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LATE QUATERNARY STRATIGRAPHY AND MORPHOTECTONICS OF GEMLIK GULF, SEA OF MARMARA

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTETİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

GEMLİK KÖRFEZİ'NİN (MARMARA DENİZİ) GEÇ KUVATERNER STRATİGRAFİSİ VE MORFOTEKTONİĞİ

YÜKSEK LİSANS TEZİ

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Hikmat Babayev, a **M.Sc.** student of ITU **Graduate School of Geological Engineering** with a student ID of **505131321**, successfully defended the **thesis** entitled "**LATE QUATERNARY STRATIGRAPHY AND MORPHOTECTONICS OF GEMLIK GULF, SEA OF MARMARA"** which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family and my colleagues,

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August 2015 Hikmat Babayev
Geological Engineer

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ABBREVIATIONS

AF	: Armutlu Fault
AMS	: Accelerator Mass Spectrometry
ARC	: Acoustic Rolling Contact
B/A	: Bølling-Allerød
BP	: Before Present
EMCOL	: Eastern Mediterranean Centre for Oceanography and Limnology
GF	: Gençali Fault
GmF	: Gemlik Fault
H1	: Heinrich event 1
KA	: Kilo Annum
KF	: Kocadere Fault
LGM	: Late Glacial Maximum
MBSF	: Meter Below Sea Floor
MF	: Mudanya fault
MIS 2	: Marine Isotope Stage 2
MS	: Magnetic Susceptibility
MSCL	: Multi Sensor Core Logger
NAF	: North Anatolian Fault
NAFMS	: North Anatolian Fault Main Strand
NAFZ	: North Anatolian Fault Zone
NCR	: Non-Contact Electric Resistivity
NS	: North-South
SI	: Magnetic Susceptibility Unit
SoI	: Strait of İstanbul
S/N	: Signal to Noise
TPAO	: Turkish Petroleum Company
TUBITAK	: Scientific and Technical Research Council of Turkey
WF	: Western Fault
YD	: Younger Dryas

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LATE QUATERNARY STRATIGRAPHY AND MORPHOTECTONICS OF GEMLIK GULF, SEA OF MARMARA

SUMMARY

Gulf of Gemlik is an east-west oriented marine inlet with a maximum depth of 113 m in the south-eastern part of the Sea of Marmara. It is located on the middle branch of the North Anatolian Fault Zone (NAFZ).

In this study, the Quaternary paleoceanographic evolution and morphotectonics of the Gemlik Gulf are investigated using high resolution seismic, bathymetric and core stratigraphic data obtained during the various cruises of R/V Urania.

The studied Core M13-08 was recovered from a depth of 73.5 m from the northern shelf of Gemlik Gulf during RV Urania 2013 expedition. The 6.70 m long core was analyzed for magnetic susceptibility (MS) using Multi Sensor Core Logger (MSCL) and dated using Accelerator Mass Spectrometry (AMS) radiocarbon analysis.

According to ^{14}C dates and fossil content, Core M13-08 covers the last 12.6 uncalibrated ka BP (all radiocarbon ages in this thesis are in uncalibrated ^{14}C years), and includes two litho-stratigraphic units: an upper marine unit (Unit L1) and the lower lacustrine-deltaic unit (Unit L2). As a result of seismic to core correlation, Unit L1 and L2 correspond to seismic stratigraphic units S1 and S2. In Core M13-08, Unit L2 consists of dark gray, well-sorted medium sand, with fresh to brackish water bivalves and high MS due to high concentrations of magnetic minerals. The upper-most part of the Unit L2 is composed of gray, well-sorted sand with normal grading that is well consistent with the decreasing MS value towards to the boundary between Unit L2 to L1. This stratigraphic boundary is associated with an unconformity surface that separate the lacustrine to marine units in the studied core. The marine unit L1 is a green mud with marine fossils (bivalves and foraminifera) showing a fining upward sequence. The highest MS value in Unit L1 is associated with a thin layer consisting brownish green banded clay and the overlaying dark to light brown green clayey mud.

As a result of detailed seismic stratigraphic analysis, four main seismic stratigraphic units have been differentiated in the seismic profiles from the Gemlik Gulf. We called these stratigraphic units in the profiles as units S4, S3, S2, and S1 from the bottom to top. The youngest lowstand unconformity surface is represented by reflector surface (marked as red) that is a shelf-crossing unconformity characterized by subtle erosional truncation of the underlying older units in shallow (<-75 m) part of the Gulf. Ages of the seismic stratigraphic can be estimated by core-to-seismic correlations, using radiocarbon chronology of Core M13-08 and previously published chronostratigraphic information of Core GE-124 from the eastern part of the Gulf.

Unit S1 is characterized by horizontal and continuous, acoustically strong internal reflectors. It extensively covers the younger units. The base of the Unit S1 separates the upper marine and the lower lacustrine sediments in the Gemlik Gulf. This unit was deposited during the last 10.6 ka BP

Unit S2 is a bedded mud drape with acoustically moderate to low internal reflectors in the basin (>-75 m) and progradational clinoforms with acoustically stronger internal reflectors on the shelf-edge, where the prograding nature of this unit implies regressive deposition. The unit is truncated by the main unconformity surface in the profiles. This unit was deposited during 13.9-10.6 ka BP.

Unit S3 includes highly-reflective, conformable and moderately continuous internal reflectors. On the shelf, Unit S3 consists of clinoforms and deltaic foresets with acoustically strong internal reflectors. The unit characterizes a deltaic system located on eastern and northern shelf margins of the Gulf. In the deep basin (> ~ -75 m), Unit S3 shows transition to horizontal and parallel-bedded sediments. This unit was deposited during 15.8-13.9 ka BP.

Unit S4 is the oldest sedimentary unit recorded in the high resolution seismic profiles. On the western part of the gulf, this unit consists of highly-reflective parallel bedded internal reflectors. Towards the eastern part of the basin, where the gulf begins to deepen below -75 m, Unit S4 comprises mound-shaped sediments with wavy internal reflectors that are truncated or separated by erosional gullies formed on a reflector (marked as blue on the interpreted seismic lines). This unit is older than 15.8 ka BP.

Using the high resolution seismic profiles and the updated bathymetric map, we produced a new fault map of the Gulf. This map shows that the main active faults in the area are roughly E-W oriented İmralı, Gemlik, Kocadere, Gençali dextral transform faults. The Armutlu, Kocadere and Gemlik faults have a clear normal component with a maximum vertical offset of 6.2 m, 8.53 and 6.97 m, respectively. The fault geometry suggests that the deep Burgaz Basin of the Gemlik Gulf has evolved as a pull-apart basin between the Armutlu and Kocadere transform faults. The transpression by the Gemlik and Western Faults resulted in the Gemlik Uplift (Rise) in the east the Gemlik sill in the west of Gemlik Gulf.

The core and seismic stratigraphic analyses show that the Gulf was a lacustrine environment prior to 10.6 ka BP, with lacustrine shelf-edge delta developments in the north and east during 15.8-13.9 ka BP. There was lowering of the lake level and erosion during part of the Bølling-Allerød and Younger Dryas, which was followed by the marine transgression at 10.6 ka BP, about one thousand years later than the first entry of Mediterranean waters in the Sea of Marmara. The reason for the 1 ka delay is the -55 m sill to the west of the Gemlik Gulf.

It is recommended that this study is extended to the west of the Gulf, using similar techniques of multi-beam bathymetric mapping, high resolution seismic reflection profiling and core analysis. The seismic reflection data is especially needed for the near shore areas along the southern shoreline of Gemlik Gulf.

GEMLİK KÖRFEZİ'NİN (MARMARA DENİZİ) GEÇ KUVATERNER STRATİGRAFİSİ VE MORFOTEKTONİĞİ

ÖZET

Gemlik Körfezi, Marmara Denizi'nin güneydoğusunda doğu-batı yönünde uzanan ve derinliği -113 m'ye ulaşan bir deniz alanıdır. Körfezin uzunluğunun 36 km ve genişliğinin 11 km olduğu bilinmektedir. Bunun yanında, merkezi kısmı oval şekilli bir depresyon bölgesidir. Gemlik Körfezi 349 km^2'lik bir alanı kaplar ve körfezin batısında bulunan -50 m eşiği ile kuzey şelfine bağlanır. Körfez, Kuzey Anadolu Fay zonunun orta kolu üzerinde yer almaktadır.

Bu çalışmada değişik R/V Urania seferlerinde toplanmış olan yüksek çözünürlüklü sismik, batimetrik veriler ve karot verileri kullanılarak, Gemlik Körfezi'nin geç Kuvaterner morfotektonik ve paleoşinografik evrimi araştırılmıştır. Fay haritası ve morfotektonik çalışmalar için Gemlik Körfezi'ni kapsayan 114 sismik profil analiz edilmiştir. Körfezin geç Pleistosen-Holosen paleoşinografik evriminin yorumlanması için 114 sismik profilden 29 adedi sismik stratigrafik analizin öğrenilmesi amacı ile kullanılmıştır.

M13-08 karotu, R/V Urania'nın 2013 seferi sırasında Gemlik Körfezi'nin kuzeyinden 73.5m su derinliğinden alınmıştır. 6.7m uzunluğundaki karotun manyetik duyarlılık (MS) analizleri çok senörlü karot tarayıcı (MSCL) ile; tarihlendirilmesi ise hızlandırılmış kütle spektrometresi (AMS) radyokarbon analizleri ile yapılmıştır. Radyokarbon analizleri, deniz tabanının altındaki 238 cm, 144,5 cm, 258 cm, 564,5 cm, 652 cm derinliklerinden alınan fosiller üzerinde yapılmıştr. Radyokarbon tarihlendirmesine göre son 12.6 kyılı kapsayan karot, fosil içeriği ve litolojisine göre, üstte denizel olan L1 ve altta gölsel-deltaik olan L2 birimlerinden oluşmaktadır.

Karotta L1 ve L2 birimleri, sismik profillerdeki S1 ve S2 sismik stratigrafik birimleri ile eşleştirilmiştir. Karot M13-08'de L2 Birimi; tatlı-acısu bivalvleri içeren, manyetik duyarlılığı (MS) yüksek, gri, iyi boylanmış orta taneli kumdan oluşmaktadır. Birimin üst kısmı, normal derecelenme gösteren iyi boylanmış gri kumdur ve Birim 2'den Birim 1 sınırına yaklaştıkça MS değerinde düşüş gözlenmektedir. Birim1-Birim2 sınırı, denizel ve gölsel sedimanlar arasındaki uyumsuzluğu göstermektedir. Birim 1, denizel fosiller (bivalve ve foraminifer) içeren ve üste doğru tane boyunda incelme gösteren yeşil çamurdur. Birimde en yüksek MS değerleri içeren kısım; ince, kahverengi, bantlı yeşil bir killi çamur ile üzerindeki koyu ve açık kahverengi yeşil killi çamurdur.

Ayrıntılı sismik stratigrafik analizler ile Gemlik Körfezi'nde, alttan üste doğru sismik stratigrafik Birim S4, Birim S3, Birim S2 ve Birim S1 olarak adlandırılan dört sismik stratigrafik birim ayırt edilmiştir. Birim 1 ve Birim 2 arasındaki yüzey (kırmızı yansıtıcı) -75 m'den sığ alanlarda daha yaşlı birimleri kesen, şelf-kat eden bir uyumsuzluk yüzeyidir. Sismik stratigrafik birimlerin yaşları, M13-08 karotu ile

Körfez doğusundan alınmış GE-124 karotunda daha önce yayınlanmış radyokarbon stratigrafi verileri ile yaşlandırılabilmektedir.

Sismik stratigrafik Birim S1 yatay ve devamlı akustik yansıma yüzeyleri içermektedir. Birim yaşlı birimleri örtmekte olup, tabanı Gemlik Körfezi'nde bulunan, üstteki deniz ve alttaki göl birimlerini birbirinden ayırmaktadır. Sismik Birim 1 Holosen yaşlı çökelleri nitelendirmekte olup, bu birimin kalınlığının kıyıya doğru 3m ile 19.5m arasında değişimi havza boyunca izlenmektedir. Birim son 10.6 kyılda (kalibre edilmemiş ^{14}C) çökelmiştir. Profillerde S1 birimi yerel Körfez paleo-vadilerini doldurmaktadır.

Sismik stratigrafik Birim S2, -75 m'den daha derinde akustik olarak orta - düşük seviyeli iç yansıma ile karakterize olan tabakalanmış çamur örtüsünü (mud drape); şelf kenarında ilerleyen yüksek akustik yansımalı klinoformları karakterize etmektedir. Birim S2'nin kalınlığı sismik profillerinde 2m ve 5m arasında değişmektedir. Genel olarak, sismik Birim S2 göl-akarsu fasiyesi temsil eden bir birim olarak yorumlanmaktadır. Bu birimin kıyı kenarlarındaki ilerlemeye ilişkin yapısı profillerde ana uyumsuzluk yüzeyi tarafından kesiliyor olması, birimin regresif özelliğini göstermektedir. Birim Günümüzden Önce (G.Ö.) 13.9-10.6 kyılları arasında çökelmiştir. Gemlik Körfezinin profillerinde, berm sedimanları kırmızı reflektör ile kapanması ve bunun Birim S2'de 10.6 kyılına takamül etmesi gözlenmektedir. Berm çökellerinin yarandığı su derinliği -63 m ve -68 m arasında değişiyor. Bu değişim aynı zamanda 10.6 kyıl önce deniz transgresyonunun Gemlik Körfezi'ndeki su seviyesinin belirten bu değişimi o zamanki paleo-kıyı çizelgesinde su seviyyesi değişiminin sabit olarak izlendiyinin göstergesidir.

Sismik stratigrafik Birim S3, yüksek sismik yansımalı, uyumlu ve orta derecede devamlı iç yansıtıcılar içermektedir. Şelf alanlarında, yüksek akustik iç yansıtıcılı klinoform yapıları ve havzanın doğu ve kuzey kıyılarında delta çökelimini temsil etmektedir. Birim, Körfezin derin kısmında (>-75m) yatay ve paralel tabakalı çökellerden oluşmuştur. Birim G.Ö. 15.8-13.9 kyılları arasında çökelmiştir.

Sismik stratigrafik Birim S4, sismik kesitlerde görülebilen en yaşlı çökel birimdir. Körfezin batı kısmında birim yüksek yansıtıcılı, paralel tabakalıdır. Ancak, havzanın doğu kısmına doğru, -75 m'den daha derinlerde birim erozyonel vadicikler tarafından kesilen, dalgalı iç yansımalı, tümsekli (moundegd) bir çökel yapısı sergiler. Birim 15.8 kyıldan daha yaşlıdır.

Yüksek çözünürlüklü sismik ve yenilenmiş batimetri verileri kullanılarak Gemlik Körfezi'nin ayrıntılı bir fay haritası oluşturulmuştur. Bu harita körfezde genel olarak doğu-batı yönlü aktif fayların ve KB-GD yönlü gerilmeli ikincil fayların varlığını göstermektedir. Körfezdeki ana faylar normal birleşeni de olan sağ-yanal transform fay özelliğindeki Armutlu, Gemlik Fayı, Kocadere ve Gençali faylarıdır. Armutlu, Kocadere ve Gemlik faylarının en yüksek düşey atımları sırası ile 6.20 m, 8.53 ve 6.97 m'dir. Fay geometrisi, körfezin Armutlu ve Gençali fayları arasında bir çek-ayır havza olarak açıldığını göstermektedir. Gemlik ve Batı faylarının sıkışma tektoniği sırası ile doğuda Gemlik Yükseltisi ve batıda Gemlik eşiğini oluşturmuştur.

Karot ve sismik stratigrafik analizler, körfezin 10.6 kyıl öncesinde Marmara'nın diğer kısmlarından izole edilmiş bir göl olduğunu ve G.Ö. 15.8-13.9 kyılları arasında bu gölün kuzey ve doğusunda şelf kenarlarında deltaların oluştuğunu göstermektedir. Bϕlling-Allerϕd döneminin bir bölümü ile Younger Dryas dönemlerinde göl seviyesinin G.Ö. 10.6 k yıldaki deniz transgresyonuna kadar bir miktar alçaldığı görülmektedir. Gemlik Körfezi, Akdeniz suları tarafından Marmara Denizi'nin derin havzaları ve güney şelfine göre yaklaşık bin yıl daha geç istila edilmiştir. Bu bin yıllık gecikme, körfezin batısında yer alan -55 m'deki eşik nedeniyledir.

Bu çalışma, ileride batimetrik haritalama, yüksek çözünürlüklü sismik profilleri ve karot verileri üzerinde benzer teknikler kullanılarak, Körfez'in batısına kadar uzatılabilir. Gemlik Körfezi'nin güney kıyısı boyunca kıyıya yakın bölgelerde sismik verilerin alınması gereklidir.

1. INTODUCTION

1.1 Objectives and Scope of the Study

The Sea of Marmara is in a transitional position between the Black Sea and the Mediterranean (Aegean) Sea, to which it is connected by the Istanbul and Çanakkale straits having sill depth of -35 m and -65 m, respectively. It consists of an up to 30 km wide northern shelf, 45 km wide southern shelf and up to 1275 m deep three deep basins, separated by NE-trending submarine highs (Fig.1.1).

