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Allochthonous blocks misidentified as the basement: Implication for petroleum exploration in the SW Thrace Basin (Turkey)

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ABSTRACT

The sedimentary sequence of the SW Thrace Basin (NW Turkey) comprises of three major sedimentary packages: a) Cretaceous (Meastrichtien)–Early Eocene package formed as pelagic carbonate, turbidite, shelf and nearshore-fluvial deposits, b) Middle Eocene–Early Oligocene package formed as shallow marine, slope apron and turbidite sediments, c) Middle Miocene–Early Pliocene package formed as alluvial fan-fluvial and nearshore deposits. This basin is structurally complex and its southern margin is represented by a fold-thrust zone. The Westward Propagation of the North Anatolian Fault (WPNAF) intersects the Thrace Basin along its southwestern flank. In the SW Thrace Basin, there are ophiolite and limestone blocks in the sedimentary succession, which previously were interpreted as suture of the Intra-Pontide Ocean, Cretaceous aged Yeniköy Mélange or Olistostromal Unit in the Eocene sediments. In this study these rocks have been defined as allochthonous blocks facies of the Gaziköy Formation aged Middle–Late Eocene.

In previous studies the Karaağaç Formation (Early Eocene) was considered to be within oil window and have an average potential for oil and gas generation. According to our data the Karaağaç Formation has a moderate TOC content, is mature and overmature. In the study area, there are potential stratigraphic traps (submarine fans and channels of the Karaağaç and Keşan Formations, fluvial channels of the Fıçıtepe Formation and reefs of the Soğucak Formation), potential fractured tuffs (the Gaziköy Formation) and, potential structural traps related to the folds, thrusts and the WPNAF. Although 17 exploration wells have been drilled in the study area and vicinity, no discovery has yet been made. The cause of this may be that the wells were terminated at depths shallower than potential targets or possibly drilling may have been terminated at the allochthonous block facies of the Gaziköy Formation, which is especially derived from ophiolite mélange and was misidentified as basement.

1. Introduction

The oil and gas-bearing Thrace Basin (NW Turkey), which extend from Çanakkale in the west to Istanbul in the east, consists of Late Cretaceous to present aged sediments, reaching a maximum thickness over 9000 m (Turgut et al., 1991). The basin is underlain by (1) the Istranca Massif, (2) Istanbul Paleozoic Unit and (3) magmatic arc volcanics to the north and (4) the Paleotethys remnants and (5) Neotethys subduction–accretionary complex to the south (Fig. 1). The Istranca Massif is a metamorphic complex that includes crustal granites of Paleozoic age, metamorphosed sediments of Triassic, Jurassic and intrusive rocks of the Late Cretaceous age (Üşümezsoy, 1989; Okay et al., 2001). The Istanbul– Zonguldak Unit is represented by a Paleozoic aged thick sedimentary succession of a passive continental margin (Kaya, 1978; Önalan, 1988) and the magmatic arc is represented by the Late Cretaceous volcanics (Yılmaz et al., 1997). The Paleotethys remnants are composed of pre-Middle Jurassic aged basement rocks (Yılmaz et al., 1997; Okay and Tüysüz, 1999). The Neotethys subduction–accretion complex consists of the Late Cretaceous aged ophiolite mélange. Sedimentary basin analyses studies suggest that the Thrace Basin has been developed as a transtensional post-collisional basin (Turgut et al., 1991), fore-arc basin (Saner, 1980; Görür and Okay, 1996) or a remnant and post-collisional basin (Tüysüz et al., 1998).

The Westward Propagation of the North Anatolian Fault (WPNAF) crosses the Sea of Marmara and emerges on land at the town of Gaziköy. Between the Sea of Marmara and the Gulf of Saroz, it intersects the SW flank of the Thrace Basin (Şengör, 1979; Sengör et al., 1985; Bargu, 1990; Barka, 1992; Armijo et al., 1999; Okay et al., 2000; Üşümezsoy, 2001; Yaltırak and Alpar, 2002; Seeber et al., 2004; Okay et al., 2004; Şengör et al., 2005; Fig. 1).

The Thrace Basin is the most important productive gas region of Turkey. The Hamitabat, Karacaoğlan, Umurca, Hayrabolu, Kandamış, Bayramşah, Kumrular, Yulaflı, Karaçalı, Tekirdağ, Değirmenköy, Ardıç, Seymen, Vakıflar, Sevindik, Turgutbey, North Marmara and Silivri fields all produce gas, whereas the Deveçatağı, K. Osmancık and Vakiflar fields produce oil (Karahanoglu et al., 1995; Coskun, 1997, 2000; Hoşgörmez and Yalçın, 2005; Gürgey et al., 2005; Huvaz et al.,

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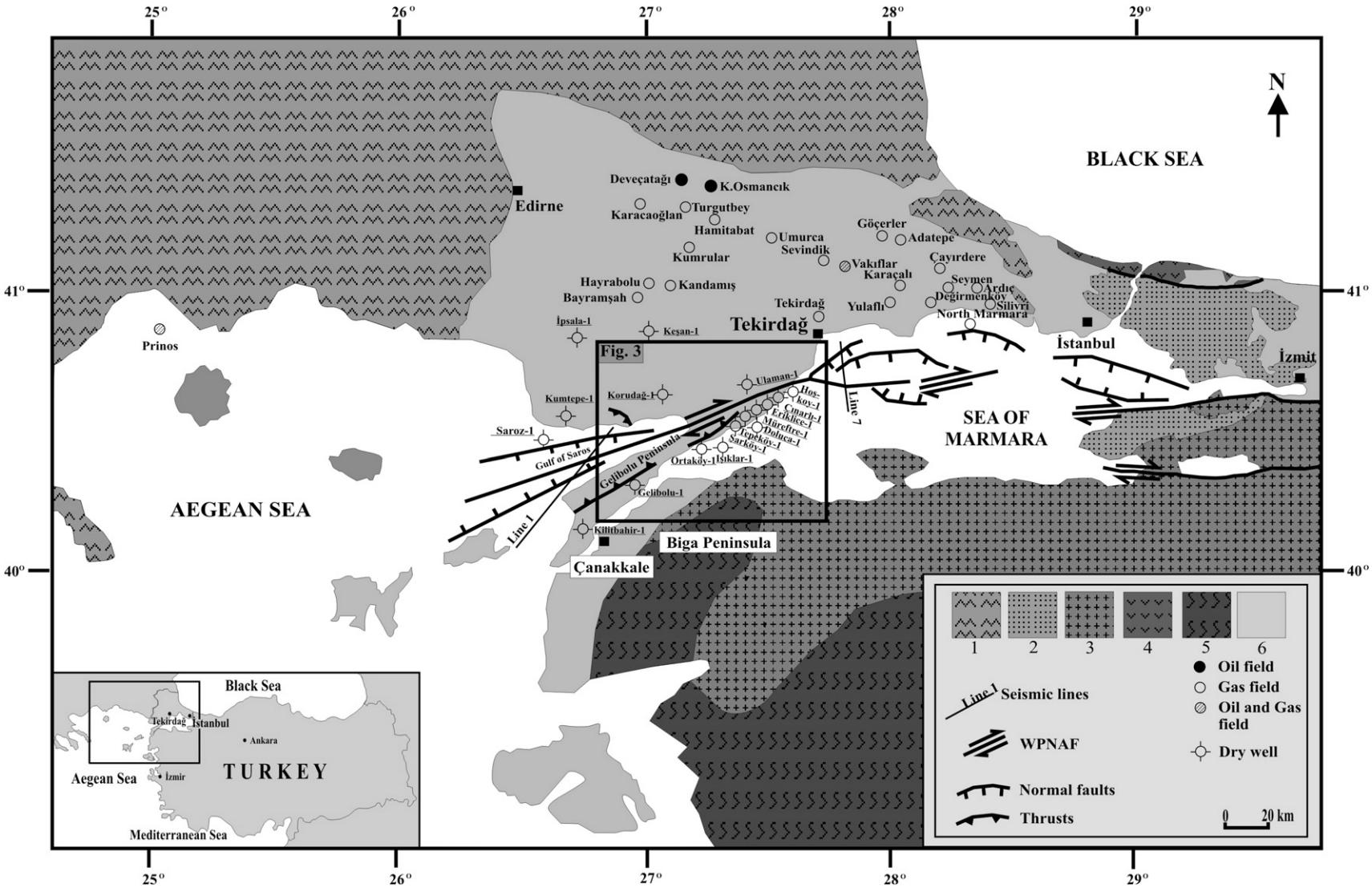

