J. Black Sea/Mediterranean Environment
Vol10: 5-20

New shallow seismic data from the southwestern Black Sea shelf; implications for recent sea-level fluctuations

Güneybatı Karadeniz şelf alanı üzerinde yeni sığ sismik veriler; son deniz seviyesi değişimleri

Bedri Alpar[1] and Valeri Gainanov[2]

[1] İstanbul University, Institute of Marine Sciences and Management
Vefa, 34116 İstanbul, Turkey

[2] Moscow State University, Moscow, Russia

Abstract

Shallow seismic profiles are used to image the stratigraphic setting in the southwestern Black Sea. Two unconformable main seismic units were detected in the sediments, which carry the effects of a major sea-level fall. The upper unit shows transgressive systems track deposits on an erosional unconformity. This marked surface extends ubiquitously all over the shelf, –100 to -110 m below the present sea level, and indicating the lowstand of sea level before the latest rise in the Black Sea (10-9 ka BP). The lower unit consists of two different formations; locally folded-faulted acoustically reflective strata and stacked prograded delta successions. The latter is divided into at least 4 distinct sub-units in a form of stacked delta successions deposited on the transgressed shelves of the Black Sea, which carry the effects of many minor short-lived sea-level variations.

Keywords: Black Sea, seismic stratigraphy, sea-level changes

Introduction

The present Black Sea forms a semi-stagnant basin with anoxic conditions below 200 m water depth, having area of 423,000 km^2, volume of 534,000 km^3, and maximum depth of 2,248 m. It has a gigantic catchment basin which exceeds by more than 5 times the area of the Black Sea basin itself. Its only connection to open seas is via two shallow (30 - 110 m) water passages, the straits of İstanbul and Çanakkale (geographical names); mostly mentioned as Bosphorus and Dardanelles in geology. The semi-enclosed water body of the Black Sea has been subjected to dramatic palaeoceanographic changes during the late Quaternary (Federov, 1971; Ross and Degens, 1974; Stanley and Blanpied, 1980; Aksu et al., 1999).

During glacial stages, lower world sea levels resulted in the loss of marine water input via the shallow Marmara Sea straits. Continued fresh water input via large Eurasian and Anatolian rivers transformed the Black Sea to a brackish water body during these times. Its last drowning happened in late Holocene. Its last transition from freshwater stage (Neoeuxine) to the modern marine stage is marked by a change in the benthic faunal assemblages and the onset of sapropel formation in the deep basin. However, its connection to the Mediterranean is still controversial. It may be mainly due to an establishment of a water passage along the Bosphorus or because of the plain global sea-level rise.

Flood Hypothesis: *Ryan and Pitman's theorize that the* Black Sea was a freshwater lake (Fig. 1) until it was flooded by the Marmara Sea about 7,100 years ago (Ryan et al., 1997; Ryan and Pitman, 1999). The level of the Marmara Sea rose to breach the Bosphorus and initiate a cascade into the Black Sea. Today's Black Sea was transformed when melting glaciers raised the level of the Mediterranean Sea, causing water to break its way through the Bosphorus. The turbulent water pouring into the Black Sea would have widened the surface of the sea by as much as a mile a day, submerging the original shoreline and any settlements under hundreds of feet of salt water.