It also has narrow E-W extending marine inlets such as the İzmit and Gemlik gulfs. The Sea of Marmara is tectonically very active, being located on the northern and middle strand of the North Anatolian Fault (NAF) zone.

In the last two decades, and particularly since the 1999 earthquakes, there has been a significant increase in interest and awareness of earthquake hazard and related studies in the Sea of Marmara, with numerous international projects. The last one is the MARSITE project funded by the European Community as part of the long-term monitoring experiment in geologically active regions of Europe prone to natural hazards in the supersite concept program.

This thesis project has been carried out in the context of MARSITE project at the İTU-EMCOL (Eastearn Mediterranean Centre for Oceanography and Limnology) office. Our main aim is to investigate the late Pleistocene-Holocene morphotectonic and paleoceanographic evolution of the Gemlik Gulf that is located on the middle strand of the North Anatolian Fault (NAF) in the southeastern Sea of Marmara. The middle strand is less active than the northern strand that extends through the İzmit Gulf in the east and connects with Ganos Fault in the west (Fig.1.1). For this reason, most of the previous studies were concentrated on the most active northern strand and more detailed work is needed on the middle strand (e.g., Yaltırak et al., 2002; Kuşçu et al., 2007; Kurtuluş et al., 2007; Vardar et al., 2014). This has been our motivation to choose the Gemlik Gulf for morphotectonic studies. Regarding the paleoceanographic aspect, Gemlik Gulf is also interesting, because it is semienclosed marine inlet separated from rest of the northern shelf of the Sea of Marmara by a ~ -55 m deep sill to its west, and hence the timing of its connection with the world ocean and its lacustrine history and water level changes would be expected to be Sea of Marmara what different from those events in the Sea of Marmara (e.g., Çağatay et al., 2000, 2003, 2009, 2015; Aksu et al., 2002; Eriş et al., 2007; 2010). Especially, studies covering such paleoceanographic aspects based on core analysis are very scarce, with only one such study recorded in the international literature (Taviani et al., 2014).

We used multibeam bathymetric mapping, high resolution seismic (chirp sub-bottom) profiles and stratigraphic analyses of cores. All data and the cores were collected during the various expeditions of R\V Urania, including the last one carried out in 2013 within the framework of the MARSITE project. We produced a multi-beam bathymetric map with data compiled from the Gemlik Gulf during the R\V Urania expeditions. For seismic study, 114 seismic profiles were analyzed for fault mapping and morpho-tectonic study. 29 of the seismic profiles were used for seismic stratigraphic analysis for the interpretation of late Pleistocene-Holocene paleoceanographic evolution of the gulf. (Figure 3.9)

We used a 6.7 m long piston core recovered during the 2013 R\V Urania expedition (Gasperini et al., 2013). The core was analysed for magnetic susceptibility using Multi Sensor Core Logger (MSCL) and for dating using Accelerator Mass Spectrometry (AMS) ^{14}C analysis. The seismic units were dated using core-seismic stratigraphic correlation. In addition, chronostratigraphic information published by Taviani et al. (2014) on a core (GE124) recovered from eastern part of Gemlik Gulf during 2005 R\V Urania expedition was also used for core to seismic correlation and paleoceanographic studies.

The specific objectives of the study in the Gemlik Gulf can be listed as:

- Creation of a reliable fault map,
- Discussion of the late Quaternary morphotectonic evolution,
- Documentation of the core stratigraphy and chronology,
- Discussions of the Late Pleistocene - Holocene paleoceanographic evolution including the water level changes.

1.2 Literature Review

Several studies have been carried out in the Sea of Marmara and more specifically in the Gemlik Gulf in last several decades. The subject of these studies was either the paleoceanographic or the morphotectonic evaluation. Investigations in the Gemlik Gulf and the Sea of Marmara in general were mainly on the tectonics. They started in 1980s and intensified after 1999 İzmit and Düzce earthquakes (Kurtuluş, 1985, Barka and Kandinsky-Cade, 1988; Smith et al., 1995; Yaltırak and Alpar 2002; Kuşçu et al 2009; Çağatay et al. 2000, 2003, 2009, 2015; Eriş et al., 2007, 2010; Kurtuluş and Canbay, 2007; Vardar et al., 2014.

Kurtuluş (1985) presented the types of faults observed in the Gemlik Gulf. The author divided the faults into three types: boundary faults, inactive faults and active faults. The paper provided no detailed explanations on fault systems.

Barka et al. (1988) presented strike-skip faults of Turkey, also defining the features of the Gemlik and Gençali faults. It has been mentioned that these strike-skip faults are right-lateral faults, which are clearly visible on land and also extending into the Gemlik Gulf. For the offshore segments of the Gençali and Gemlik faults, the authors referred to unpublished seismic reflection and single beam bathymetry data.

Barka and Kuşçu (1996) mapped the active faults in the Gemlik Gulf, based mainly on morphology and single beam bathymetry.

Smith et al. (1995) determined the relative contributions of tectonics and glacio-eustatic sea-level changes in controlling the morphology of the sea bed and the patterns of late Quaternary sedimentation and erosion in the Sea of Marmara. The database included high resolution sparker seismic reflection profiles and multichannel seismic reflection profiles acquired by Turkish Petroleum Company (TPAO). The chronologies of the seismic stratigraphic depositional units were based on a global sea level curve.

Emre et al. (1998) discussed the Neogene - Quaternary paleogeographic evolution of the eastern Marmara region using the depositional setting of the widely exposed

Neogene-Quaternary sedimentary rocks and discussing the interrelation between the tectonics, morphology and sedimentation processes.

Yaltırak and Alpar (2002) provided a new evolutionary model for the Gulf of Gemlik based on shallow seismic reflection data and the NAF's westward propagation and its slip rate estimated from the GPS readings. The authors estimated ages of the sedimentary sequences were re-estimated based on the regional tectonic uplift and global sea-level changes. These analyses were done on the basis age of the delta sequences defined by Aksu et al. (1999), based on the global sea level curve.

Aksu et al. (2002) discussed the Last Glacial-Holocene paleoceanography of the Sea of Marmara based on core and shallow seismic stratigraphy. The authors discussed the marine connections of the Sea of Marmara. They concluded that the Sea of Marmara was connected with the Mediterranean during marine isotope stage 3 with the last connection taking place 12 ka BP.

Gürer et al. (2002) studied the geometry of faults and structural characteristics of the NAFZ in the southeast Marmara region and discussed the commencement age of strike–slip tectonics using deformation patterns of Neogene units and available published information. They discussed the geological and stratigraphical features of the southeastern Marmara region based on the basis of field observations on the structural patterns and morphotectonics of the region.

Kuşçu et al. (2009) mapped the major faults in the Gemlik Gulf that played a main role in the morpho-tectonic evolution of the Gemlik Gulf, using high resolution seismic reflection data acquired in 2002. The purpose of this study was to create a model of the fault geometry of the area.

Kurtuluş et al. (2007) investigated the active deformation within the uppermost sedimentary layers using high resolution seismic data, as well as discussing the deeper sedimentary strata, focusing on the tectonic and stratigraphic settings between Gemlik Gulf and Bandırma Bay. Authors also mapped the strike-slip character of fault systems of the middle strand of the NAF in the Sea of Marmara. As a result, the authors assessed how these faults interacted in the region.

Çağatay et al. (2000) presented a comprehensive sedimentary, paleontological and chronostratigraphic analyses of cores from the Sea of Marmara. The results showed that the Sea of Marmara was transgressed by the Mediterranean waters ~12 ka. A sapropel was deposited during 10.6-6.3 ka BP following the marine transgression.

Çağatay et al. (2003) discussed the sea level changes and environmental conditions based on the sedimentary and chronostratigraphic analyses of cores and coastal sedimentary sequences, and seismic stratigraphic analysis from the İzmit Gulf. The study also mapped the seafloor features, such as active faults, pressure highs, and paleoshorelines, based on bathymetric and high resolution seismic reflection data.

Eriş et al. (2007) discussed the chronostratigraphic evolution of the transgressive sediments up through the formation of the delta-like deposits and shedded light on water exchange between the Marmara and the Black Seas as the Holocene rise of sea level progressed. The high-resolution seismic reflection profiles and analyses of the sedimentary substrate at the Sea of Marmara entrance to the Strait of İstanbul (SoI, Bosphorus) provided a detailed record of the transgression that took place after the Sea of Marmara reconnected with the Mediterranean. In total, this study observed seven seismic reflection units that were confidently correlated with physical properties and lithochronological features of the cores in the area.

Çağatay et al. (2009) presented detailed seismic–stratigraphic analysis of Chirp sub-bottom profiles from the northern shelf of the Sea of Marmara, together with lithology, paleontology and isotope analysis, which extended the record back to MIS-7. These recovered sediments revealed the presence of two new sapropel layers deposited during MIS-5, in addition to the previously discovered Holocene sapropels (Çağatay et al., 1999, 2000; Tolun et al., 2002). Moreover, water exchanges between the Mediterranean and Black Seas, water level excursions and other paleo-oceanographic parameters such as salinity and oxygen conditions were discussed in the paper.

Eriş et al. (2010) presented sedimentary record of the northern shelf of the Sea of Marmara from late Glacial to Holocene with detailed seismostratigraphic, chronostratigraphic and biostratigraphic analyses using sub-bottom profiles and sediment cores. The authors discussed the relationships between sea-level changes and depositional sequences by correlation of seismic units and core sediment chronology.

Gasperini et al (2011) discussed the geomorphic features and slip rates along the different NAF segments in the Gulf of Gemlik, as well as Izmit and Saros gulfs, with a view towards neo-tectonic reconstructions, fault interactions and seismic hazard estimation in the Marmara region. High-resolution geophysical data and stratigraphic constraints from sediment cores enabled the authors to estimate the horizontal slip rates in three key locations along the submerged portion of the NAF in the Sea of Marmara. Studies showed that the sedimentary features, such as a river channel, a submarine canyon, and a delta, that were passively displaced by strike-slip deformation and subsequently buried below the Holocene hemipelagic sediments after their abandonment.

Taviani et al. (2014) provided new information about the non-marine paleoenvironments that predate the post-glacial marine ingression of the easternmost part of the Mediterranean Sea and shed Sea of Marmara light on the modality of Mediterranean flooding using cores GE123 and GE124 located in the eastern Gemlik Gulf.

Vardar et al. (2014) investigated late Pleistocene-Holocene evolution of the southern shelf of the Sea of Marmara using multi-beam bathymetric and high resolution seismic data. They produced a fault map including the middle strand of the NAF in the bays of Gemlik, Bandırma and Erdek, and estimated a new slip rate in the Gemlik Gulf. The authors also discussed the paleogeographic evolution in Sea of Marmara detail based on the seismic stratigraphic data.

Çağatay et al. (2015) studied the paleoceanography of the Sea of Marmara based on multi-proxy analyses of a 28m long piston core representing a continuous stratigraphy of the last 70 ka. The authors showed that the Sea of Marmara was lacustrine during isotope stages 3 and 4, with only one lacustrine/marine transition during 12.6 ka BP. Another interesting finding was the excellent correlation of Marmara multi-proxy records with North Greenland Ice Core isotope record.

1.3 Physiography of Study Area

Gemlik Gulf is an E-W elongated inlet located on eastern part of the southern shelf of the Sea of Marmara (Figure 1.1). The gulf is on average 36 km long and 11 km wide and has a maximum depth of -113 m in the oval shaped central depression. It covers an area of 349 km^2 and is connected to the rest of the southern shelf with -50 m sill in the west (Yaltırak and Alpar, 2002; Gasperini et al., 2011; Vardar et al., 2014). The Gemlik Gulf is located on the middle strand of the NAF that extends to Lake İznik to the east.

The southern shelf of the Sea of Marmara covers a larger area (4,194 km^2) compared to the northern one (Gazioğlu et al., 2002), and includes two other depressions of Bandırma and Erdek bays, with depths in the order of -50 m. The depressions of Erdek, Bandırma and Gemlik are located between the Karabiga town in the west and Gemlik town in the east, being aligned north of the 290-km long southern coast Sea of Marmara. The southern mountains are parallel to the coast and occur in front of the low-lying plains (100 m) drained by the rivers of Kocasu, Gönen and Biga. The most important geographic element is Kocasu River by its drainage area of 27,600 km^2 and with an average of 158 m^3/s river discharge in the region (Ünlü and Alpar, 2006).

The Gemlik Gulf as part of Sea of Marmara is characterized by two water masses of Mediterranean Sea and Black Sea origins forming the lower and upper layers, respectively. The two water masses are separated by a permanent pycnocline at -25 m (Beşiktepe et al., 1994). The Sea of Marmara is connected to the Mediterranean and the Black Seas via the Çanakkale (Dardanelles) and İstanbul (Bosporus) straits which have -65 m and -35 m thresholds, respectively.

The Marmara Sea is located 210 km long in east-west direction by longitude and 75 km long by latitude to the north-south direction. The surface area is about 11500 km^2 and volume varies up to of 3380 km^3 (Adatepe, 1988). The Marmara basin includes three ~ -1275 m deep, rhombic and wedge-shaped basins (Çınarcık, Central and Tekirdağ) separated by NE-trending pressure highs (Eastern and Central).

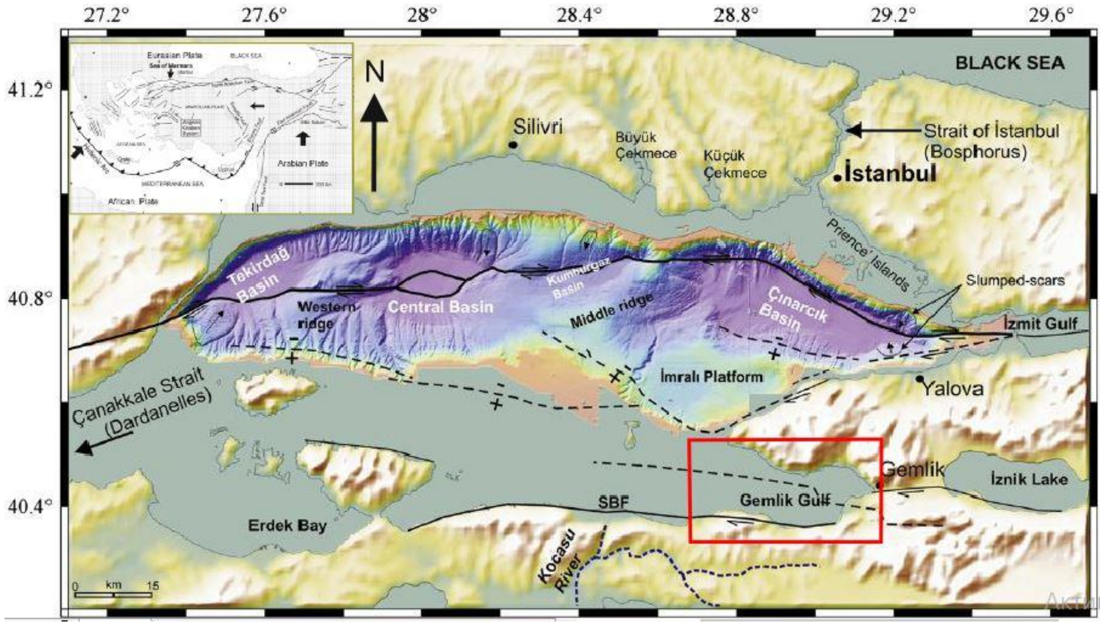

Figure 1.1 Morpho-bathymetric map of the Sea of Marmara showing study area (red rectangle) (adapted from (Le Pichon et al., 2001; Armijo, 2003)). The inset map in the top left corner shows basic active tectonics of the wider region including the Sea of Marmara.

The most notable industrial towns in the Gulf of Gemlik are Mudanya and Trilye. The Mudanya Port in the Gulf is an export gate for Turkey's second largest industrial city of Bursa, (Ünlü and Alpar, 2006). Despite of intensive industrialization in the South coast of the Gulf, villages - Armutlu, Fıstıklı, Kapaklı, Karacaali, Büyükkumla and Küçükkumla, which are located along the northern coast of the Gulf, are touristic centres. The total population of the Gemlik town exceeds 129,000, and this number doubles in the summer time mainly due to tourist arrivals (Ünlü and Alpar, 2006). The most densely populated towns are Gemlik (129,000) and Mudanya (24,000).

1.4 Geology of the Onshore Area

The basinal areas of Gemlik Gulf, Lake Iznik to the east (Öztürk, 2009), and the Bandırma Bay were developed between the transtensional fault segments of the middle NAF strand during Late Pliocene–Early Pleistocene (Barka, 1997; Barka and Kadinsky-Cade, 1988; Gasperini et al., 2011). Concerning the main fault system in the region, Yaltırak and Alpar (2002) defined three en-echelon right-lateral fault segments between the Gemlik and Bandırma Bay.

In the southern drainage basin of the Sea of Marmara Sea includes the Sakarya Zone, Pontian, Izmir and Ankara suture zones and the Miocene sedimentary cover rocks. The Intra-Pontian suture zone rocks form a melange consisting of oceanic peridotites and the volcano-sedimentary units of Triassic-Paleocene age (Okay et al., 1996). These units exposed around Mudanya, Bursa - Orhaneli and Dursunbey areas south of Gemlik Gulf (Figure 1.2).

