, indicating metamorphic temperatures lower than 300 °C. The slate-limestone association represents a basinal marine sequence.

The second metamorphic series is dominated by grey, silvery grey, greyish pink, well foliated, medium-grained phyllites, containing rare metasiltstone and metasandstone intercalations, and are cut by boudinaged quartz veins. The metamorphism is in greenschist facies with newly formed quartz, muscovite, albite and opaque minerals making up the bulk of the rock. The phyllite series represents a distal turbidite sequence. The contact between the slate-limestone series and the phyllite series is not exposed but, based on the difference in metamorphic grade, is probably tectonic. Sümengen & Terlemez (1991) and Şentürk *et al*. (1998a) regarded the metamorphic rocks of the Mecidiye area as part of an ophiolitic mélange, although they differ lithologically and structurally from ophiolitic mélanges. However, low-grade metamorphic rocks consisting of recrystallized limestone, calc-schist and phyllite have also been reported from the Circum-Rhodope Belt north of Dedeağaç/Alexandroupolis (Kopp 1969; Magganas 2002). Based on scarce fossils they are assigned a Mesozoic age. The metamorphic rocks of the Mecidiye area, which probably form an extension of this Circum-Rhodope Belt, are unconformably overlain by Upper Eocene conglomerate and limestone (Figure 3).

Ophiolitic Mélange: Basement South of the Ganos Fault

The hydrocarbon exploration wells indicate that the Eocene sequence south of the Ganos Fault rests on an ophiolitic mélange. The wells in southern Thrace penetrated basement between 1000 and 2000 metres below the surface. In the Ortaköy-1, Şarköy-1, Işıklar-1 and Doluca-1wells (Figures 1 & 4) basement described as serpentinite was encountered below the Eocene limestone or siliciclastic rocks (Yaltırak 1996; Yazman 1997; Siyako & Huvaz 2007). As serpentinite also occurs as clasts in debris and grain flows in the overlying Eocene series, the question arises whether some of the larger outcrops of ophiolitic rocks north of Şarköy are basement, as shown for example in Şentürk *et al*. (1998a, b), or just very large olistoliths (Saner 1985; Şen *et al.* 2009). Two lines of evidence indicate that, with the exception of the Sarıkaya sliver (Figure 4), the ophiolitic rocks north of Şarköy are olistoliths in the Eocene sequence. First, where the margins of the blocks are exposed, they are surrounded by sandstone, shale and grain flows with no contacts that can be described as an unconformity. Secondly, detailed mapping and geological cross-sections, controlled by hydrocarbon exploration wells, show the presence of several hundred metres of Eocene clastic deposits beneath even the largest ophiolitic outcrops. The only exception is the Sarıkaya sliver, which is discussed in the following section.

Sarıkaya Sliver: an Ophiolitic Sliver from the pre-Eocene Basement

The Sarıkaya sliver is a 9-km-long and 1-km-wide serpentinite ridge, bounded by strands of the Ganos Fault (Figures 4 & 5). The Ortaköy-1 and Işıklar-1 wells, located 4 and 13 kilometres south of the Sarıkaya sliver, encountered serpentinite basement beneath the Eocene sediments at depths of 1731 and 830 metres, respectively (Figures 1, 4 & 5). The relative shallowness of the basement, the reduced thickness of the Eocene siliciclastics (< 500 m) and the size of the Sarıkaya sliver indicate that it represents an uplifted segment of the ophiolitic basement rather than a megablock in the Eocene sequence. The uplift and exhumation of the Sarıkaya sliver is related to the activity of the Ganos Fault.

The Sarıkaya sliver consists mainly of highly sheared and fractured serpentinite with diabase bodies, all thrust bilaterally over the Miocene sediments. The diabase bodies, a few metres to 30 metres across, make up about 10% of the Sarıkaya sliver and were probably dykes in the peridotite, but the present serpentinite-diabase contacts are sheared (Figure 6a). The diabase forms grey, medium-grained, extremely hard rock in sheared scaly serpentinite. Because of its extreme toughness, it was used a tool in prehistoric times (Özbek & Erol 2001). The diabase shows an incipient high pressure metamorphism with development of lawsonite and sodic amphibole (Şentürk & Okay 1984; Erol 2003;

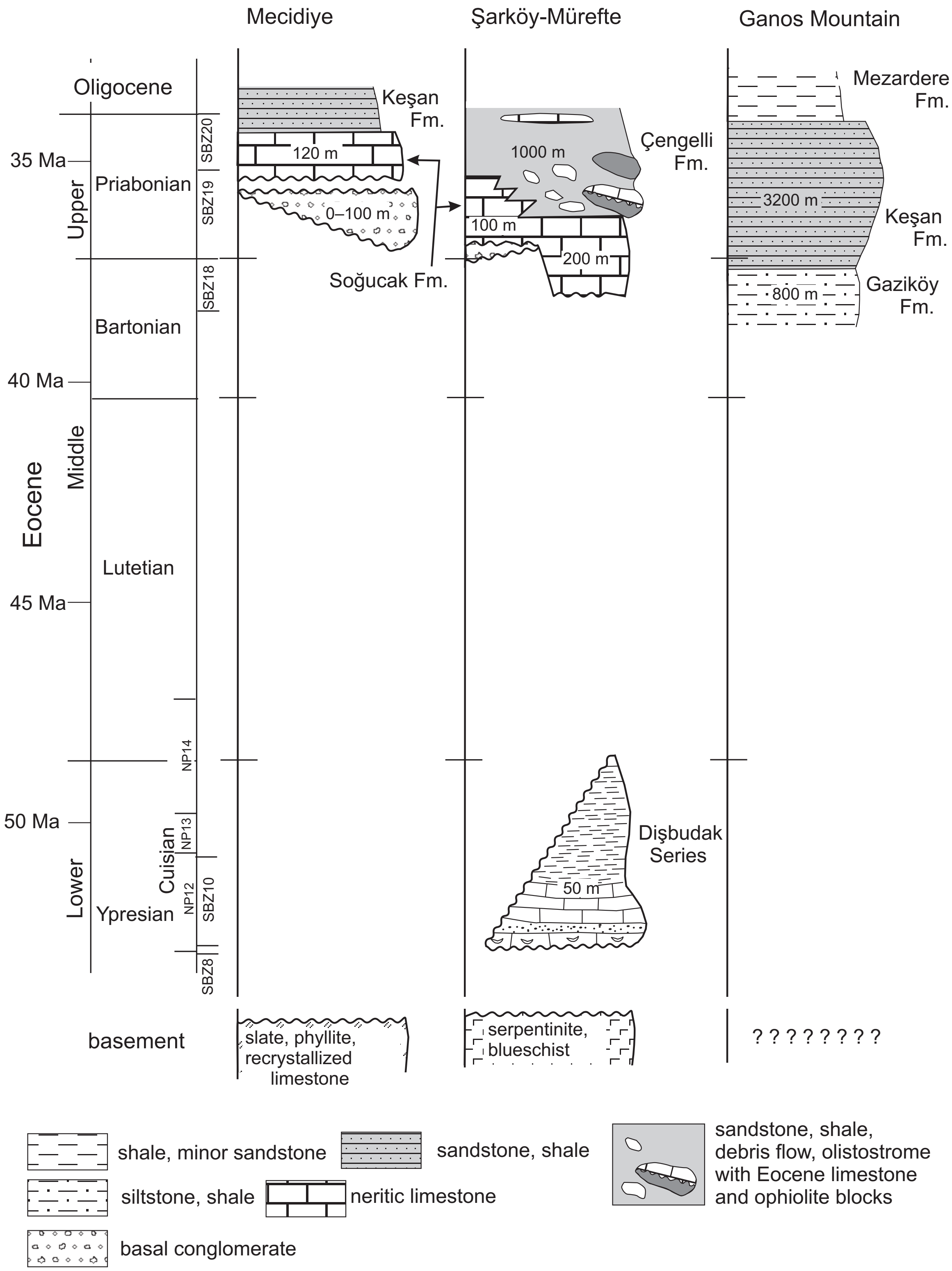

Figure 3. Eocene–Lower Oligocene stratigraphic sections of the Mecidiye, Ganos Mountain and Şarköy–Mürefte areas. Fm– formation. The shallow benthic (SBZ) and nannoplankton (NP) zones are after Serra-Kiel *et al*. (1998).

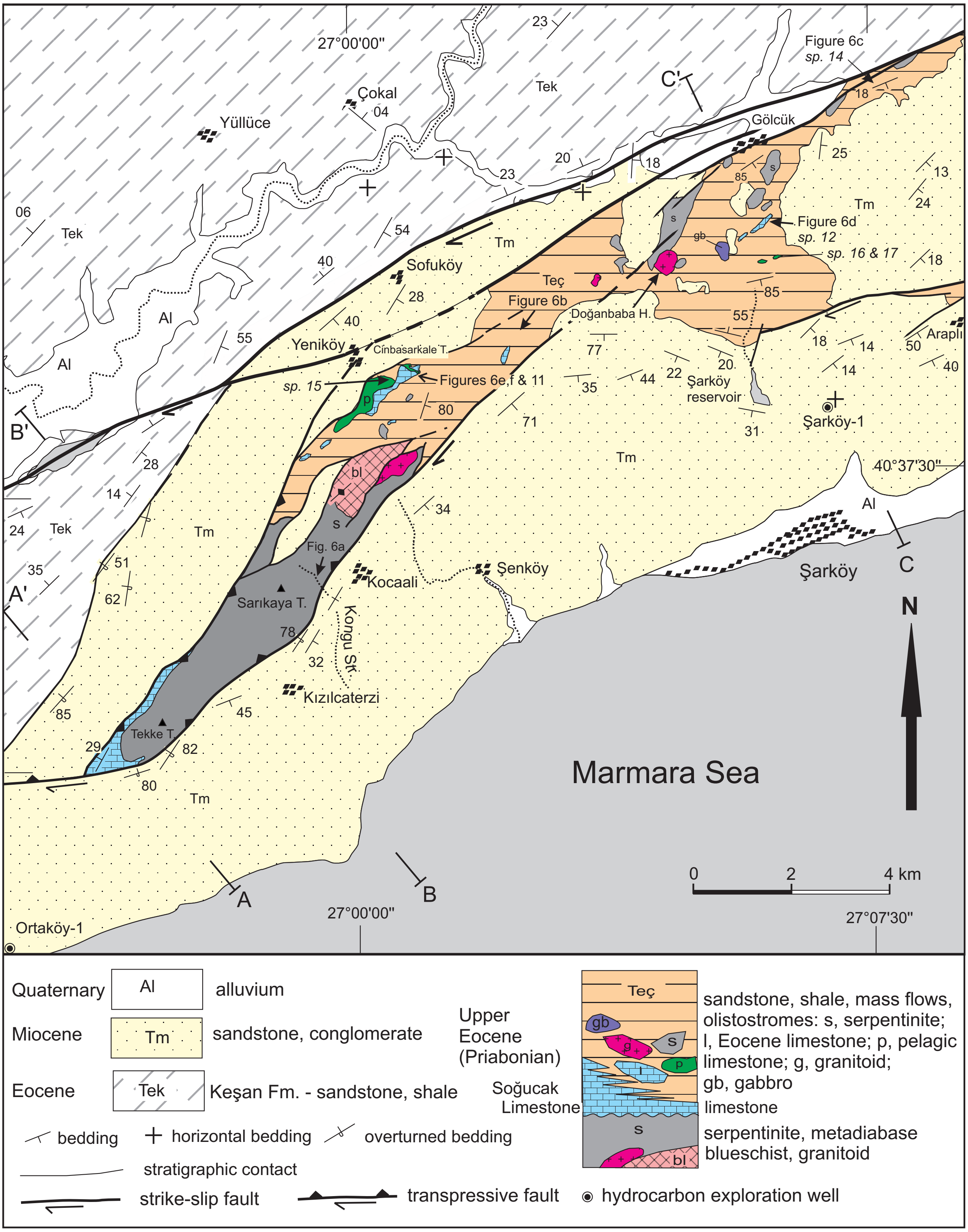

Figure 4. Geological map of the northern Şarköy region. For location, see Figure 1.