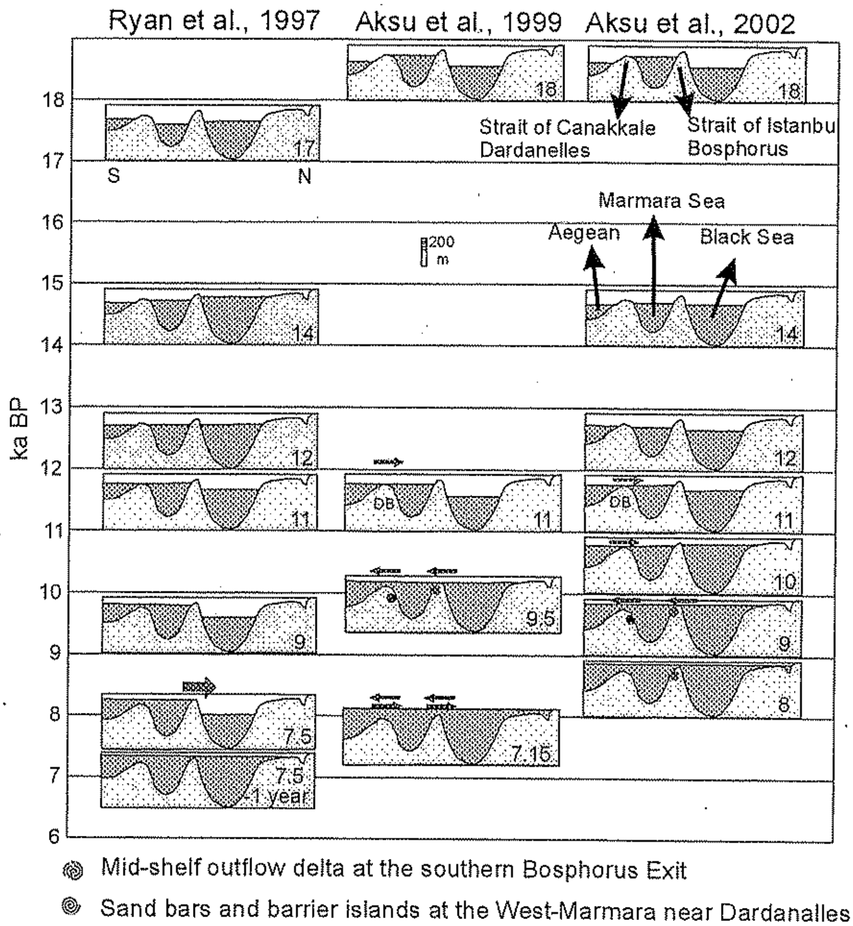

Figure 1. Conceptual diagrams of flow (Ryan et al., 1997) and outflow (Aksu et al. 1999; 2002) hypotheses.

<u>Outflow Hypothesis:</u> In recent years, Aksu and his friends proposed a new hypothesis. The Black Sea swelled to the level of the Bosphorus sill depth by 11 to 10 ka BP (Fig. 1). At that time, the Marmara Sea was about 20 m lower. The torrent of Black Sea waters influenced strongly the sediment and fossil characteristics across the Bosphorus and deposited a delta at the southern end of this strait. The age of this delta is 10 to 6.5 ka BP. Meanwhile, the Black Sea was refilled by northerly rivers (Aksu et al., 1999, 2002a,b: Hiscott et al., 2002).

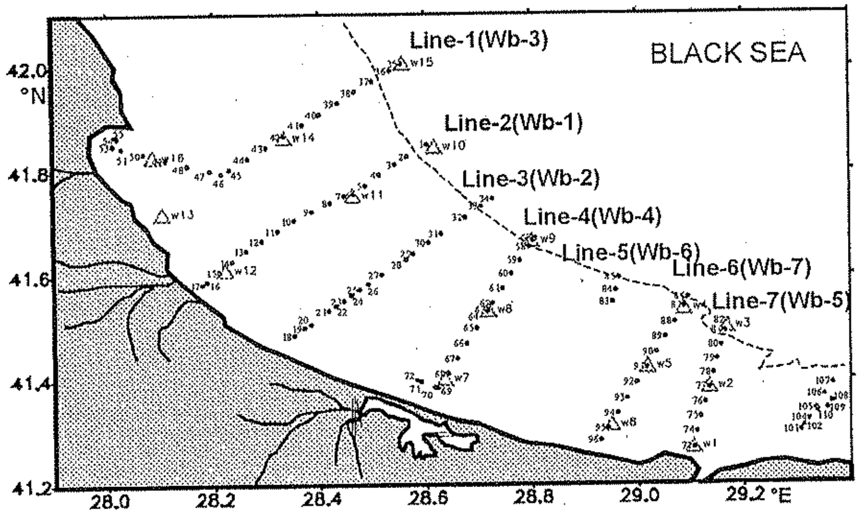

Figure 2. Location of the seismic lines.

Data Handling

In order to understand the sedimentary evolution and the late Pleistocene-Holocene sea-level changes, we carried out two cruises along the Turkish Black Sea shelf between the Bulgarian border and the Strait of İstanbul on board R/V Arar of the İstanbul University. The database consists of bottom samples and 250 km-line of high-resolution digital seismic profiles (Fig. 2). The reflection profiles were collected using a 1.25 kJ multielectrode sparker array (6 kV and 30 mF) and an 11-element 10 m-long surface-towed single-channel hydrophone streamer. The sparkarray and streamer were kept floating about a half metre below sea surface. The sampling interval was ¼ ms and the shots were fired every 2 seconds (~4.1 m). Return echoes were recorded for 250 ms (two-way-travel time, twt) and a part of preliminary raw sections were presented in a technical report by Ergin et al. (2003). Positioning was carried out by using an integrated GPS with an accuracy of ±20 meters.