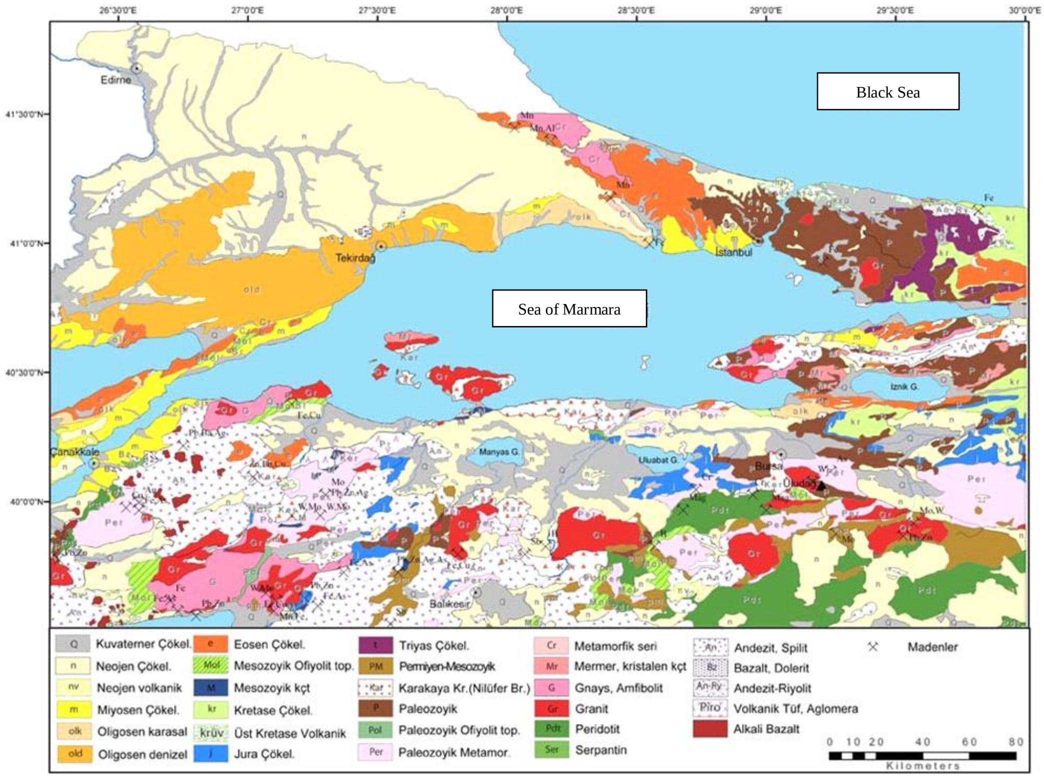

Figure 1.2 Simplified geological map of the Marmara Region (Geology modified by Çağatay et al., 2006) after Türkecan and Yurtsever (2002); to Okay et al. (1996); Aldanmaz (2002). The distribution of mineral deposits was taken from Gümüş (1970)

Rocks related to the Sakarya Zone are belong to two tectonic units that merged together in the Late Triassic Age (Okay and Whitney, 2010). They consist of mixed granitic and metamorphic rocks of Palaeozoic Age and the Paleozoic-Triassic Karakaya Complex that evolved as subduction accretionary wedge. Granitic-metamorphic rocks formed from felsic gneiss, quartz-feldspar-mica-schist and interlayered amphibolite and marbles. Metamorphism is from the high grade amphibolite and granulite facies. These rocks are exposed in Uludağ south of Gemlik Gulf and west of the Armutlu Peninsula. Karakaya Complex of the Sakarya zone consists of Nilufer, Play, Hodul and Orhanlar units. The Nilüfer unit consists mainly of mafic volcanic tuff and its sedimentary debris. Greenschist facies has undergone high-pressure metamorphism (Okay et al., 1996). The nature of the alkaline basalts contains titanium-augite and kaersutite. This unit is exposed on the coast of Mudanya and on the south and southwest of Manyas and southwest of Bursa. The Hodul unit is exposed in the Biga River drainage area, in the east of Biga and Çan. Orhan Greywacke is more prevalent and seen in the north of Karacabey and south of Lake Uluabat. Beside this, Oligo-Miocene aged granites are available between Mustafa Kemal Paşa - Kepsut and Balya-Manyas, in Uludağ and Armutlu Peninsula. There are Eocene basalt and andesites that extensively outcrop in Armutlu Peninsula.

2. METHODOLOGY

2.1 Core Studies

Core M13-08 was recovered from a depth of 73.5 m in the Gemlik Gulf during the MARMACORE cruise on board R/V Urania 2013 expedition, using 1.5 ton piston corer with 12 m pipes having 12 cm diameter and a trigger release mechanism. The total length of the studied core is 6.7 m. Due to bending of the core barrel, the 5th section of the core M13-08 was disturbed during recovery. The damaged core section was wrapped with stretch film and kept separately.

The core was described lithologically and analysed for the physical properties (magnetic susceptibility, the P-wave velocity and gamma-density) using a multisensor core logger (GEOTEK MSCL) in EMCOL Core Analysis Laboratory. Only the magnetic susceptibility results determined with Bartington point sensor at 0.5 cm resolution was used in this study.

The chronology of the core was established by radiocarbon analysis of bivalves at 238 cm, 144.5 cm, 258 cm, 564.5 cm and 652 cm, using accelerated mass spectrometry (AMS) method at Poznan Radiocarbon Laboratory in Poland (Table 2.1). The radiocarbon dates are presented without reservoir correction and calibration to calendar years.

Table 2.1 Radiocarbon data for Core M2013-08 (Poznan Radiocarbon Laboratory in Poznan, Poland)

Sample code	**Depth below sea floor (cm)**	**Species**	**Radiocarbon age (^{14}C-yr BP)**
Poz-71741	238	Cardium sp.	10.060 ± 60
Poz-71742	144.5	Turtella sp.	7.660 ± 50
Poz-71743	258	Didacna	10.660 ± 60
Poz-71744	564.5	Dreisenna polymorpha	13.380 ± 70
Poz-71745	652	Theodoxus	12.630 ± 70

Table 2.2 Radiocarbon data for Core GE-124 (Isotope Geochemistry Laboratory of University of Arizona, U.S.A., (Taviani et al. 2014))

Sample code	**Depth below sea floor (cm)**	**Species**	**Radiocarbon age (^{14}C-yr BP)**
OS- 53533	45-47	Mactra sp.	11.250 ± 60
OS- 53534	83-85	Dreissena rostriformis	13.950 ± 65
Poz-22446	208-218	Euxinipyrgula cf. lincta	15.860 ± 90

We also used core GE-124 located on the Kocadere River delta in the eastern part of Gemlik Gulf, for core to seismic stratigraphic correlation This core was previously studied by Taviani et al. (2014), who provided useful radiocarbon dates for the core.

2.2 Multibeam Bathymetric and Seismic Methods

2.2.1 Data acquisition

Bathymetric data were obtained using a pole mounted Elac Sea Beam 1185 multibeam sonar operating at 180 kHz. This system utilizes 126 beams with 1.5T resolution which provides total swath coverage of 153T. The multibeam data were processed using the HYPACK and MBSYSTEM software programs with the following processing steps: beam editing and despiking, correction of navigation errors, data interpolation, including tide, sound velocity, and vessel offset correction and data cleaning, and DTM construction. The final step was gridding with 5-m grid interval to create a high resolution bathymetric map of Gemlik Gulf. The combined data were then arranged in 1-m contour intervals using Surfer 9.0 software program. Depth values in the Gemlik Gulf were combined in one spreadsheet, which were then transferred to data frame feature in Surfer 9.0. As a final product, colour scale bathymetric and contour map of the Gulf of Gemlik was produced (Figure 3.4 and Figure 3.6)

A total of 114 high resolution seismic reflection profiles with frequencies ranging between 2 and 7 kHz were acquired in Gemlik Gulf using a Datasonics SIMSAP-1000, Datasonics Chirp-II and Edge-Tech SB424 high-resolution sub-bottom profiler systems. The data were recorded in both XTF format (Figure 2.1). The navigation system NAVPRO V5.53 was enhanced with a DGPS satellite link by Skyfix of RACAL-NESA. Depths of reflectors below the sea surface were calculated using average water and sediment velocities of 1450 ms^{-1} and 1550 ms^{-1}, respectively.

All acquired XTF files (114 XTF files) that acquired during this expedition were analyzed one by one. Firstly, these available XTF files were converted to SEG-Y format using the Seisphro application, and later all these SEG-Y formatted files were converted to JPGS files by using the same software application. In fact, this software application allows us to change the parameters to enlarge the view of the vertical thickness, brightness, and so on to get the better viewed seismic profile as an output.

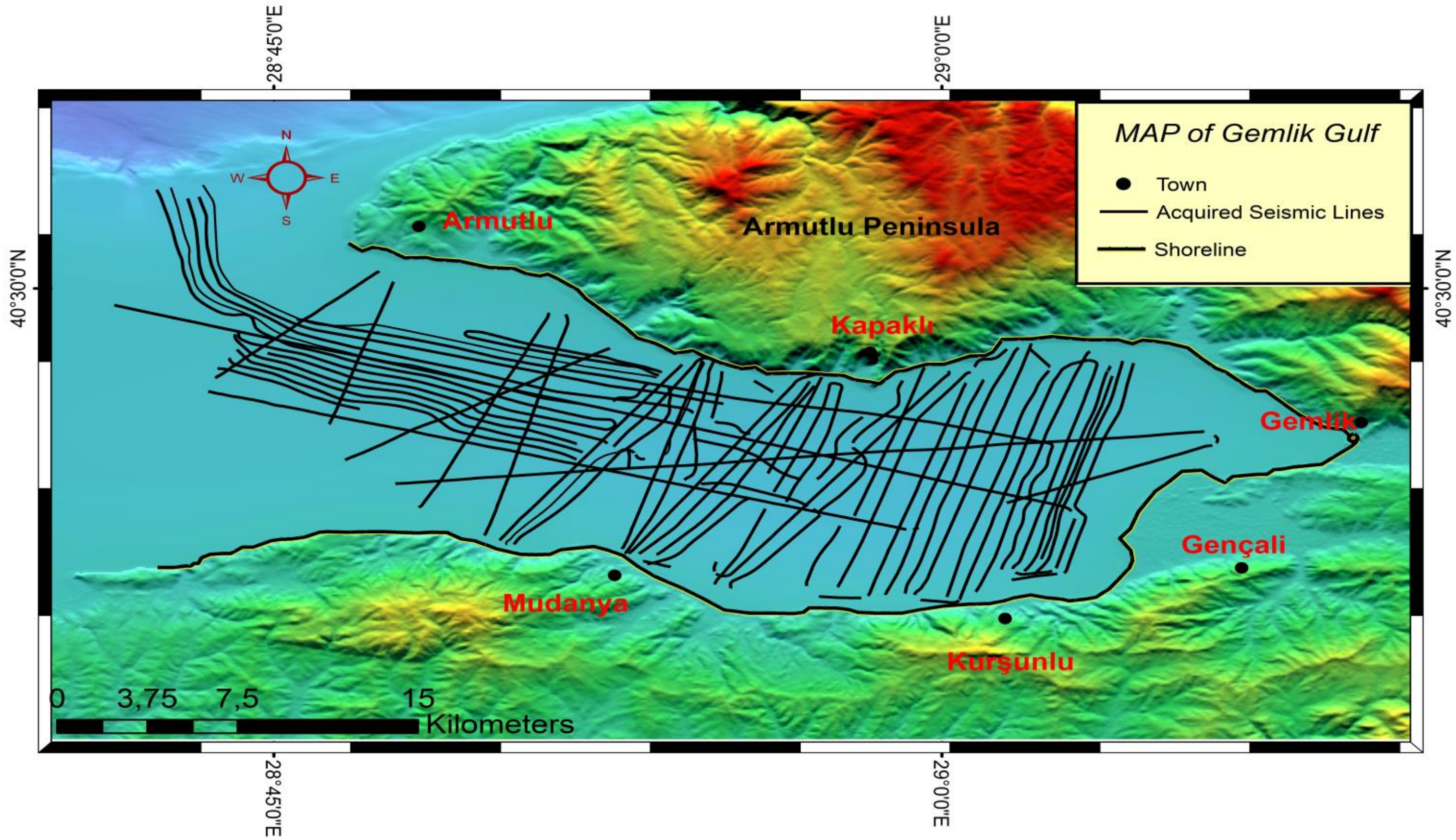

Figure 2.1 The seismic lines acquired in Gemlik Gulf**.**

2.2.2 Seismic stratigraphy

Seismic stratigraphic studies include the determination of different sedimentary units in the seismic profiles and identification of the types of their upper and lower boundaries in accordance with the principles of seismic stratigraphy (Vail and Mitchum, 1979). Seismic stratigraphic studies commonly provide a wide range of information on the lithofacies changes, overall depositional environments, discontinuities in sedimentation and sea level changes.

Seismic stratigraphic interpretation methods and sequences of steps are as follows (Vail and Mitchum, 1979).

- Identification of seismic reflection surface
- Analysis of seismic reflection surface, its geometry and continuity
- Defining the geometry of internal reflection of the sedimentary units bounded by the seismic reflection surfaces

The seismic reflection surfaces are produced because of the variation in the physical properties of adjacent sediments or rock units, such as density and acoustic velocity (acoustic impedance). The contact surfaces between the units basically are Sea of Marmara time's unconformable surfaces, which represents erosion or non-deposition that characterizes a particular stratigraphic gap. The unconformity surfaces are neither simultaneous nor chronostratigraphic (Vail and Mitchum, 1979).

Seismic reflection surfaces follows geological timelines approximately in a half-length of the geological time (Vail and Mitchum, 1979).

The principles of seismic stratigraphy can be used for:

1) Geological timeline correlation,
2) Identification of depositional units,
3) Assessment of depositional environments of units and their thicknesses,
4) Determination of paleo-bathymetry.

The geometry of seismic reflection surfaces bounding the units and of the internal reflection surfaces can be characterized by different terminologies (Vail and Mitchum, 1979) (Fig 2.2):

- Downlap: Reflection surfaces that end up towards a downward slope.

- Onlap: Reflection surfaces that finish against laterally ending and an inclined surface.
- Erosional truncation: Generated by the erosional exposure of the sigmoid or oblique clinoforms.

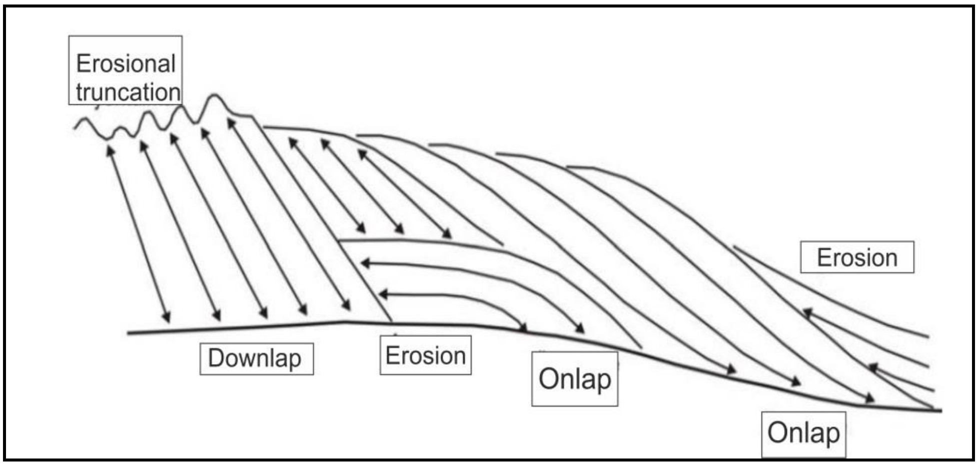

Figure 2.2 Geometric terminology of reflection surfaces**.**

Seismic reflection patterns are directly related to the stratigraphic features. Depositional features are controlled by the depositional environment, paleo-topography or paleo-bathymetry and erosion. Continuity of reflection surfaces is related to the acoustic impedance along the strata surface. This property is directly related to the "deposition function" and the depositional environment itself. The amplitude of the reflection surfaces is related to the lithostratigraphic features that controlled by the contrast in the acoustic impedance along the strata (Vail and Mitchum, 1979).

Seismic facies analysis involves determination of the depositional environment based observation of the geometry of seismic reflection surfaces in the seismic units and packages, as summarized below (Vail and Mitchum, 1979) (Figure 2.3):

a) Parallel and semi-parallel seismic reflection surfaces generally characterize shelf / platform, alluvial plains, delta platform and the delta plain,

b) Progradational seismic reflection surfaces characterize the progressive slope with the shelf, progressive shelf delta or shelf edge,

c) Aggradational seismic reflection surfaces characterize shelf/platform, delta / platform (Figure 2.3).

d) Onlap-fill seismic reflection surfaces mostly characterize coastal area, frontal slopes, overhanging fillings, submarine canyon fillings;

e) Regressive seismic reflection surfaces characterize the shelf, shelf slope, and delta front (Figure 2.3).