Fig. 1. Simplified regional geology of NW Turkey (modified from Turgut et al., 1991; Yılmaz et al., 1997; Okay and Tüysüz, 1999; Üşümezsoy, 2001; MTA, 2002; Armijo et al., 2002) and oil and gas fields, dry wells and seismic lines. 1) Istranca Massif, 2) Istanbul Paleozoic sediments, 3) Paleotethys remnants, 4) Upper Cretaceous arc volcanics, 5) Neotethys subduction–accretionary complex, 6) Thrace Basin sediments.

2005, 2007; Fig. 1). Despite 17 exploration wells, oil and gas has not yet been discovered in the SW Thrace Basin (Fig. 1).

The available surface and subsurface data suggest that the wells in the study area may possibly have been drilled in the allochthonous blocks facies that are mainly derived of ophiolite mélange. At first, the allochthonous blocks facies were interpreted by Şengör and Yılmaz (1981) as Late Cretaceous suture of the Intra-Pontide Ocean and was described by Şentürk and Okay (1984) as Late Cretaceous aged Yeniköy mélange. Later, the allochthonous blocks facies were described by Okay and Tansel (1992) as olistostromal bodies in the Eocene sediments. In this paper, they have been defined as allochthonous blocks facies of the Gaziköy Formation aged Middle–Late Eocene. The active strike-slip fault of the WPNAF has complicated the geology of the allochthonous blocks facies in the study area.

In this study, two of seismic lines and data from 17 wells have been interpreted. Ages of strata shown in seismic lines have been determined from geological maps, stratigraphy, well logs and well completion reports. In addition, field studies for geological (mapping of formations), structural geological (mapping of structures), sedimentary (depositional environments and reservoir architecture analysis) and organic geochemical–paleontological (sample collecting) proposes have been carried out. The aim of this study is to

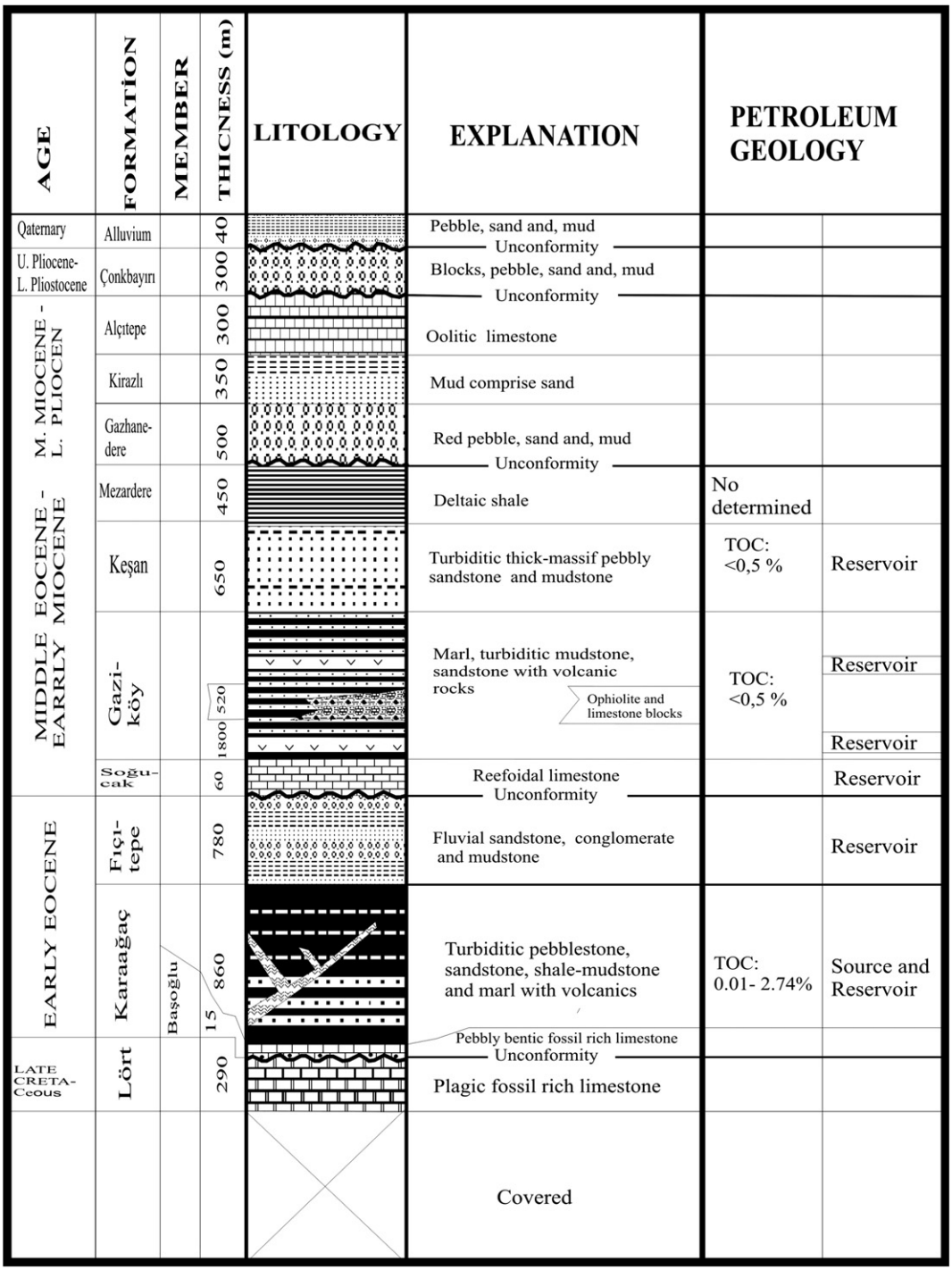

Fig. 2. Generalized stratigraphic succession of the southern Thrace Basin (modified from Saner, 1985; Önal, 1986a,b; Siyako et al., 1989; Sümengen and ve Terlemez, 1991; Siyako and Huvaz, 2007).