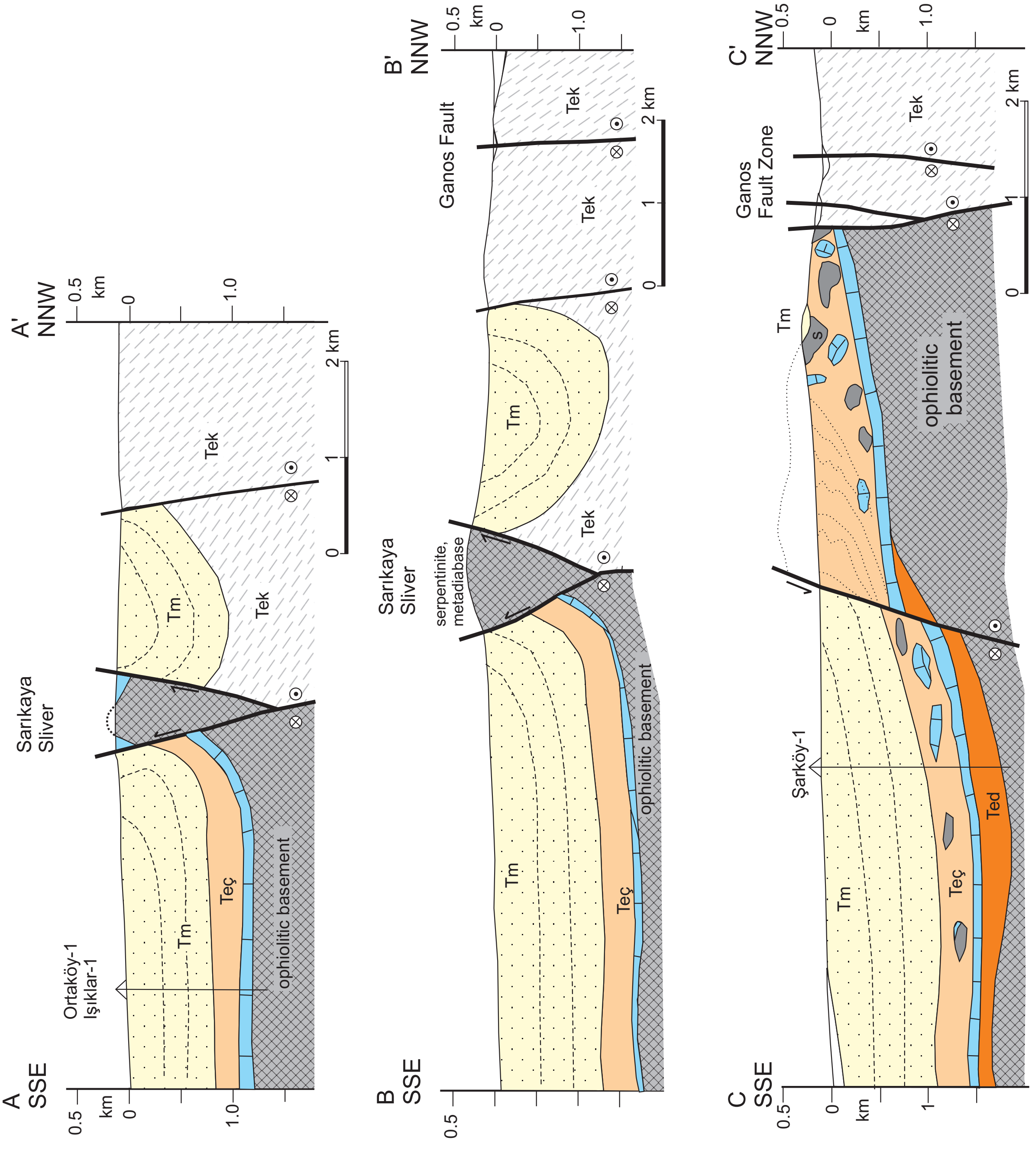

Figure 5. Geological cross-sections from the Şarköy region. For the legend and location of the sections, see Figure 4. Ted–Dişbudak series.

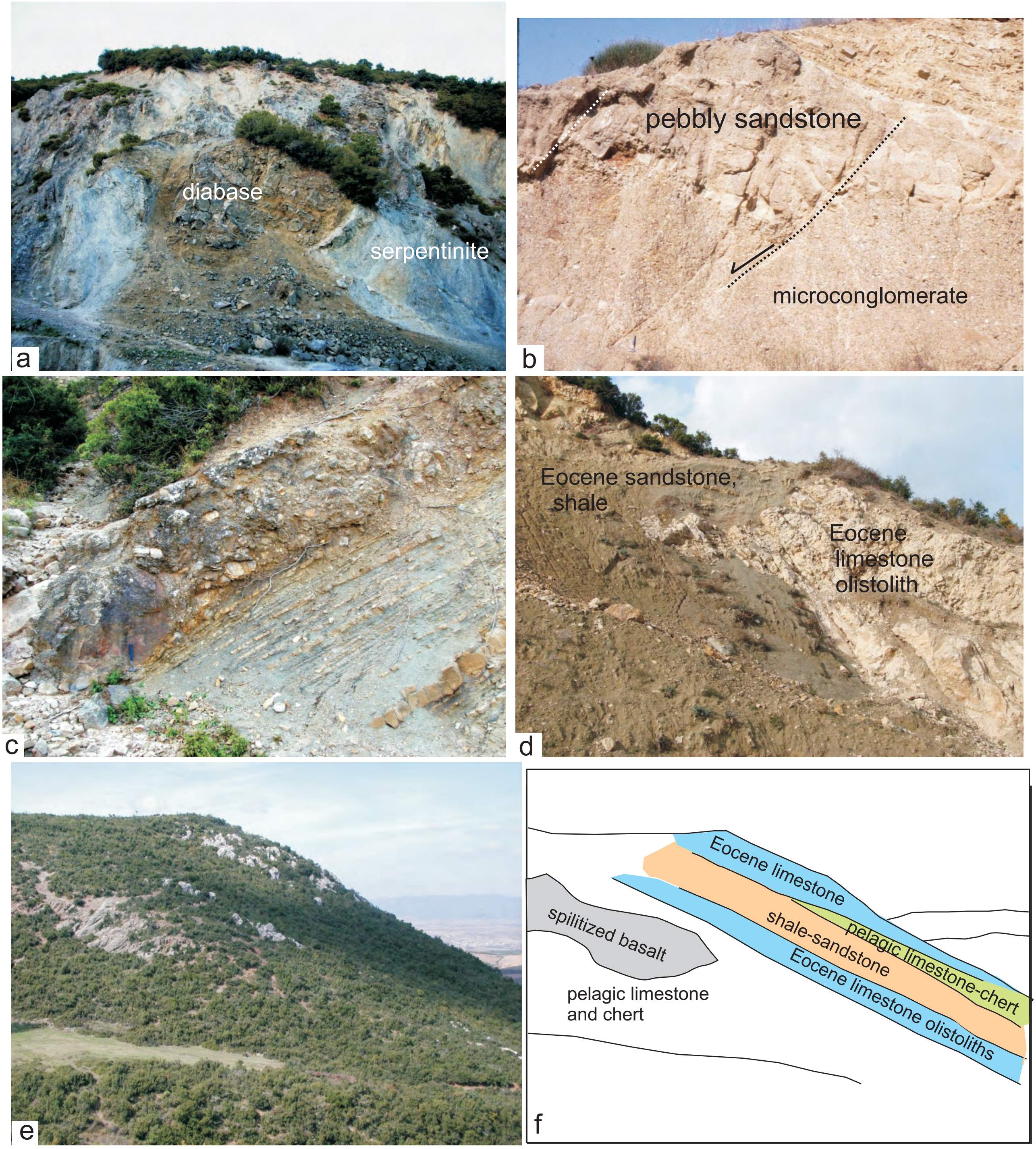

Figure 6. **(a)** Metadiabase and sheared serpentinite, Sarıkaya sliver, Kongu creek, west of Şarköy. **(b)** Syn-sedimentary growth fault (075°/52°SE) in sandstones and microconglomerates of the Çengelli Formation, east of Yeniköy. **(c)** A 2-m-thick debris flow bed in the Çengelli Formation. The clasts in the debris flow include basalt, pelagic limestone and schist, west of Gölcük (UTM 09 804 – 04 090). **(d)** An Upper Eocene limestone olistolith (2B) in Çengelli Formation turbidites, Harmankaya, north of Şarköy. **(e, f)** Composite olistoliths with basalt and pelagic limestone overlain by Eocene limestone, Cinbasarkaletepe, Yeniköy. For location of the photographs, see Figure 4.

Topuz *et al.* 2008). Foliated blueschist facies metamorphic rocks occur in a small area at the eastern margin of the Sarıkaya sliver (Figure 4). They consist of metabasite, marble, metachert and phyllite and have yielded Late Cretaceous (ca. 86 Ma) Rb-Sr and Ar-Ar phengite ages (Topuz *et al.* 2008). The serpentinite and the metamorphic rocks are intruded by microdioritic subvolcanic rocks. On the western margin of the Sarıkaya sliver, the serpentinite is unconformably overlain by the shallow marine Soğucak Limestone of early Priabonian age (Figure 3).

The Eocene Sequence in the Mecidiye Area

The metamorphic rocks south of Mecidiye are unconformably overlain by red continental conglomerates and by Upper Eocene (Priabonian) shallow marine limestones of the Soğucak Formation (Figure 2, Tüysüz *et al.* 1998; Siyako 2006; Siyako & Huvaz 2007). The conglomerates are red to green, very poorly sorted, massive to thickly-bedded and contain rare lenticular sandstone and siltstone beds. The angular clasts in the conglomerates are mainly phyllite with lesser amounts of metasiltstone, metasandstone and quartz; the clast size varies from 0.5 cm to one metre and all clasts are locally derived. These red clastics – interpreted as alluvial fan deposits – are overlain unconformably by shallow-marine limestones of the Soğucak Formation containing algae, corals and foraminifera (cf. *figure 12* of Siyako & Huvaz 2007). The benthic foraminiferal assemblage (*Spiroclypeus carpaticus*, *Heterostegina gracilis*, *Nummulites fabianii* and orthophragmines) identified in the lowermost part of the limestone sequence (Özcan *et al.* 2010) indicates a late Priabonian age based on the presence of the first two forms cited above (Less *et al.* 2008; Less & Özcan 2008). The red clastic rocks have a patchy development, possibly filling hollows in the palaeotopography; along the Sudere valley they are completely missing and the limestones lie directly upon the metamorphic rocks, with a basal pebbly sandstone bed less than one metre thick (Figure 2). East of Mecidiye the Soğucak Formation is in turn overlain by the Upper Eocene siliciclastic turbiditides of the Keşan Formation (Figure 3).

The Eocene Sequence South of the Ganos Fault

The Ganos Fault in Thrace separates two distinctly different Tertiary sequences. North of the fault there is a siliciclastic Eocene–Oligocene sequence, ca. 5 km thick, which ranges from Middle Eocene distal turbidites, through proximal turbidites and deltaic facies to Oligocene marginal-marine and continental sandstones-shales with lignite horizons (Figure 3, Turgut *et al.* 1991; Sümengen & Terlemez 1991; Yıldız *et al.* 1997; Siyako & Huvaz 2007; İslamoğlu *et al.* 2008). This clastic sequence dips away from the Ganos Fault and is well exposed in the steep limb of a major monocline on Ganos Mountain (Okay *et al.* 2004).

