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GAS-CHARGED LATE QUATERNARY SEDIMENTS IN STRAIT OF ÇANAKKALE (DARDANELLES)

ÇANAKKALE BOĞAZINDAKİ GAZ İÇEREN GEÇ KUVATERNER ÇÖKELLERİ

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Abstract

The nature of bottom sediments in the Strait of Çanakkale (Dardanelles) depends on the interaction of the channel geometry and flow conditions. The sand-size sediments are found in narrow parts of the strait's channel where high-energy conditions prevail. Such high-energy flow sections of the channel include the narrows of Çanakkale and Nara. Sand and silty sand are also distributed in narrow bands along both shores of the channel. Terrigenous mud is the major sediment type covering deeper and wider parts of the strait channel where bottom currents are relatively weak.

Shallow seismic profiling shows the presence of two main seismic sedimentary sequences in the Dardanelles; late Quaternary sediments and acoustic basement. These are separated by an erosional truncation surface. The late Quaternary sediments consists of at least three sediment sub-units. These sub-units can be interpreted as Holocene posttransgression marine deposits (A_1), basinward-prograding deltaic sediments deposited during the Würm glaciation (A_2), and basal transgressive marine sediments (A_3), possibly Tyrrhenian age. The acoustic basement is formed from the Miocene shallow marine clastic sediments distributed widely on both sides of the strait. The lower two sub-units of the late Quaternary sediments are locally gas-charged in the wider parts of the straits channel. The origin of the gas is not adequately known; it could have been formed by fermantation reactions during the early diagenesis of sub-unit A_3. The channel of the strait appears to be fault controlled with the faults being generally parallel to the coast. Some faults are still active and cut the late Quaternary sediments.

Introduction

The Strait of Çanakkale (Dardanelles) is a 62-km long NE-trending water passage connecting the Aegean Sea and the Sea of Marmara (Figure 1). Its smooth NE-trend is broken by a NS trending bend between Eceabat and Çanakkale. Its width ranges from 1.2 to 7 km, with the narrowest part at the Nara Pass (Figure 1). The average depth of the strait is 55 m; deepest part is more than 100 m deep. The strait channel extends across the Marmara shelf towards the deep basin through a canyon.

The present sill depth of the Dardanelles (about 60 m) is shallower than the 115-118 m deep fossil shorelines in the Aegean (van Andel and Lianos, 1984). The glacio-eustatic sea-level oscillations must have been a major control on the paleogeographic and sedimentological evolution of the Dardanelles. Similarly, being located in a tectonically active area, the Dardanelles must also have been affected by tectono-eustatic sea-level changes.

The rivers at present flow in the perpendicular valleys to the Strait. Most rivers draining from the south create deltaic systems along the southern coasts of the Dardanelles. The length of the rivers and the size of the drainage basin area along the southern coast is more than those placed in the northern coast. The rivers in Thrace flow away from the Sea of Marmara and into the north Aegean while the young drainage in the Gelibolu Peninsula is towards to the Dardanelles. Howvere, small drainage area and dominant currents of the strait prevent the development of deltaic systems along the coasts of the Gelibolu Peninsula.

The hydrography of the Dardanelles is characterized by a permanent two-layer current flow; a surface outflow from the Sea of Marmara towards the Aegean Sea, and a bottom inflow from the Aegean Sea towards the Sea of Marmara in the reverse direction. The upper and lower flow layers exhibit salinities ranging from 23 to 28 and from 38.5 to 38.7 ppt, respectively (Özsoy et al., 1988). The amount of surface outflow increases downstream from 850 to 1250 km^3/year and of the bottom inflow decreases in the upcanyon direction from 950 to 550 km^3/year, between 23% and 41% of the Aegean inflow being transported into the upper layer by the entrainment process and restored to the sea of origin (Oğuz and Sur, 1989; Ünlüata et al., 1990).

The current velocities in the Dardanelles are not precisely known. The classical study by Merz (1918) (cf. Möller, 1928; cf. Memoranda, 1941 and Defant, 1961) informed the current velocities range from 0.5 to 2 m/s in the surface or near-surface (average: 0.8-0.9 m/s) and from 0.2 to 0.4 m/s near the bottom. The velocity of the northerly flowing lower-layer current attains typically a value of 0.3 m/s. The course of the currents in the Dardanelles is largely determined by the trend of the channel.