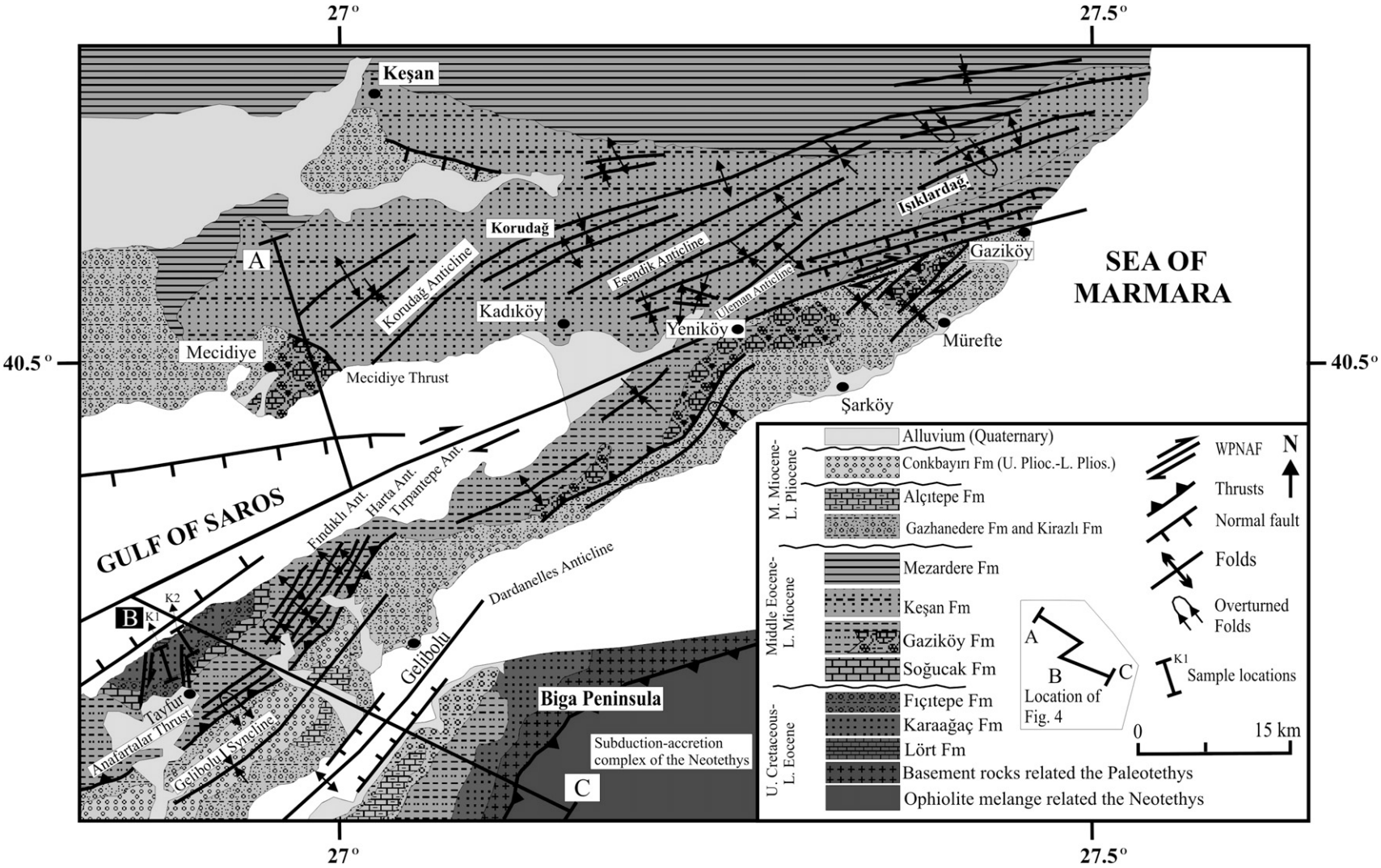

Fig. 3. The geological map of the study area (modified from Önal, 1986a; Siyako et al., 1989; Sümengen and ve Terlemez, 1991; MTA, 2002).

investigate the allochthonous blocks facies in the SW Thrace Basin sediments and interpret their significance in the petroleum exploration.

2. Sedimentary features of the SW Thrace Basin

Sedimentary succession comprises three major sedimentary packages:

a) **Late Cretaceous–Early Eocene Package:** The base of this sedimentary sequence is concealed by the Sea of Marmara and the Gulf of Saroz. The lowest part of the package is comprised of basinal pelagic limestone aged Late Cretaceous, termed the Lört Formation (Önal, 1986a). The Lört Formation is unconformably overlain by benthic fossil rich limestone (Başoğlu member), submarine fan sandstone–mudstone and shelf mudstones (Koyunlimanı member of Saner, 1985 and Siyako et al., 1989; Siyako and Huvaz, 2007) with intrusive rocks such as andesite dykes and sills of the Karaagaç Formation aged the Early Eocene (Saner, 1985; Önal, 1986a; Siyako et al., 1989; Siyako and Huvaz, 2007). This formation is conformably succeeded by nearshore (Karaburun members of Saner, 1985, Siyako et al., 1989 and Siyako and Huvaz, 2007) and fluvial mudstones, sandstones and conglomerates of the Fıçıtepe Formation aged the Early Eocene (Siyako et al., 1989; Sümengen and ve Terlemez, 1991; Siyako and Huvaz, 2007; Figs. 2 and 3).

b) **Middle Eocene–Early Oligocene Package:** The unconformable base of this package starts with reefoidal limestone of the Soğucak Formation of the Middle–Late Eocene age (Siyako et al., 1989; Sümengen and ve Terlemez, 1991; Siyako and Huvaz, 2007). These are followed by shelf and slope apron deposits represented by marls, slumped shale and thin-bedded sandstones with volcanic rocks assigned to the Gaziköy Formation aged the Middle–Late Eocene (Aksoy, 1987; Sümengen and ve Terlemez, 1991; Yıldız et al., 1997). The Gaziköy Formation also contains allochthonous ophiolite and limestone blocks of slope apron deposits. The Gaziköy Formation is gradationally succeeded by thick-bedded sandstone and shale of the Keşan Formation aged the Late Eocene, interpreted as proximal and middle submarine fan deposits (Gökçen, 1967; Aksoy, 1987; Sümengen and ve Terlemez, 1991). These formations are gradationally overlain by prodeltaic shale of the Mezardere Formation aged the Early Oligocene (Aksoy, 1987; Figs. 2 and 3).

c) **Middle Miocene–Early Pliocene Package;** This package rests unconformably on the former packages and begins with the Gazhanedere Formation aged the Middle Miocene represented by alluvial fan-fluvial conglomerates, sandstones and mudstones with a rich fauna of freshwater Ostracods and micro-mammalian remains

