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The Miocene Sill at the Aegean Prolongation of the Strait of Çanakkale

Çanakkale Boğazının Ege Uzanımı Üzerindeki Miyosen Eşiği

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Abstract

The exit of the Strait of Çanakkale into the North Aegean Sea was explored by high-resolution shallow seismic method. The morphological and structural elements of the area were examined. The stratigraphic units were delineated. The role of a buried Miocene sill at the 9-km west part of the strait on the paleoceanographic evolution of the area has been discussed. An approximate paleoceanographic coastline representing the time 135-150 ky B.P. when the sea level was 130 m lower than it is today was reconstructed.

Keywords: Strait of Çanakkale, Aegean, Marmara, paleoceanography, Plio-Quaternary, seismic stratigraphy

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Introduction

The Strait of Çanakkale and its prolongation into the Northeast Aegean Sea is placed between two tectonically active regimes; the tensional regime forming the Aegean Sea (Mc Kenzie, 1978; Seyitoğlu and Scott, 1991;

Armijo *et al.*, 1996) and the transpressional and transecstensional regimes of the North Anatolian Fault (Dewey and Şengör, 1979; Şengör *et al.*, 1985; Tüysüz *et al.*, 1998; Yaltırak *et al.*, 1998b).

The Strait of Çanakkale (Dardanelles) is a 62-km long water passage connecting the Aegean Sea and the Marmara Sea. The average depth of the strait is 55 m; deepest part is more than 100 m deep.

Different evolution models have been proposed for the opening of the Strait of Çanakkale. Önem (1974) and later Demirbağ *et al.* (1998) suggested that it was opened as a graben or at least evolved into its final form as a graben. Erol (1992) proposed that it was developed as a fault controlled epigenic stream valley in Pliocene-Pleistocene on the gentle folded formations of the Upper Miocene rocks of the Çanakkale Basin. The raised sea levels in Upper Pleistocene and Holocene subsequently inundated this valley. In accord with the most modern ideas, the evolution of the Strait of Çanakkale depends on the compressional and escape tectonics caused by the Anatolian Block, which were observed on the Gelibolu Peninsula and its western regions, and global sea-level changes (Yaltırak *et al.,* 1998a,b). The most effective structural element responsible for the evolution of the Strait of Çanakkale are the Ganos Fault and the Anafartalar Trust Fault (ATF).

The stratigraphic sequences on land represent 3 main evolution periods. The first sequence consists of fluvio-lacustrine and marine sediments deposited during the early–late Miocene. This sequence represents the last depositional period before the evolution of the Strait of Çanakkale and constitutes the youngest basement (Önal, 1984; Siyako *et al.*, 1989; Yaltırak, 1995a; 1995b; 1996a; Yaltırak *et al.* 1998b). The second depositional sequence corresponds to the Late Pliocene units; the Conkbayırı formations (alluvial fan) and the Özbek formations (marine) formations (Yaltırak *et al.*, 1998b). They unconformably overlay the Miocene units. Both of these formations correspond to the period when the Strait of Çanakkale was formed structurally. Finally, the Marmara Formation, which indicates the Mediterranean incursion along the Strait, was placed on top of these formations (Yaltırak, 1996b; Sakınç and Yaltırak, 1997).

Starting from Middle-late Miocene, the Strait of Çanakkale, in generally speaking, the region of Northeast Aegean Sea has been on a water passage between two marine realms; the Mediterranean and the Black Sea (a part of the Neogene Paratethys). This water passage has been affected by tectono-eustatic sea-level changes. The Aegean and Marmara Seas were joined and separated many times during the interglacial and glacial stages. The Mediterranean sea level raised in early Pliocene and important transgressions occurred on continental shelves. In late Pliocene – Lower Pleistocene, sea level raised furthermore and connected with the Marmara Basin (Toker and Şengüler, 1995). In the region, sea level decreased during the glacial stages (Riss and Würm) while the Mediterranean conditions prevailed during the interglacial stages. In Holocene (9 ky B.P.), sea level rose last time (Flandrian Transgression) and connected with the Marmara Basin (Şengör *et al.*, 1985; Görür *et al.*, 1997; Çağatay *et al.*, 1998).