The sedimentary and structural subbottom features in the Dardanelles have not been previously studied apart from a single study (Ergin et al., 1991) dealing with the nature of the surficial sediments in the channel. In order to investigate the distribution of bottom sediments, the structural and lithological features of the sub-bottom layers, the distribution of gas-charged sediments in these layers along the Dardanelles Strait and also to realize their relations, the present study is based on the

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Geological and Tectonic Setting

The geology and geomorphology of vicinity of the study area have been the subject of numerous studies (Barka, 1985; Dewey and Şengör, 1979; Erol 1982, 1987, 1992; Görür et al. (under review); Sakınç and Yaltırak, 1995; Saner 1985; Siyako et al., 1989; Sümengen et al., 1987; Şengör, 1982; Şengör et al., 1985; Şentürk et al., 1987).

The Dardanelles is a cut into a Tertiary land with low hills. The onshore area is up to 150 m high and build up of Miocene sandstones in part with some carbonates towards the top. Many workers believe that the Dardanelles strait developed during the Pleistocene as a fluvial valley along the axis of an anticline (Penck, 1917, Erol, 1987) or along a graben structure (Önem, 1974). However, the time of its formation and its late Quaternary evolution is not properly known.

Data acquisition, analysis and processing

Bathymetric map of the Dardanelles (Figure 1) was derived from the recorded seismic data in accordance with the Admiralty charts and unpublished Turkish Navy data. For depth conversion, the average sound velocity of water column was chosen as $1500 \, ms^{-1}$.

Some 450 surficial samples were obtained using a van Veen-type grab on board the Turkish Navy ships; TCG Çubuklu and Mesaha I-II. The samples were subjected to grain size determination using standart procedures (sieve plus pipette) in the laboratories of the Department of the Navigation, Hydrography and Oceanography. The biological material in the samples such as shells, detritic shell materials and residuals of other organisms were considered in analysis (Figure 2). The granulometric composition method were used for sediment classification.

A total of 270 analog Uniboom (200 Joulle) profiles (more than 1240 km) were obtained in the Dardanelles during several cruises between 1977 and 1991 on board of the same Turkish Navy ships. Navigation was by Trisponder, using two shore-based radio beacons with an accuracy of about 10 meters. Data were recorded directly onto paper, usually to 200 ms TWT (two-way-time), and imaged about 60 m sub-surface below the sea bottom (Özturan, 1996). The records were generally of good quality, but deteriorated in areas of steep sea-floor gradients. The data were also affected by the reverbatory nature of the source wavelet. The reflection intensity and structural elements were taken into account for the interpretation of the seismic stratigraphy.

Results and Discussion

Bathymetry

On the seismic records, sea bottom generally shows valley-like topography across the strait, but gentler where the strait becomes wider (Figure 3). The Dardanelles strait has a bathymetry without uniform bottom slopes, and holes deeper than 80 m (Figure 1). The width of the shallow areas (< 30 m) are rather narrow along the Gelibolu Peninsula, while it is large at the Asiatic side except Gocuk Br., Nara Br. and offshore Çanakkale. The sudden slope changes along the shores of the Gelibolu Peninsula occur around 10-20 m at NE, 30-40 m at center and 40-50 m at SW part of the Dardanelles. For Anatolian side, on the other hand, sudden slope changes occur around the depths of 20-40 m at NE (Çardak delta), 10-30 m at center and 40-50 m at SW part of the Dardanelles. The mean bottom slopes along the shores of the Gelibolu Peninsula are higher than those along the Asiatic side.

Bottom Sediments

The sedimentation rate in the Dardanelles is high; only between the narrows Nara and Çanakkale bottom current speed is high enough to inhibit sedimentation. The bottom samples point out a clear distribution of bottom deposits ranging from sand to mud depending on the channel geometry (Figure 2). Not only the source of the sediments but also the bathymetry and the dominant currents in the depositional area control the distribution of sediments.