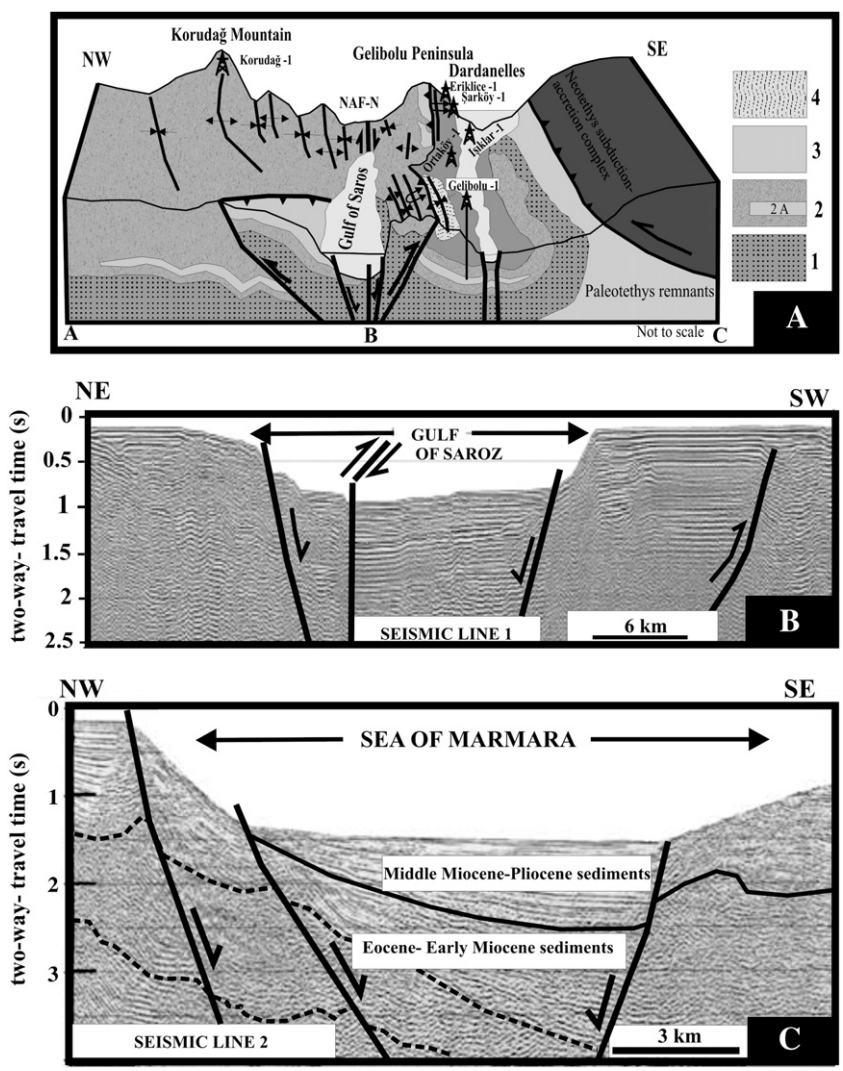

Fig. 4. A, The block diagram of the study area along A, B, C line (See Fig. 3 for location); 1) Late Cretaceus–Early Eocene Package, 2) Middle Eocene–Early Oligocene Package, 2A) Allochthonous blocks facies of the Gaziköy Formation,, 3) Middle Miocene–Early Pliocene Package, 4) Late Pliocene–Early Pleistocene rocks, B, Time migrated seismic section along line 1 (see Fig. 2 for location, modified from Kurt et al., 2000), C) Time migrated seismic section along line 2 (see Fig. 2 for location, modified from Seeber et al., 2004).

(Kaya, 1989; Tüysüz et al., 1998; Yaltırak and Alpar, 2002). The succeeding Kirazlı Formation aged the Middle–Late Miocene comprises of fluvio-lacustrine clastics also yielding a rich fauna of freshwater Ostracods and Mammalian fossils. These deposits gradually pass upwards into the brackish-marine clastics and oolitic limestones with abundant Mactra fossils of the Alçıtepe Formation aged the Late Miocene (Kaya, 1989; Tüysüz et al., 1998; Yaltırak and Alpar, 2002). Finally, alluvial fan coarse clastic sediments of the Middle Pliocene–Early Pleistocene age (the Conkbayırı Formation) were deposited (Tüysüz et al., 1998; Okay et al., 1999; Yaltırak et al., 2000; Figs. 2 and 3).

3. Structural features of the SW Thrace Basin

The SW Thrace Basin is highly folded and faulted (Figs. 3 and 4ABC). The Neotethys Ocean subduction–accretion complex has been thrusted over the basement rocks to the south of the basin in Biga Peninsula (Figs. 3 and 4A; MTA, 2002). The WSW–ENE trending Westward Propagation of the North Anatolian Fault (WPNAF) which is a dextral strike-slip fault running from southwest of the West Marmara Sea through to the Gulf of Saroz, has been cut by the SW Thrace Basin deposits. It is responsible for the formation of the Işıklar (Ganos) Mountain and the Gelibolu Peninsula uplifts, the Sea of Marmara and the Gulf of Saroz depressions (Şengör, 1979; Sengör et al., 1985; Bargu, 1990; Barka, 1992; Armijo et al., 1999; Yaltırak et al., 2000; Kurt et al., 2000; Okay et al., 2000; Yaltırak and Alpar, 2002; Seeber et al., 2004; Okay et al., 2004; Şengör et al., 2005; Figs. 1, 3 and 4ABC).

Generally it is accepted that the North Anatolian Fault became active in eastern Anatolia in the Miocene or 13 to 11 Ma (Sengör et al., 1985; Barka, 1992; Hubert-Ferrari et al., 2002; Şengör et al., 2005). However, activity of the Westward Propagation of North Anatolian Fault is questioned. On the one hand, Armijo et al. (1999) suggest that WPNAF became active in 5 Ma, Tüysüz et al. (1998) and Yaltırak et al. (2000) offer 3.4 Ma. In addition, according to Zattin et al. (2005), the WPNAF follows a preexisting structural discontinuity which was active during late Oligocene (12.5 Ma). On the other hand, according to recent studies by Le Pichon et al. (2001) and Şengör et al. (2005) the Northern Strand of the NAF reached the Sea of Marmara no earlier than 200 ka ago based on 4 km of slip measured in the Sea of Marmara and its correlation with GPS data. GPS data show that NAF-N slip is nearly 20 mm/year.

Besides the activity, offset amounts of WPNAF is also questioned. Armijo et al. (1999) concludes that the two major structures seen on either side of the WPNAF (in Işıklar Mountain and the Gelibolu Peninsula) were anticline features that display comparable sedimentary sequences and have been displaced 85 km along the WPNAF. However, Armijo et al. (1999) was criticized by Yaltırak et al. (2000) and Okay et al. (2004). According to Yaltırak et al. (2000), the Işıklar Mountain is a synclinal structure, with a sedimentary sequence that is significantly different from that exposed in the Gelibolu Peninsula. Okay et al. (2004) concluded that the structure of the Işıklar Mountain is a monoclinal and shortening of the Işıklar Mountain suggests a 40 km offset for WPNAF. However, total offset of the WPNAF in the Sea of Marmara is recently measured as 4 km based on detailed bathymetry, seismic and paleo-seismic studies (Armijo et al., 2002; Le Pichon et al., 2003).

Moreover, both in the southern Gelibolu Peninsula and Şarköy–Gaziköy–Mecidiye areas pre-Middle Miocene rocks have been thrusted (Anafartalar and Mecidiye thrusts) over Middle Miocene–Early Pliocene sediments (Önal, 1986a; Sümengen and ve Terlemez, 1991; Tüysüz et al., 1998; Yaltırak and Alpar, 2002; Figs. 3 and 4AB).

The SW Thrace Basin contains many synclines and anticlines, ranging in length from ones of kilometers to tens of kilometers and most axes are parallel to sub-parallel with each other. In detail, three set of NE–SW trending anticlines (Korudağ, Esendik and Uleman anticlines) and synclines, which represent an anticlinorium, have been observed in the Korudağ and Işıklardağ (Ganos) Mountains surroundings (Saner, 1985; Sümengen and ve Terlemez, 1991; Tüysüz et al., 1998; Yaltırak and Alpar, 2002; Figs. 3 and 4AB). The folds were defined in the Korudağ area as Korudağ Anticlinorium by Saner (1985).

According to the mapping in the present study, Işıklardağ Mountain is represented by an anticlinorium (not a single anticline, syncline or monocline) cut by the WPNAF, because recumbent and upright folds mapped by Okay et al. (2004) are represent by sometimes overturned, second and third order folds set of the Korudağ Anticlinorium affected and deformed by WPNAF (Figs. 3 and 4C).