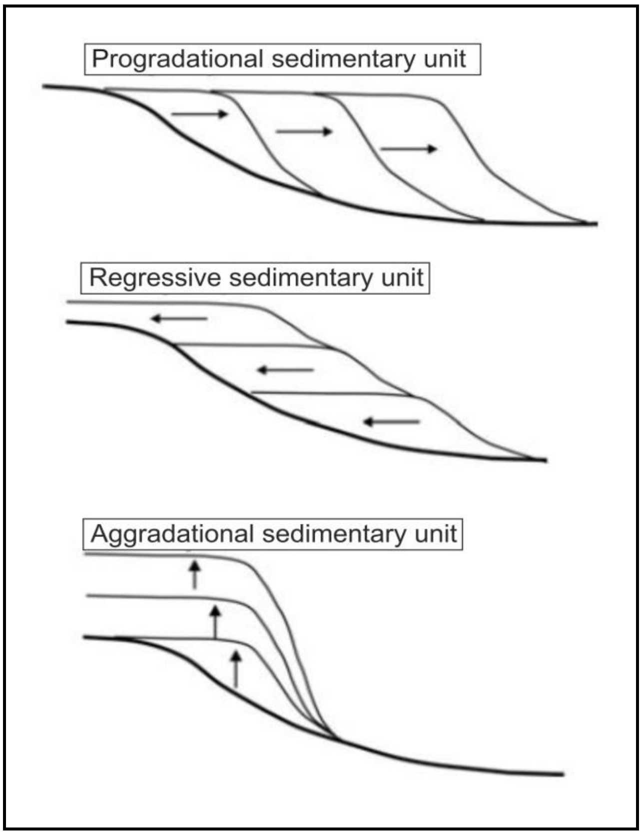

Figure 2.3 Geometric and structural features that observed seismic reflection packages show in seismic profiles (Vail and Mitchum, 1979).

3. RESULTS

3.1 Core Sedimentology and Chronostratigraphy

In this study, we examined two piston cores retrieved from the Gemlik Gulf. Core M13-08 was described and its litho- and chronostratigraphy were documented for the first time in this study. Another core GE-124 has been previously studied by Taviani et al. (2014), and was also used for facies analysis and core-to-seismic correlation, together with its chronostratigraphic data.

Detailed lithostratigraphic and faunal analyses of Core M13-08 from the northern shelf of the Gemlik Gulf enabled a subdivision of depositional sequence into two sedimentary units that have been labeled Unit L2 and L1 from the base (oldest) to the top (youngest) (Figure 3.1). Units L1 and L2 were deposited under marine and lacustrine conditions according to their fossil content. ^{14}C dates from *Dreissena polymorpha* shells near the base of Unit L2 in Core M13-08 indicates that the core sedimentary section covers the last 12.6 ka BP. The boundary between two units at 3.6 m below sea floor (mbsf) is dated 10.6 ka BP (Table 2.1; Figure 3.1).

The oldest lithostratigraphic Unit L2 in the core is represented by, dark gray, well-sorted medium sand containing the neoeuxinian bivalve fauna *Dreissena polymorpha* (Figure 3.1). In the top 25 cm of the unit between 2.62 and 2.87 cmbsf the grey sand shows normal size grading and contains shells of *Plagiocardium*. According to the lithology and faunal content, this Unit represents deltaic sediments deposited under lacustrine conditions.

Unit L2 is characterized by high magnetic susceptibility (MS) values compared to those of Unit L1. This suggests the coarse grain size and the relative enrichment of magnetic heavy minerals in Unit L2 (Figure 3.1). The lower part of the unit below 3.75 mbsf displays high MS values of up to 80 SI. The MS values show a relative decrease in the levels showing an enrichment Dreissena shells. Upward in Unit L2, an abrupt decrease in MS value from 70 SI to 20 SI occurs above 3.65 mbsf, mainly due to high biogenic content. The upper-most part of the unit with gray, normally graded, well-sorted sand shows an upward decrease in MS values that are well consistent with the decreasing grain size towards to the boundary between Unit L2 to L1 at 2.62 mbsf.

As a result of seismic to core correlation in this study, Unit L2 corresponds to Unit S2 in seismic profile #596 (see section 3.2). This stratigraphic boundary is associated with an unconformity surface (red reflection surface in the profile) in seismic profile #596 and is dated 10.6 ^{14}C ka BP using AMS ^{14}C analyses of mollusc shells (cardium edule) close to the boundary (Figure 3.1).

Unit L1 represents the marine part of the core sedimentary section. This unit displays variable lithology that enables us to differentiate different depositional subunits from base to top, and comprises euryhaline bivalves such as *Cardium edule, Turitella* sp., *Corbula gibba* (Figure 3.1). The lower-most layer in Unit L1 is represented by dark gray silty clay with abundant marine shells such as *Corbula gibba*. Above 2.59 mbsf in the core, this layer grades upwards into greenish gray clay with rarer marine shells. At the base of this subunit, AMS ^{14}C analyses of bivalve shell (cardium edule) gave age of 10 ^{14}C ka BP. Upward in the core, this layer is overlain by dark green clay between 1.77 and 1.52 mbsf, and bioturbated green clay between 1.52 and 1.35 mbsf (Figure 3.1). Another radiocarbon date of 7.66 ^{14}C ka BP was obtained from mollusc shell (cardium edule) at 1.44 mbsf.

The magnetic susceptibility (MS) values from base of Unit L1 up to 1.35 mbsf are low and do not display any remarkable change except for a small increase at the base of Unit L1 (Figure 3.1). These low values are most probably due to the reduction of iron oxides. Above 1.35 mbsf, MS values begin to increase gradually, reaching 35 SI at 0.85 mbsf. The highest MS value in Unit L1 is associated with a thin layer consisting greenish brown banded clay and overlaying dark and light greenish brown clays with rare marine shells. Unit L1 is equivalent to the youngest seismic stratigraphic unit S1 in the seismic profiles (see chapter 3.2).

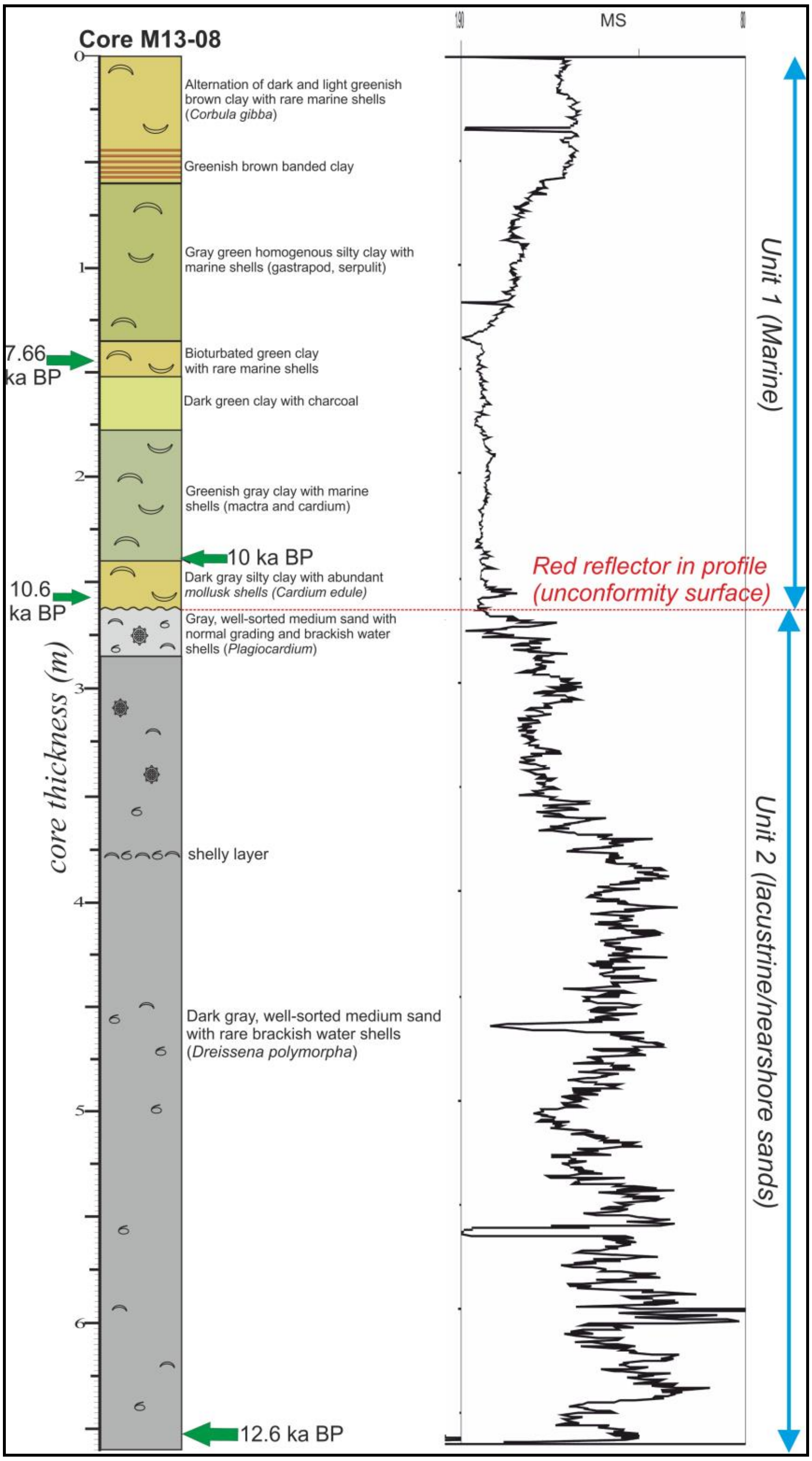

Figure 3.1 Lithological description and magnetic susceptibility (MS) profile of Core M13-08.

On the other hand, Core GE-124 extends back to 15 ka BP, and its correlation with the seismic stratigraphy reveals that this core penetrated the base of Unit S3 in the profile (Appendix C1). Our seismic Unit S3 was described in Core GE-124 by Taviani et al. (2014) as subaerial to subaqueous delta platform deposits with freshwater faunal assemblages. Our Unit S2, and its lithological equivalent Unit L2, was also recovered in Core GE-124, which was described as lacustrine sediments (Taviani et al., 2014). In detail, Unit L3 in the cored sequence consists of a 128 cm-thick, unfossiliferous reddish brown mud and ±10 cm thick greyish basal mud. The basal Unit L3 is interpreted to represent subaerial to subaqueous delta deposits and gives an uncalibrated age of 15.860 ± 90 ka BP. This unit is overlain by a 23 cm thick greyish mud with *Euxinipyrgula cf. lincta* shells and 10 cm thick greenish mud with rare *Euxinipyrgula cf. lincta* shells, representing lacustrine sediments of the basin (Taviani et al. 2014). An AMS ^{14}C age from the brackish water bivalve *Dreissena Rostriformis* in this unit, at 85cm bsf gives an uncalibrated age of 13.950 ± 65 ka BP (uncalibrated). The topmost unit is made of a fining-upward transgressive sequence with marine shells. The base of Unit L1 is dated using a fossil of Mactra, at 11,250 ± 60 ka BP (uncalibrated). (Figure 3.2)

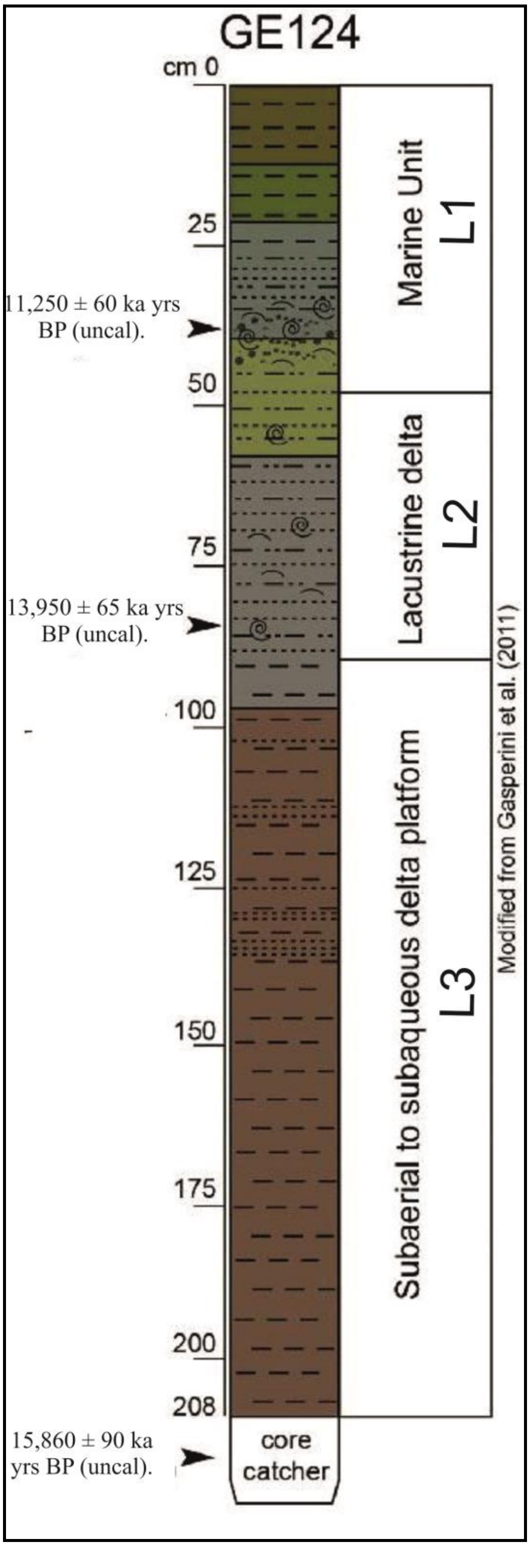

Figure 3.2 Lithological description Core GE 124 (Taviani et. al 2014)

3.2 Seismic Stratigraphy and Core-Seismic Stratigraphic Correlation

As a result of seismic stratigraphic analysis of numerous high resolution seismic reflection profiles in the Gemlik Gulf, we identify four stratigraphic units and labeled them: Unit S4, Unit S3, Unit S2, and Unit S1 from oldest to youngest. In total, there are four reflector surfaces that delimit the units, excluding the seafloor. Two of these reflectors are erosional truncation surfaces. In the seismic profiles, the youngest lowstand unconformity surface is represented by the red reflector surface that can be a shelf-crossing unconformity characterized by subtle erosional truncation of the underlying older units. Ages of these units can be estimated in this study by core-to-seismic stratigraphic correlations. For this purpose we used the chronostratigraphy and facies analysis of core M13-08 and Core GE-124 (Figure 3.3).

As explained in the previous section, Core M13-08 covers a sedimentary section with two stratigraphic units covering the last 12.6 ka BP. The lithostratigraphic units observed and dated in the core can be correlated with the seismic stratigraphic units S1 and S2 in profile #596 (see Appendix B1). On the other hand, Core GE-124 located on seismic profile GE-40 penetrated up to the base of seismic stratigraphic Unit S3 (Appendix C1).

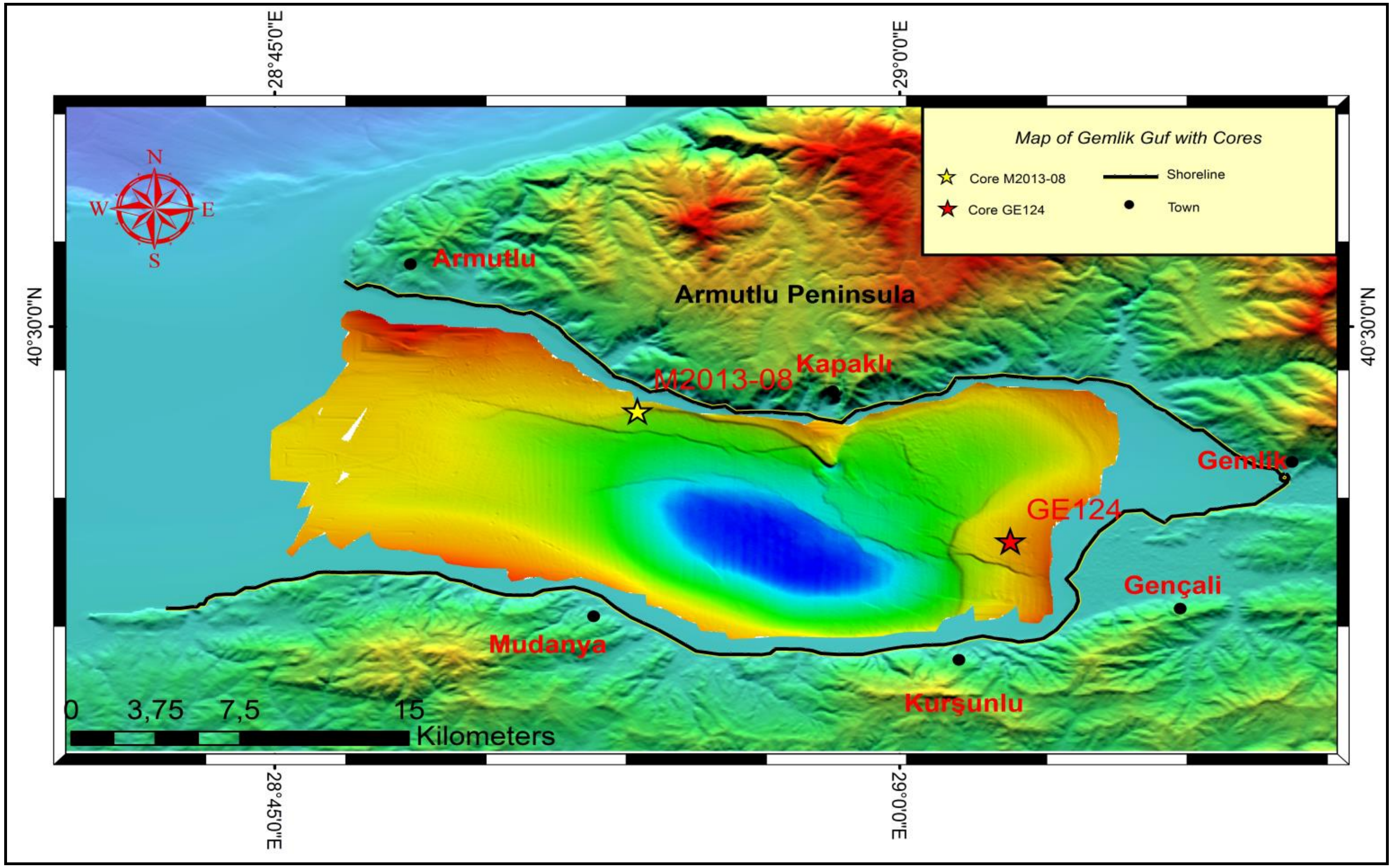

Figure 3.3 Location of the Core M13-08 and GE-124

In the profiles, the seismic units are described and interpreted from top to bottom as given below;

Unit S1:

On the overall profiles, Unit S1 is identified as acoustically strong internal reflectors that are characterized by horizontal and continuous sedimentary deposits. The top of this unit represents the seafloor and its base is the red reflector that is the main unconformity surface in the Gemlik Gulf. Unit S1 is interpreted as transgressive mud drape; while it is associated with the onlapping architectures over the red reflector (unconformity) in the profiles (see Appendices).