However, it is not precisely known the importance of the morphological and structural characteristics of the Strait of Çanakkale and its surroundings on this connections and on the paleoceanographic and sedimentological evolution of the Marmara Sea. It is not also definite whether the present sea-bottom sill at the Aegean exit (about 60 m) or any other structural element controlled the sedimentological processes and the paleoceanographic evolution.

In this study, in order to elucidate the above-mentioned questions, the morphology of the channel of the Strait of Çanakkale continuing into the Aegean Sea and its shallow structural and stratigraphical features will be given with the aid of seismic digital reflection profiles.

Material and Method

A total of 260 line-km of high-resolution sparker seismic profiles have been shot (Figure 1). A single-channel streamer was used to record the reflections of a sparker sound source (1.25 kJ). The sampling rate was ¼ ms, the trace length was 250 ms TWT and the shot interval was 2 sec (about 4.1 m), These field parameters brought about 150-m penetration below the sea bottom. Positioning was carried out by using an integrated GPS system with an accuracy of ± 30 m.

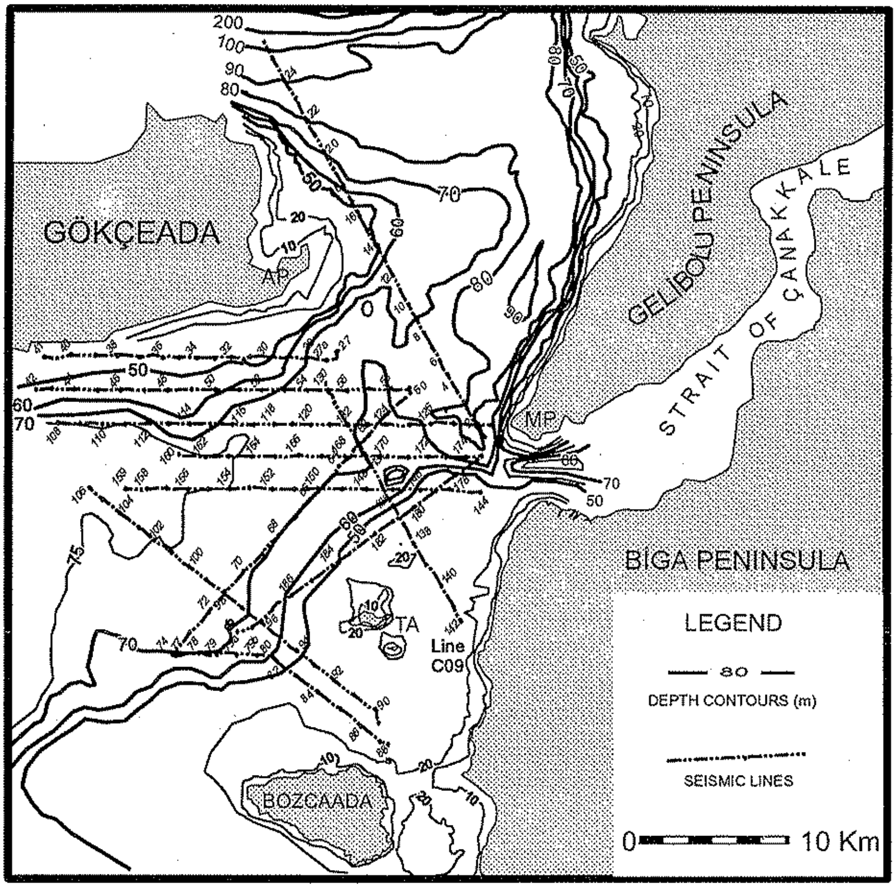

Figure 1. Bathymetric map of the study area. Some depth contours have been dismissed for simplicity. Therefore the contour interval is not systematic. Broken lines show the locations of the high-resolution shallow seismic survey profiles. The map also gives the location of geographycal features mentioned in the text: MP, Mehmetçik Point; AP, Aydıncık Point, TA; Tavşan Adası.

Seismic Interpretation

On seismic sections, many seismic reflections from the sea bottom to the acoustic basement have been observed with different characteristic features. The sea bottom gives continuous high-amplitude reflections.