Four set of NE–SW trending anticlines (Fındıklı, Harta, Tırpantepe and Dardanelles anticlines) and synclines have been observed and mapped that they are neither symmetrical nor consistently overturned in the Gelibolu Peninsula and the Gulf of Saros (Saner, 1985; Önal, 1986a; Sümengen and ve Terlemez, 1991; Tüysüz et al., 1998; Yaltırak and Alpar, 2002; Figs. 3 and 4AB).

4. Petroleum geology of the SW Thrace Basin

4.1. Source rock potential of the SW Thrace Basin

According to Bürkan (1992), in the northern and central Thrace Basin, shale of the Hamitabat Formation (equivalent of the Karaagaç Formation) is a gas-prone source rock and the Ceylan Formation (equivalent of the Gaziköy Formation) is a moderate source rock potential for oil and gas generation. However, shales of the Hamitabat and Ceylan Formations are described as gas and limited oil source rock potential by Soylu et al. (1992). The Mezardere Formation is considered as a good oil and gas-prone source rock (Soylu et al., 1992; Bürkan, 1992).

In the SW Thrace Basin, Önal (1986b) and Temel et al. (2005) suggest that due to the 0.47–1% TOC and III–II type organic material content the Karaağaç Formation has moderate oil and gas generation potential. They propose that the Karaağaç Formation is generally within the oil

Table 1
Rock-Eval and TOC data of samples from the Karaağaç Formation (See Fig. 3 for sample locations)

Sample no	TOC* (wt.%)	S_1* (mg HC/g sample)	S_2* (mg HC/g sample)	S_3* (mg HC/g sample)	Tmax* (°C)	HI* (mg HC/g org C)	OI* (mg CO_2/g org C)
K1-1	0.49	0.00	0.00	0.37	N/A	0	76
K1-2	0.43	0.00	0.00	0.60	N/A	0	140
K1-3	2.74	0.00	0.09	0.92	585	3	34
K1-4	0.85	0.00	0.01	0.38	520	1	45
K1-5	0.52	0.00	0.00	0.30	N/A	0	58
K1-6	0.05	0.00	0.00	0.16	N/A	0	320
K1-7	0.06	0.00	0.00	0.07	N/A	0	117
K2-1	1.74	0.13	0.23	0.14	488	13	8
K2-2	0.61	0.06	0.44	0.64	537	72	104
K2-3	0.17	0.03	0.06	0.10	486	35	58
K2-4	0.34	0.03	0.07	0.29	529	20	85
K2-5	0.33	0.03	0.04	0.31	520	12	93
K2-6	0.68	0.04	0.08	0.23	519	11	33
K2-7	0.01	0.05	0.15	0.24	581	0	N/A
K2-8	0.01	0.03	0.12	0.20	531	N/A	N/A
K2-9	1.47	0.03	0.06	0.33	539	4	22
K2-10	0.08	0.09	0.97	0.27	591	0	337
K2-11	1.25	0.02	0.55	0.27	444	44	21
K2-12	0.36	0.05	0.13	0.15	484	36	41
K2-13	0.54	0.06	0.14	0.25	515	25	46
K2-14	0.01	0.07	0.1	0.07	482	N/A	N/A

*TOC = total organic carbon, S_1 = the amount of volatile organic compounds in the sample, S_2 = the amount of HC compounds generated from thermal cracking of the koregen, S_3 = the amount of CO_2 from generated the koregen, Tmax = pyrolysis temperature at the maximum rate of kerogen conversion, HI = hydrogen index, 0I = oxygen index.

Table 2
Summary of the reservoirs in the study area

Formation	Facies architecture	Thickness (m)	Porosity (%)	Permeability (mD)	References
Karaağaç	Turbiditic normally graded pebbly sandstone	280	12–15	0.1–10	Sonel and Büyükutku (1998), Büyükutku (2003)
Fıçıtepe	Nearshore sandstone- fluvial gravel bars and bedforms, sandy bedforms	780	4.47–19.49	0.16–104	Sonel and Büyükutku (1998), Büyükutku (2003)
Soğucak	Boundstone and grainstone/packe-stone	60	10–30	0.1–10	Huvaz et al. (2005, 2007)
Gaziköy	Fractured tuff	160	6–9	0.1–0.2	Büyükutku (2006)
Keşan	Turbiditic normally graded pebbly sandstone	650	15–20	1–3	A. Büyükutku, (personal communication)

window. Based on a TOC content of 1.2% referenced by Harput (1998), Coşkun (2000) suggested that the Mezardere Formation in the Gulf of Saros has a good source rock potential.

Analysis of surface samples taken from north of Tayfur village (Fig. 3) indicated that the Karaağaç Formation has moderate source rock potential. Its TOC content ranges from 0.01% to 2.74% with an average 0.63%. However, S2 and HI values are very low, which reflect that most of its HC-generation potential is already converted. Vitrinite reflection (Ro) has not been determined due to inert organic mater content but T-max values between 444 and 591 °C show that the Karaağaç Formation is mature and overmature (Table 1).

The Gaziköy (equivalent of the Ceylan Formation) and Keşan Formations have no source rock potential because TOC contents of 16 surface samples determined in this study are lower than 0.5%. In addition, source rock potential of the Mezardere Formation has not been determined in this study because it has a very restricted distribution in the study area (only located north of the study area (Fig. 3).

Gürgey et al. (2001) reported that the waxy oils from the K. Osmancik and Devecatagi fields were generated from the Eocene Hamitabat Formation (equivalent of the Karaagac Formation) based on oil to source rock correlation. According to gas to source rock correlation (Gürgey et al., 2005) and basin modeling studies (Hoşgörmez and Yalçın, 2005), sediments of the Karaağaç, Ceylan and Mezardere Formations are source to producing gas in the basin.

Basin modeling studies suggest that hydrocarbons were generated in the central part of the basin (Hoşgörmez an Yalçın, 2005; Huvaz et al., 2005, 2007). According to Huvaz et al. (2005, 2007), hydrocarbon generated in the Early Oligocene and expulsion reached a peak in the Early Miocene and subsequently gradually decreased through the Late Miocene due to erosion which uplifted the source rocks above the oil window. Thus, active oil and gas expulsion occurred from 30 to 10 Ma, and charged Early Miocene traps. However, Middle–Late Miocene and Middle Pliocene subsidence has reactivated the petroleum system which is actively generating hydrocarbons. This indicates that the Early Miocene (associated with the Korudag Anticlinorium and Gelibolu folds), and 200 Ka (associated with the WPNAF) traps may be charged.

4.2. Reservoirs, seals and traps of SW Thrace Basin

In the northern and central Thrace Basin, gas in the Hamitabat field is produced from turbiditic sandstone of the Hamitabat Formation (equivalent of the Karaağaç Formation). Gas of the Karacaoğlan and Kumrular fields have been produced from tuffs of the Ceylan Formation (equivalent of the Gaziköy). Deltaic sandstone of the