The unit is penetrated by Core M13-08, in which the base of the unit (red reflector) is dated at 10.6 ka BP. On the other hand, Core GE-124 dates the same unit boundary (reflector) at 11.2 ka BP that is in broad agreement with our ^{14}C age. Based on this core-to-seismic stratigraphic correlation, Unit S1 is equivalent to Holocene marine unit L1 (see Appendices). This youngest unit in the profiles locally fills the paleo-valleys in the gulf. In the seismic profiles, the thickness of the Holocene unit ranges from approximately 3m to 19.5m, with the thickness of decreasing towards the shoreline (see Appendices). In Sea of Marmara profiles, Unit S1 pinches out towards the shoreline (see Appendices). Unit S1 is a mud drape extensively covering the older units nearly in all profiles, except in profile no 388, where Unit S1 has been eroded (see Appendices). Unit S1 is equivalent to Unit C3 of Vardar et al. (2014).

Unit S2:

Unit S2 is underlying Unit S1 over an unconformity surface (red reflector). Its lower boundary (yellow reflector is a truncation surface over underlaying Unit S3 (Appendices; profiles #354, 388, 594, 596, 603). This unit was penetrated by cores M13-08, and Core GE-124. According to chronostratigraphic studies in core M13-08 and Core GE-124described in the previous section, Unit S2 consists of deltaic sands deposited under lacustrine conditions. Using the radiocarbon chronology of Core GE-124 and core-to-seismic stratigraphic correlation, we dated the base of the unit (yellow reflector) at 13.9 ka BP.

In different seismic profiles, Unit S2 indicates different facies and lithologies on basis of internal seismic configurations. In the basin, it shows parallel bedded mud drape that is characterized by acoustically moderate to low internal reflectors, whereas on the shelf-edge, it indicates progradational clinoforms characterized by acoustically strong internal reflectors. On the shelf edge, prograding nature of this unit implies regressive nature of these sediments that are truncated by the main unconformity surface (red reflector) in the profiles. The truncation water depth (~ -68 m) is correlated with the formation of berms that can be attributed to paleoshoreline of the Gemlik Gulf during the stillstand of sea level.

The thickness of the Unit S2 commonly ranges between 2m and 5m in the profiles. Unit S2 is correlated with Unit C2 in Vardar et al. (2014), who interpreted the unit to represent lacustrine-fluvial facies, and dated the base of the unit at 30 ka BP. This inconsistency is due to the use of global sea level curve for dating, instead of core chronostratigraphic data by Vardar et al.'s (2014).

Unit S3:

Based on the internal reflection configurations, Unit S3 also shows variable facies that can be attributed to different depositional settings. In general, this unit comprises highly-reflective, conformable and moderately continuous internal reflectors. On the shelf, Unit S3 consists of acoustically strong internal reflectors with clinoform architectures that indicate the formation of the deltaic system located on eastern and northern shelf margins of the gulf. In the deep basin (more than ~-75 m), Unit S3 is associated with horizontal and parallel-bedded sediments. In Sea of Marmara profiles, Unit S3 appears to be filling the erosional gullies formed with horizontal internal reflectors having limited lateral extent on the blue reflector underlying this unit (see Appendices; most of the profiles).

Unit S3 is only penetrated by Core GE-124. Using the chronostratigraphic data in this core documented by Taviani et al. (2014), we date the base of the unit (blue reflector) at 15.8 ka BP. Deltaic sediments of Unit S3 comprise the bottomset and foreset, whereas the topset was eroded locally by the red reflector at water depths ranging from -68 m to -65 m in the profiles. This topset truncation is also associated with the formation of wave-cut platform that provides evidence of sea-level change in the gulf during the termination of deltaic deposition. The foresets of the deltaic sediments consists of highly inclined sigmoidal clinoforms that presumably represent pro-delta environment during the transgressive water level rise in the gulf. The transgressive nature of the deltaic system is confirmed in the profiles by infilling of the erosional gullies as parallel bedded mud drapes. On the basis of radiocarbon chronology from core GE-124, this transgressive sea level in the gulf is tentatively date to be during 15.8-13.9 ka BP. This unit can be correlated with Unit C2 of Vardar et al. (2014). However, the age of this unit is not consistent with our assigned age for this unit.

Unit S4:

Unit S4 underlies Unit S3 below the blue reflector in the profiles. It is the oldest sedimentary unit that is encountered in the high resolution seismic profiles. Unit S4 is delimited by the pink reflector that is not imaged very well in all seismic profiles. Therefore, our interpretation for this unit is only based on a few profiles. On the western part of the gulf, this unit consists of highly-reflective parallel bedded internal reflectors. Towards the eastern part of the basin, where the gulf begins to deepen below -75 m, Unit S4 comprises mounded sediments with wavy internal reflectors that are truncated by erosional gullies formed on the blue reflector. In the profiles, the depth of the erosional gullies range between 3-9 m and the width varies from 25 to 150 m. The formation of Unit S4 can be estimated to be older than 15.8 ka BP, the age of the blue reflector in core GE-124.

3.3 Bathymetry and General Seafloor Morphology

The Gemlik Gulf is 36 km long, 11 km wide and -113 m deep (maximum), E-W oriented marine inlet covering a 349 km^2 area in the southeastern part of the Sea of Marmara. It is connected to rest of the southern shelf of the Sea of Marmara with about -50 m sill (Yaltırak and Alpar, 2002; Gasperini et al., 2011; Vardar et al., 2014).

The new bathymetry map produced in this study shows many morphological features, including the oval shaped Burgaz Depression in the central part, a spur offshore Kapaklı in the north, the Gençali delta in the east, a rise (Gemlik rise) between Gençali and Kurşunlu, and numerous fault scarps (Figures 3.4-3.6).

The central Burgaz depression has a WNW-ESE trend and a maximum depth of -113 m. As can be seen in the seismic sections (see next section), this basin is controlled by faults dipping towards the depocenter.

The spur south of Kapaklı in the north is an uplift structure formed by basement rocks with a thin cover of units S1 and S2 (Appendix E, profile #406). The Gençali delta platform formed during the lacustrine stage of the gulf prior to the marine transgression at 10.6-11.2 ka BP (this study, Gasperini et al., 2011; Taviani et al., 2014) (Appendices, profiles #282, 401, and 406). The east–west oriented submarine rise between Gençali and Gemlik, which we call Gemlik Rise, is also a basement uplift structure (Appendices; profiles #401, 404, 406) (Figure 3.4; also see section 3.4). The rise is covered by the Gençali delta and younger Holocene sediments. The Gemlik Rise is expressed by lower (0.1°) slopes which grade on land, north of the Gençali Delta and west of Gemlik, to a local high relative to the delta plain.

The offshore escarpment along the northern coastline between Armutlu and Kapaklı (Figure 3.3) is a sedimentary feature formed by prograding shelf-edge deltas that were sourced from the small rivers in the Armutlu Peninsula. This is supported by the internal architecture and morphology of the sediment package located close to the mouth of the Armutlu stream at the western edge of the gulf (Appendices; profiles #594, 596, 340). The slopes connecting the deep Burgaz Basin with the northern and southern nearshore areas is rapid compared with the slope towards the sill of the Gemlik Gulf in the west, where the change is more gradual. The steep slopes in the north and south of the gulf are in conformity with presence of 20-30 m high cliffs and 70-80 m deep N-S trending deep submarine valleys on both margins.

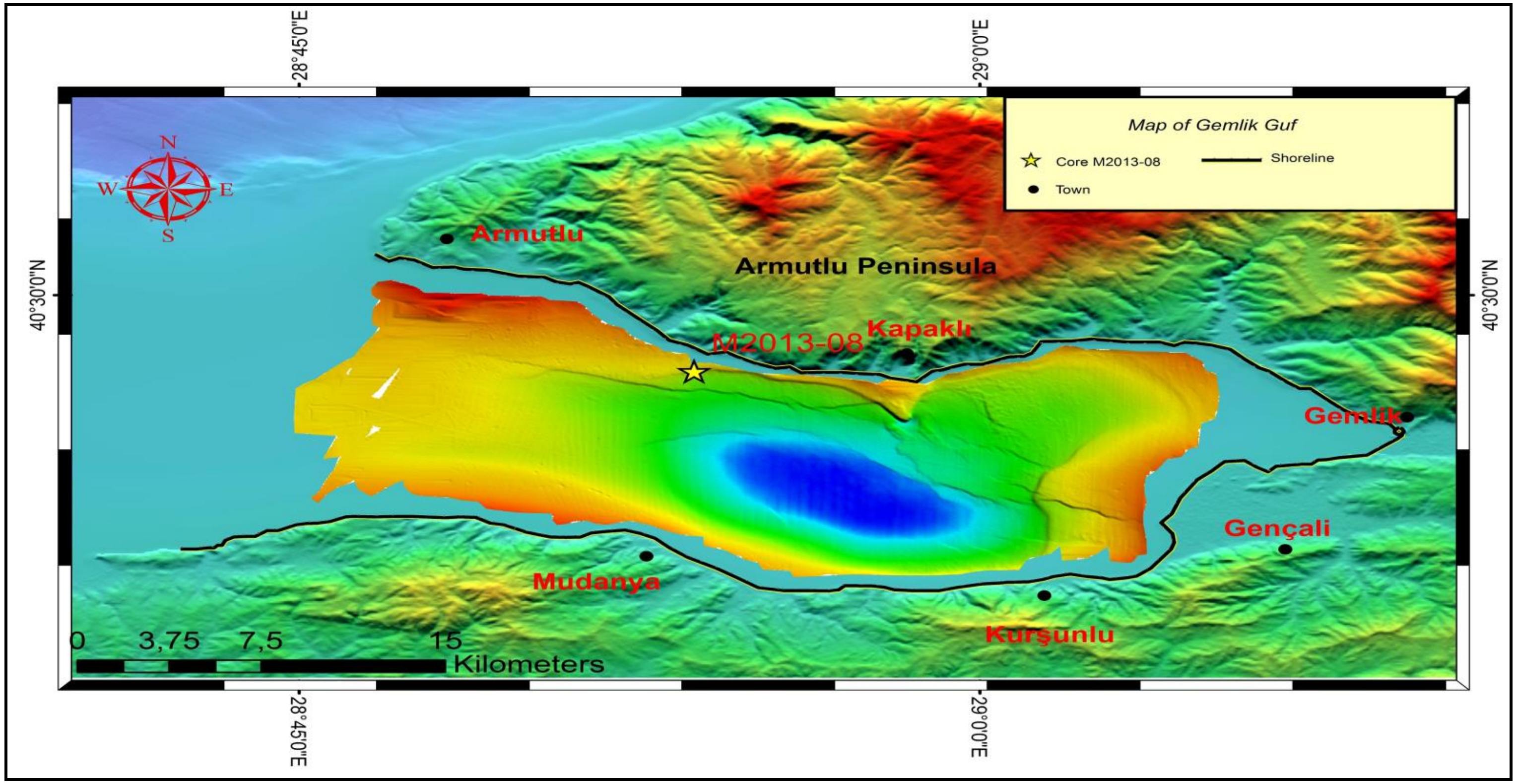

Figure 3.4 Bathymetry Map of the Gemlik Gulf. Bathymetry made on the basis of the data set acquired R/V URANIA expeditions (For colour depth scale please, see 3D view of Gemlik Gulf in Figure 3.4).

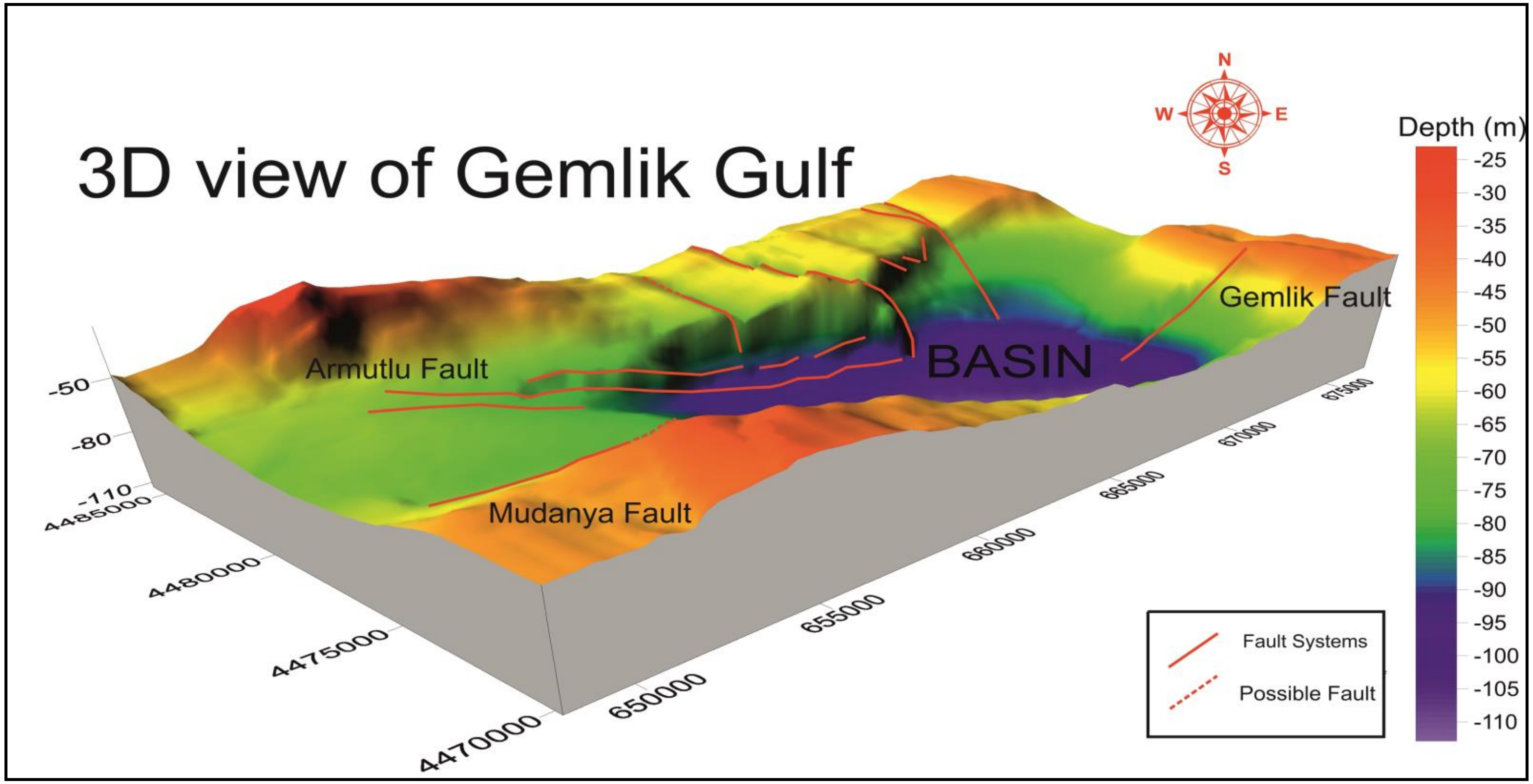

Figure 3.5 3D view of the Gemlik Gulf

3.4 Structural Features

Bathymetry map clearly shows the presence of numerous active fault scarps on the seafloor, which implies that the gulf is tectonically very active (Figure 3.3). The fault scarps on bathymetric map have predominantly NNW-SSE to NW-SE orientations indicating that the faults are extensional or transtensional and played important role in the formation of the central depression.