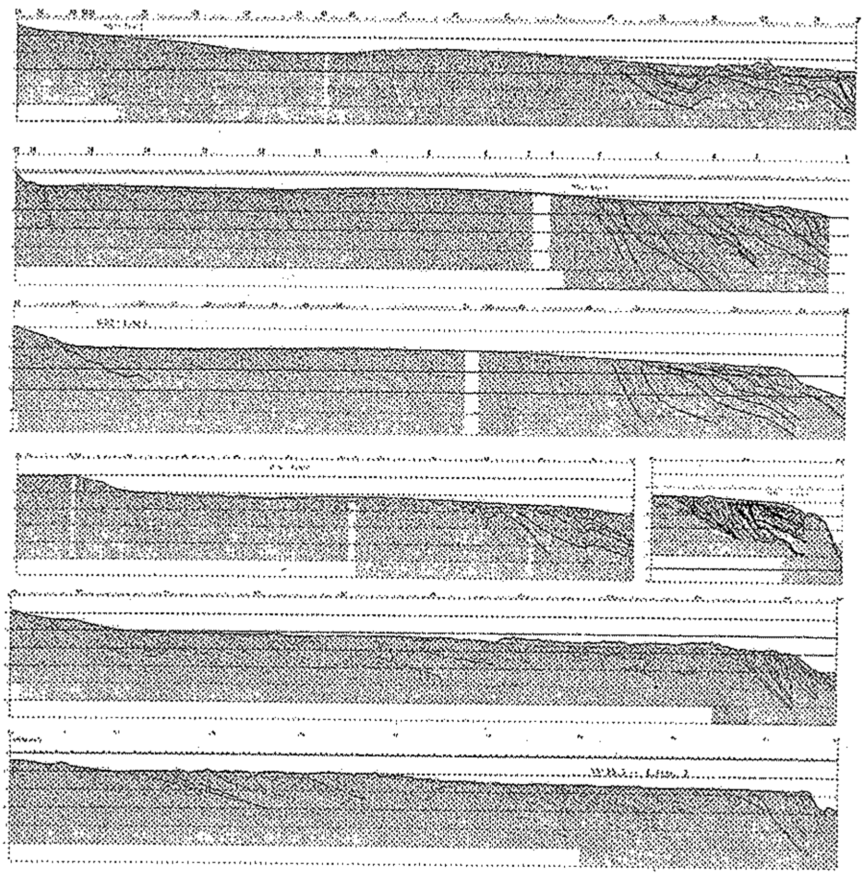

Figure 3. Interpretation of processed seismic profiles from west to east (top to bottom). See Fig. 2 for location.

The field parameters used and the modern data processing applied at a subsequent stage have provided important details on sedimentary deposits up to 150 m below the seafloor with a vertical resolution of 1 m (Fig. 3). Data processing methods such as trim-statics, filtering and multiple suppression have much contributed in better definition of the depositional sequences (Fig. 4). Even the signal distortions due to amplification were somewhat high; we have managed to decrease the multiples remarkably.

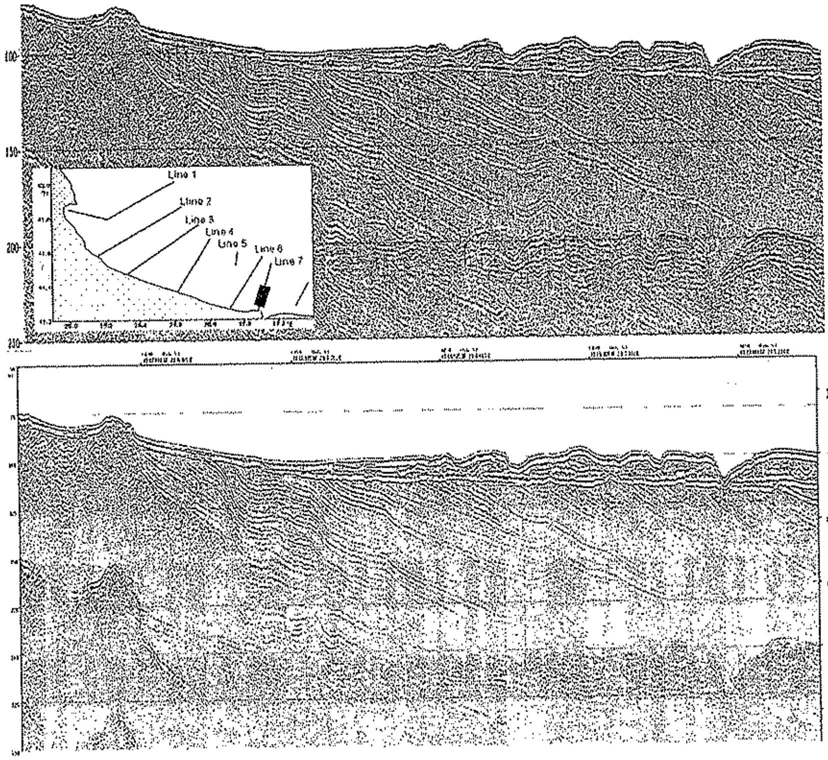

Figure 4. a) Trim-statics helped the elimination of the arrival time shifts caused by rough sea states. b) Multiple reflection attenuation was successful to suppress the seabottom multiples.

Results

We have outlined 2 main seismic units separated by a major self-crossing unconformity (Fig. 5). This eroded surface starts in a water depth of 50 m and extends down to the continental slope. The overall seismic picture may show an evidence of a significantly low sea level, up to 150 m below the present level, occurred possibly between the Pliocene and Quaternary periods.