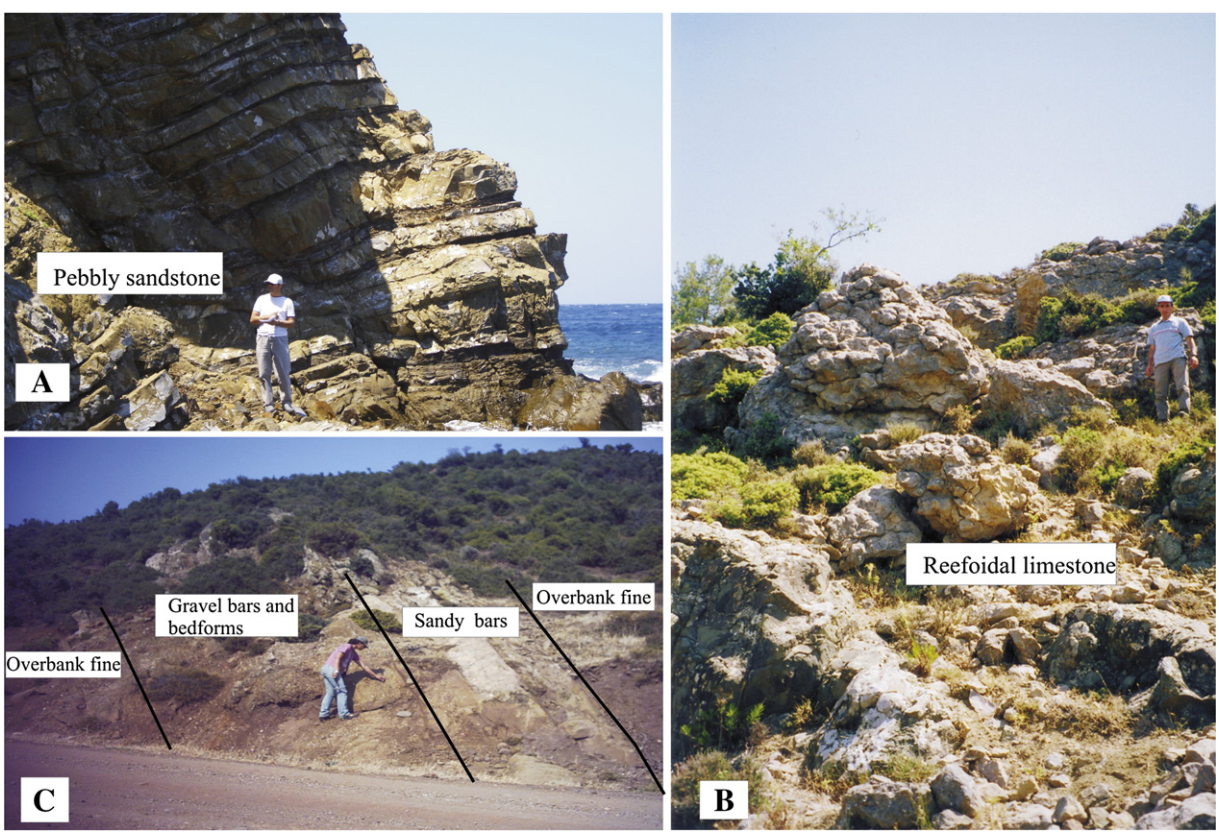

Fig. 5. A, a photograph from Karaağaç Formation (north of Tayfur village), B, a photograph from Fıcıtepe Formation (north of the Tayfur village), C, a photo form Soğucak Formation (Tayfur village).

Osmancık Formation, which is not represented in the study area, is a gas reservoir in the Umurca, Hayrabolu and Kandamış fields. Oil in the Deveçatağı and the North Osmancık fields and gas in the Kuzey Marmara and the Değirmenköy fields have been produced from the reefal limestone of the Soğucak Formation (Fig. 1; Coskun, 1997, 2000; Hoşgörmez and Yalçın, 2005; Gürgey et al., 2005). As seen Table 2, the expected reservoir rocks in SW Thrace Basin are represented by the lower section of the Karaağaç Formation (turbiditic course grained sandstone, Fig. 5A), Fıçıtepe Formation (nearshore and fluvial conglomerate and sandstone, Fig. 5B), the Soğucak Formation (reefoidal limestone, Fig. 5C), the Gaziköy Formation (fractured tuff levels) and the Keşan Formation (coarse grained turbiditic sandstone.).

In the study area, stratigraphic traps related to reef and fluvial to submarine channels are expected. Reefoidal limestone of Soğucak Formation is covered by mudstones of the Gaziköy Formation. Fluvial pebble and sandstones of the Fıçıtepe Formation and submarine pebbly sandstone of the Karaağaç and Keşan formations are sealed by fluvial flood plain mudstones and basin plain mudstones, respectively.

The SW Thrace Basin has also a number of prospect structural traps related to the fold-thrust zone and the Westward Propagation of North Anatolian Fault (WPNAF). They consist of the Korudağ, Beğendik, Uleman, Fındıklı, Harta, Tırpantepe and Dardanelles anticlines Anafartalar –Mecidiye thrusts and normal to strike-slip fault related to the WPNAF (Figs. 1, 3 and 4ABC). Formation time of the folds (Korudağ Anticlinorium and Gelibolu folds) is thought to be Early Miocene because Eocene–Early Miocene sediments are unconformably overlaid by Middle Miocene sediments (Figs. 2 and 4ABC). Formation time of the WPNAF related traps are debated as mentioned above resent studies support the 200 Ka.

5. Allochthonous blocks facies and its implication for petroleum exploration

In the SW Thrace Basin, there are outcrops of the ophiolite and limestone blocks in the sedimentary succession around the towns of Gelibolu, Şarköy and Mecidiye. Firstly, ophiolite blocks, which were interpreted as suture of the Intra-Pontide Ocean by Şengör and Yılmaz (1981), were defined as Late Cretaceous aged Yeniköy mélange uplifted by the WPNAF (Şentürk and Okay, 1984). Later, the ophiolite and limestone blocks were described as Olistostromal Unit in the Eocene sediments to the north of Şarköy by Okay and Tansel (1992). Definition of olistolith in Sci-Tech Dictionary is "An exotic block or other rock mass that has been transported by submarine gravity sliding or slumping and is included in the binder of an olistostrome. Therefore, the Olistostromal Unit has been defined as allochthonous blocks facies in the Gaziköy Formation in this study. Sümengen and ve

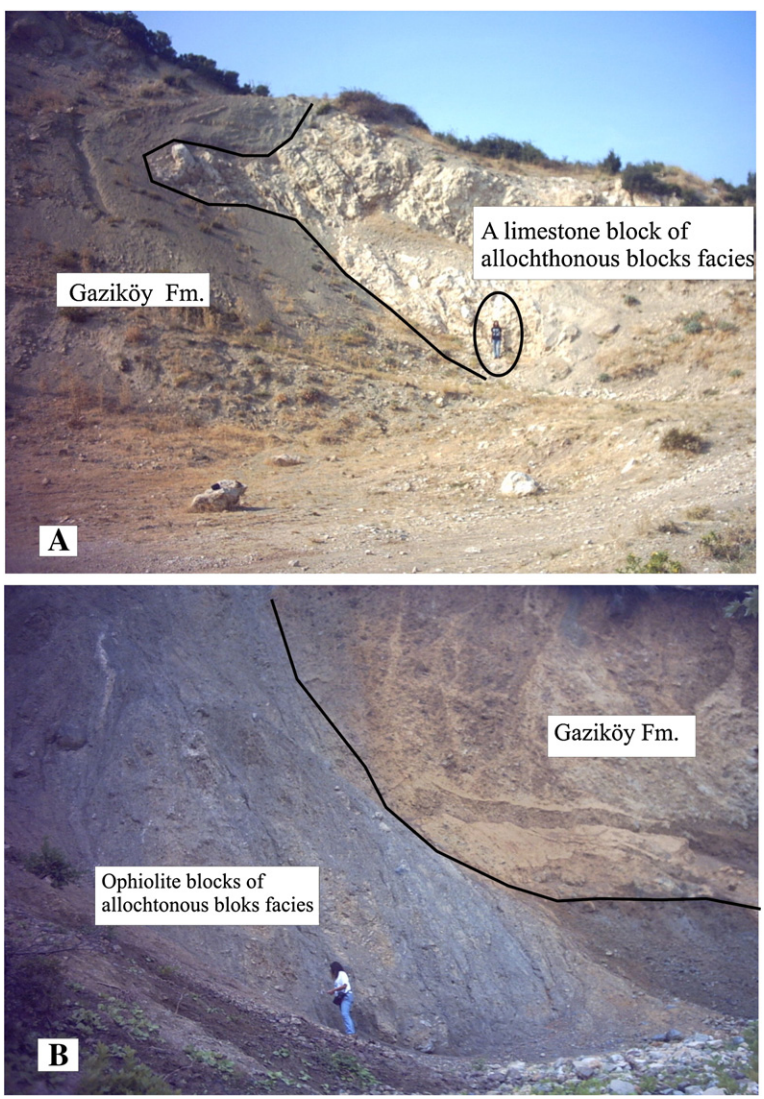

Fig. 6. A, a photograph from allochthonous limestone block in the Gaziköy Formation (N of Şarköy), B, a photograph from allochthonous ophiolite blocks in the Gaziköy Formation (NE of Şarköy).