Sea Bottom : Bathymetric map (Figure 1) was prepared from seismic sections and navigation maps for seismically unexplored areas. A NE-SW trending channel, which is bounded by 70 m contour line, meanders towards the North Anatolian Trough. A sill is placed between 60 and 65 m contour lines at the Aegean exit of the Strait of Çanakkale, indicating that the connection between the Sea of Marmara and the Aegean Sea would be interrupted if the sea level dropped about 65 m. This sill is more shallow than the fossil shores placed at the depths of –115 and –118 metres in the Aegean Sea (van Andel and Lianos, 1984). Hence, the sea level changes during the late Quaternary controlled the paleoceanographic and stratigraphic features of the Sea of Marmara (Smith *et al.*, 1995).

The shelf is well developed at the northern and eastern parts of the Aegean Sea. The shelf area at the Aegean exit of the Strait of Çanakkale extends up to the central axis of the Aegean. It is separated from the deep (1000-1500 m) Anatolian Trough at north by the Ganos Fault.

Deposits after Early Pliocene : The deepest high-amplitude reflections on the seismic sections represent the acoustic basement (Figure 2) which forms an irregular erosional truncation surface (Early Pliocene). Many continuous and well bounded seismic reflections have been observed between the acoustic basement and the sea bottom. These reflections represent the Plio-Quaternary sediments which are composed of mostly continental clastics. The thickness of the sedimentary units is changing between 0 and 132 ms (about 130 m) from coasts to deeper basins. It is the thickest between Gökçeada and Bozcaada. A second depositional area with a maximum thickness of 85 m is placed between the Aydıncık and Mehmetçik Points (see Figure 2d in Alpar *et al.*, 1998). The sedimentary layers are rather thin between these depositional areas.

At least 4 stratigraphic units (Pleistocene) were determined above the Early Pliocene acoustic basement (Figure 2). Each unit is separated from one another by a disconformity characterised by a strong reflector.