In general, the terrigenous mud with a dominance of silt is the major sediment type covering the sea bottom (deeper than 20 m depth contour), except for its side slopes where coarser materials were deposited. Sandy facies, which consists of sand, silty sand and muddy sand, was placed along a narrow band lying parallel to the shores if the depth is less than 10 m. Different size rocks were also scattered along the sandy facies which changes into the silty sand facies laterally. The silty sand facies expands parallel to the shores with varying width and then temporarily changes into muddy sand and sandy mud beyond 15-20 m depth contours. The muddy sands are not continuous since they are frequently covered with sandy muds. Sandy mud and mud are dominant beyond 20 m depth contour and cover the deepest parts of the channel, except the vicinity of Nara Pass where surface and bottom currents reach their maximum velocities (up to 1.6 m/s) and the trough bottom is covered with coarsest sediments (with the maximum sand and gravel percentages, mussel fragments, coarse sandy mud, and rounded stone fragments up to 4 cm diameter). This is a sign of the more intensive erosion there; towards the shores there flows in sequence, coarse sand, fine sand, sandy mud, and mussel sand. This seams to be somewhat similar to many other fluviatile environments having meandering channels, where finer grained bottom materials are usually current swept as a result of the maximum flow velocities in the narrowing and shoaling channels (Ergin et al, 1991).

In contrast, in the areas where relatively low current energy conditions prevail, the sediments comprise much finer materials. The clay and silt percentages generally increase on the areas corresponding to the less severe current regimes, such as the area between Çanakkale and Seddülbahir and also areas in the upper strait. Besides the currents, the irregular bottom topography of the strait also plays an important role in trapping muddy sediments.

Since the water depths become shallow at the approaches of the Aegean Sea and the Sea of Marmara, muds temporarily change into the sand and sandy facies. The shells which are distributed mainly along the shores are mostly encountered in the sandy facies. All bays are flooded with gray mud which is always found on the 5 and 40 m deep terraces and this points out the occurrence of little erosion there. The terraces are therefore not being modified in the present age.

Seismic Stratigraphy

The seismic reflections in the Dardanelles Strait were mainly controlled by sea bottom topography and faults. Most of the faults can be traced across several adjacent profiles and named as Post-Holocene and Pre-Holocene faults. A much more detailed dating can not be implied because of the lack of drilling data. The Post-Holocene faults affects all of the stratigraphic sequences including the sea floor while the older (Pre-Holocene) faults only affect the seismic basement sometimes causing step-shaped structures (Figure 3 c). The faults are generally parallel to the coastal line of the Strait (Figure 4). The geometric positions of the faults, bending and folding of the stratigraphic layers in the vicinity of these fault zones and at some places along the integration of the bathymetric slopes with the fault zones may indicate that the faulting is simultaneous or just after the sedimentation.

There are two main reflection characters on the seismic records; the acoustic (seismic) basement with high reflection amplitudes and the late Quaternary sediments with weaker reflection amplitudes (sometimes transparent) and low continuity.

Acoustic Basement : The reflections from acoustic basement is generally continuous, but sometimes coated with multiples and ambient noise (Figure 3 c). Acoustic basement is much more evident at deeper parts of the sections bounded by strong reflectors. The layering in the acoustic basement is sometimes folded and complex (Figure 3 b). Acoustic basement consists of a series of sub-units with generally complex, but parallel to each other and sometimes continuous reflectors. The layering within each sub-unit appears to be stronger in the upper part than in the lower part. Acoustic basement could not be traced on the deeper parts of some profiles because of the limited wave penetration. Since there is no drilling data, the acoustic basement may be interpreted as the upper surface of shallow marine sediments (possibly sandstone), and probably deposited during the upper Miocene. This may indicate that upper Pliocene and Pleistocene sedimentary basins were existed in the area.

Late Quaternary Sediments : The reflections which are seperated from the acoustic basement by a strong reflector can be easily recognized on the seismic profiles. These reflectors represent the late Quaternary sediments and marked as "A" on the seismic sections (Figure 3 a). The late Quaternary sediments are generally parallel to the sea-bottom topography and placed just on top of the overlaid layers (an erosional truncation) (Figure 3). The late Quaternary sediments are occasionally gas bearing.