South of the Ganos Fault the Eocene–Oligocene section comprises three formations (Figure 3). At the base there are small erosional remnants of a Lower Eocene carbonate-clastic sequence, here called as the Dişbudak series. This is overlain unconformably by the Middle to Upper Eocene Soğucak Formation, which passes up into an Upper Eocene–Lower Oligocene siliciclastic turbidite series with widespread olistostrome horizons.

Lower Eocene Carbonate-Clastic sequence – The Dişbudak Series

The Lower Eocene sequence crops out in two localities northwest of Mürefte between Doluca and Deve hills under the Soğucak Limestone (Figures 7 & 8). The 30-m-thick sequence is best exposed on the south side of the Dişbudak valley north of Deve Hill, but the base of the series is not exposed. It begins with an oyster bank, ~1.5 m thick, which passes up in turn through pebbly sandstones, sandy and then nodular limestones, marl and carbonate-rich mudstone and shale (Figure 9). The marls are overlain by the Upper Bartonian limestones of the Soğucak Formation: the contact, although disturbed by subsequent deformation, is interpreted as an unconformity (Figure 10a).

The sandy limestones (samples 1 and 2, see Table 1 for information on the palaeontological samples) in the Dişbudak series contain a wealth of larger foraminifera: *Discocyclina fortisi fortisi*, *D. augustae sourbetensis*, *D. archiaci archiaci*, *Nemkovella*

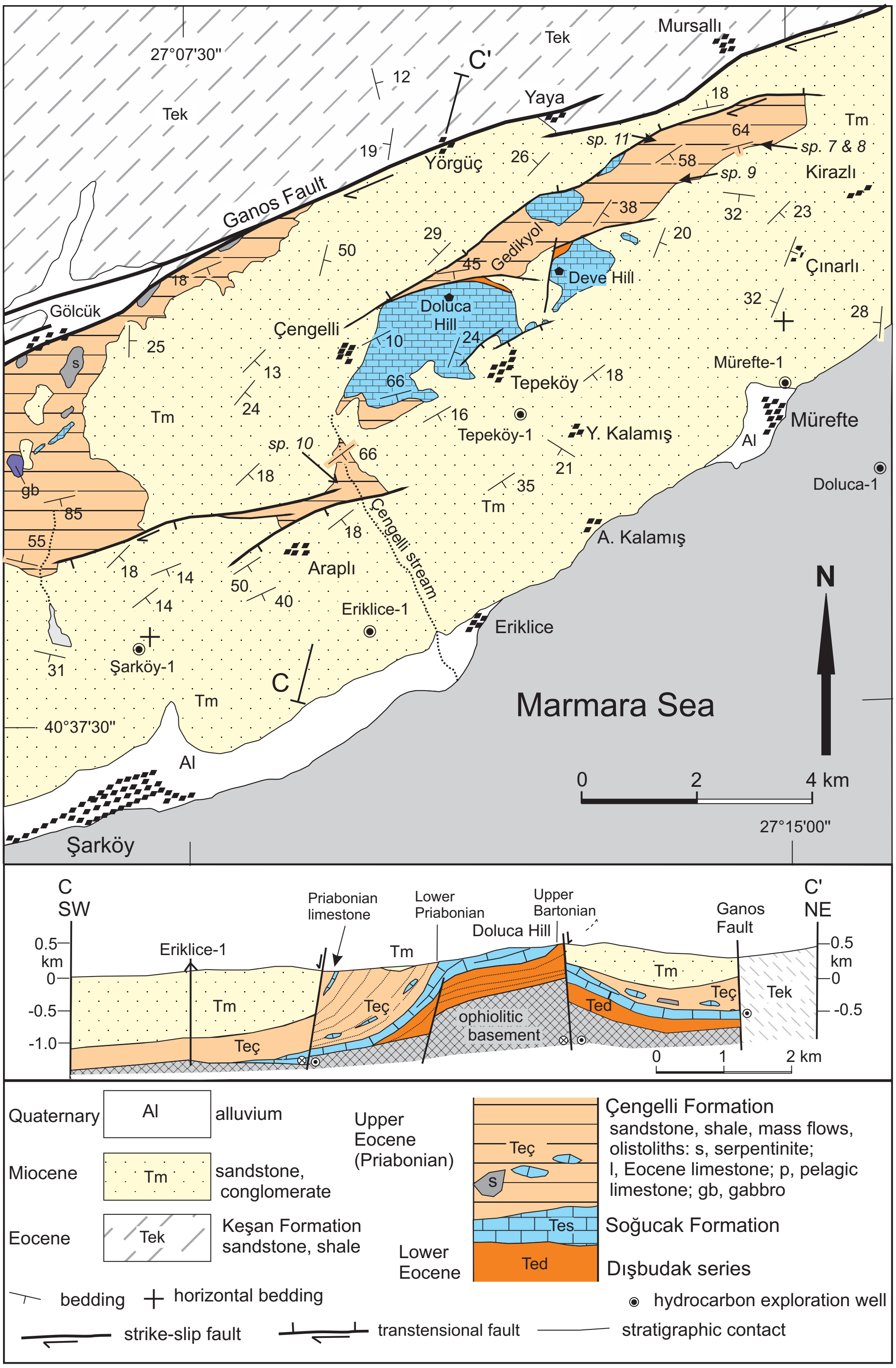

Figure 7. Geological map and cross-section of the region northwest of Mürefte. For location, see Figure 1.

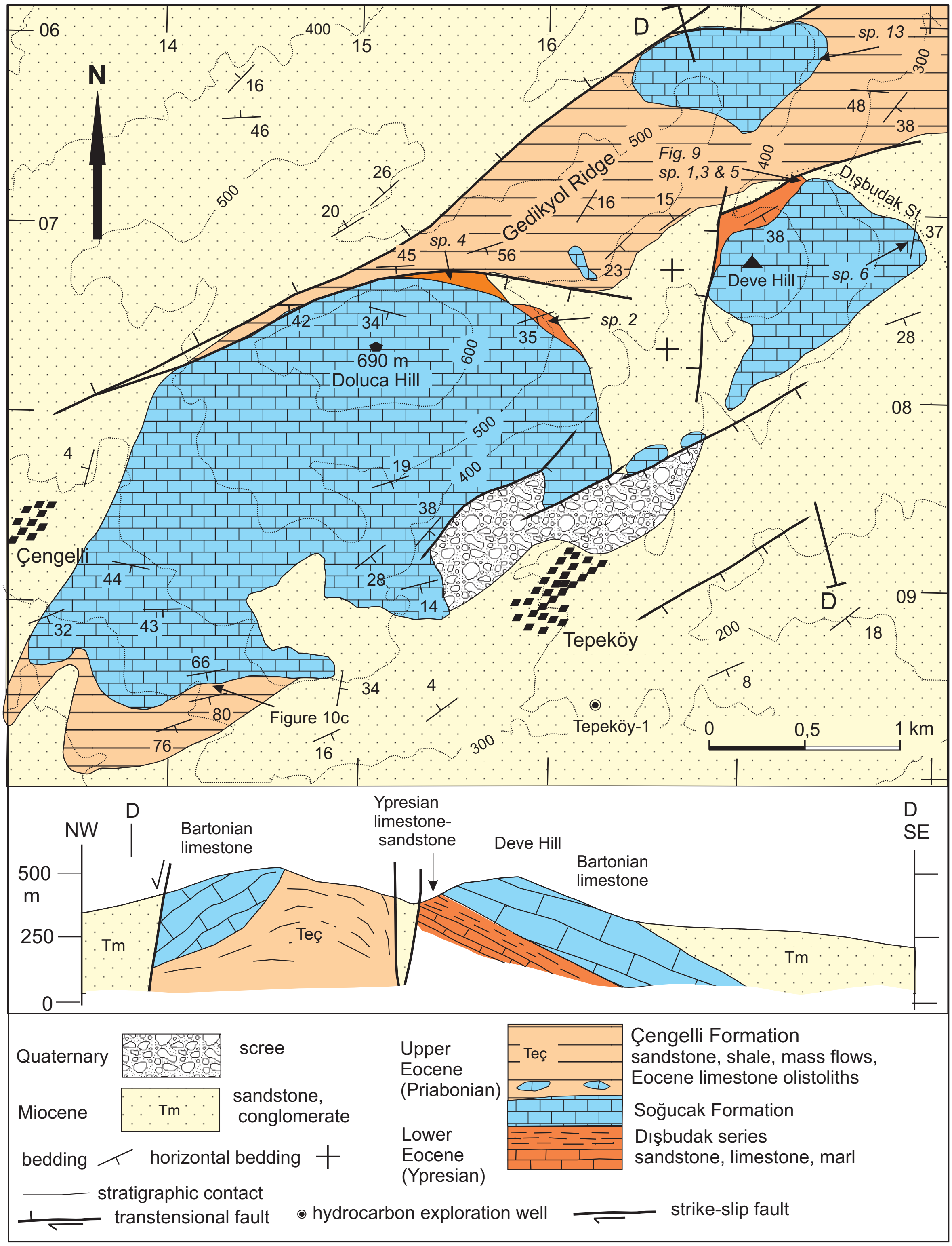

Figure 8. Detailed geological map and cross-section of the Doluca and Deve hills region northwest of Mürefte showing the position of the Lower Eocene series. For location, see Figure 7.

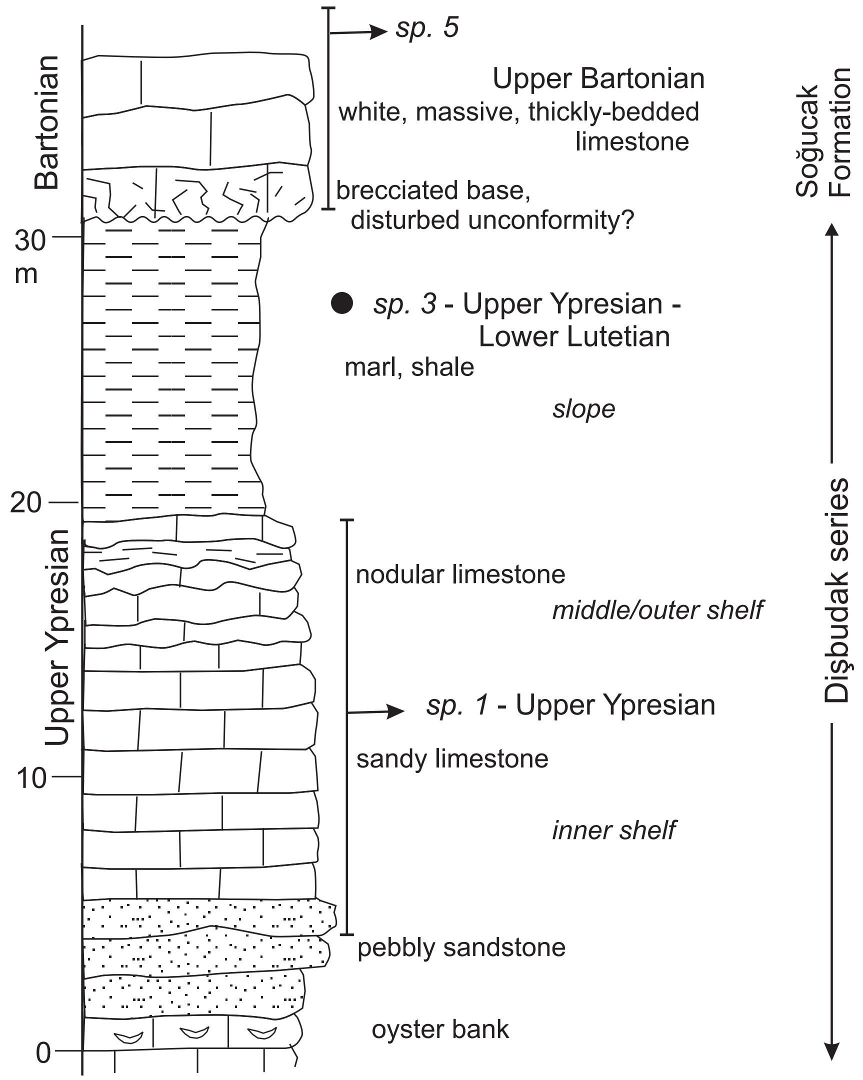

Figure 9. Lithostratigraphic section of the Lower Eocene Dişbudak Series. For location, see Figure 8.