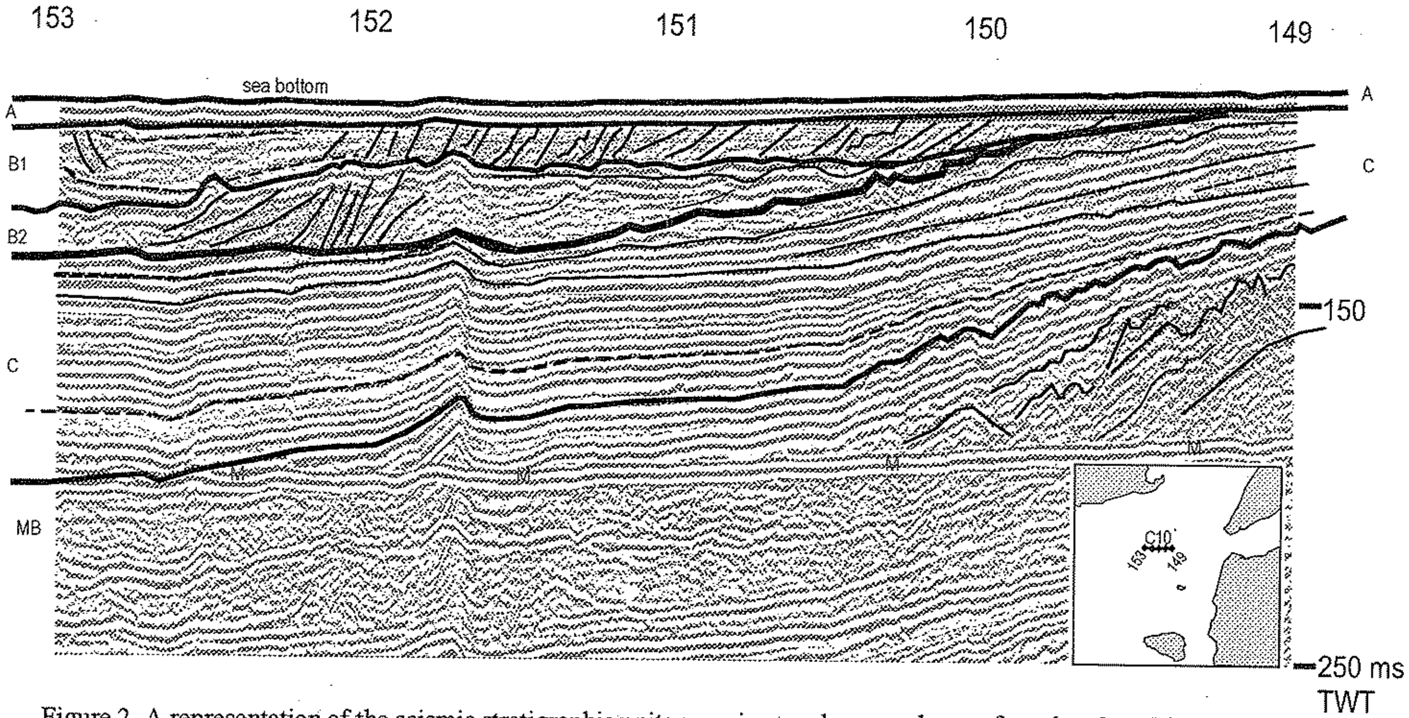

Figure 2. A representation of the seismic stratigraphic units superimposed on a real part of sparker data. The inset shows the location of the profile (Line C10). A, B1, B2 and C refer to stratigraphic units. MB is the Miocene Basement. M is the first sea-bed multiple. TWT is two-way travel time. See text for detailed description of the units.description.

Unit A : The uppermost unit forms the top of the sequence and consists of a thin sediment blanket characterised by weak and internally parallel reflectors (Figure 2). Its thickness changes between 0 and 10 ms TWT, less than the dominant wave length of the seismic wavelet. This stratigraphic unit was deposited in Holocene after the last biggest lowstand of sea level (17-18 ky,-130 m / -150 m).

Unit B1 : Under the Unit A, some deltaic units are defined by a sigmoid and oblique and seaward progradational pattern with toplap and bottomlap terminations (see Figure 3 in Alpar *et al.*, 1998; C01:25-23; C12:178-176). Its thickness varies between 0 and 40 m. This stratigraphic unit corresponds to the second biggest lowstand of sea level (135-150 ky, -130m/-145m). This unit may correspond to the upper levels of the Marmara Formation (Tirhenien) which has been determined all along the southern coasts of Thrace by Sakınç and Yaltırak (1997).

Unit B2 : Another transgressive stratigraphic unit was overlain by Unit B1. It can be distinguished by chaotic reflections. Its maximum thickness is about 40 m. The major (-130 m) and some other minor lowstands of sea level caused erosion of depositional units. Therefore, depending to its location, Unit B2 unconformably overlies two different units; Unit C (Figure 2 and 3) and the deformed Miocene basement (see Figure 3 in Alpar *et al.*, 1998; C08:123-127; C12:178-176). Unit B2 is possibly correlated with the lower levels of the Marmara Formation.

Unit C : Under these units, the bottommost sedimentary unit unconformably overlies the basement (Figure 3; C09:130-136 and 139-142). Taking into account the similar discontinuities observed on land, Unit C may be correlated with the Conkbayırı and Özbek formations on land. The postglacial transgressive layers of Unit C can be evidently traced between Gökçeada and Bozcaada.

Miocene Basement : According to geology and previous marine seismic data, the acoustic basement mainly represents the Miocene Formations. Since there is no deep cores and also limited acoustic penetration, the offshore Miocene sequence could not be subdivided. The Miocene basement was formed by folded layers on all of the seismic sections (Figure 2). This folding period coincides with the development period of the ATF on the Gelibolu Peninsula. This period is Upper Pliocene –Lower Pleistocene when the Conkbayırı formation was deposited (Yaltırak, 1995b). Therefore, high-amplitude reflections on top of the acoustic basement can be interpreted as early Pliocene erosional truncation surface.