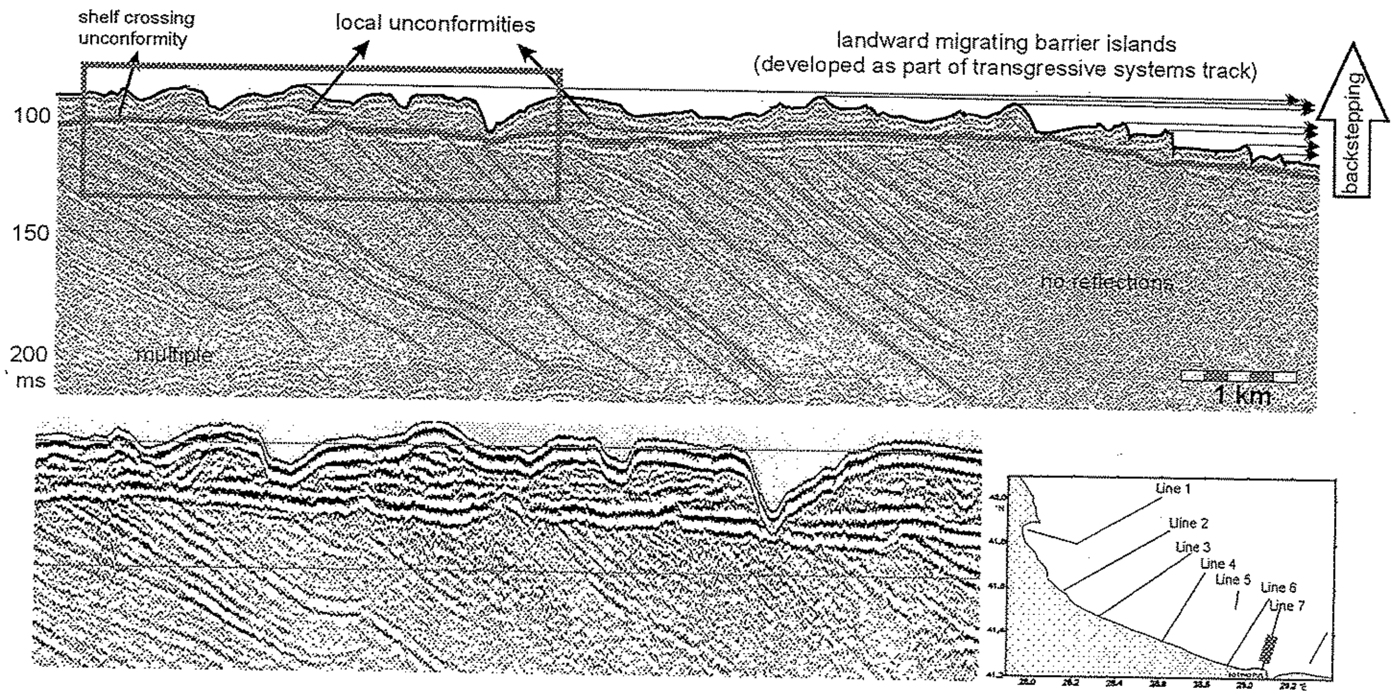

Figure 5. Seismic sections in detail. Prograding bedforms along the mid-shelf of the SW Black Sea.