strophiolata, *N. evae*, *Orbitoclypeus douvillei* cf. *douvillei*, *O. schopeni*, *Nummulites leupoldi*, *N. burdigalensis, N. nemkovi, N. soerenbergensis*, *Assilina placentula*, *Orbitolina* sp. and Alveolinidae. Based on Less (1998) and Özcan *et al.* (2007a), orthophragmines suggest an early part of late Ypresian age (shallow benthic zone SBZ 10 of Serra-Kiel *et al.* 1998). The Eocene nannoplankton taxa in the overlying marls (sample 3) are *Discolithina multipora*, *Cyclicargolithus floridanus*, *Coccolithus pelagicus*, *Cyclicoccolithus formosus*, *Discoaster lodoensis*, and *Sphenolithus radians*. Among these species *Discoaster lodoensis*, has the shortest stratigraphic range (nannoplankton zones NP 12-14) corresponding to the late Ypresian to earliest Lutetian. In the same sample there are also planktonic foraminifera indicating a Early–Middle Eocene age: *Acarinina primitive* and *A.* sp., and large numbers of reworked nannoplanktons from the Cretaceous (Campanian) rocks: *Eiffellithus turriseiffelli*, *Eiffellithus eximius*, *Watznaueria barnesae*, *Arkhangelskiella cymbiformis*, *Broinsonia parca* s. l., *Bukryaster hayi*, *Cretarhabdus* sp. An additional shale sample (sample 4) close to the

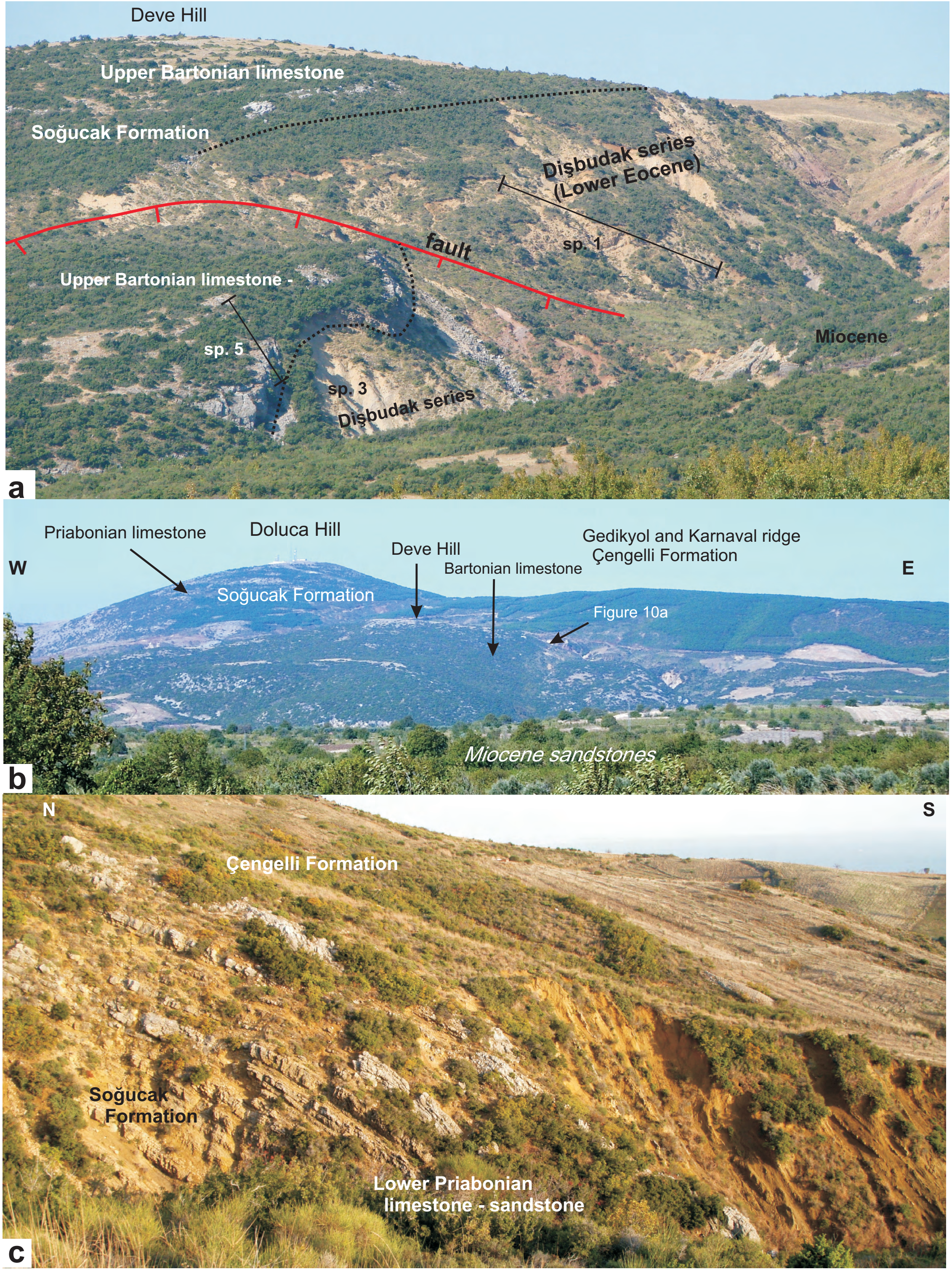

Figure 10. **(a)** The Lower Eocene Dişbudak Series and the overlying Upper Bartonian limestones of Deve Hill, Dişbudak valley. **(b)** The Eocene limestone of Doluca Hill and the Çengelli Formation of the Gedikyol and Karnaval ridges. **(c)** The upper contact of the Doluca Hill Eocene limestone in the Ballık Valley (cf. Figure 8).

Table 1. Palaeontological sample numbers and ages.

Eocene, Palaeocene and Upper Cretaceous limestone, marn, shale.

no.	field no.	samples	UTM coordinates	age
1	MÜF.A	18-m-thick section – benthic foraminifera	E 35 T 05 17 102 - N 35 04 938	Late Ypresian (SBZ 10)
2	1894	point sample – benthic foraminifera	E 35 T 05 16 027 - N 35 04 475	Late Ypresian (SBZ 10)
3	MÜF.A-11	point sample – nannoplanktons & planktic foraminifera	E 35 T 05 17 102 - N 35 04 938	Late Ypresian–Early Lutetian (NP12-14)
4	1909	point sample – planktic foraminifera	E 35 T 05 15 451 - N 35 04 677	latest Ypresian to Lutetian
5	MÜF.B	19-m-thick section – benthic foraminifera	E 35 T 05 17 306 - N 35 05 185	Late Bartonian (SBZ 18)
6	638	point sample – benthic foraminifera	E 35 T 05 17 890 - N 35 04 885	Bartonian–Priabonian
7	1900	point sample – nannoplanktons	E 35 T 05 20 406 - N 35 06 812	Bartonian–Early Rupelian (NP16-22)
8	1901	point sample – nannoplanktons	E 35 T 05 20 416 - N 35 06 801	Ypresian–Early Rupelian (NP19-22)
9	1907	point sample – nannoplanktons	E 35 T 05 19 106 - N 35 06 241	Ypresian–Early Rupelian (NP19-22)
10	564	point sample – benthic foraminifera	E 35 T 05 13 050 - N 35 01 200	Late Bartonian–Early Priabonian
11	1902	point sample – benthic foraminifera	E 35 T 05 18 755 - N 35 06 858	Late Bartonian (SBZ 18)
12	2B	point sample – benthic foraminifera	E 35 T 05 08 250 - N 35 02 200	Priabonian
13	MÜF.C	5-m-thick section – benthic foraminifera	E 35 T 05 17 497 - N 35 05 958	Late Bartonian early Priabonian (SBZ 18-19)
14	1645	point sample – planktic foraminifera	E 35 T 05 09 845 - N 35 04 212	Campanian–Maastrichtian
15	1681	point sample – planktic foraminifera	E 35 T 05 00 597 - N 34 99 340	Early Palaeocene (P0-P1)
16	100	point sample – planktic foraminifera	E 35 T 05 08 905 - N 35 01 425	Mid–Late Palaeocene (P4)
17	102	point sample – planktic foraminifera	E 35 T 05 08 910 - N 35 01 436	Mid–Late Palaeocene (P3-P4)

SBZ, shallow benthic zones; NP, nannoplankton zones; P, planktic foraminifer zones

Doluca Tepe limestone contains planktonic foraminifera of latest Ypresian to Lutetian age with *Globigerina senni* and *Morozovella spinulosa*.

Palaeontological data indicate conclusively a Late Ypresian age for the Dişbudak series, and its age may extend into early Lutetian. The fine-grained clastic lithology in the upper part of the Dişbudak section precludes an olistolith origin. The Dişbudak series is interpreted as an erosional remnant of an Early Eocene transgression. Although it has very small exposures on the surface, the Tepeköy-1 and Şarköy-1 wells have cut through a few hundred metres of predominantly clastic rocks underneath the Soğucak Formation. This sandstone-shale series, which is 200-m-thick in the Tepeköy-1 well and 264-m-thick in the Şarköy-1 well (Yaltırak 1996) most probably belongs to the Lower Eocene Dişbudak series (Figures 7 & 8).

The Soğucak Formation – Middle to Upper Eocene Limestones

In the Sarıkaya sliver, Cretaceous ophiolites are directly overlain by the Soğucak Limestone on Tekke Hill, without any intervening Disbudak series. The Soğucak Limestone on Tekke Hill contains abundant larger foraminifera including *Spiroclypeus sirottii* and *Heterostegina reticulata mossanensis*, which are marker forms for the early Priabonian (Less & Özcan 2008; Less *et al.* 2008; Özcan *et al.* 2010).

In the Şarköy-Mürefte region the Soğucak Formation overlies the Dişbudak series in the Doluca and Deve hills. A section was measured at the base of the Soğucak Formation north of Deve Hill above the Dışbudak series (Figures 8 & 9). Samples from this section (sp. 5) contain an assemblage of *Nummulites hormoensis*, *N. biedai*, *N. striatus*, *Fabiania cassis*, *Chapmanina gassinensis*, *Asterigerina rotula*, *Sphaerogypsina globula*, *Gyroidinella magna*, *Heterostegina reticulata*, *Halkyardia* sp., and *Gypsina* sp. The occurrence of *N. hormoensis* and *N. biedai* accompanied by *Heterostegina reticulata* suggests a late Bartonian age (SBZ 18) for the base of the Soğucak Limestone. The Soğucak Limestone on the nearby Doluca Hill forms a 200-m-thick sequence of thickly-bedded to massive, white, shallow-marine limestone with algae, corals, bryozoa and foraminifera (Figures 8 & 10b). The top of the Soğucak Limestone on Doluca Hill is Early Priabonian in age (SBZ 19), as described in Özcan *et al.* (2007b) on the basis of larger foraminifera in a 28-m-thick measured section (Figure 10c). The top of the limestone sequence on Deve Hill (sample 6) also yielded Bartonian–Priabonian foraminifera: *Gyroidinella magna*, *Silvestriella tetraedra*, orthophragmines and *Nummulites* sp.