The overall average thickess of the late Quaternary sediments (A) is about 16 m along the Dardanelles. The highest sedimentation occurs at the offshore areas of Kayaüstü-Kabageven Br. (55 m), Kepez Br. (50 m), Kumkale Br. (45 m), Çanakkale (40 m) and Karanfil Br. (30-35 m). These local areas and the places where the late Quaternary sediments are relatively thicker coincide with the wider water passages along the Strait. On the other hand, the late Quaternary sediments have less thicknesses around the narrow water passages such as the approaches of the neighbouring seas (about 5 and 7 m at the Aegean and the Sea of Marmara exits, respectively), Nara Br. (12-13 m between Çanakkale and Kabageven Br.) and Gocuk Br. (4 m). The thickness of the late Quaternary sediments is almost zero around some particular areas between Çanakkale and Saltık Br., where the spatial distribution of the isopach contours of the late Quaternary sediments are rather complex, and also in the vicinity of Aegean exit.

Even though it is not easy to correlate between successive profiles because of their rapid lateral variations, the late Quaternary sediments in the Dardanelles may be divided at least 3 sub-units (Figure 3 a). The uppermost sub-unit representing actual sediments can be interpreted as Holocene posttransgressional marine deposits (A_1). These Holocene deposits, which are reported to be less than 18 m at western Sea of Marmara by Smith et al., 1995, are not thicker than 10 m in the Dardanelles Strait. The successive sub-units may be interpreted as subaqueous sedimentary units (A_2 and A_3). The bottom of sub-unit A_1 represents the last glacial maximum (21 k.y. before present) when the sea level is lower more than 120 m than today's mean sea level. The sub-units A_2 and A_3 are the Middle-Late Pleistocene age sediments as indicated by Erol (1992) and Smith et al. (1995). The basal transgressive marine sediment sub-unit A_3 is possibly deposited during Riss-Würm interglacial stage. This means that the Dardanelles was a marine strait at least between 27-124 k.y. before present. The deposits of this period may correspond to A_3 sub-unit which can be traced on most of the seismic profiles (Figure 3). This assumption may indicate that the altitude of the sill located at the Dardanelles did not changed significantly from today (about 60-70 m from present sea level). Because of the insufficient number of tie-profiles and also no drilling data, the correlation between profiles is not fully completed yet. Therefore we prefer not to give the spatial distribution of these sub-units here and it deserves a further comprehensive study.

The subaqueous sedimentary sub-units (A_2 and A_3) were charged with gas in some parts of the study area (Figure 3 a,b,c) and their boundaries along the Dardanelles were plotted on the map (Figure 4). The Holocene posttrangressional marine deposits (A_1) acts as a cap over the gas-charged sediments. The gas-charged sediments are generally placed on both sides of the channel axis along the strait, especially where the strait becomes wider. The origin of gas is not properly known. However, the coincidence of the spatial distribution of the gas-charged sediments with the low-energy mud-deposited broader channel areas suggests that the fine-grained and presumably organic-rich sediments of sub-unit A_3 could be a possible source of the gas. The gas could have been produced in this sub-unit by bacterial fermentation reactions during the early diagenesis (Curtis, 1977). These reactions produce large amounts of methane and carbon dioxide as a result of microbial degradation of organic matter in the sediments. Contrary, sudden lateral discontinuities between the gas-charged sediments and their environment may suggest that the gas source is deeper in the Miocene units and controlled by small-scale pre-Holocene faults or cracks in these units.