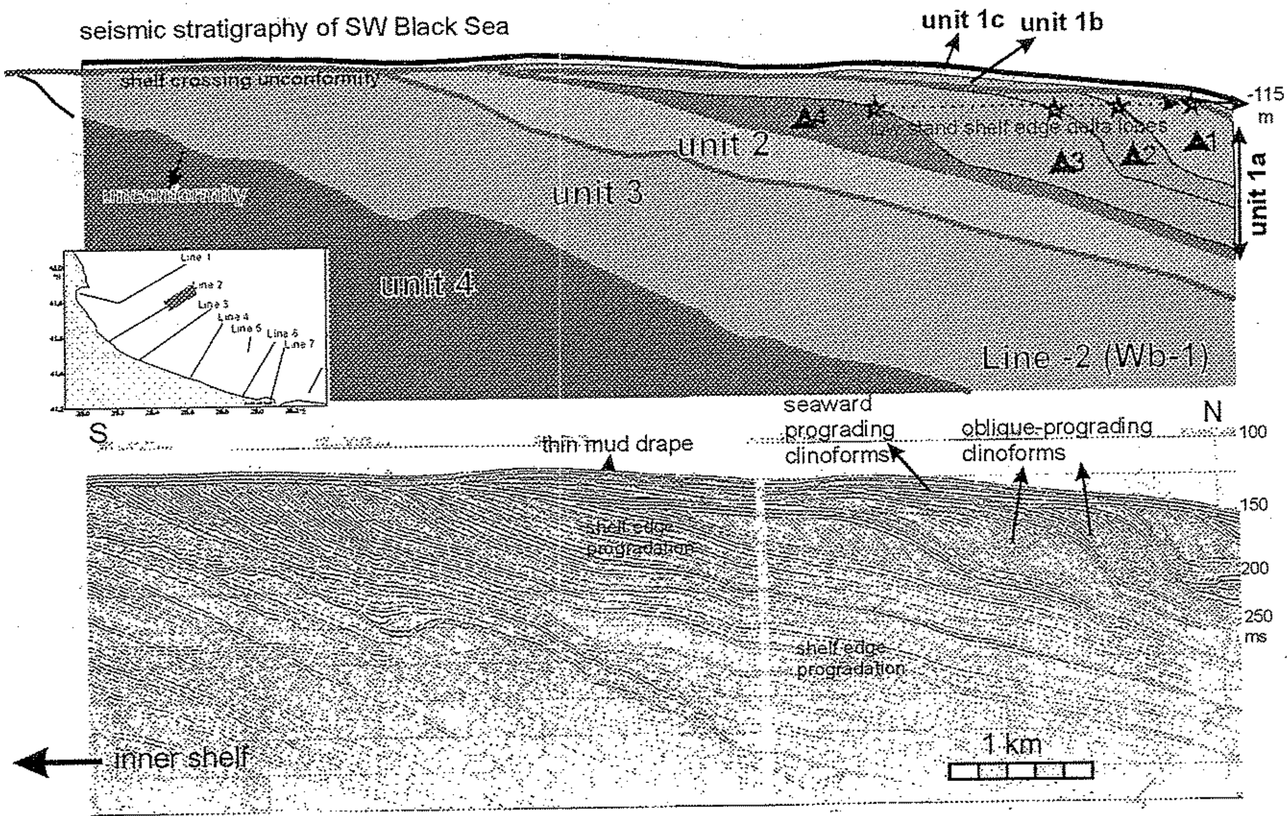

Figure 6. Seismic sections in detail. Seaward prograding clinoforms and low stand shelf edge delta lobes along the outer shelf.

The upper unit (late Pleistocene-Holocene): The upper unit takes place deeper than 50-60 m isobath. It shows varying cross sectional geometry (Fig. 3). It is 5-30 m thick over the mid- and inner shelf areas (Fig. 5). One reason may be that the sediments might be transported into the deep basins when the shelf was being subaerially exposed. Another reason may be the continuous sweep effects of the high-energy waves and long shore currents on the bottom sediments during the latest transgression. The upper unit shows transgressive systems track deposits. It is composed of parallel to sub-parallel reflectors, seaward prograding clinoforms, beach facieses, sand waves etc., which are gently inclined offshore.

It laterally passes into basinward prograding deltaic sequences at the outer shelf (Fig. 6). These are lowstand deltas deposited along the prograding shelf edge, corresponding to the ancient shoreline (Fig. 7). Their internal stratification (sigmoid, sigmoid-oblique and tangential oblique) shows that they are fluvial deltas. We distinguished 4 regressive sequences which may be correlated with the mid and late Pleistocene glaciations. They are separated by transgressive sections. The boundaries between delta successions are all unconformable. Their topset-to-foreset transitions show similar elevations. These sequences were partly bounded with the same erosional surface which occurs in a water depth of about 90-95 m to 110-120 m, with a gentle slope. The average depth to the top surfaces of the successive deltaic sequences is about -105 m below present sea level. These basinward prograded delta sequences indicate that the sediments were deposited during the sea-level lowstands during the late-Pleistocene glacial stages or neo-euxinian lake phase, and were possibly produced by the terrigenous load carried by the rivers.

On the basis of available borehole data in the area, the Quaternary sediments are thicker than 80 m. In the Karadeniz–1 borehole drilled at 79 m water depth, unconsolidated Quaternary muds (86 m thick) unconformably overlie the Pliocene mudstone (107 m). In the İğneada–1 borehole (85 m water depth), the Quaternary successions (140 m) unconformably overlie the Pliocene mudstone (284 m).