The Çengelli Formation – Upper Eocene–Lower Oligocene Olistostromal Flysch Series

The Soğucak Formation is conformably overlain by an Upper Eocene–Lower Oligocene siliciclastic turbidite series with widespread debris flow and olistostrome horizons, named the Çengelli Formation after the Çengelli Valley to the south of Doluca hill. The type section is along the road between Şarköy and Gölcük and a reference section is along the Çengelli stream (Figure 7). Previous publications ascribed the Eocene sequence south of the Ganos Fault to the Ceylan Formation (Siyako 2006; Siyako & Huvaz 2007). However, the Ceylan Formation typically consists of marl, sandstone and shale, and is thus lithologically different from the Çengelli Formation. Önal (1986), Siyako *et al.* (1989) and Temel & Çiftçi (2002) mentioned the presence of Eocene limestone olistoliths in the Upper Eocene flysch (Ceylan Formation) in the Gelibolu and Biga peninsulas. However, these are neither mapped nor described, and our observations indicate that they are local and make up a very minor part (less than 1%) of the Upper Eocene section in the region. For example, there is not a single debris flow or olistolith along the well exposed type section of the Ceylan Formation between the village of Tayfur and the Tayfur dam in the Gelibolu Peninsula (Siyako 2006).

About 80% of the Çengelli Formation is made up of distal turbidites with a rhythmic alternation of sandstone and shale. The sandstones are fine- to coarse-grained, medium-bedded, grey, brown and are extensively bioturbated. The pelitic divisions are 10 cm to one metre in thickness. Sedimentary structures such as flutes or grooves are rare. Syn-sedimentary growth faults with normal separations are observed at several localities southeast of Yeniköy

(Figure 6b). The remaining 20% of the Çengelli Formation is made up calciturbidite beds and debris flow and olistostrome horizons (Figure 6c, d; Schindler 1959; Saner 1985; Okay & Tansel 1992; Şen *et al.* 2009). The clasts in the mass flows include ophiolitic lithologies and Eocene limestone of the Soğucak Formation and will be described below. The petrography of the sandstones was studied in ten thin sections to constrain the provenance. The sandstones are feldspathic and lithic arenites; most of the lithic grains are subvolcanic to volcanic, the rest consists of quartz-mica schist and carbonate; ophiolitic lithic grains, e.g. serpentinite, chert and basalt, total about 5%. The idioblastic plagioclase clasts in the sandstones also indicate a magmatic source.

The Çengelli Formation forms a southward younging and fining-upward sequence with the debris flows and olistostromes forming the lower part. It is underlain by the lower Priabonian Soğucak Limestone, and is overlain unconformably by the terrigeneous to marginal-marine Miocene sandstones and conglomerates. Its maximum thickness exceeds 600 m; a more precise estimate is difficult, as it was partly eroded and deformed by faulting in the Late Oligocene–Early Miocene and in the Pliocene–Quaternary. In the hydrocarbon exploration wells its thickness varies between 485 m (Işıklar-1) and 618 m (Mürefte-1). It crops out in two erosional windows under the Miocene cover: in the west between Yeniköy and Gölcük (Figure 4) and in the east around Doluca Hill (Figures 7 & 8).

The base of the Çengelli Formation is exposed south of Doluca Hill, where thickly bedded to massive limestones of the Soğucak Formation pass up into sandstones intercalated with shales and limestones (Figure 10c). This basal part of the Çengelli Formation is well dated by larger foraminifera as Early Priabonian (SBZ 19) (Figure 3). We constrained the age of the Çengelli Formation through nannoplanktons from three shale samples (samples 7, 8 & 9). The richest nannofossil assemblage occurs in sample 9: *Helicosphaera compacta*, *H. intermedia*, *H. euphratis*, *H. seminulum*, *Discolithina multipora*, *Transversopontis pulcher*, *Isthmolithus recurvus*, *Blackites* sp., *Cyclicargolithus floridanus*, *Reticulofenestra bisecta*, *R. placomorpha*, *Coccolithus pelagicus*, *Cyclococcolithus formosus*, *Lanternithus minutes*, *Zygrhablithus bijugatus*, *Braarudosphaera bigelowi*, *Micrantholithus vesper*, *Discoaster* cf. *distinctus*, *D. deflandrei*, *D. tani*, *D.* cf. *mirus*, *Sphenolithus predistentus*, *S. moriformis*, *S. radians*. The age of this assemblage is defined by the range of *Isthmolithus recurvus*, which is NP 19-22 (Priabonian to early Rupelian). In this sample, as well as in the other samples, there are reworked nannoplanktons of Late Cretaceous and Early–Middle Eocene ages. The age of the Çengelli Formation is Priabonian and may extend into the Early Oligocene.

The upper parts of the Çengelli Formation can be observed along the Çengelli stream northeast of Araplı village (Figure 7), where it consists of thickly-bedded debris flows intercalated with pebbly sandstones. The rounded and poorly sorted clasts in the debris flows range in size from a few centimetres to 1.5 metres across, and consist of siltstone, quartz, andesite, shale, phyllite, red jasper, limestone, green chert, basalt, microconglomerate, marble and sandstone. At the top of the conglomerate-sandstone sequence, there are medium-bedded white, or pale grey bioclastic limestones with bluish grey marl intercalations, ca. 20 m thick. Samples (10) from these bioclastic limestones contain Upper Bartonian–Lower Priabonian foraminifera: *Chapmanina gassinensis*, *Gyroidinella magna*, *Fabiania* cf. *cassis, Nummulites* sp., *Victoriellina* sp., Amphisteginidae.

Block Types in the Çengelli Formation

The debris flows and olistostromes in the Çengelli Formation are exposed over an area of 16 km by 3 km. The debris flows contain very poorly sorted, angular to subangular clasts, up to 2 m across, in a sandy matrix (Figure 6c). The olistoliths range up to 500 metres across. The lithology of the clasts and their relative frequency are size-independent. The clast types are, in decreasing order of frequency: Eocene shallow-marine limestone, serpentinite, pelagic limestone, metabasite, basalt, diorite, gabbro and greywacke. There are also composite olistoliths consisting of two different rock types. Some of the more important clasts types in the Çengelli Formation are described below.

Middle-Upper Eocene Shallow Marine Limestone of the Soğucak Formation. These are white, massive to thick-bedded limestones with coralline algae, corals, bryozoans and foraminifera. Eocene limestone clasts in the Çengelli Formation range from sand grains to olistoliths several hundred metres across. Eocene limestones are also the most common clasts in the calciturbidite beds, which are intercalated within the sandstone-shale sequence. The calciturbidites are especially common along the Gedikyol ridge northeast of Doluca Tepe; they consist of pale grey, medium-bedded, often parallel laminated beds. Ten samples from different calciturbidite beds within the Çengelli Formation have yielded the following foraminifera assemblage of Bartonian–Priabonian age: *Chapmanina gassinensis*, *Asterigerina rotula*, *Gyroidinella magna*, *Eoannularia eocenica*, *Fabiania cassis*, *Nummulites* sp., *Heterostegina* sp., *Halkyardia* sp., *Planorbulina* sp., orthophragmines, miliolidae and textularidae (Özcan *et al*. 2010).

A debris flow northeast of Deve Hill (Figure 7) contains clasts of the Soğucak Limestone; the foraminifera in the clasts (sample 11) are characteristic for the Late Bartonian (SBZ 18): *Heterostegina armenica*, *Discocyclina pratti*, *D. augustae, Pellatispira madaraszi* and *Nummulites fabianii*- group. The large Eocene limestone blocks are best observed in the quarries. A ca. 20-m-long Eocene limestone olistolith is well exposed in an abandoned quarry near Harmankaya, east of the Şarköy-Gölcük road (Figure 6d). The Eocene limestone is surrounded by turbidites and is associated with other olistoliths of pelagic limestone, marl and metabasite. It (sample 12) contains *Gyroidinella magna* and *Planorbulina* sp. indicative a Priabonian age. The large Soğucak Limestone outcrop north of Deve Hill is probably also a block in the Çengelli Formation. A section measured in this block (sample 13) contains the following foraminifera, characteristic of a late Bartonian–early Priabonian age (SBZ 18-19): *Nummulites hormoensis - fabianii*, *Silvestriella tetraedra*, *Fabiania cassis, Chapmanina gassinensis, Asterigerina rotula*, *Gyroidinella magna, Eoannularia eocenica, Fabiania cassis*, *Chapmanina gassinensis*, *Asterigerina rotula*, *Sphaerogypsina globula*, *Gyroidinella magna*, *Heterostegina* sp., *Halkyardia* sp. and *Gypsina* sp.

Serpentinite. Serpentinite forms dark greyish green friable clasts with a sheared scaly fabric. It ranges in size from sand grains to blocks measuring a few hundred metres to one kilometre in length. Most of the serpentinite blocks crop out west of Gölcük (Figure 4), including debris flows with blocks of serpentinite and Eocene limestone. In one locality, east of Yeniköy (UTM co-ord. 05 02 21 and 44 99 726), 10–15-cm-thick beds are made up of clastic serpentinite grains. The sedimentary serpentinite indicates a proximal source area and rapid deposition.

Pelagic Limestone and Marl. Pelagic limestone blocks are pink, pale pink, grey and generally form 20 cm to 2 m large clasts in a sandy matrix (Figure 6c). The blocks consist of thinly-bedded to laminated micrite intercalated with thin calciturbidite. Pelagic limestone clasts, 20 cm across, from a debris flow east of Gölcük (sample 14) have yielded foraminifera characteristic of Campanian–Maastrichtian ages: *Globotruncana linneiana*, *G. arca*, *G. aegyptiaca*, *Globotruncanella havanensis*, *Rugoglobigerina* sp., *R. rugosa*, *Heterohelix globosa*, *Hedbergella* sp., *Archeoglobigerina* sp. A marl sample from a one-kilometre-long block of pelagic limestone and marl (15) cropping out south of Yeniköy (Figure 4) contains a Lower Palaeocene (Paleogene planktic foraminifera zones P0-P1) pelagic fauna of morozovellids and acarinids, *Parasubbotina pseudobulloides*, *Subbotina triloculinoides-triangularis*. Small blocks (0.2–1.0 m) of pale greenish grey limestone consisting of thin micritic and calciturbiditic lamellae occur north of Şarköy (Figure 4). Samples from two such blocks (16 & 17) contain a Middle–Upper Paleocene (P4) fauna of *Morozovella aequa*, *Morozovella apanthesma*, *Globanomalina chapmani*, *Globanomalina pseudomenardii*, *Acarinina mckanni*. Okay & Tansel (1992) have also described Campanian, Maastrichtian and Palaeocene foraminifera in the pelagic limestone and marl from the debris flows.

Metabasite. Metabasite blocks, a few metres to 50 metres across, crop out south of Gölcük. They are dark green, greyish green, medium- to fine-grained with a crude foliation and often show cataclasis. The typical mineral assemblage is actinolite + chlorite + albite + epidote + leucoxene.

Quartz-Diorite. White to pale grey blocks of a medium-grained subvolcanic rock crop out southwest of Gölcük. The largest block, forming Doğanbaba Hill, is a fresh quartz-diorite with zoned plagioclase, green hornblende, quartz and minor opaque minerals. It is lithologically similar to those cropping out in the Sarıkaya sliver.