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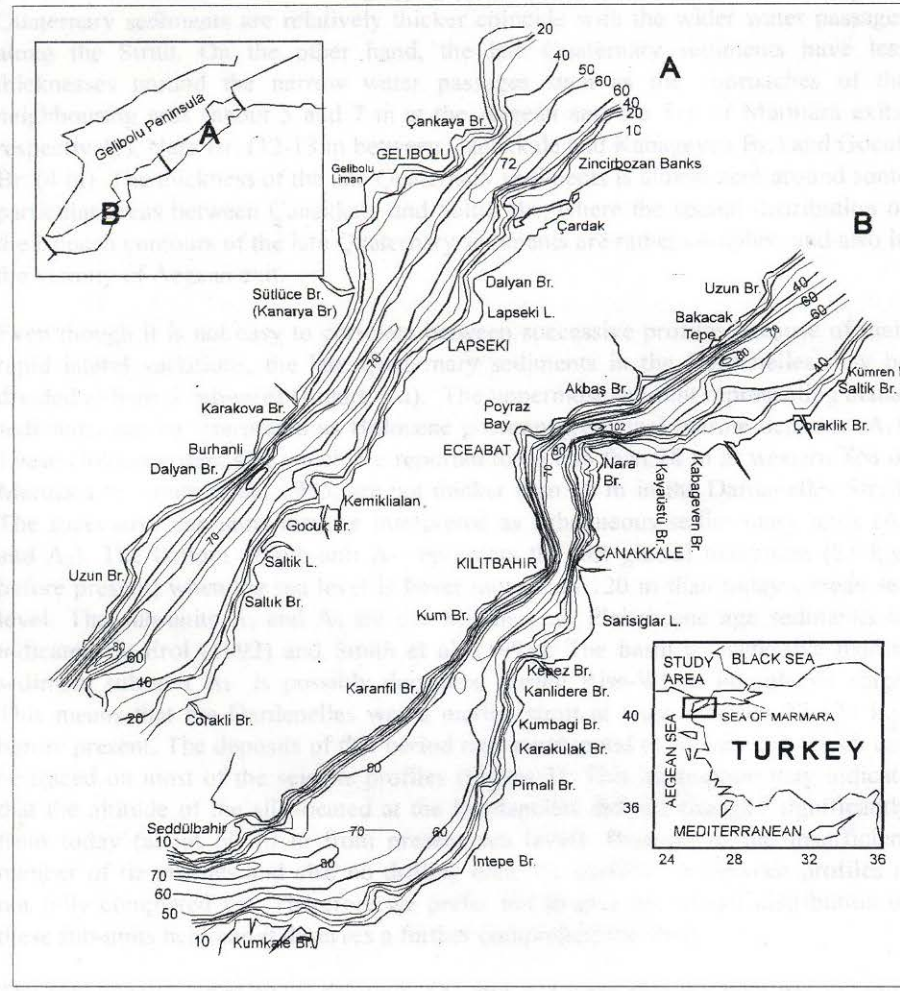

Figure 1. Location of the places mentioned in the text and the bathymetric map of the Dardanelles.