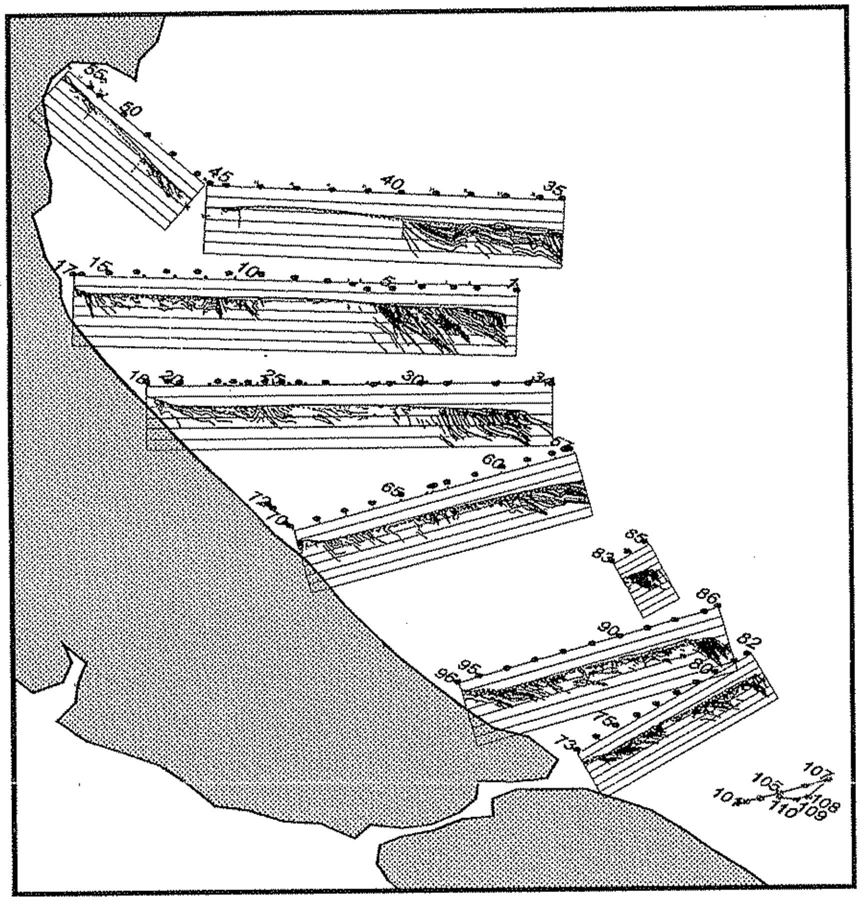

Figure 7. A fence diagram produced from the line drawings of seismic data. Geometrical arrangement of the structural elements and distribution of the stratigraphic units, which are inclined offshore, is evident.

The lower unit (Mesozoic to Pliocene): The lower unit, which is unconformably overlaid by upper unit, is divided into at least 4 distinct seismic sub-units which are bounded by erosional unconformities (Figs. 6 and 7). These units become younger basinward.

The oldest sub-unit strikes parallel to the coastline. It is made up of locally folded and acoustically reflective strata, mainly dipping offshore (Fig. 7). On the basis of onland geology of the basement in Thrace, we interpret these slightly folded deposits as Mesozoic strata. It forms the acoustical basement of the seismic sections along the inner and mid-shelf areas. Basinward, its upper boundary is truncated by the shelf, shelf-crossing angular unconformity and upper sub-unit.

Other younger sub-units (Eocene to Pliocene) form north-dipping clinoforms between the mid-shelf and shelf break (Fig. 6). Comparing to the oldest Mesozoic sub-unit, they exhibit less deformative deltaic or lacustrine sediments. The erosional surface between the units 2 and 3 is possibly associated with the post Chauda regression (600-1000 ka BP), in other words, separating the deposits of the early and the middle Pleistocene. All these sub-units were sub-aerially exposed during the late glaciation (25? - 9 ka BP).

Discussion and Conclusions

The shelf-edge deltas (Fig. 7) indicate that the sea level fell 4-5 times during the Quaternary period, as much as 120 m below present sea level. At those times, entire shelf region became subaerially exposed; seaward prograding low-stand deltas developed, as the rivers in Thrace extended to the shelf-edge. Similar elevations of the topset-to-foreset transitions of deltas show either little vertical movement of the shelf area or a rapid deltaic development.

On the mid-shelf area, transgressive systems track deposits (back-stepping sand waves, barrier island, beach deposits) are dominant (Figs. 3-6). It is hard to believe that such sort of shore-parallel sequences could be formed during a catastrophic sea-level rise (Flood Hypothesis postulated by Ryan and Pitman, 1997). These sequences should be associated with a rapid post-glacial fresh water transgression of the Black Sea (11-12 ka BP). This idea implies that the Black Sea related sediments should be looked for in its connected marine realms.

Seismic data show some Black Sea related sediment fills in the Bosphorus which was formed in the Quaternary by incision of a river valley into the basement rocks of Palaeozoic to Upper Cretaceous age and at its Marmara Sea exit (Alavi et al., 1989). The Quaternary fill in the strait is mainly made up of two different facies

(Kerey et al., 2001). Because of meandering depositions and removal of sedimentary layers due to severe erosional processes, these interstratified, mainly sandy and clayey associations with shelly fragments show varying thickness along the strait. In such a sense, unplanned and local studies of the mixed units in the strait may not be sufficient to define the depositional environments along the strait and to explain the Mediterranean-Black Sea connections in a radical sense. There are well-known deltas placed between 40-65 m isobaths to south of the strait (Fig. 8). They give moderate dipping clinoforms passing distally to seaward-converging continuous reflections. The latest delta is interpreted due to persistent Black Sea outflow to the Marmara Sea 10-9 ka BP (Hiscott et al., 2002).

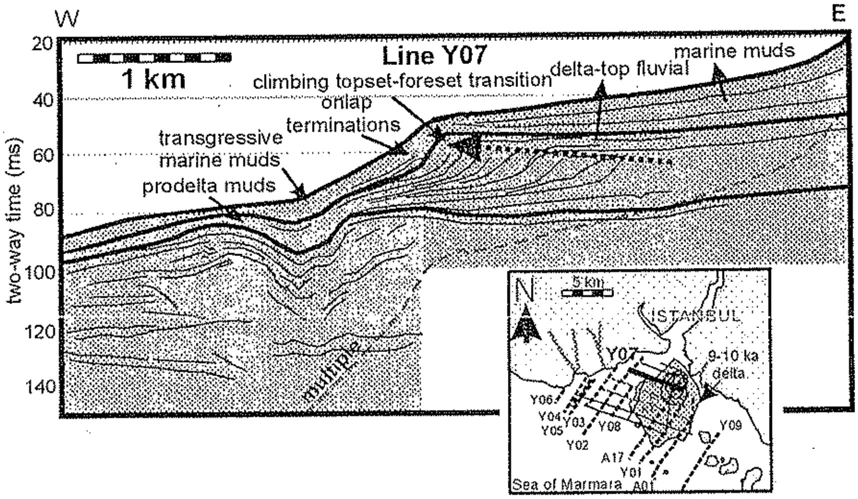

Figure 8. The Kadıköy submarine delta is placed around 60-80 ms bmsl to south of the Strait of İstanbul (modified from Hiscott et al., 2002 on the basis of the seismic data obtained by the first author).