There are possible fault scarps on the NNW margin of the basin, which appear to be high-angled. The center of the basin is smooth with absence fault scarps (Figure 3.3 and 3.5). NNE-trending fault scarps of Sea of Marmara represent the active secondary faults that cut the Holocene sediments. Their trends indicate that these faults are transtensional.

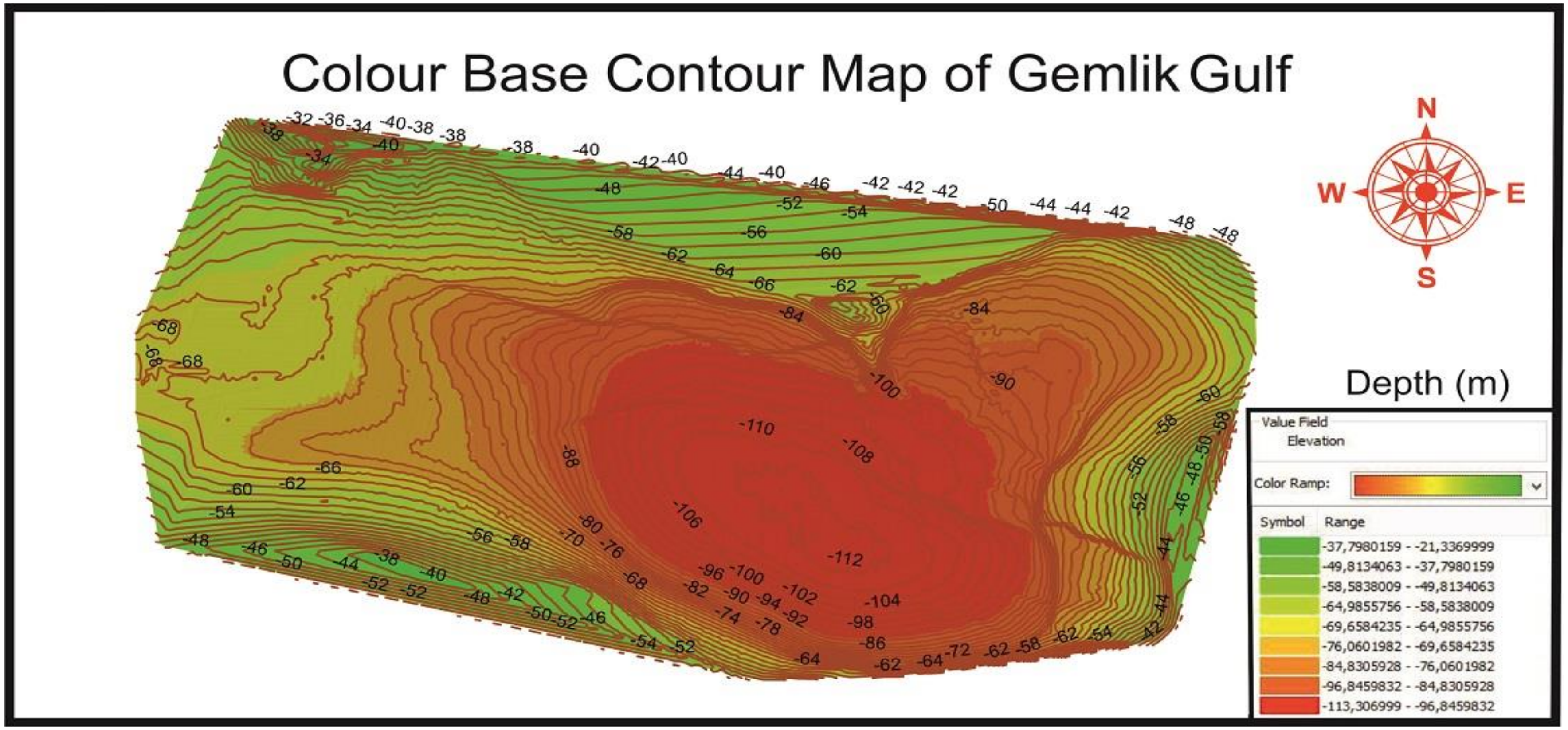

Figure 3.6 Contour Map of the Gemlik Gulf

The active fault map prepared on the basis of high resolution seismic sections and bathymetry is presented in Figures 3.7 and 3.8. There is perfect match between the active faults observed in the bathymetric map with those observed in seismic profiles.

The distribution of the faults indicate that the seafloor in the eastern half of the gulf is highly deformed due to extensive, east–west trending short (secondary) fault segments, especially in the vicinity of the Gemlik Rise. West of the line between Mudanya– Armutlu towns, the faults are become seldom and simpler (Figure 3.8)

We labeled the main faults, with the initial letter of their names. These include Armutlu Fault (AF); Kocadere Fault (KF); Gemlik Fault (GmF) and Gençali Fault (GF). All faults are drawn in black coloured line on seismic profiles and named shortly based on initial letters of each fault. For example, the Armutlu Fault is AF; Gençali Fault is GF, and secondary faults are labeled as SF.

The main faults played a significant role in the present day morphology of the Gemlik Basin. The trend of the Armutlu and Kocadere faults are in SSW, whereas the Gençali and Gemlik faults trend E. Bathymetric and seismic data indicate that the Kocadere and Gemlik Faults are likely to be connected in the area. The left step between the right lateral Gemlik and the Kocadere Faults is responsible for the formation of the Gemlik Rise as a push-up structure, which is clearly seen as a bulge in the offshore are in the east of Gemlik Gulf and as the high topography with respect to the Gençali Delta plain in the southeastern shore of the gulf on land. Likewise, the secondary faults are rather short and have small vertical offsets. We present the general characteristics of the main faults below (Figure 3.8).

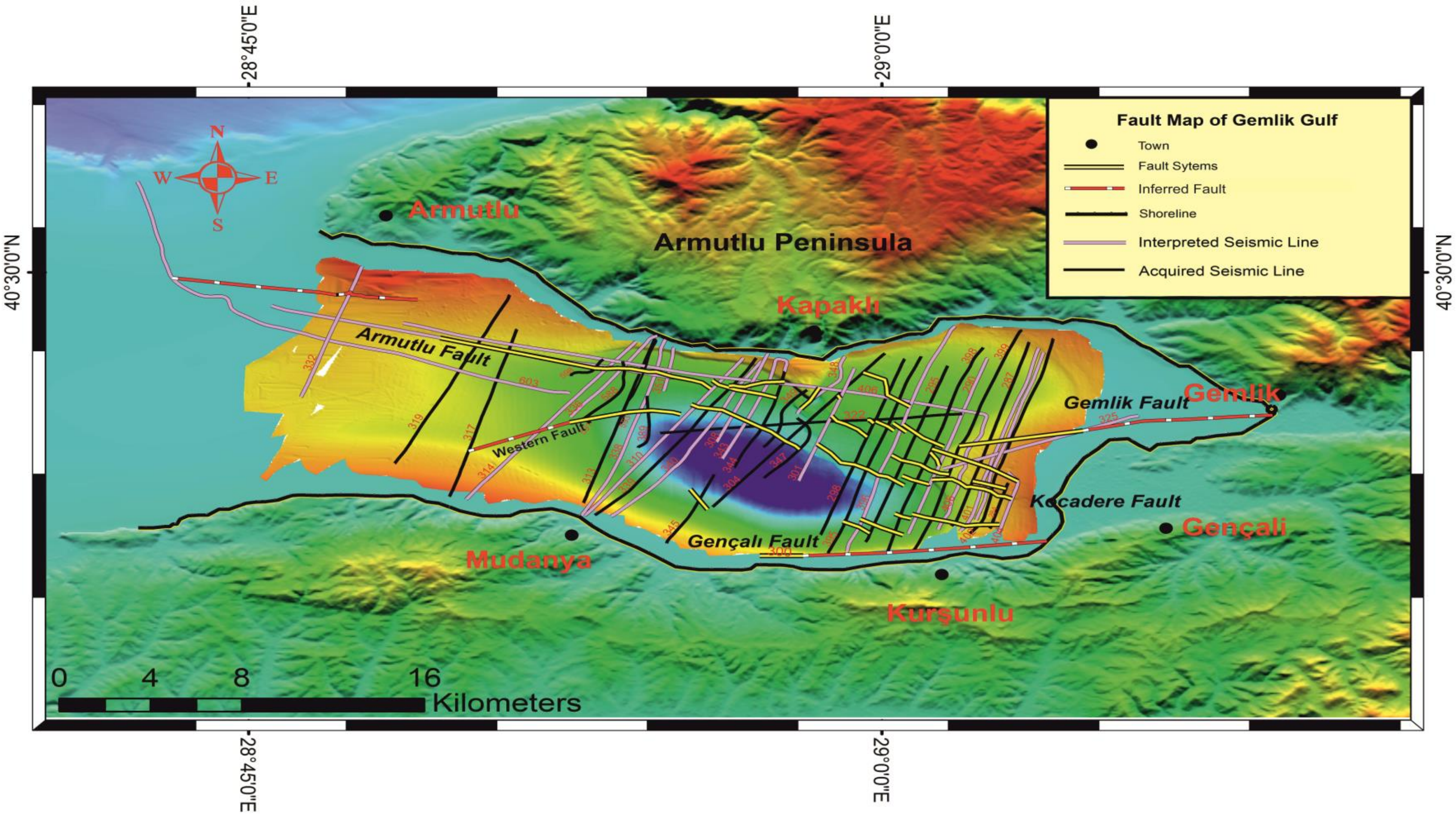

Figure 3.7 Faults map of Gemlik Gulf with high resolution seismic profiles crossing the faults

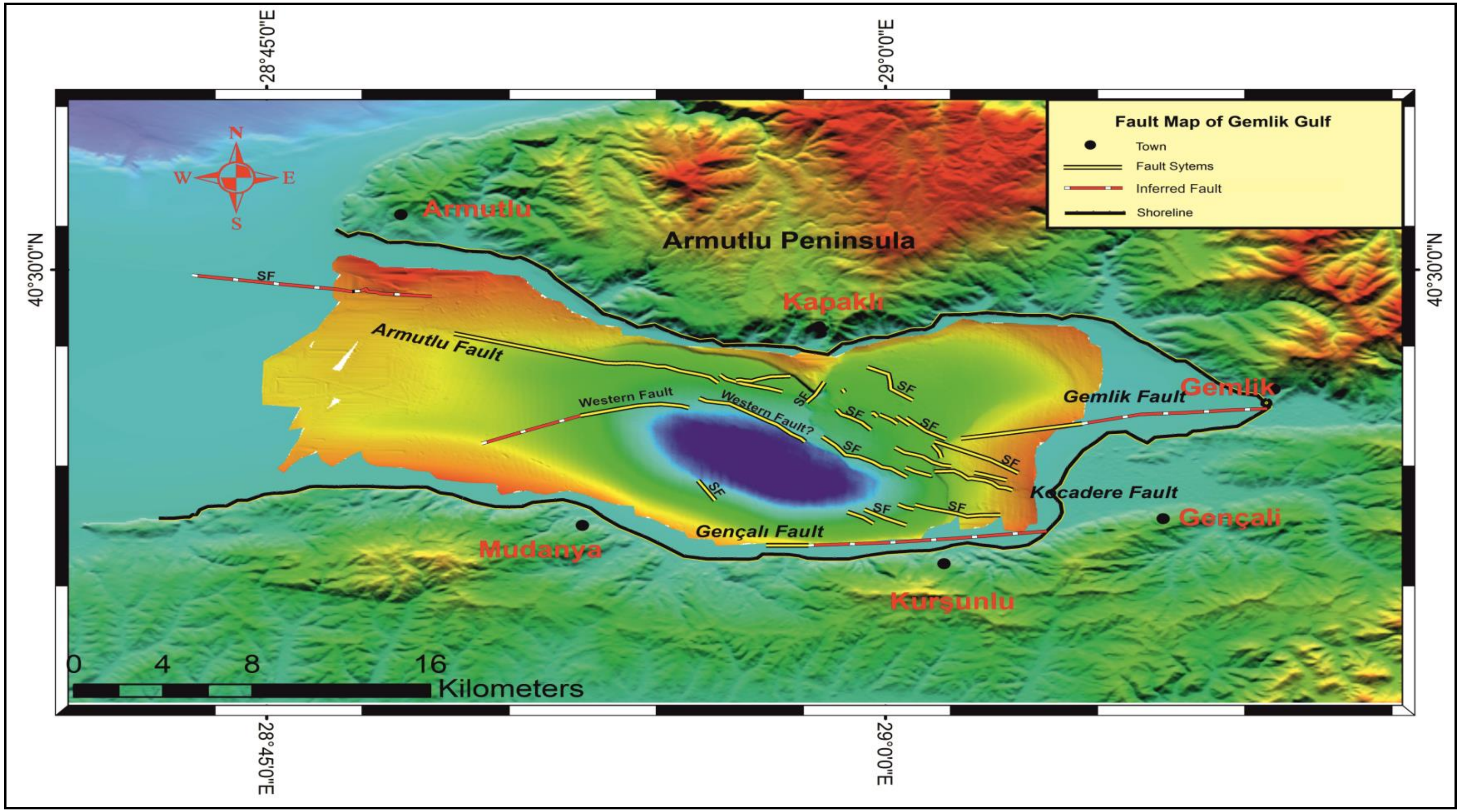

Figure 3.8 Fault Map of the Gemlik Gulf. Faults mapped as “inferred” are observed only in a few profiles

The Gemlik Fault is continuous with the on-land trace of the fault that underlies the town of Gemlik, and trends WSW approximately 12 km on the sea floor. Its northern side is downthrown, bounding the Gemlik Rise in the north. The Gemlik Fault is also clearly expressed seismic lines.
The Armutlu Fault trends WNW at the boundary between the gently sloping seafloor in the south and the steeper northern margin of the gulf southwest of Kapaklı. This is a very well-expressed fault with its downthrown southern block. Towards the west northwest, the fault ends in the bathymetric map (Figure 3.8).
The Kocadere Fault is present a discontinuous fault zone trending NW in the eastern part of Gemlik Fault (Figure 3.8). Kocadere Fault appears to intercept the Gemlik Fault at the western extension of Gençali Delta. The Kocadere Fault continues eastwards on land and intercepts the Gençali Fault.
The Gençali Fault trends E in the offshore area for at least 10 km along southeastern margin of Gemlik Gulf. Towards the east, it joins with its on land extension. The fault is an important structural element in evolution of the Gulf of Gemlik.
The Western Fault is about 8 km long and located south of the Armutlu Fault. It has a general NE-trend, curving towards east at its eastern tip. This fault is therefore mainly transpressional and may have been responsible for the uplift of the sill connecting Gemlik Gulf with the rest of the southern Marmara shelf.

3.5 Fault Geometry

In this section, we discuss the geometry of the Gemlik Gulf Fault System - with their length and vertical offset, and their inter-relationship with each other. For these we use both the bathymetric and high resolution seismic data.
Concerning the high resolution seismic data, we made detailed analysis of 29 seismic profiles of the total 114 profiles. However, almost all 114 profiles were used in producing the final fault map (Figures 3.7 and Figure 3.8).

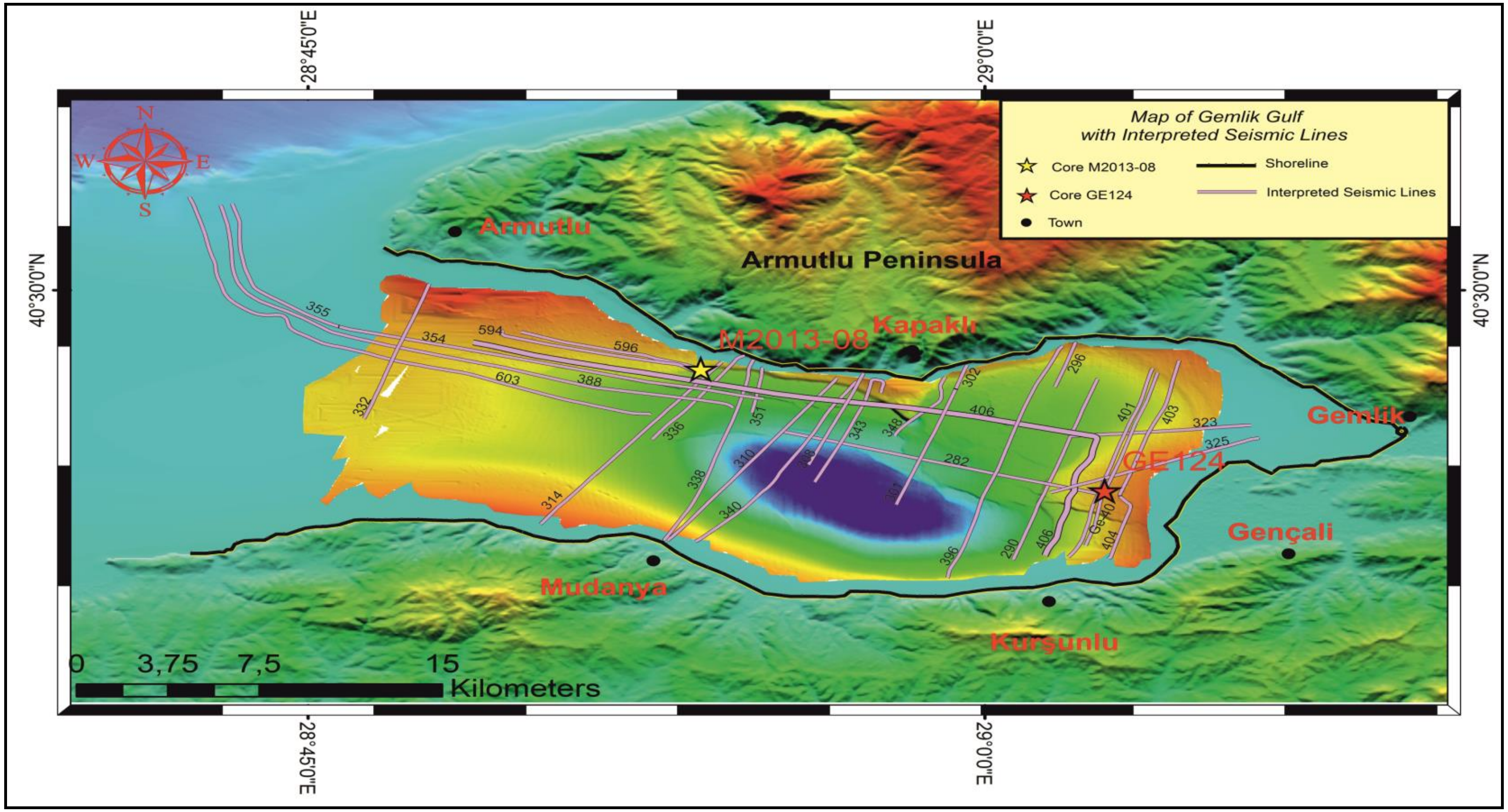

Figure 3.9 Interpreted seismic lines in Gemlik Gulf

In conformity with interpretation of the bathymetric map in terms of fault mapping and characterization, we classified the faults into 2 groups in the seismic profiles:

- Main faults - faults that could be clearly seen in our seismic profiles and bathymetric maps. These included the Armutlu, Gemlik, Gençali, Kocadere and Western faults,
- Secondary faults are short (<3 km) minor faults that are mainly observed in the vicinity of the major faults.