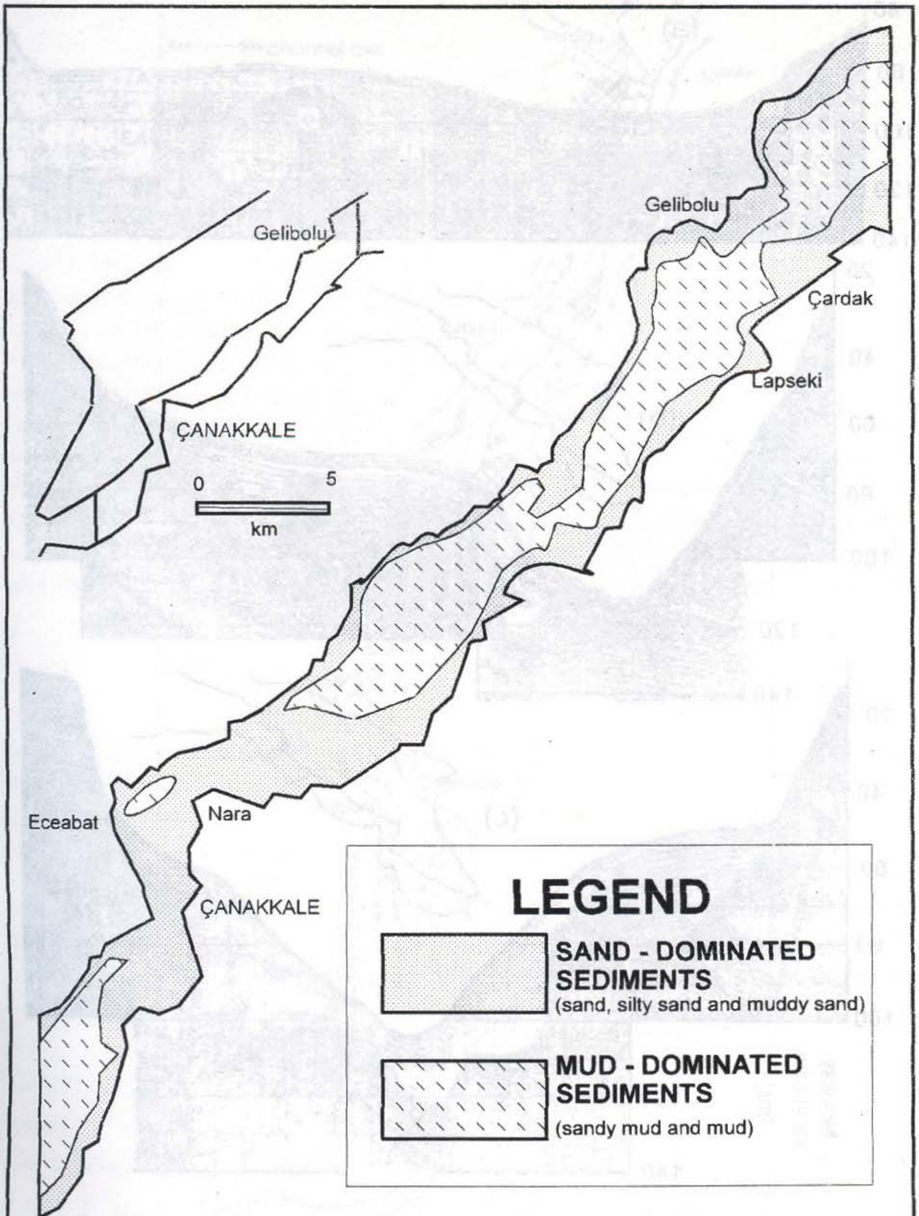

Figure 2. Grain size distribution map of the sediments in the sea-bottom surface of the Dardanelles (after Kırca and Eryılmaz, 1991).