Finally, some clues are the west-directed bed-forms and associated barrier islands at the entrance to the Strait of Çanakkale as defined by Aksu et al. (1999). They drowned by rapid transgression. This implies a vigorous unidirectional flow westward into the Aegean Sea through a river along the Dardanelles. Vigorous outflow from the Marmara Sea into the Aegean decreased in intensity after about 7 ka BP, and water levels reached their present height by about 3 ka BP (Stanley and Blanpied, 1980).

An age (i.e. 5.3 ka BP) of the interface between lower and upper sediment fill in the Bosphorus represents the arrival time of the saline Med-water reached into the area, not the onset of Black Sea outflow. Therefore this young discontinuity could not be against the Outflow Hypothesis. Continued sea-level rise and the reduction in Black Sea outflow led to the establishment of a permanent two-way flow across the strait at that time. Uppermost sediments in the strait indicate an environment above the wave base and starting this two-way flow regime.

The delta at the southern exit of the Strait of İstanbul and the transparent unit overlaying the west-directed bedforms at the entrance to the Strait of Çanakkale may be fed by the accentuated Black Sea outflows, which are also in favour of the Outflow Hypothesis.

The multi-proxy core data of Aksu et al. (2002a, b) do not support the Ryan and Pitman's hypothesis. They showed that at about 10.5 ka the Black Sea rose to the breach depth of the Bosphorus and flowed into the Marmara Sea, promoting the deposition of sapropel layers in the Marmara and Aegean seas.

There are also other clues, such as sapropel layers, palynological data etc., which support the Outflow Hypothesis. For example, topmost sapropel layer was deposited in the Marmara Sea between 10.5 to 6 ka BP. However, for such estimations, one should not forget that the inland basins are not always entirely fresh. Paleo oceanographic conditions should not be underestimated. In addition, the Flood Hypothesis requires that Eastern Europe was dry prior to 7.5 ka BP. However, on the basis of palynological data in the region, a wetter climate started earlier, e.g. 12 ka BP.

In conclusion, our very high-quality and high-resolution processed seismic data supports the Outflow Hypothesis postulated by Aksu et al. (1999). A final attempt may be to correlate the seismic sequences at different marine environments (Fig. 9) with available borehole data and with a composite global oxygen isotope curve. So an Upper Quaternary relative sea-level curve for this area could be established.

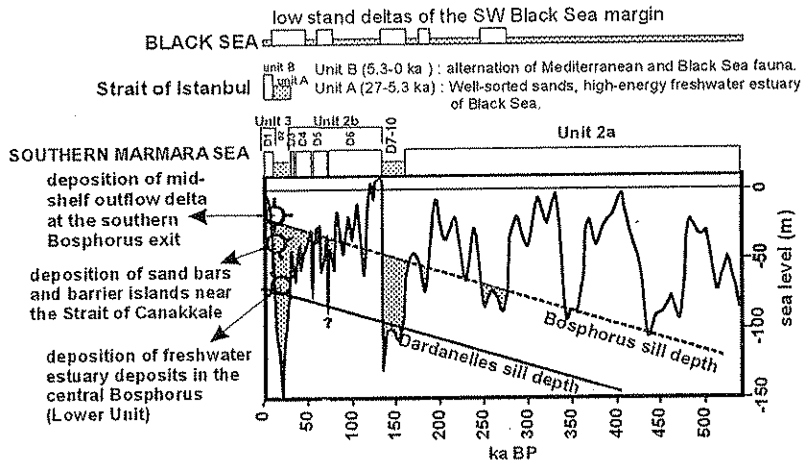

Figure 9. Correlation of seismic units at different marine realms. The approximate position of the Bosphorus ridge (i.e. SW Black Sea shelves above this level) during the late Pleistocene period and its relation with the eustatic sea-level curve is assumed on the basis of tectonic uplift rate at the Marmara Sea region (0.24 mm/year for Dardanelles and 0.22 mm/year for Armutlu block, Yaltırak and Alpar, 2002). For seismic units, original depositional places were considered below the ascending sill depth.