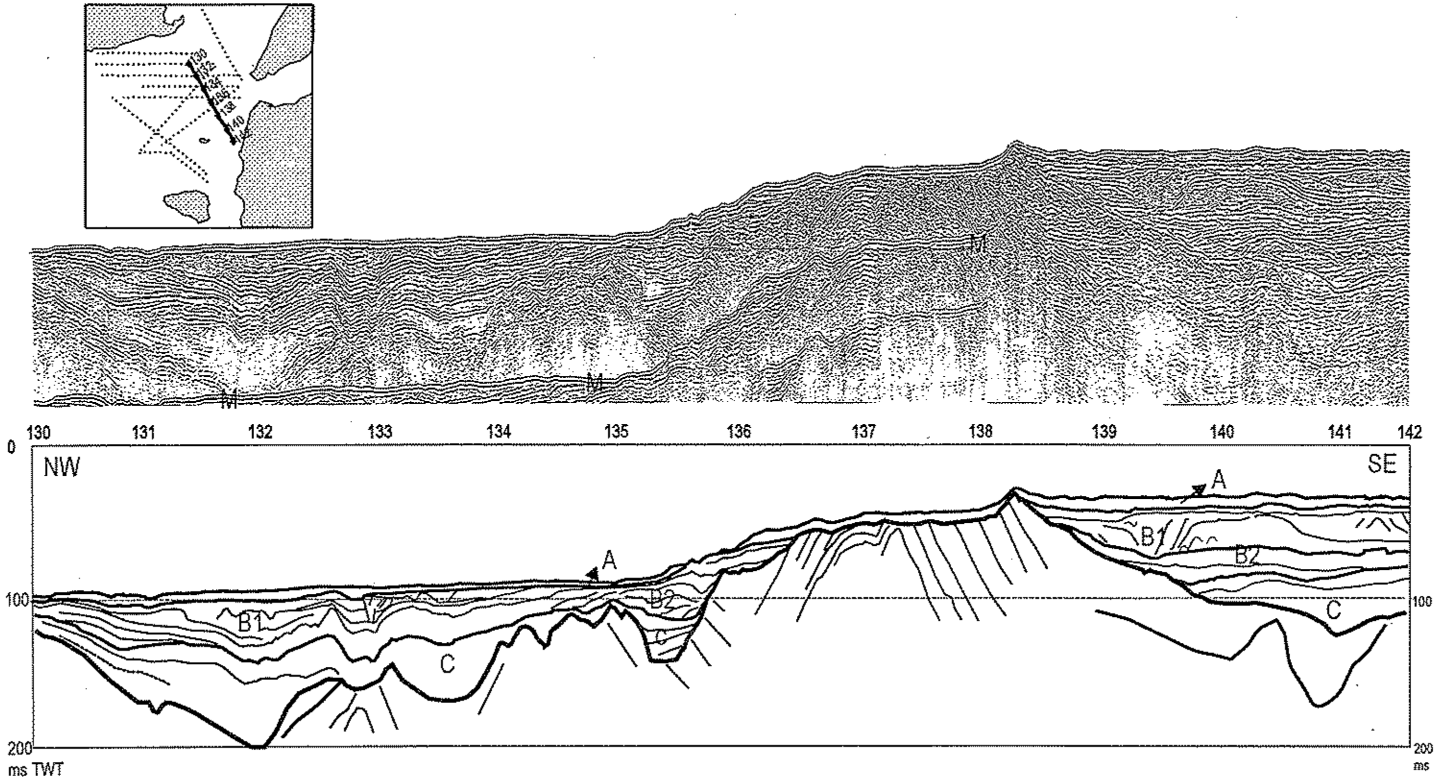

Figure 3. Sparker profile C09, below which is an interpretation of the profile, passes over the Miocene Basement and contiguous stratigraphic units. A, B1, B2 and C refer to stratigraphic units. MB is the Miocene Basement. M is the first sea-bed multiple. The inset shows the location of the profile.

Conclusion

Seismic records indicate that the Miocene basement is one of the most dominant factors forming the sea floor morphology. The depth to the Miocene basement from the present sea level is highly variable. In a locality about 9 km west of the Aegean exit of the Strait of Çanakkale, the Miocene basement is rather shallow (50 m) (Figure 3, between fixes 136 and 138). This elevated formation is formed by the relatively higher parts of the arc-shaped (concave towards Aegean Sea) ridge placed between the Bozcaada-Tavşan Adası and the Southeast corner of the Gökçeada. This formation forms a horizontal mass of rock between two depositional areas. So we call this raised formation as the Miocene sill.