Terlemez (1991) described the upper part of the Gaziköy Formation in the vicinity of the town of Gaziköy and the nature of the base of the Gaziköy Formation remained as a gap for further research. We suggest that the basal part of the Gaziköy Formation is located in the Gelibolu Peninsula (Fig. 3) due to sedimentary facies studies and nanoplankton contents, while it was formerly known as the a) Karaağaç member of Burgas Formation (Önal, 1986a), b) Ceylan Formation (Siyako et al., 1989; Siyako and Huvaz, 2007) and c) Burgaz and Korudağ Formation (Sümengen and ve Terlemez, 1991).

Huvaz et al. (2005, 2007) and Siyako and Huvaz (2007) suggest that the Karaağaç Formation is equivalent to the Gaziköy Formation. However, it is clear that the age of the Karaağaç Formation is Lower Eocene (Saner, 1985; Önal, 1986a; Siyako et al., 1989; Sümengen and ve Terlemez, 1991; in this study) and age of the Gaziköy Formation according to fossil content is Middle–Upper Eocene (Aksoy, 1987; Sümengen and ve Terlemez, 1991; Yıldız et al., 1997; in this study). In addition, according to sedimentary facies analysis studies, Karaağaç Formation is regressively followed by nearshore and fluvial sediments of the Fıçıtepe Formation (Saner, 1985; Önal, 1986a; in this study). Unlikely, the Gaziköy Formation is transgresively followed by turbiditic sediments of the Keşan Formation (Aksoy, 1987, in this study). It is interesting to note that an unproven unconformity to the base of the Gaziköy Formation is also offered by Siyako and Huvaz (2007).

Through the measurements in the field, Gaziköy Formation consists of a) mudstone facies, b) interbedded non-graded sandstone and mudstone facies, c) interbedded graded pebbly sandstone and mudstones facies, c) slumped interbedded mudstone and sandstone facies, d) allochthonous blocks facies and e) volcanic rocks. The facies indicated that deposition environments of the Gaziköy Formation are shelf and slope apron.

The basal part of the Gaziköy Formation in the Gelibolu Peninsula and the upper part in the Gaziköy area has the same nanoplanktons such as Sphonolithus obtucus (BUKRY), Cyclicargolithus floridanus (ROTH and HAY), Coccolithus pelagicus (BRAMLETTE and RIEDEL) and Dictyococcites bisectus (HAY, MOHLER and WADE). The fossil contents indicate that the age of the Gaziköy Formation is Middle–Late Eocene. Similarly, fossil determinations by Aksoy (1987), Sümengen and ve Terlemez (1991) and Yıldız et al. (1997) also suggests that age of the Gaziköy Formation is Middle–Late Eocene. However, Siyako and Huvaz (2007) suggest that age of the Gaziköy Formation is Early Eocene based on stratigraphical correlation within the basin.

The allochthonous blocks facies of the Gaziköy Formation are composed of blocks of serpantinite, metadiabase, diorite, gabbro, radiolarian chert, quartzite, recrystallised limestone, Late Cretaceous–Paleocene pelagic limestone and Middle Eocene reefoidal limestone. The provenance of most of the blocks is the Neotethys subduction–accretion complex, which is located south of the basin (Figs. 1 and 3). The thickness of the facies is 520 m (Fig. 3). These deposits display a sharp contact with turbitidic interbed sandstone and mudstone of the Gaziköy Formation (Figs. 6AB, 7 and 8). The blocks are generally sub-angular, and range in size from mega blocks (such as hundreds of meters) to blocks (tens of centimeters). The blocks have a chaotic internal fabric and lack any evidence of grading. They are known as deposits of debris flow in the slope apron (Mullins and Cook, 1986; Lomas, 1999).

Seventeen exploration wells have been drilled in the study area (Fig. 1). Doluca-1 well cut the Gazhanedere and Kirazlı Formations and was terminated in the allochthonous blocks facies of the Gaziköy Formation. According to Hoşköy-1, Çınarlı-1, Mürefte-1, Tepeköy-1, Eriklice-1, Şarköy-1, Işıklar-1, Ortaköy-1 and Saroz-1 wells, allochthonous blocks facies is covered by the Gazhanedere, Kirazlı and Gaziköy Formations. Similarly, the Kilitbahir-1, Gelibolu-1 and Kumtepe-1 wells were drilled through the Alçıtepe, Kirazlı, Gazhanedere, Keşan and Gaziköy Formations and they were also terminated in the allochthonous blocks facies (Fig. 7). In addition, allochthonous blocks were covered by the Mezardere, Keşan and Gaziköy Formations in the Keşan-1 well. The detailed logs of the allochthonous blocks facies in the wells are shown in Fig. 8.

The primary cause of both the outcrops in the surface area around the towns of Gelibolu, Şarköy and Mecidiye and different depth in the wells of the allochthonous blocks facies is due to the fold-thrust zone and effects of the WPNAF. The WPNAF cut the SW Thrace Basin and complicated the sedimentary succession (Figs. 3 and 4ABC). Therefore, all wells were terminated in the allochthonous blocks facies of the Gaziköy Formation and the Soğucak, Fıçıtepe and Karaağaç Formations could not be tested deeper in these wells. Unfortunately, all wells in the area were drilled before olistrostral unit has been described by Okay and Tansel (1992).

The SW Thrace Basin has a number folds and thrusts (Figs. 3 and 4ABC). Although two of these structures were tested with the Ulaman-1 (drilled in 1961) and Korudağ-1 (drilled in 1965) wells, both were terminated in Gaziköy Formation at 2351 m and 1718 m depths before reaching the Soğucak Fıcıtepe and Karaağaç Formations due to technological restrictions. Similarly, the İpsila-1 well (drilled in 1988) was terminated at 2375 m in the Gaziköy Formation (Fig. 7). Thus, deeper wells might be drilled in order to test reservoir potential of the Soğucak, Fıçıtepe and Karaağaç Formations in the study area. In addition, the Gelibolu-1, Ortaköy-1 and Şarköy-1 wells were interestingly, drilled in the Gelibolu Syncline (Figs. 3 and 4AB), because the wells were possibly targeted stratigraphical trap of the reefodial limestone blocks.