Other Rock Types. A highly sheared sequence of silicified dark grey shale, siltstone and greywacke crops out south of Yeniköy. These lithofacies are tectonically intersliced with spilitized basalts (Figure 11b). A block of metagabbro, a few tens of metres across is found southwest of Gölcük. It is a medium- to coarse-grained rock with magmatic augite partly replaced by actinolite. Plagioclase in the rock is completely replaced by zoisite, sericitic white mica and albite. Another block observed south of Yeniköy consists of an alternation of thinly-bedded red radiolarian cherts and pelagic limestone.

Composite Blocks. The best outcrops of composite blocks can be found in a small valley west of Cinbasarkale Hill south of Yeniköy (Figure 4). Here, the first composite olistolith consists of spilitized basalt and greywacke unconformably overlain in turn by a 10-m-thick nummulitic limestone (Figure 11b) followed by an upward-coarsening sequence of shale, sandstone and pebbly sandstone (Figures 6e, f & 11), a second composite olistolith of pink pelagic limestone chert alternation, covered by the Eocene limestone (Figure 11d). A second shale-sandstone sequence overlies this second olistolith (Figure 11c). The section illustrates a recurring shale-sandstone/pebbly sandstone-olistostrome cycle.

The stratigraphic relationship between the pelagic limestone-chert sequence and the Eocene limestones is also well exposed in a nearby abandoned quarry. Here, the pelagic limestone-chert sequence is unconformably overlain by a basal conglomerate layer consisting mainly of pelagic limestone and red radiolarian cherts clasts, 1 to 5 cm across, in a carbonate matrix. With increasing carbonate content and decrease in the size and density of the clasts, the conglomerate grades upward into the Eocene limestone. The thickness of the conglomerate layer varies over short distances between a few metres to 30 metres. The Eocene limestone contains a foraminiferal assemblage of *Spiroclypeus* sp., *Heterostegina reticulata mossanensis*, *Nummulites fabianii*, *Assilina* ex. gr. *alpina*, and taxa belonging to *Operculina*, *Orbitoclypeus*, *Asterocyclina*, *Gyroidinella,* and *Asterigerina* indicating an early Priabonian age (SBZ 19, Özcan *et al.* 2010).

Discussion

The Nature of the Basement in Southern Thrace and the Intra-Pontide Suture

The basement of the south Thrace Basin north of the Ganos Fault consists of low-grade metasedimentary rocks belonging to the Circum-Rhodope Belt (Figure 1). In contrast, the basement south of the Ganos Fault is made up of an ophiolitic mélange with Late Cretaceous blueschists (~86 Ma, Topuz *et al.* 2008). The age of the blueschists indicates continuing subduction during the Santonian. This Çetmi mélange crops out in the Biga Peninsula in the Karabiga region, west of Kazdağ and on the northern shores of Marmara Island (Figure 1). In the Karabiga region, the mélange is intruded by Lower Eocene (ca. 53 Ma) granodiorite and is unconformably overlain by Eocene rocks (Figure 1, Okay *et al.* 1991; Beccaletto *et al.* 2007). The limestone blocks in the mélange range from Late Triassic to Cretaceous in age; the youngest blocks are Cenomanian–Turonian west of Karabiga and Turonian–Coniacian west of Kazdağ (Okay *et al.* 1991).

The pelagic limestone blocks in the Çengelli Formation are Campanian, Maastrichtian and Palaeocene in age. Limestones of similar age and facies from the Lört Formation (Önal 1986) have been described from the northwestern margin of the Gelibolu Peninsula. Our field observations in the Gelibolu Peninsula indicate that the Lört Formation consists of several large allochthonous blocks in the Eocene clastics (cf. Siyako *et al.* 1989). These blocks and those from the Çengelli Formation could have been derived from the Çetmi mélange. These data indicate that the subduction leading to the formation of the accretionary complex continued in the Late Cretaceous (Santonian). Beccaletto *et al.* (2005) argued for a pre-Albian age for the Çetmi mélange. However, apart from field evidence for the block nature of the Upper Cretaceous sediments in the

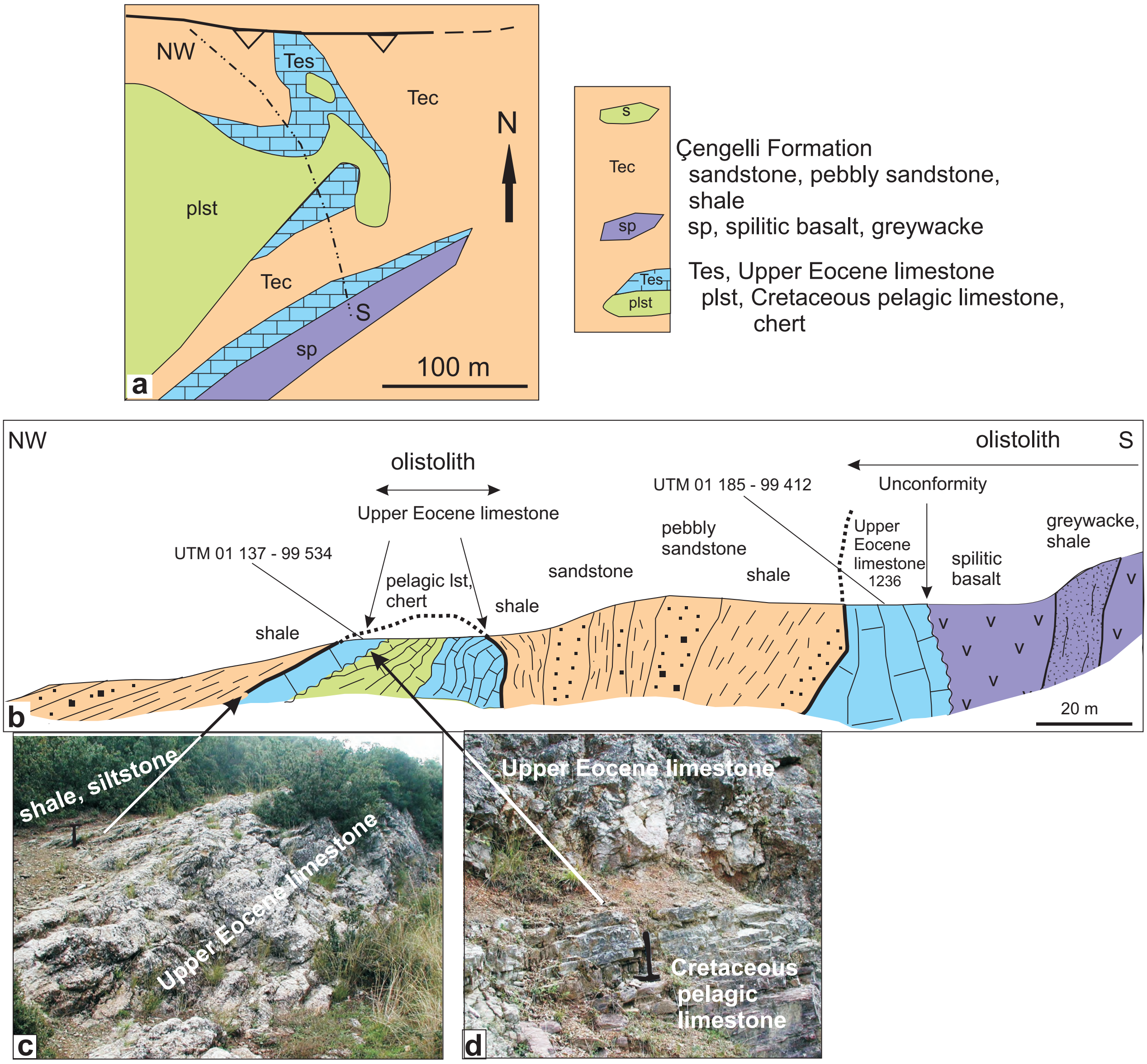

Figure 11. **(a)** Schematic geological map, **(b)** field cross-section and **(c)**, **(d)** field photographs of the Cinbasarkaletepe south of Yeniköy illustrating the composite olistoliths in the Çengelli Formation. For location of the map, see Figure 4.

mélange, the geochronological data from the blueschists in the Şarköy area indicate active subduction during the Santonian (Topuz *et al.* 2008).

Şengör & Yılmaz (1981) regarded the ophiolitic mélange outcrops north of Şarköy as marking the location of the Intra-Pontide suture. However, ophiolitic mélanges can be transported far from their place of formation. Large number of geological studies have documented remobilization of accretionary prism strata into the adjacent forearc basins and trenches by submarine gravity flows (debris, slump and slide) (e.g., Page & Suppe 1981; Pettinga 1982; Fortuin *et al.* 1992; van der Werff *et al.* 1994; Bonardi *et al.* 2001). A more reliable indicator for the location of the sutures is tectonic contacts, characterized by abrupt changes in the tectonostratigraphy. The ophiolitic mélanges west of Kazdağ and west of Karabiga mark the western end of the Sakarya terrane (Okay & Satır 2000; Beccaletto & Jenny 2004). Typical tectono-stratigraphic features of the Sakarya Zone, such as Karakaya Complex, Liassic unconformity, Jurassic–Tertiary sedimentary sequence, are not found in the northwestern part of the Biga Peninsula, which is considered as part of the Rhodope Massif.

Therefore, the Intra-Pontide suture passes through the centre of the Biga Peninsula and extends north to Marmara Island (Figure 1). This in turn implies that the ophiolitic basement in the Şarköy region was tectonically derived from the south, and possibly rests on low-grade metamorphic rocks, such as those exposed in the Mecidiye area. The age of the mélange and that of the cross-cutting Eocene granitoids constrains the northward emplacement of the mélange to the Palaeocene. The emplacement could be related either to the steepening and eventually back-thrusting of the accretionary complex (Figure 12a) or to the collision between the Sakarya Zone and the Rhodope-Strandja Massif. The common unconformable Eocene cover on the Sakarya Zone and the Rhodope Massif (Konak 2002) shows that the collision was pre-Late Eocene.

The Ganos Fault marks the approximate boundary between two different basement types in southern Thrace. Although the North Anatolian Fault is known to have been active only since the Pliocene in the Marmara region (e.g., Şengör 1979), apatite fission track data have shown that the Ganos Fault was operating in the Late Oligocene and Miocene (Zattin *et al.* 2005). In the Palaeocene it may have been active as a strike-slip fault taking up the lateral component of oblique subduction, similar to the strike-slip faults north of the Sumatra-Java trenches in southeast Asia (e.g., Hamilton 1979).

Lower Eocene Series – Remnants of an Earlier Marine Transgression

The Dişbudak series, described for the first time in this study, forms an upward deepening and upward fining transgressive sequence (Figure 9), which is unconformably overlain by the Upper Bartonian Soğucak Formation. Similar sequences are described from the Bozcaada area (Varol *et al.* 2007) and from northwest Turkey (Saner 1980; Özgörüş *et al.* 2009). The Lower Eocene (Upper Ypresian) series is missing in the observed basement-Eocene contacts of the Sarıkaya sliver and in several boreholes in the region studied, indicating deep erosion before the late Bartonian marine transgression. The Dişbudak series marks a marine transgression before the initiation of the Thrace Basin. Its deposition was followed by a major phase of uplift and erosion.