Figure 4 gives a 3D description of the present sea bottom and the erosional truncation surface (Early Pliocene) observed on the seismic sections. Because of the graphical inadequateness the vertical distance between the interface surfaces is not in scale. Nevertheless, the depression areas which existed in early Pliocene at the NE and SW sides of the Miocene sill are apparent.

Many folds in the Miocene basement have been observed on seismic sections (Figure 2 and 3). Most of the main EW trending fold axes at sea follow those on the Biga and Gelibolu Peninsulas (Figure 5). This finding expresses that, besides the global sea-level changes and the escape tectonics caused by the Anatolian Block, the compressional forces are also important on the evolution model of the area.

The eroded material of the Gelibolu Peninsula, which was started to be uplift with the effect of the ATF, was transported to the Aegean Sea. During the lowstands of sea level most of the material has been wiped out. The remainders of these eroded materials between Gökçeada and Bozcaada should be the origin of the Unit C.

On the other hand, the materials of the Units B1 and B2, which were deposited mainly along some specific cut-and-fill channels (Figure 5), possibly transported via an ancient big stream. Its tributaries may be the present Strait of Çanakkale and the Karamenderes Creek placed at the western part of the strait. The transportation is towards either the North Anatolian Trough or the deep basins in the North Aegean Sea. The buried Miocene sill is highly responsible from this deposition.

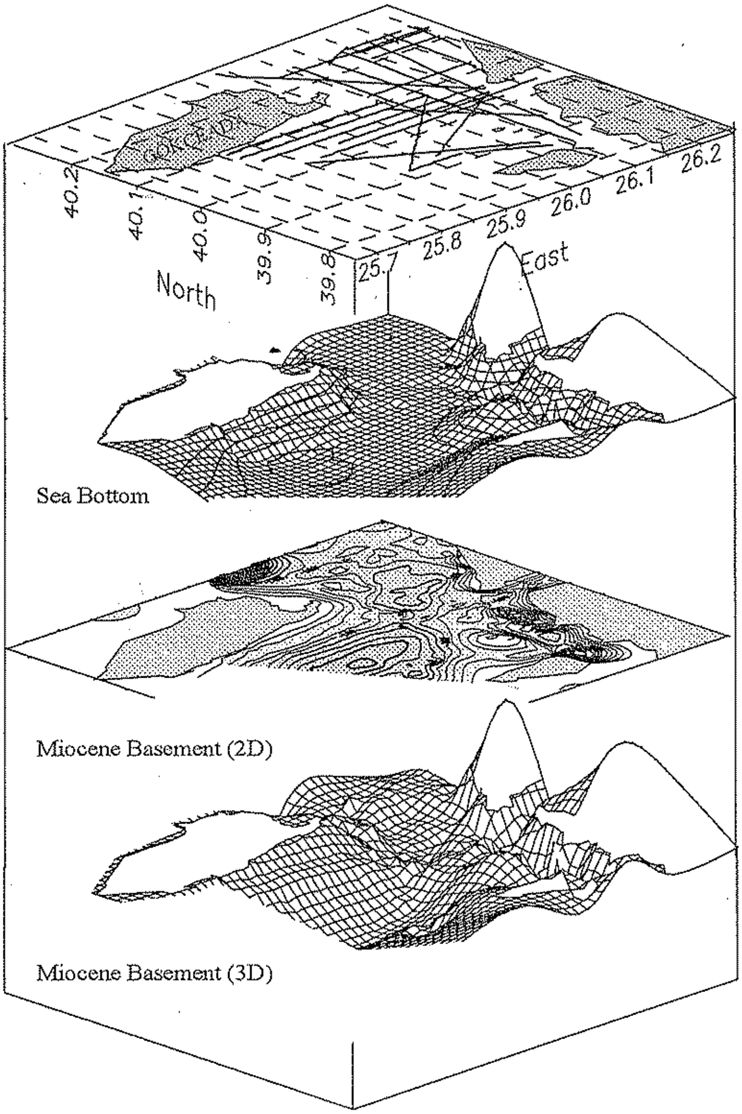

Figure 4. 3D block diagrams of the present sea bottom and the Miocene basement. For depth conversations, the average seismic velocity of the Late Quaternary sediments on top of the erosional truncation surface (Early Pliocene) is assumed as 2000 m/s. A 2D contour map of the Miocene Basement is inserted between the 3D block diagrams for more effective interpretation. Depths are contoured every 20 metres. Vertical distance between the 3D surfaces is not in scale.