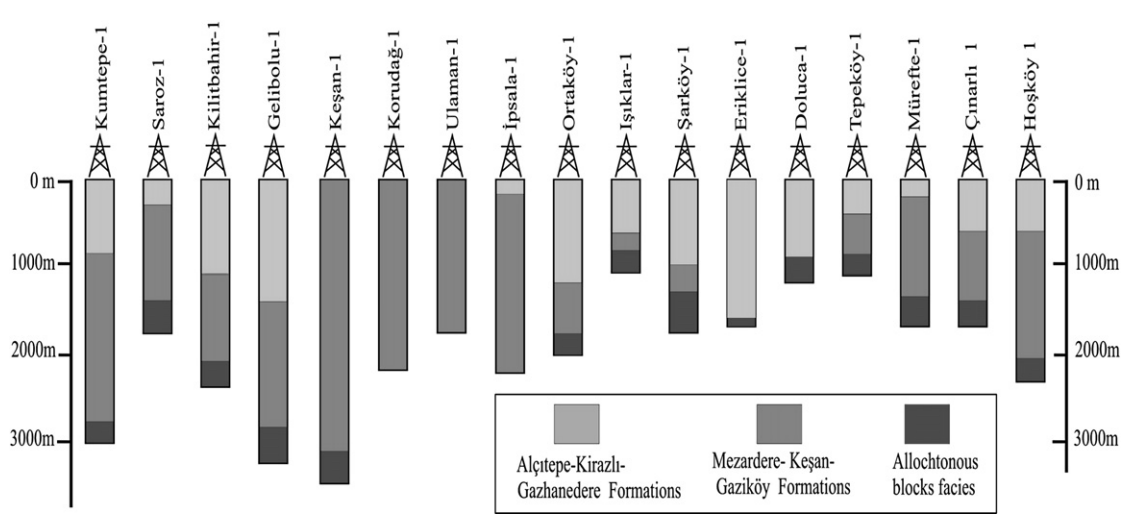

Fig. 7. The borehole data of exploration wells in the study area (modified from Siyako et al., 1989; Çoskun, 2000; Yaltırak and Alpar, 2002 and unpublished data).

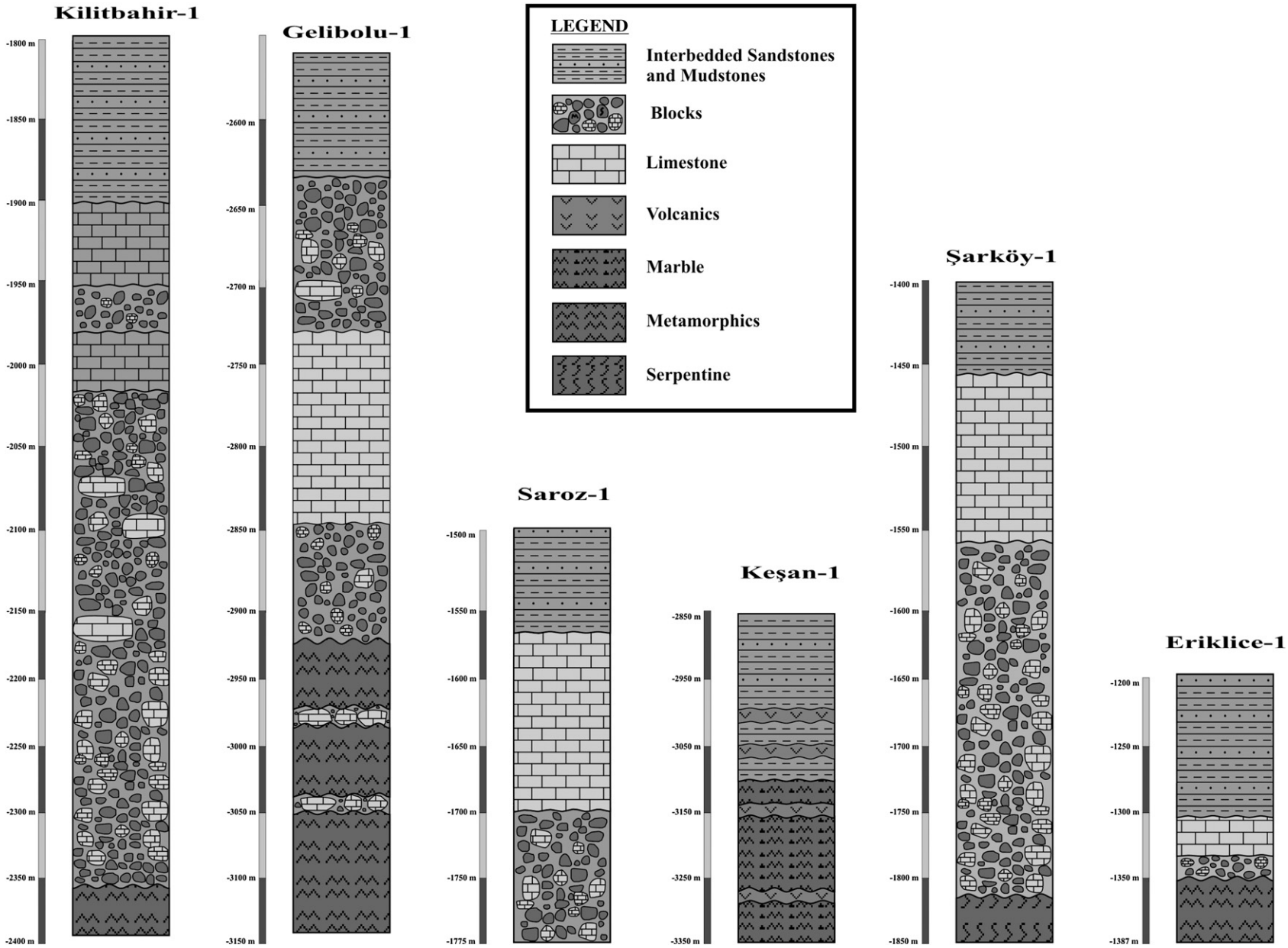

Fig. 8. Detailed logs of the allochthonous blocks in the exploration wells in the study area.

It is important to note that misidentified as the basement of the allochthonous blocks have also affected to the basin sediment thickness. Therefore, thickness map (Turgut et al., 1991), burial history, thermal gradient history and drainage areas of the SW Thrace Basin are miscalculated (Huvaz et al., 2005, 2007; Hoşgörmez and Yalcın, 2005).

6. Conclusions

The sedimentary fill of the Thrace Basin comprises of three major sedimentary packages: (a) a Late Cretaceous–Early Eocene Package; (b) a Middle Eocene–Early Oligocene Package; (c) a Middle Miocene–Early Pliocene Package. Sediments of the Karaağaç Formation aged Early Eocene have oil and gas generation potential according to Önal (1986b) and Temel et al. (2005). Our studies showed also that the Karaağaç Formation has moderate source rock potential. However, S2 and HI values are very low, which reflect that most of its HC-generation potential is already converted. The Karaağaç, Fıcıtepe, Soğucak, Gaziköy and Keşan Formations have a reservoir potential. Trap opportunity is as vast as stratigraphic traps of reefs (Soğucak Formation) and channels (Karaağaç, Fıçıtepe and Keşan Formations) and the structural traps of folds, thrusts and WPNAF.

Although 17 exploration wells have been drilled, so far no oil and gas has been discovered. The cause of unsuccessful explorations is most probably due to the fact that wells were terminated at shallower depths than prospects or that possibly the wells were terminated in the allochthonous block facies of the Gaziköy Formation, which is especially derived from mélange and misidentified as basement. All of the data collected in the current study suggests that the additional source rock analyses and the deeper wells to test the potential Soğucak, Fıçıtepe and Kaaraağaç Formation reservoirs along fold-thrust zone and WPNAF, are required. The depths of the prospects are expected to range from 2000 m to 5500 m depending on the erosion (Figs. 2–4ABC).

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