The overall description of the major faults based on both high resolution seismic reflection and bathymetric data are presented below.

The Armutlu Fault (AF) is approximately 16km long and extends in WNW-ESE direction following the boundary between the gently sloping deeper and the steeper northern margin of the Gemlik Gulf basin southwest of Kapaklı. The dextral AF is intercepted by eighteen seismic profiles. These profiles from west to east are: 319, 317, 406, 598, 314, 354, 336, 313, 593, 338, 351, 310, 339, 340, 308, 343, 344, and 348. Vertical offset varies considerably high resolution seismic between 1.2 m and 6.2 m along the AF. The highest vertical displacement is observed in the profiles 308, 351 and 589 in the NW of the Burgaz Basin, offshore area SW of Kapaklı (Figures 3.6 and 3.7). In contrary, the minimum vertical displacement of AF is 1.2 m in the profile #319, close to the western tip of the fault (Table 3.1).

Table 3.1 The length and vertical offset of Armutlu Fault in different seismic profiles in Gemlik Gulf (+ displays lines on which AF observed)

Seismic line №	Armutlu Fault	Vertical displacement
284		
287		
290		
300		
308	+	6.2m
310	+	4.60m
313	+	4.58m
314	+	2.30m
317	+	2.00m
319	+	1.20m
336	+	1.70m
338	+	3.10m
339	+	1.50m
340	+	5.40m
343	+	5.41m
344	+	2.30m
348	+	Around pressure rich zone
349		
351	+	6.20m
354	+	2.32m
398		
401		
402		
406	+	2.17m
598	+	6.20m
593	+	3.10m

The Kocadere Fault (KF) is ~9km long discontinuous right lateral fault zone with several faults aligned in SW-NE direction in east of Gemlik Gulf (Figure 3.7). The KF is intercepted in seismic profiles #290, 399, 406, 287, 401, 402, and 284 (Table 3.2). Vertical offset along this fault varies 3.12 m and 8.53 m. The maximum displacement occurs in SE tip of the fault 8.53m seen in profile #284 (Table 3.2). The minimum vertical offset is observed in middle of the line 290 at the western end of the Gençali Delta (Figure 3.7). Compared to the AF, the KF displays a consistent increase in the values of vertical displacement towards SE.

Table 3.2 The length and vertical offset of Kocadere Fault in different seismic profiles in Gemlik Gulf (+ displays lines on which KF observed)

Seismic line №	Kocadere Fault	Vertical displacement
284	+	8.53m
287	+	5.42m
290	+	3.12m
300		
308		
310		
313		
338		
339		
340		
343		
344		
348		
349		
398		
399	+	2.71m
401	+	6.97m
402	+	7.74m
406	+	7.77m

The Gençali Fault (GF) can be followed for 10km in the offshore from its onland exposure. It is only intercepted by only one seismic profile (profile #300), where the vertical displacement on the eastern block is only 1.2 m. The other seismic profiles on the southern side of the Gemlik gulf do not reach the fault itself, which prevents a detailed analysis of the fault.

The Gemlik Fault (GmF) is 11km long continuous dextral fault in the eastern Gemlik Gulf. It has a slight WNW trend, which suggests its transpressional character (Figure 3.7). The GmF is intercepted by seismic profiles 398, 290, 399, and 325. The vertical offset in these profiles along the GmF are 1.20m, 6.97m, 1.10m, and 2.20m, respectively (Table 3.3).

Table 3.3 The length and vertical offset of Gemlik Fault in different seismic profiles in Gemlik Gulf (+ displays lines on which GmF observed)

Seismic line №	Gemlik Fault	Vertical displacement
284		
287		
290	+	6.97m
300		
308		
314		
317		
319		
325	+	2.20m
344		
348		
349		
351		
354		
398	+	1.30m
399	+	1.10m
401		

The Western Fault: (WF) is ~8km long continuous dextral fault in the western Gemlik Gulf. It has a slight WSW trend, which suggests its transpressional character (Figure 3.7). The WF is intercepted by seismic profiles 313, 317, 338, 389, 588, 591 and 593. The vertical offset in these profiles along the WF are 2.20m, 1.02m, 2.25m, 1.20m, 0,87m, 1.11m and 1.93m, respectively (Table 3.4).

Table 3.4 The length and vertical offset of Western Fault in different seismic profiles in Gemlik Gulf (+ displays lines on which WF observed)

Seismic line №	Western Fault	Vertical displacement
284		
287		
310		
313	+	2.20m
314		
317	+	1.02m
319		
325		
336		
338	+	2.25m
339		
340		
343		
351		
354		
389	+	1.20m
399		
406		
588	+	0.87m
591	+	1.11m
593	+	1.93m

The geometry of the right lateral Gençali Fault extending along the southern margin of the bay and the right-lateral Armutlu Fault extending sub-parallel to the Armutlu Peninsula are organized in a releasing step, which is responsible for creation of the WNW trending oval Burgaz Depression as a pull-apart basin in the center of the gulf, as has been previously suggested by Kuşçu et al. (2011). The basin margins are characterized by the presence of normal faults dipping toward the depocenter. The transpressional Gemlik Fault and the Western Fault are most probably responsible for the Gemlik uplift and the Gemlik sill located in the east and west of Gemlik Gulf, respectively.

4. DISCUSSION

4.1 Morphotectonic Evolution of Gemlik Gulf

Relatively fewer studies were carried out on the middle strand of NAF, compared with the most active northern strand (i.e., the Main Marmara Fault of Le Pichon et al., 2001). However, several previous studies are available on the morphotectonic evolution of Gemlik Gulf, including the paleogeographic evolution, the main fault systems and their dynamics (see section 1.2 Literature Review). Among these studies we may highlight Barka and Kadinsky-Cade (1988), Yaltırak and Alpar (2002) Gasperini (2013), Kurtuluş and Canbay (2007), Kuşçu et al., (2009) and Vardar et al. (2014).

Our new fault map of Gemlik Gulf based on high resolution seismic profiles and multi beam bathymetry fault map presented in Figure 3.8 shows that the main faults are Armutlu Fault (AF), Gemlik Fault (GmF), Kocadere fault (KF), Gençali Fault (GF) and Western Fault (WF). There are also, mainly NW trending minor or secondary faults (see Appendices; seismic profiles; e.g., #406, 343, 603). These main faults are long (>5 km) and large have vertical offsets (>1 m) and significant seafloor expressions on the bathymetry.

Comparing our fault map with that of that of the previous studies, we find similarities and difference. For example, in Barka and Kusçu's (1996) fault map Armutlu, Gençali, Gemlik, Kocadere and Western Faults are present. However, many of the details and minor faults are missing because their map is based mainly on morphology and single beam bathymetry. Yaltırak and Alpar's (2002) fault map is more detailed than that of Barka and Kuşçu (1996), and also shows the same faults in the Gemlik Gulf with other NW-trending faults offshore Mudanya which were also shown lately on the fault map of Kuşçu et al (2009). We could not detect the ENE-trending Mudanya Fault, even though the area is covered by our seismic lines. Moreover, two secondary faults traced by (Kuşçu et al., 2009), could not be detected by our study. One of them is located north of the Armutlu fault (offshore south-west of Kapakli town), and second one is in offshore along north-east coast of Gemlik Gulf. Even though fault-like expressions of these faults appear on the bathymetry map, their presence is not confirmed by our high resolution seismic profiles. Recently, Vardar et al. (2014) produced a fault map of the southern Marmara shelf, including Gemlik Gulf. In this map the authors label the Gemlik Fault as the “New Segment” and show the Gençali Fault with NE-trend, rather than it’s approximately E-trend shown on our map and on many previous studies. They trace another NW-trending fault north of the Armutlu Fault, with these two faults merging offshore south of the Kapaklı town. We have no evidence of the fault south of the Armutlu fault.

Despite these differences, our fault map shows that the five main faults have played a significant role in the evolution of Gemlik Basin, which is consistent with the most previous studies (e.g., Yaltırak and Alpar, 2002; Kuşçu et al., 2009). The central Burgaz depression is a pull-apart basin formed as a result of right stepping Gençali and Armutlu Faults and the Gemlik Rise as a push-up structure has evolved because of the left-stepping of Gemlik and the Kocadere Faults. The high topography of the southern shore of the eastern Gemlik Gulf is also an uplift structure, which rises above the Gençali Delta plain in the north. Our core chronostratigraphic and seismic stratigraphic correlations show that the Gençali Delta, in the east and the amalgamation of small deltas along the northern margin, as important morphological elements of Gemlik Gulf, started forming 15.8 ka BP under lacustrine conditions, which ended by 10.6 ka BP with the marine transgression. This finding is in disagreement with 30 ka age of the delta assigned by Vardar et al. (2014).

Bathymetry map and seismic profiles confirms that the central area of the Gemlik Gulf is not much affected by imprinting faults; instead, shorter faults bounding the Burgaz Depression are observed. Moreover, in bathymetry map we can assume that Kocadere and Gemlik Faults are likely connected in the area based on their direction of extension (Figure 3.8). It shows that the Gemlik Fault which represents the main southern strand of the NAF in the east makes a left step over to the Kocadere Fault.

The slip rate along the important Gemlik Fault is estimated to be 4 mm/yr by Vardar et al. (2014), based on the 60±5 m lateral offset in the last 30 ka. Even though this estimate is consistent with geodetic models of McClusky et al. (2000) and Meade et al. (2002) giving a slip rate of about 2 mm/yr for the middle NAF strand, it is based on Sea of Marmara assumptions that need to be tested. The estimate assumes that the Gemlik fault as a “new segment” started its activity 30 ka BP, the age of the erosion surface estimated from the correlation of the seismic stratigraphic unit with the global sea level curve. Our age direct estimate for the same erosion surface from the radiocarbon dated Core GE124 is 15.8 ka BP. This result and a recent study by Çağatay et al. (2015) shows that the seismic stratigraphic units in the Sea of Marmara cannot be strictly correlated with the global sea level curves mainly because of the changes in the Çanakkale Strait’s sill depth. Previously Gasperini et al. (2011) determined a lateral offset 42 ± 4 m on the delta front along the Gemlik Gulf and estimated a slip rate of 4 mm/yr over the last 11 ka BP, with this age corresponding to the age of marine transgression and abandonment of the delta. This age and the interpretation are in agreement with our results. Geologic slip rate of Gasperini et al. (2011) suggests that the middle strand has been more active over the last 11 ka than its recent activity. Therefore, this strand poses a greater earthquake risk than suggested by the geodetic data.

In the southwest of Gemlik gulf, the quality of the seismic data is poor due to poor penetration. There are multiples on the data where it shows a strong impedance contrast between the water and seafloor, suggesting that the southwestern shelf is made of basement rocks or old consolidated sediments. Numerous active faults convey gas seepages from sediments into the water column, which an indicator of active tectonics in Gemlik Gulf.

4.2 Late Pleistocene- Holocene Water Level Changes

Our detailed core stratigraphy together with the seismic stratigraphy provides evidence of post-glacial water level changes in the Gemlik Gulf. In the seismic profiles, the four main seismic stratigraphic units covering the time period for the last 15 ka BP were defined and dated on the basis of core-to-seismic stratigraphic correlations. The depositional history of these chronostratigraphic units was presumably governed by water level changes in the gulf, which might have been affected by mainly local climate and also sea-level changes in the Sea of Marmara. During the post-glacial period, the water level changes in the Sea of Marmara and water mass exchange with the global sea-level via the Mediterranean Sea have been well documented by previous researches (Aksu et al., 2002; M. Çağatay et al., 2009; Çağatay et al., 2015; Eriş et al., 2007; Eriş et al., 2010; Eriş et al., 2012; Hiscott et al., 2002; McHugh et al., 2014; Vidal et al., 2010). When global sea-level dropped below the Çanakkale Strait bedrock sill at around −83 m during Marine Isotope Stage 2 (MIS 2) of the last glacial period, the Sea of Marmara lost its Mediterranean input and freshened accordingly with fresh waters from Black Sea that was supplied by rivers, rain and ice sheet melting (Chepalyga, 1995; Chepalyga, 2007; Ryan et al., 2003; Major et al., 2006; Bahr et al., 2006; Bahr et al., 2008;). Marmara sediments record the freshening of this seaway by the presence of a Neoeuxine fauna including Dreissena rostriformis (bivalve) and Spiniferites cruciformis (dinoflagellate cyst), sensitive indicators of fresh to slightly brackish conditions (Aksu et al., 2002; M. Çağatay et al., 2009; M. N. Çağatay et al., 2015; Kaminski et al., 2002; Mudie et al., 2007).

The vertical resolution of the seismic data in the Gemlik Gulf allowed us to define the depositional unit S4 that is older than 15.8 ka BP on the basis of core-to-seismic correlation. This depositional period in the gulf corresponds to post-glacial period in MIS-2. The seismic configuration of this unit, with parallel bedded mud drape character, can be attributed to the transgressive phase of water level in the Gemlik Gulf prior to 15.8 ka BP. Previous researches concur that water level of the Sea of Marmara was below −110 m during the Late Glacial Maximum (LGM) due to a disconnection from the global ocean (Çağatay et al., 2000, Çağatay et al., 2009; Çağatay et al., 2015; Eriş et al., 2007; Eriş et al., 2010; McHugh et al., 2014; Vidal et al., 2010). A post-glacial transgression in the Sea of Marmara occurred only after 16 ka BP due to an intense Black Sea outflow via the Bosphorus (Chepalyga, 1995; Chepalyga, 2007; Ryan et al., 2003; Bahr et al., 2006; Bahr et al., 2008; Major et al., 2006; Eriş et al., 2007; Eriş et al., 2010; Eriş et al., 2012; Çağatay et a., 2015). This highstand for Black Sea level occurred because of the collapse of the Eurasian ice sheets, synchronous with the North Atlantic Heinrich event 1 (H1). Considering presence of the −55 m sill between the North İmralı Basin and the Gemlik Gulf, there was not any water exchange between the Gemlik Gulf and the Sea of Marmara during the sea-level lowstand until at least 16 ka BP. For this reason, the transgressive water level in the Gemlik Gulf cannot be associated with the post-glacial transgression in the Sea of Marmara prior to 15.8 ka BP, when Unit S4 was deposited in the Gulf. After this time, erosional gullies formed at 15.8 ka BP on the northern slope of Gemlik Gulf, which are represented by the blue reflection surface in the profiles (see Appendices; profiles #314, 336, 338, 348, 351, 406). This erosional surface could be formed during water level decrease due to an excess evaporation in the Gemlik lake at around 15.8 ka BP, when high sediment supply from the land may have favoured the powerful sediment gravity flows. Such an evaporative drawdown of water level in the Gemlik Gulf seems to have been maintained for a very short duration, while the depositional nature of Unit S3 over the erosional blue reflector demonstrates the existence of a transgressive water level rise from 15.8 ka to 13.9 ka BP. In the seismic profiles, the erosional gullies were filled by parallel bedded mud drapes (Unit S3) on the shelf slopes during this transgressive water level, whereas Gilbert-type deltaic deposition are documented in the eastern and northern margins of the gulf. This transgression in the Gemlik Gulf after 15.8 ka BP can be explained by two different hypotheses. First, if we consider the existence of the −55 m threshold that must be breached in the case of connection with the Sea of Marmara, the most plausible reason for such a transgression in the gulf is the excess precipitation by high river discharges. This option can also explain the deposition of deltaic units in the profiles. Another approach for explaining the transgression in the gulf might be a possible water connection with the Sea of Marmara. In this situation, we must take into consideration of sill depth to be much deeper than −55 m, otherwise the water level in the Sea of Marmara between 15.8 ka BP and 13.9 ka BP could not have reached above this threshold, assuming that sill depth of the Çanakkale Strait was -84 m at the time (Ryan et al., 1997; Çağatay et al., 2009).