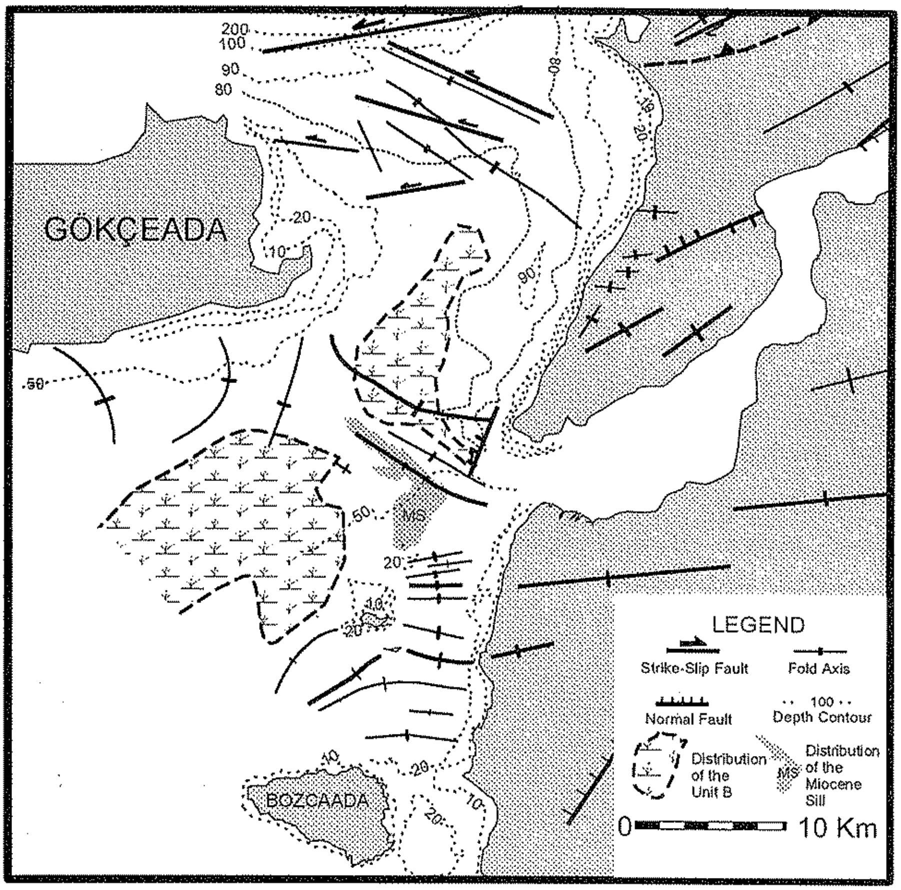

Figure 5. The distribution of deltaic sediments (Unit B1) along the old depositional areas separated by the Miocene sill. For comparison, they were superimposed on the bathymetry and main structural elements as they were interpreted from shallow seismic data. Main fold and faults on land, on the other hand, are from Çağatay *et al.*, 1998; Yaltırak *et al.*, 1998b).

If we ignore the vertical tectonic movements such as the regional uplifts of the Gelibolu and Biga Peninsulas in Pliocene as a result of compressional forces caused by the strike-slip faulting of the Ganos Fault, we may draw an approximate paleoceanographic coastline representing the time 135-150 ky B.P (Riss) when the sea level was about -130 m lower than it is today and the Sea of Marmara was a lacustrine environment (Figure 6). Even though that this coastline is approximate because of the limited knowledge of seismic velocity, it is clear that the water exchange between the two main depositional areas at both sides of the Miocene sill should be cut off during Riss glacial period when the sea level had been 130 m (or more) lower than it is today. This line should not be confused with the coastline during the last biggest (-130 m) lowstand of sea level 17-18 ky B.P. (Würm) which should be somewhere beyond the limits of the seismic data. Between the Riss and Würm glacial periods (medial to Late Pleistocene), the Marmara and Aegean basins should have been connected along some valleys on the Gelibolu Peninsula. Besides the global sea level changes, the Ganos Fault and the ATF, which affects the Miocene basement, are the most important factors on these connections and they deserve further studies. Finally, during Upper Pleistocene and Holocene, the Mediterranean incursion occurs by way of the Strait of Çanakkale.