Upper Eocene Ophiolitic Olistostromes and Their Tectonic Significance

The clasts in the Upper Eocene mass flows can be classified into two types: (a) Ophiolitic mélange, (b) Eocene shallow-marine limestones. Observations in the composite blocks, as well as in the Sarıkaya sliver, indicate that the accretionary complex was locally overlain by Upper Eocene neritic limestones. Palaeontological data from the Çengelli Formation indicate that there is no measurable difference in the age of the siliciclastic turbidites, Eocene limestones and their transfer into the turbidite basin, all occurring within the Priabonian (37–34 Ma). The source was quite close as blocks are up to 1 km across and include fragile lithologies such as serpentinite or greywacke-shale, which cannot be transported unbroken over great distances. As there are no olistostromal Eocene facies north of the Ganos Fault the source area must have been situated to the south. The blocks could have been shed either from the footwall of normal faults or from northward verging thrust slices. Late Eocene normal faults are mapped on the northeastern margin of the Thrace Basin (Turgut *et al.* 1991). Thus, the presence of extensional growth faults in the Eocene sequence (Figure 6b) and absence of data for syn-sedimentary shortening suggest that the clasts in the mass flows were derived from normal fault scarps (Figure 12b). In the Priabonian, large north-facing normal fault scarps were shedding clasts to the north. The southward migration of normal faulting led to the subsidence of the Eocene limestones, which were covered by siliciclastic sediments derived from the ophiolitic and subvolcanic basement. This model explains the contemporaneous deposition of the shallow marine limestones and their transfer to the clastic basin, and also agrees with the observation that Priabonian was a period of major subsidence in the Thrace Basin (Huvaz *et al.* 2005) and indicates that the southern Thrace Basin was initiated in the Late Bartonian.

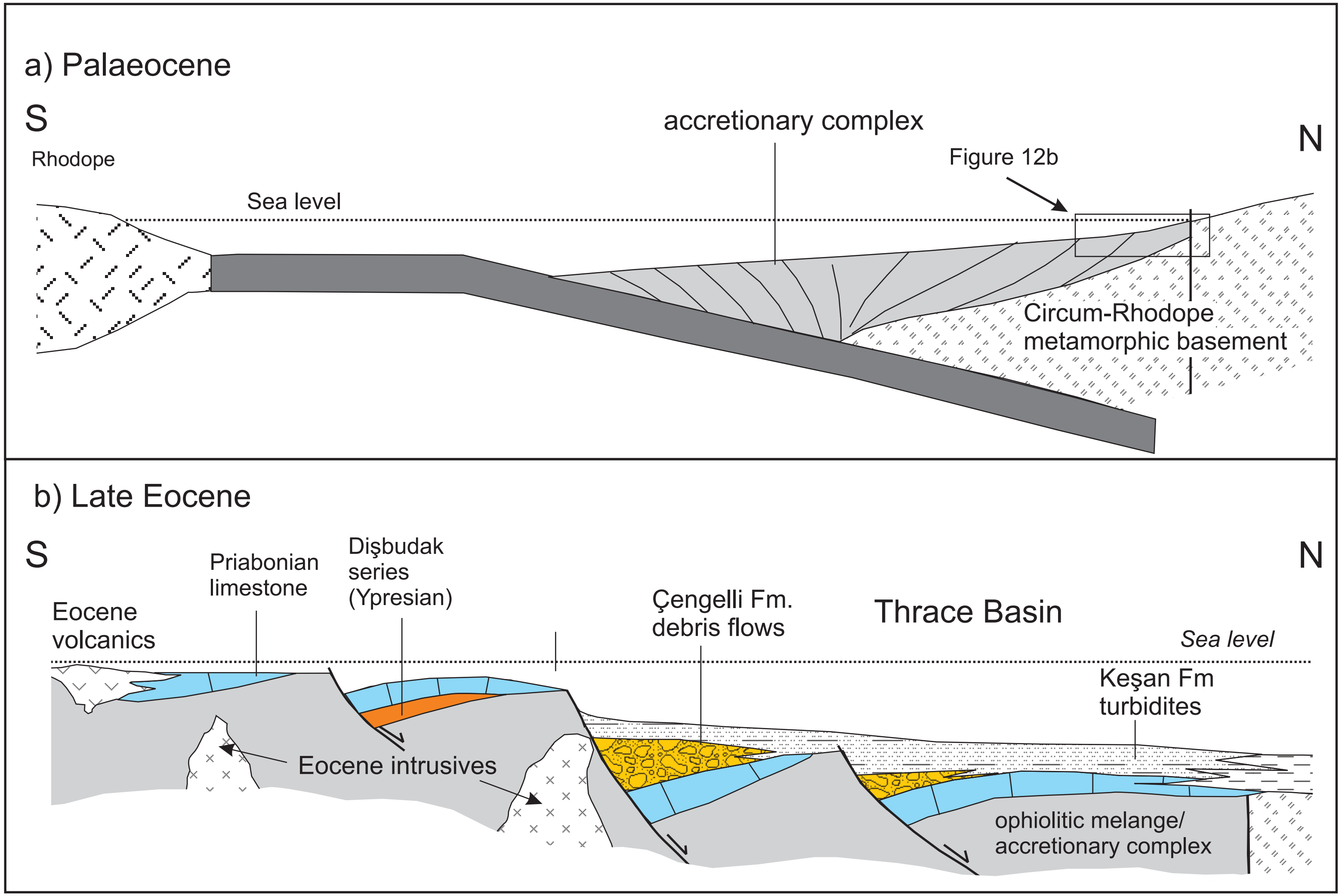

Figure 12. Sketches illustrating the evolution of the southern Thrace Basin. **(a)** In the late Palaeocene the accretionary complex was emplaced northward over the Circum-Rhodope Belt. **(b)** In the Late Eocene large normal faults associated with the opening of the southern part of the Thrace Basin led to the deposition of mass flows. Note that the deposition of the Soğucak Limestone on the shelf is contemporaneous with that of the mass flows in the basin.

Conclusions

The pre-Eocene basement north of the Ganos Fault is composed of low-grade metamorphic rocks, phyllite and recrystallized limestone belonging to the circum-Rhodope belt. This metamorphic sequence crops out north of Saros Bay in the Mecidiye region. The basement south of the Ganos Fault, on the other hand, consists of an ophiolitic mélange with serpentinite, metadiabase and Late Cretaceous (~86 Ma) blueschists. The Ganos Fault marks the boundary between the ophiolitic and continental basement types, as also suggested by Siyako & Huvaz (2007). The ophiolitic mélange in the Şarköy region was tectonically emplaced, probably from the south in the Palaeocene over the low-grade metamorphic rocks. Both basement types are unconformably overlain by upper Bartonian to Priabonian limestones.

Erosional remnants of a transgressive Lower Eocene series were discovered beneath the Upper Bartonian limestones. This Dişbudak series starts with sandstones and sandy limestones and passes up into marl and shale. Although it has small surface exposures, it is cut at depth in petroleum wells under the Eocene limestones.

The ophiolitic rocks in the Şarköy region have two modes of origin. One large outcrop of serpentinite and metadiabase, the Sarıkaya sliver, represents a tectonic slice from the basement exhumed during Plio–Quaternary faulting, but most outcrops expose olistoliths in the Eocene flysch (Saner 1985). The Upper Eocene sequence south of the Ganos Fault is characterized by an olistostromal, coarse-grained turbidite series. The clasts in the coarser mass flows include Eocene (Bartonian and Priabonian) neritic limestone, serpentinite, gabbro, basalt, metabasite, pelagic limestone, radiolarian chert, gabbro, greywacke-shale and quartz-diorite. The source of the clasts in the mass flows was an ophiolitic mélange, unconformably overlain by neritic Upper Eocene limestones. Field observations and regional geological arguments indicate that the source was proximal and to the south. The Late Eocene sedimentation occurred in an extensional tectonic setting, with clasts derived from scarps of normal faults (Figure 12b).

Debris flows and olistostromes of the Çengelli Formation crop out immediately south of the Ganos Fault; they are missing in the contemporaneous Keşan Formation north of the fault. This indicates a minimum total dextral offset of 50 km along the Ganos Fault, based on the map distribution of the Çengelli and Keşan formations (Figure 1).

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References

Beccaletto, L. & Jenny, C. 2004. Geology and correlations of the Ezine Zone: a Rhodope fragment in NW Turkey? *Turkish Journal of Earth Sciences* **13**, 145–176.

Beccaletto, L., Bartolini, A.C., Martini, R., Hochuli, P.A. & Kozur, H. 2005. Biostratigraphic data from the Çetmi Melange, northwest Turkey: palaeogeographic and tectonic implications. *Palaeogeography Palaeoclimatology Palaeoecology* **221**, 215–244.

Beccaletto, L., Bonev, N., Bosch, D. & Bruguier, O. 2007. Record of a Palaeogene syn-collisional extension in the north Aegean region: evidence from the Kemer micaschists (NW Turkey). *Geological Magazine* **144**, 393–400.

Bonardi, G., Cavazza, W., Perrone, V. & Rossi, S. 2001, Calabria-Peloritani terrane and northern Ionian Sea. *In*: Vai, G.B. & Martini, I.P. (eds), *Anatomy of an Orogen: the Apennines and Adjacent Mediterranean Basins.* Kluwer Academic Publishers, 287–306.

Doust, H. & Arikan, Y. 1974. The geology of the Thrace Basin. *Proceedings of the Second Petroleum Congress of Turkey*, 119–136.

Erol, K. 2003. Yeniköy Karışığının (GB Trakya) metamorfik evrimi [Metamorphic evolution of the Yeniköy complex (SW Thrace)]. *Türkiye Jeoloji Bülteni* **46**, 53–61 [in Turkish with English abstract].

Fortuin, A.R., Roep, Th.B., Sumosusastro, P.A., van Weering Tj.C.E. & van de Werff, W. 1992. Slumping and sliding in Miocene and Recent developing arc basins, onshore and offshore Sumba (Indonesia). *Marine Geology* **108**, 345–363.

Görür, N. & Okay, A.I. 1996. Fore-arc origin of the Thrace Basin, northwest Turkey. *Geologische Rundschau* **85**, 662–668.

Hamilton, W. 1979. *Tectonics of the Indonesian Region*. U.S. Geological Survey Professional paper 1078.

Huvaz, O., Sarikaya, H. & Nohut, Ö.M. 2005. Nature of a regional dogleg pattern in maturity profiles from Thrace Basin, northwestern Turkey: a newly discovered unconformity or a thermal anomaly. *American Association of Petroleum Geologists Bulletin* **89**, 1373–1396.

İslamoğlu, Y., Harzhauser, M., Gross, M., Jimenez-Moreno, G., Coric, S., Kroh, A., Rögl, F. &van der Made, J. 2008. From Tethys to Eastern Paratethys: Oligocene depositional environments, paleoecology and paleobiogeography of the Thrace Basin (NW Turkey). *International Journal of Earth Sciences*, DOI 10.1007/s00531–008-0378-0.

Janssen, C., Bohnhoff, M., Vapnik, Y., Görgün, E., Bulut, F., Plessen, B., Pohl, D., Aktar, M., Okay, A.I. & Dresen, G. 2009. Tectonic evolution of the Ganos segment of the North Anatolian Fault (NW Turkey). *Journal of Structural Geology* **31**, 11–28.

Konak, N. 2002. *Geological Map of Turkey. İstanbul Sheet, Scale 1:500 000*. Publication of the General Directorate of the Mineral Research and Exploration (MTA), Ankara.

Kopp, K.-O. 1969. Geologie Thrakiens VI: Der Çoban Dağ (Frenk Bunar) westlich von Alexandroupolis). *Geotektonische Forschungen* **31**, 97–116.

Kopp, K.-O., Pavoni, N. & Schindler, C. 1969. Geologie Thrakiens IV: Das Ergene-Becken. *Beihefte zum Geologischen Jahrbuch*, Heft 76, Hannover.

Less, Gy. 1998. The zonation of the Mediterranean Upper Paleocene and Eocene by Orthophragminae. *Opera Dela Slovenska Akademija Znanosti in Umetnosti*, IV **34**, 21–43, Ljubljana.