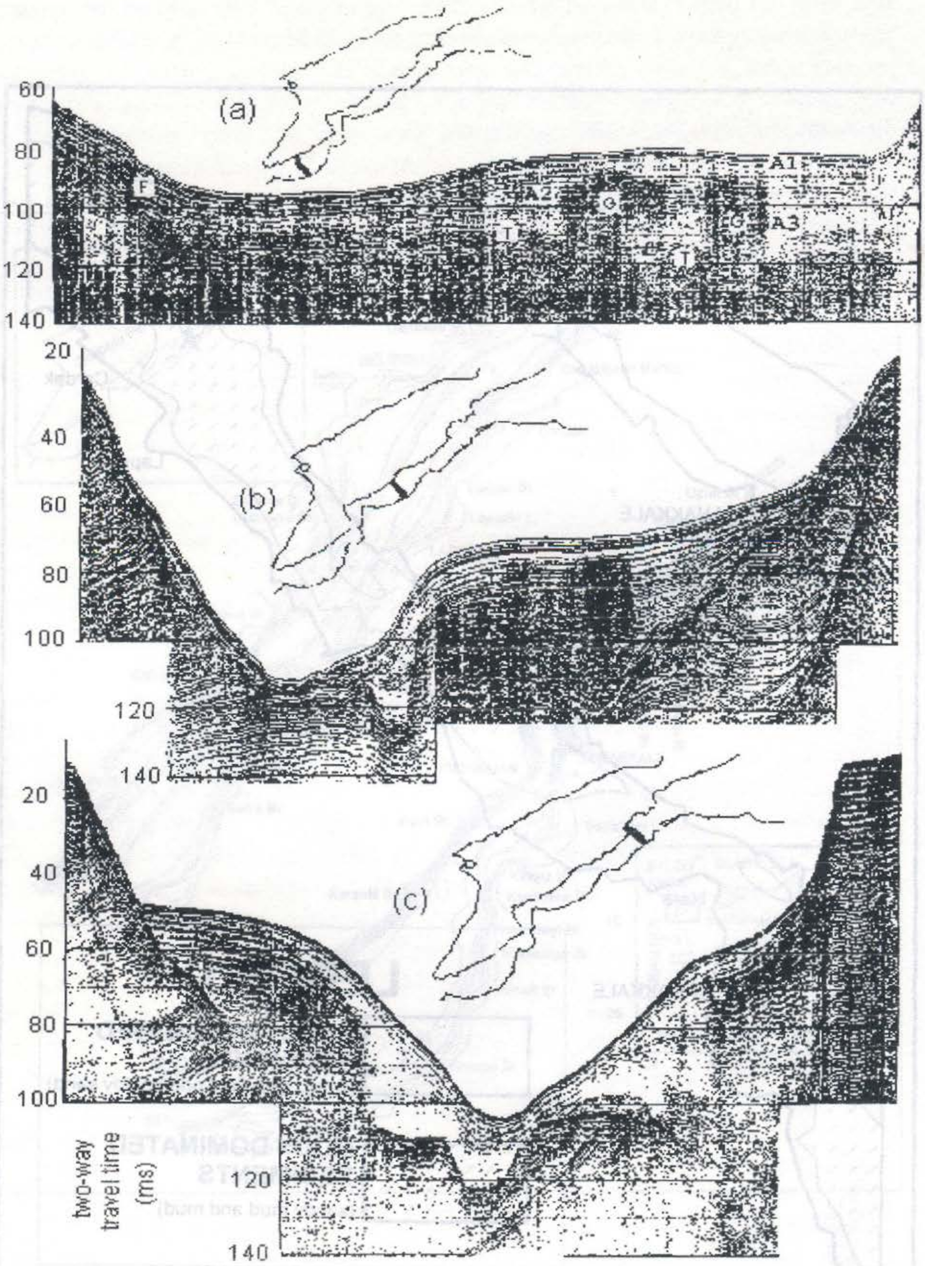

Figure 3. Sample high-resolution seismic records in the Dardanelles (after, Özturan, 1996). The left side of the profiles are close to Gelibolu Peninsula. A stands for prominent reflections in the late Quaternary sediments (unconsolidated and less consolidated deposits), T represents the top of the acoustic basement and F is fault. Gas-charged sediments (G) can be recognized easily in the actual sediments by their inherent dark colour and sudden lateral discontinuities.