The area under discussion deserves further detailed seismic studies with more precise seismic velocities and with finer defined stratigraphic sequences to reconstruct more detailed paleoceanographic environmental frames in order to better understand the water exchange between the two marine realms.

Özet

Çanakkale Boğazı kanalının batıda Ege Denizi içindeki devamının morfolojisi, yapısal unsurları ve dolgusunun stratigrafik özellikleri sığ sismik yöntemlerle araştırılmıştır. Boğazın 9 km kadar batısında yer alan Miyosen eşiğinin yakın çevre ve Marmara Denizi paleo-oşinografik gelişimi üzerindeki rolü incelenmiştir. Deniz düzeyinin günümüzden 130 metre aşağıda olduğu 135-150 bin yıl öncesini temsil eden yaklaşık kıyı çizgisi çizilmiştir.

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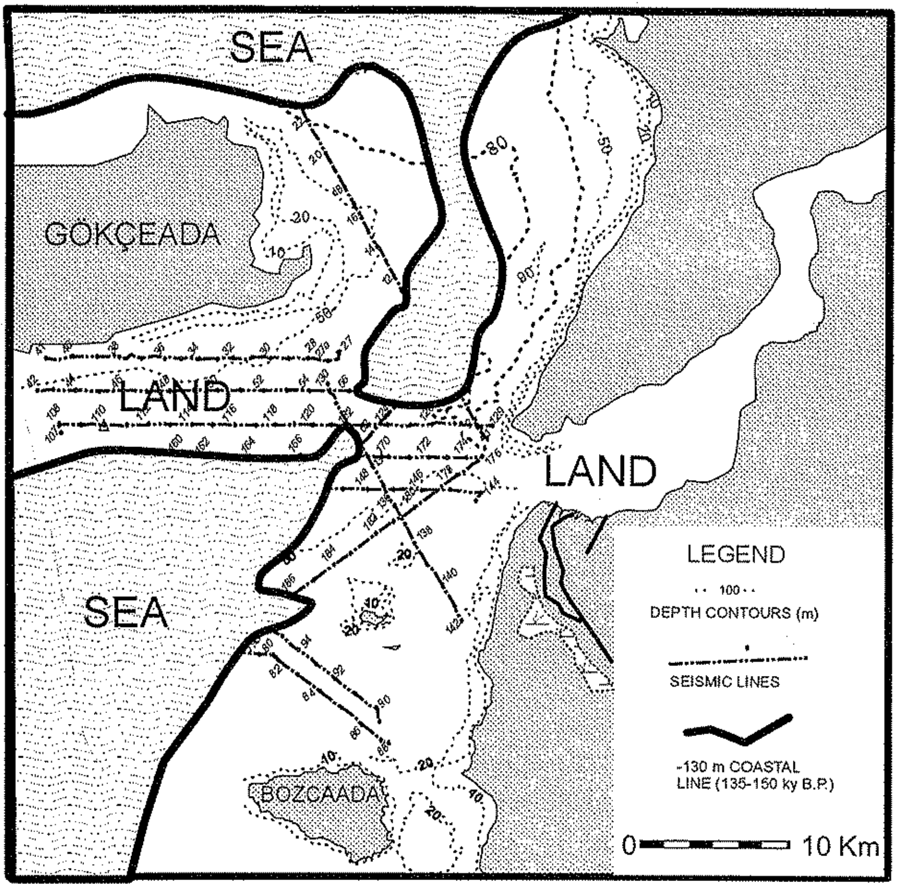

Figure 6. This figure depicts where the possible paleogeographic coastline was positioned during the glacial period occurred 135-150 ky B.P. The global climate was significantly colder than present, and the sea level was 130 m lower than it is today.

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