Özet

Karadeniz kıyı oynamalarının çokça tartışıldığı bir ortamda, Trakya şelfi üzerinde toplanan sığ sismik veriler ile stratigrafik yapı araştırılmıştır. Esas amaç, mitoloji masalları yazmak değil, ancak çok disiplinli araştırmalara bilimsel ve modern veri işlem teknikleri kullanılarak işlenmiş yeni veriler sunmaktır. Bu veriler, Aksu ve arkadaşları tarafından öne sürülen ve tüm şelf alanını kapsayan depolanma sistemlerini desteklemektedir. Ek olarak, üst ve alt temel birimler içerisindeki kısa süreli deniz seviyesi değişimlerini gösteren alt sismik birimler detaylı bir şekilde ayırt edilmiştir. Elde edilen jeofizik sonuçlar, Marmara Bölgesinin değişik yerlerinde belirlenen düşey kabuk hareket hızları üzerine inşa edilen varsayımsal fakat olası bir tektonik yükselme modeli de dikkate alınarak, Marmara Denizi ve İstanbul Boğazındaki örnek sismik birimler ile karşılaştırılmıştır.

Acknowledgements

We are indebted to officers and crew of the R/V Arar without whom none of the data discussed here would be available. This work was supported by TÜBİTAK (Project 198Y083).

References

Aksu, A.E., Hiscott, R.N., and Yaşar, D. (1999). Oscillating Quaternary water levels of the Marmara Sea and vigorous outflow into the Aegean Sea from the Marmara Sea-Black Sea drainage corridor. *Marine Geology*, 153: 275-302.

Aksu, A.E., Hiscott, R.N., Yaşar, D., İşler, F.I. and Marsh, S. (2002a). Seismic stratigraphy of Late Quaternary deposits from the southwestern Black Sea shelf: evidence for non-catastrophic variations in sea-level during the last about 10,000 years. *Marine Geology*, 190: 61-94.

Aksu, A.E., Hiscott, R.N., Kaminski, M.A., Mudie, P.J. Gillespie, H., Abrajano T. and Yaşar, D. (2002b). Last glacial-Holocene paleoceanography of the Black Sea and Marmara Sea: stable isotopic, foraminiferal and coccolith evidence, *Marine Geology*, 190: 119-149.

Alavi, S.N., Okyar, M. and Timur, K. (1989). Late Quaternery sedimentation in the Strait of Bosphorus: High Resolution seismic profiling. *Marine Geology*, 89: 185-205.

Alpar, B., Yaltırak, C. and Gainanov, V. (2002). Seismic mapping on the Thrace shelf (SW Black Sea); implications for recent sea-level fluctuations, 3rd Balkan Geophysical Congress and Exhibition, 24-28 June 2002, Sofia, Bulgaria, Book of Abstracts, pp. 279-280.

Ergin, M., Keskin, Ş., Algan, O., Alpar, B., Ongan, D., Kırcı, E., Bayhan, E. and Temel, A. (2003). Güneybatı Karadeniz Kıta Sahanlığının Geç Kuvaterner Jeolojisi: Sedimantolojik, Sığ-Sismik Stratigrafik, Minerolojik ve Jeokimyasal Araştırmalar, Technical Report, TÜBİTAK Project 198Y083, 175p.

Federov, P.V. (1971). Postglacial transgression of the Black Sea. *International Geology Reviews*, 14: 160-164.

Hiscott, R.N., Aksu, A.E., Yaşar, D., Kaminski, M.A., Mudie, P.J., Kostylev, V.E., MacDonald, J.C., İşler, F.I. and Lord, A.R. (2002). Deltas south of the Bosphorus Strait record persistent Black Sea outflow to the Marmara Sea since ~10 ka. *Marine Geology*, 190: 95-118.

Kerey, R., Meriç, E., Tunoğlu, C., Kelling, G., Brenner, R.L. and Doğan, A.U. (2001). Black Sea - Marmara Sea Quaternary Connections: New

Data from the Bosporus, İstanbul, Turkey. International Association of Sedimentologists, IAS 2001, 21st Meeting, 3-5 September 2001, Abstracts, Ulrich G. Wortmann & Hanspeter Funk (Editors), 95.

Ross, D.A. and Degens, E.T. (1974). Recent sediments of the Black Sea. In: E. T. Degens and D. A. Ross (Eds.), The Black Sea - Geology, Chemistry, and Biology. The American Association of Petroleum Geologists, Memoir 20, Tulsa, Oklahama, pp. 183-189.

Ryan, W.B.F., Pitman, W.C.,III, Major, C.O., Shimkus, K., Maskalenko, V., Jones, G.A., Dimitrov, P., Görür, N., Sakınç, M. and Yüce, H. (1997). An abrupt drowning of the Black Sea shelf. *Marine Geology*, 138: 119-126.

Ryan, W.B.F. and Pitman III, W.C. (1999). Noah's Flood: the New Scientific Discoveries about Events that Changed History. Simon and Schuster, New York, 319 pp.

Stanley, D.J. and Blanpied, C. (1980). Late Quaternary water exchange between the eastern Mediterranean and the Black Sea. *Nature*, 285: 537-541.

Yaltırak, C. and Alpar, B. (2002). Evolution of the NAF Middle segment and shallow seismic investigation of the Southestern Sea of Marmara (Gemlik Bay). *Marine Geology*, 190: 307-327.

Received 18.10.2002
Accepted 18.03.2003