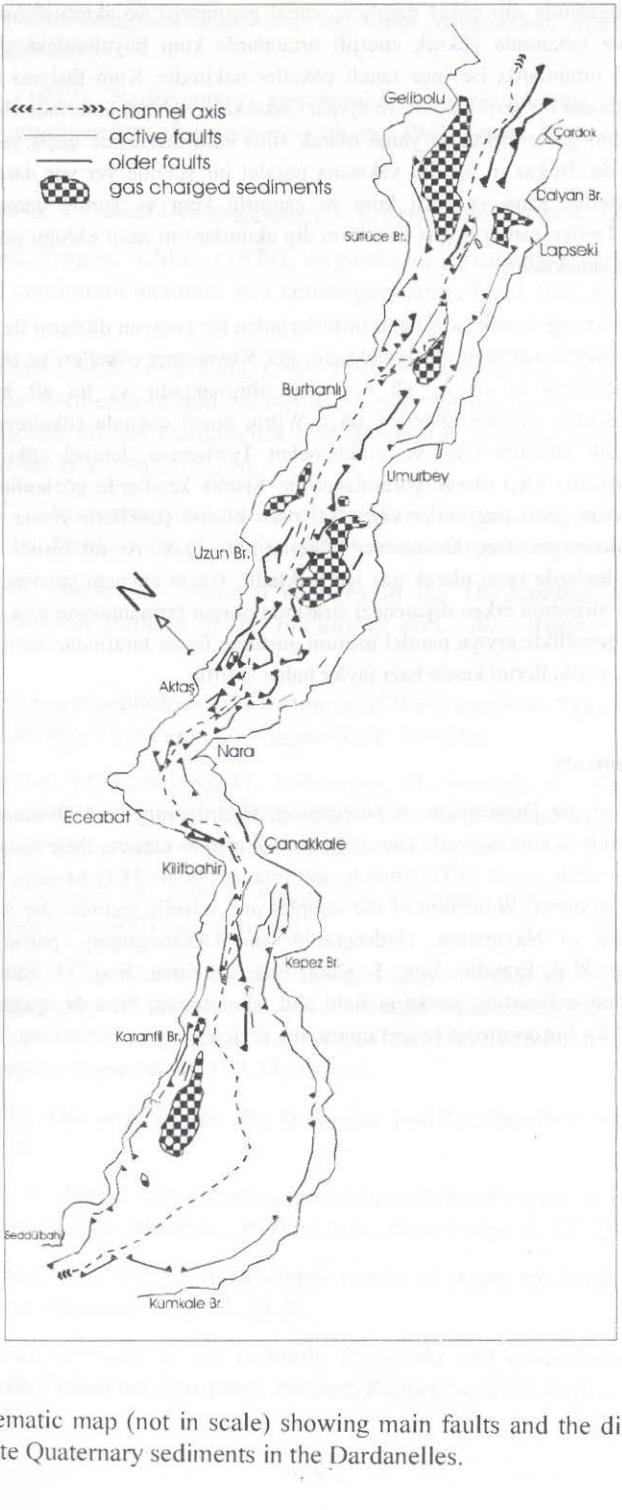

Figure 4. Schematic map (not in scale) showing main faults and the distribution of gas-charged late Quaternary sediments in the Dardanelles.

Özet

Çanakkale Boğazında dip çökel dağılımı, kanal geometrisi ve akıntı durumu etkileşiminin eseridir. Deniz tabanında yüksek enerjili ortamlarda kum boyutundaki çökeller, nispeten düşük enerjili ortamlarda ise ince taneli çökeller hakimdir. Kum fasiyesi her iki yakadaki kıyılar boyunca dar bir şerit halinde ve ayrıca Çanakkale ve Nara önlerinde Boğaz'ın daraldığı yerlerde dağılım göstermekte ve yanal olarak siltli kum fasiyesine geçiş yapmaktadır. Siltli kum fasiyesi de, Boğaz'ın her iki yakasına paralel bir şekilde yer yer daralıp genişleyerek devam etmektedir. Kum ve siltli kum su çamurlu kum ve kumlu çamura tedrici geçiş yapmaktadır. Terijen çamur boğaz kanalının dip akıntılarının zayıf olduğu geniş ve derin olan bölümünü kaplamaktadır.

Boğaz'da yapılan sığ sismik çalışmalar birbirlerinden bir erozyon düzlemi ile ayrılan iki temel sismik tortul birimin varlığını göstermektedir; geç Kuvaterner çökelleri ve akustik temel. Geç Kuvaterner çökelleri en az üç alt birimden oluşmaktadır ve bu alt birimler Holosen transgresyon sonrası denizel çökelleri (A_1), Würm buzul çağında çökelmiş basen yönünde ilerleyen deltaik çökeller (A_2) ve muhtemelen Tyrrhenian denizel çökellerinden oluşan transgressif çökeller (A_3) olarak yorumlanabilir. Sismik kesitlerde gözlenilen akustik temel, boğaz kıyılarında geniş dağılımlar veren Miyosen klastik çökellerin deniz altındaki devamı olarak yorumlanmıştır. Geç Kuvaterner çökellerinin alttaki iki alt birimi boğaz kanalının genişlediği bölgelerde yerel olarak gaz içermektedir. Gazın kaynağı yeterince bilinmemesine rağmen A_3 alt biriminin erken diyajenezi sırasında oluşan fermantasyon reaksiyonları olabilir. Boğaz kanalı genellikle kıyıya paralel uzanım gösteren faylar tarafından kontrol edilmektedir. Geç Kuvaterner çökellerini kesen bazı faylar halen aktiftir.

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