Less, Gy. & Özcan, E. 2008. The late Eocene evolution of nummulitid foraminifer *Spiroclypeus* in the Western Tethys. *Acta Palaeontologica Polonica* **53**, 303–316.

Less, Gy., Özcan, E., Papazzoni, C.A. & Stöckar, R. 2008. The middle to late Eocene evolution of nummulitid foraminifer *Heterostegina* in the Western Tethys. *Acta Palaeontologica Polonica* **53**, 317–350.

Magganas, A.C. 2002. Constraints on the petrogenesis of Evros ophiolite extrusives, NE Greece. *Lithos* **65**, 165–182.

Okay, A.I., Demirbağ, E., Kurt, H., Okay, N. & Kuşçu, İ. 1999. An active, deep marine strike-slip basin along the North Anatolian fault in Turkey. *Tectonics* **18**, 129–148.

Okay, A.I. & Satir, M. 2000. Upper Cretaceous eclogite facies metamorphic rocks from the Biga Peninsula, northwest Turkey. *Turkish Journal of Earth Sciences* **9**, 47–56.

Okay, A.I., Siyako, M. & Bürkan, K.A. 1991. Geology and tectonic evolution of the Biga Peninsula. *Bulletin of the Technical University of İstanbul* **44**, 191–255.

Okay, A.I. & Tansel, İ. 1992. New data on the upper age of the Intra-Pontide ocean from north of Şarköy (Thrace). *Bulletin of the Mineral Research and Exploration* **114**, 23–26.

Okay, A.I. & Tüysüz, O. 1999. Tethyan sutures of northern Turkey. *In*: Durand, B., Jolivet, L., Horváth, F. & Séranne, M. (eds), *The Mediterranean Basins: Tertiary Extension Within the Alpine Orogen*. Geological Society, London, Special Publications **156**, 475–515.

Okay, A.I., Tüysüz, O. & Kaya, Ş. 2004. From transpression to transtension: changes in morphology and structure around a bend on the North Anatolian Fault in the Marmara region. *Tectonophysics* **391**, 259–282.

Önal, M. 1986. Gelibolu Yarımadası orta bölümünün sedimanter fasiyesleri ve tektonik evrimi, KB Anadolu, Türkiye [Tectonic evolution and sedimentary facies of the central part of the Gelibolu Peninsula]. *Jeoloji Mühendisliği* **29**, 37–46 [in Turkish with English abstract].

Özbek, O. & Erol, K. 2001. Etude petrographique des haches polies de Hamaylıtarla et Fenerkaradutlar (Turquie). *Anatolia Antiqua* **9**, 1–7.

Özcan, E., Less, Gy. & Kertész B. 2007a. Late Ypresian to Middle Lutetian Orthophragminid record from central and northern Turkey: taxonomy and remarks on zonal scheme. *Turkish Journal of Earth Sciences* **16**, 281–318.

Özcan, E., Less, Gy., Báldi-Beke, M., Kollányi, K. & Kertész, B. 2007b. Biometric analysis of middle and upper Eocene Discocyclinidae and Orbitoclypeidae (Foraminifera) from Turkey and updated orthophragmine zonation in the Western Tethys. *Micropaleontology* **52**, 485–520.

Özcan, E., Less, Gy., Okay, A.I., Báldi-Beke, M., Kollányi, K. & Yilmaz, İ.Ö. 2010. Stratigraphy and larger foraminifera of the Eocene shallow-marine and olistostromal units of the southern part of the Thrace Basin, NW Turkey. *Turkish Journal of Earth Sciences* **19**, 27–77.

Özgörüş, Z., Okay, A.I. & Özcan, E. 2009. Late-Cretaceous–Eocene evolution of the western margin of the İstanbul and Sakarya zones. *Abstracts, 62. Geological Congress of Turkey, Ankara,* p. 462.

Page, B.M. & Suppe, J. 1981. The Pliocene Lichi mélange of Taiwan: its plate-tectonic and olistostromal origin. *American Journal of Science* **281**, 193–227.

Pettinga, J.R. 1982. Upper Cenozoic structural history, coastal Southern Hawke's Bay, New Zealand. *New Zealand Journal of Geology and Geophysics* **25**, 149–191.

SANER, S. 1980. Mudurnu-Göynük havzasının Jura ve sonrası çökelim nitelikleriyle paleocoğrafya yorumlanması [Paleogeography and sedimentary environment of the Jurassic and younger sequences of the Mudurnu-Göynük basin]. *Türkiye Jeoloji Kurumu Bülteni* **23**, 39–52 [in Turkish with English abstract].

SANER, S. 1985. Saros Körfezi dolayının çökelme istifleri ve tektonik yerleşimi, Kuzeydoğu Ege Denizi, Türkiye [Sedimentary sequences and tectonic setting of the region around the Saros Bay, northeastern Aegean, Turkey]. *Türkiye Jeoloji Kurumu Bülteni* **28**, 1–10 [in Turkish with English abstract].

SCHINDLER, C. 1959. Die Strörüngzone von Gölcük (Türkisch-Thracien) und ihr Einfluss auf die Sedimentation des Alttertiars. *Eclogae Geologicae Helvetiae* **52**, 695–707.

SERRA-KIEL, J., HOTTINGER, L., CAUS, E., DROBNE, K., FERRÁNDEZ C., JAUHRI, A.K., LESS GY., PAVLOVEC, R., PIGNATTI, J.S., SAMSÓ, J.M., SCHAUB, H., SIREL, E., STROUGO, A., TAMBAREAU, Y., TOSQUELLA, J. & ZAKREVSKAYA, E. 1998. Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. *Bulletin de la Societé géologique de France* **169**, 281–299.

SİREL, E. & ACAR, Ş. 1982. *Praebullalveolina*, a new foraminiferal genus from the Upper Eocene of the Afyon and Çanakkale region (west of Turkey). *Eclogae Geologicae Helvetiae* **75**, 821–839.

SİYAKO, M. 2006. Trakya havzası Tersiyer kaya birimleri [Tertiary rock units of the Thrace Basin]. *In*: *Trakya Bölgesi Litostratigrafi Birimleri [Lithostratigraphical Units of the Thrace Region]*. Litostratigrafi Birimleri Serisi **2**, 43–83. Publication of the General Directorate of the Mineral Research and Exploration (MTA), Ankara [in Turkish].

SİYAKO, M. & HUVAZ, O. 2007. Eocene stratigraphic evolution of the Thrace Basin, Turkey. *Sedimentary Geology* **198**, 75–91.

SİYAKO, M., BÜRKAN, K.A. & OKAY, A.I. 1989. Biga ve Gelibolu yarımadalarının Tersiyer jeolojisi ve hidrokarbon olanakları [Tertiary geology and hydrocarbon potential of the Biga and Gelibolu peninsulas]. *Türkiye Petrol Jeologlari Derneği Bülteni* **1**, 183–199 [in Turkish with English abstract].

SÜMENGEN, M. & TERLEMEZ, İ. 1991. Stratigraphy of Eocene sediments in the southwest Thrace. *Bulletin of the Mineral Research and Exploration (MTA) of Turkey* **113**, 15–29.

ŞEN, Ş., YILLAR, S. & KEREY, İ.E. 2009. Allochthonous blocks misidentified as the basement: Implication for petroleum exploration in the SW Thrace Basin (Turkey). *Journal of Petroleum Science and Engineering* **64**, 55–66.

ŞENGÖR, A.M.C. 1979. The North Anatolian transform fault: Its age, offset and tectonic significance. *Journal of the Geological Society, London* **136**, 269–282.

ŞENGÖR, A.M.C. & YILMAZ, Y. 1981. Tethyan evolution of Turkey, a plate tectonic approach. *Tectonophysics* **75**, 181–241.

ŞENTÜRK, K. & OKAY, A.I. 1984. Blueschists discovered east of Saros Bay in Thrace. *Bulletin of the Mineral Research and Exploration Institute (MTA) of Turkey* **97/98**, 72–75.

ŞENTÜRK, K., SÜMENGEN, M., TERLEMEZ, İ. & KARAKÖSE, C. 1998a. *1:100 000 Scale Geological Maps and Explanatory Notes, Turkey, Çanakkale–D3 (G17) Sheet, No. 63*. Publication of the General Directorate of the Mineral Research and Exploration (MTA), Ankara.

ŞENTÜRK, K., SÜMENGEN, M., TERLEMEZ, İ. & KARAKÖSE, C. 1998b. *1:100 000 Scale Geological Maps and Explanatory Notes, Turkey, Çanakkale–D4 (G18) Sheet, No. 64*. Publication of the General Directorate of the Mineral Research and Exploration (MTA), Ankara.

TEMEL, R.Ö. & ÇİFTÇİ, N.B. 2002. Gelibolu Yarımadası, Gökçeada ve Bozcaada Tersiyer çökellerinin stratigrafisi ve ortamsal özellikleri [Stratigraphy and depositional environments of the Tertiary sedimentary units in Gelibolu Peninsula and islands of Gökçeada and Bozcada]. *Türkiye Petrol Jeologları Derneği Bülteni* **14**, 17–40 [in Turkish with English abstract].

TOPUZ, G., OKAY, A.I., ALTHERR, R., SATIR, M. & SCHWARZ, W.H. 2008. Late Cretaceous blueschist-facies metamorphism in southeastern Thrace (Turkey) and its geodynamic implications. *Journal of Metamorphic Geology* **26**, 895–913.

TURGUT, S., TÜRKASLAN, M. & PERINÇEK, D. 1991. Evolution of the Thrace sedimentary basin and its hydrocarbon prospectivity. *In*: SPENCER, A.M. (ed), *Generation, Accumulation, and Production of Europe's Hydrocarbons*. Special Publication of European Association of Petroleum Geoscientists **1**, 415–437.

TÜRKECAN, A. & YURTSEVER, A. 2002. *Geological Map of Turkey, Zonguldak Sheet, Scale 1:500 000*. Publication of the General Directorate of the Mineral Research and Exploration (MTA), Ankara.

TÜYSÜZ, O., BARKA, A. & YİĞİTBAŞ, E. 1998. Geology of the Saros graben and its implications for the evolution of the North Anatolian fault in the Ganos-Saros region, northwest Turkey. *Tectonophysics* **292**, 105–126.

VAN DER WERFF, W., PRASETYO, H., KUSNİDA, D. & VAN WEERİNG, T.C.E. 1994. Seismic stratigraphy and Cenozoic evolution of the Lombok Forearc Basin, Eastern Sunda Arc. *Marine Geology* **117**, 119–134.

VAROL, B., SİREL, E., AYYILDIZ, T. & BAYKAL, M. 2007. New sedimentological and paleontological data from the Soğucak Formation in the Bozcaada (Çanakkale). *Bulletin of the Mineral Research and Exploration Institute (MTA) of Turkey* **135**, 83–86 [in Turkish].

YALTIRAK, C. 1996. Ganos Fay sisteminin tektonik tarihi [The tectonic history of the Ganos Fault]. *Türkiye Petrol Jeologları Derneği Bülteni* **8**, 137–150 [in Turkish with English abstract].

YAZMAN, M. 1997. Western Turkey poses exploration challenges on/offshore. *The Leading Edge*, June 1997, 897–899.

YILDIZ, A., TOKER, V. & ŞENGÜLER, İ. 1997. The nannoplankton biostratigraphy of the Middle Eocene–Oligocene units in southern Thrace Basin and the surface water temperature variations. *Türkiye Petrol Jeologlari Derneği Bülteni* **9**, 31–44.

ZATTIN, M., OKAY, A.I. & CAVAZZA, W. 2005. Fission–track evidence for late Oligocene and mid–Miocene activity along the North Anatolian Fault in south-western Thrace. *Terra Nova* **17**, 95–101.