According to the studied seismic profiles, foresets were truncated by the yellow reflector at around −68 m. The yellow reflector is dated to be 13.9 ka BP on the basis radiocarbon chronology of Core GE-124 (Taviani et al., 2014; see AppendixC1). This truncation surface coincides with the formation of wave-cut platforms documented in the Gemlik Gulf seismic profiles (see Appendices; profiles #354, 388, 594, 596, 603). This finding demonstrates that water level of the Gemlik Gulf prior to 13.9 ka BP was around −68 m, when there was a still-stand for a while to form the extensive wave-cut platforms around the shelves. On the basis of the penetration of Core GE-124, deposition of Unit S2 in the Gemlik Gulf can be assumed to be later than 13.9 ka BP that is coincides with the age of yellow reflector in the profiles (see seismic stratigraphy section 3.2). The termination of Unit S2 is represented by the red reflector that has been dated 10.6 ka BP in Core M13-08. Seismic stratigraphic architecture of Unit S2 mainly indicates deposition of progradational clinoforms on the shelf edge, which are truncated by the red reflector. According to lithological description of Core M13-08, Unit S2 comprises well-sorted fine to medium sands with abundant freshwater molluscs that clearly implies deposition in a nearshore lacustrine environment during a progradation. An existence of such progradation between 13.9 ka BP and 10.6 ka BP clearly indicates that a regression occurred during the Bølling-Allerød (B/A) and Younger Dryas (YD) periods during the late MIS-2. Around the Marmara region, lower lake levels due to reduced freshwater inputs and excess of evaporation have been documented during the Bølling-Allerød (B/A) and preboreal warm periods (Leroy et al., 2002; Viehberg et al., 2012).

In the Gemlik Gulf profiles, Unit S2 has been observed as a berm deposit covered by the red reflector with the age of 10.6 ka BP. The water depth of the berm deposits ranges from −63 m to −68 m, indicating a paleoshoreline during a stillstand water level in the Gemlik Gulf prior to the marine transgression at 10.6 ka BP. The existence of similar erosional truncation surface elsewhere in the Sea of Marmara has been documented by high resolution seismic data, and attributed to a stillstand sea-level during the termination of YD (Çağatay et al., 2003, 2009; Eriş et al., 2007, 2010). This indicates that the water level in the gulf would be nearly 10 m lower than the Sea of Marmara at the time of the inundation by Sea of Marmara waters, while the global ocean level was around −55 m at 10.6 ka BP (Figure 4.1).

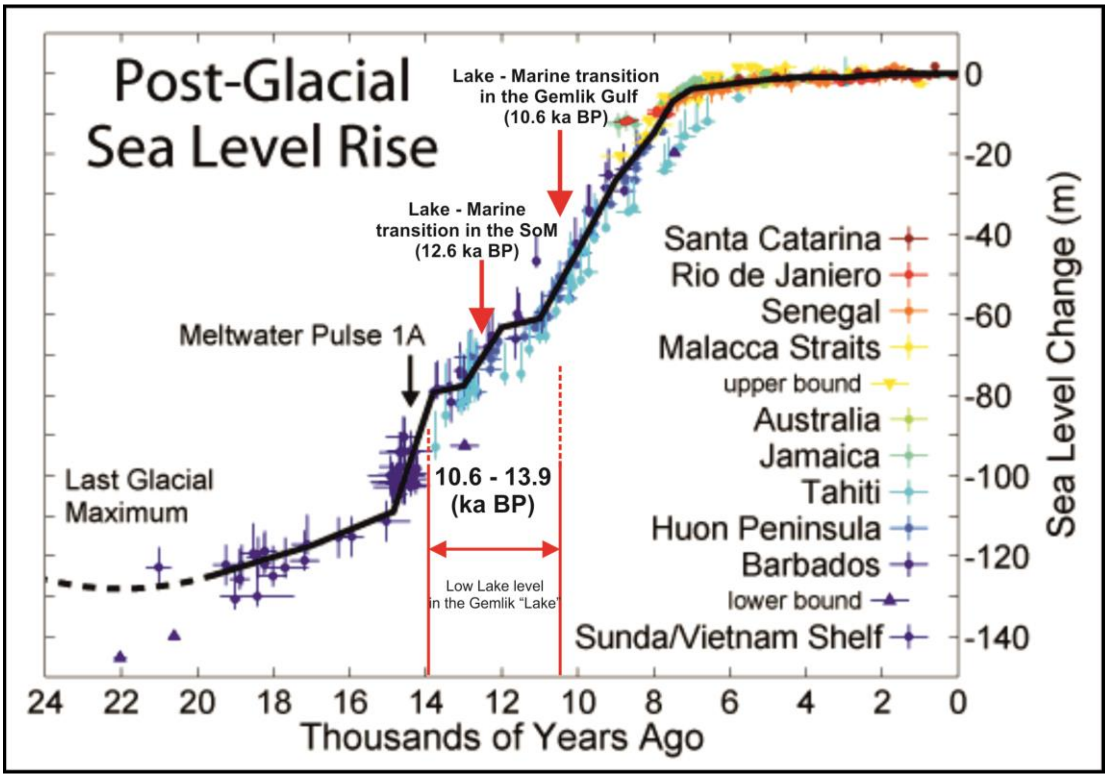

Figure 4.1 Paleoenvironmental changes and events in Gemlik Gulf, superimposed over global sea-level curve produced by Fleming et al. (1998), Fleming (2000), Milne et al. (2005).

This is also well consistent with the sill depth situated between the North İmralı Basin and the Gemlik Gulf and demonstrates that this threshold separating the Gemlik Gulf from the Sea of Marmara delayed the marine connection of the Gulf some hundred years after the connection of the Sea of Marmara with the Mediterranean Sea. After the inundation by salty waters, Unit S1 was deposited as a mud drape in the Gemlik Gulf. Onlapping nature of these sediments onto the red reflector (main unconformity surface) implies transgressive water level in the gulf after the Younger Dryas (YD). This is consistent with sea-level changes in the Sea of Marmara that has been well documented by many researches regarding to core and seismic studies over the Marmara shelves (Çağatay et al., 1999; 2000, 2003, 2009, 2015; Eriş et al., 2007, 2010; Aksu et al., 1999, 2002; Hiscott et al., 2002, 2007, 2008; McHugh et al., 2008, 2014; Vidal et al., 2010; Gasperini et al., 2011).

5. CONCLUSIONS AND RECOMMENDATIONS

In this study, the Quaternary paleoceanographic evolution and morphotectonics of the Gemlik Gulf are investigated mainly using of high resolution seismic, bathymetric and core stratigraphic data sets.

The studied 6.70m long Core M13-08 was analyzed magnetic susceptibility and performed ^{14}C radiocarbon analysis. According to ^{14}C dates and fossil content, Unit L1 (an upper marine unit) and Unit L2 (the lower lacustrine-deltaic unit) were identified. Mainly, Unit L2 shows fluctuation of high magnetic susceptibility, where the decrease in the magnetic susceptibility observed nearby the stratigraphic boundary that associated with an unconformity surface that separate the lacustrine to marine units in the studied core. Likewise, magnetic susceptibility values from base of Unit L1 up to 1.35 mbsf are low and do not display any remarkable change except for a small increase at the base of Unit L1. These low values are most probably due to the reduction of iron oxides. Seismic to core correlations approved that Unit L1 and L2 corresponds to seismic stratigraphic units Unit S1 and Unit S2, respectively.

Ages of the seismic stratigraphic units estimated by core-to-seismic correlations, using radiocarbon chronology of Core M13-08 and chronostratigraphic information from preciously studied Core GE-124. Although, every seismic unit corresponds to the features of related depositional environments. However, the Unit S1 formed by deposition of the youngest deposits and its base separates the upper marine and the lower lacustrine sediments in the Gemlik Gulf. Moreover, it was observed that S1 unit was deposited during the last 10.6 ka BP. Moving on from top to bottom unit S2 is truncated by the main unconformity surface in the profiles. This unit was deposited during 13.9-10.6 ka BP. Deltaic system is characterized by unit S3 that located on eastern and northern shelf margins of the Gulf and it was determined that unit S3 was deposited during 15.8-13.9 ka BP. The unit S4 is the oldest sedimentary unit, and specifically comprises mound-shaped sediments with wavy internal reflectors that are truncated or separated by erosional gullies formed on a reflector. In fact, unit S4 is older than 15.8 ka BP.

Main active faults in the area are roughly E-W oriented Gemlik, Kocadere, Gençali dextral transform faults. Vertical displacement and length of the main faults suggest that the deep Burgaz Basin of the Gemlik Gulf has evolved as a pull-apart basin between the Armutlu and Kocadere transform faults. The transpression by the Gemlik and Western Faults resulted in the Gemlik Uplift (Rise) in the east the Gemlik sill in the west of Gemlik Gulf. A new fault map of the Gulf created using the high resolution seismic profiles and the updated bathymetric map.

The core and seismic stratigraphic analyses show that the Gulf was a lacustrine environment prior to 10.6 ka BP, with lacustrine shelf-edge delta developments in the north and east during 15.8-13.9 ka BP. There was lowering of the lake level and erosion during part of the Bølling-Allerød and Younger Dryas, which was followed by the marine transgression at 10.6 ka BP, about one thousand years later than the first entry of Mediterranean waters in the Sea of Marmara. The reason for the 1 ka delay is the -55 m sill to the west of the Gemlik Gulf.

It is recommended that this study is extended to the west of the Gulf, using similar techniques of multi-beam bathymetric mapping, high resolution seismic reflection profiling and core analysis. The seismic reflection data is especially needed for the near shore areas along the southern shoreline of Gemlik Gulf.

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APPENDICES

Appendices cover the list of the interpreted seismic lines in this study (thesis). In next pages seismic profiles #GE-40, 302, 308, 325, 348, 354, 406 and 596 have been inserted here in jpg format. It will make easy to follow the seismic and there characteristics interpreted in the study area.

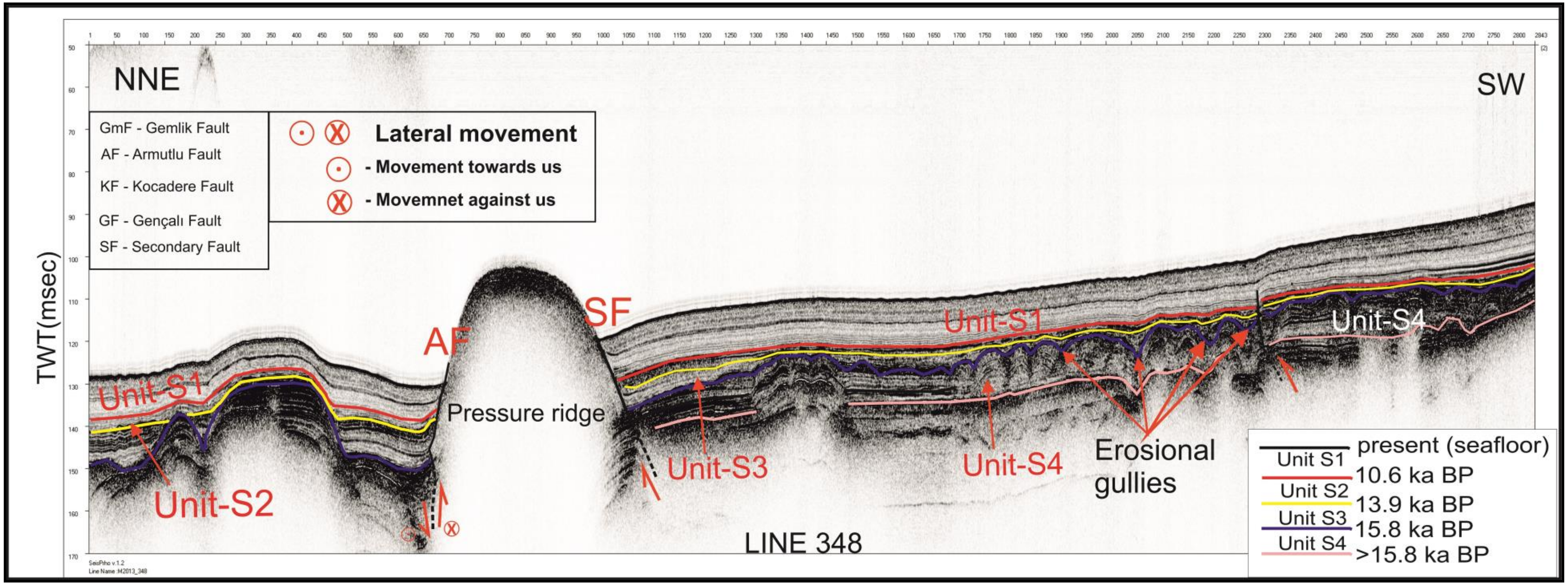
Rest of the seismic profiles (in jpg format), due to its huge storage size are uploaded to CD. CD is placed in an envelope attached to the inner side of the back cover of the thesis.

Here are the name and number of the seismic profiles (in jpg format) uploaded to CD:

1. Seismic profile #282 (vertical exaggeration is 8,9)
2. Seismic profile #290 (vertical exaggeration is 16,1)
3. Seismic profile #296 (vertical exaggeration is 17,1)
4. Seismic profile #301 (vertical exaggeration is 15,2)
5. Seismic profile #302 (vertical exaggeration is 13,3)
6. Seismic profile #308 (vertical exaggeration is 9,5)
7. Seismic profile #310 (vertical exaggeration is 7,6)
8. Seismic profile #314 (vertical exaggeration is 11,4)
9. Seismic profile #323 (vertical exaggeration is 15,2)
10. Seismic profile #325 (vertical exaggeration is 16,2)
11. Seismic profile #332 (vertical exaggeration is 9,5)
12. Seismic profile #336 (vertical exaggeration is 11,4)
13. Seismic profile #338 (vertical exaggeration is 7,6)
14. Seismic profile #340 (vertical exaggeration is 11,8)
15. Seismic profile #343 (vertical exaggeration is 10,5)
16. Seismic profile #348 (vertical exaggeration is 11,4)

17. Seismic profile #351 (vertical exaggeration is 11,4)
18. Seismic profile #354 (vertical exaggeration is 11,4)
19. Seismic profile #355 (vertical exaggeration is 19,1)
20. Seismic profile #388 (vertical exaggeration is 11,4)
21. Seismic profile #396 (vertical exaggeration is 11,4)
22. Seismic profile #401 (vertical exaggeration is 15,2)
23. Seismic profile #403 (vertical exaggeration is 19,1)
24. Seismic profile #404 (vertical exaggeration is 22,5)
25. Seismic profile #406 (vertical exaggeration is 1,1)
26. Seismic profile #594 (vertical exaggeration is 17,1)
27. Seismic profile #596 (vertical exaggeration is 2,7)
28. Seismic profile #603 (vertical exaggeration is 11,3)
29. Seismic profile #GE-40 (vertical exaggeration is 17,1)

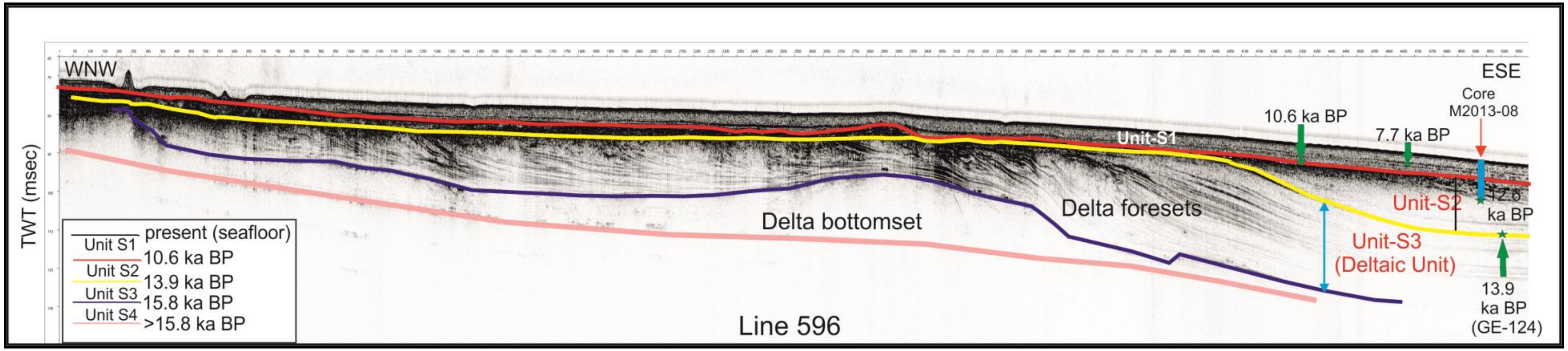
Appendix A



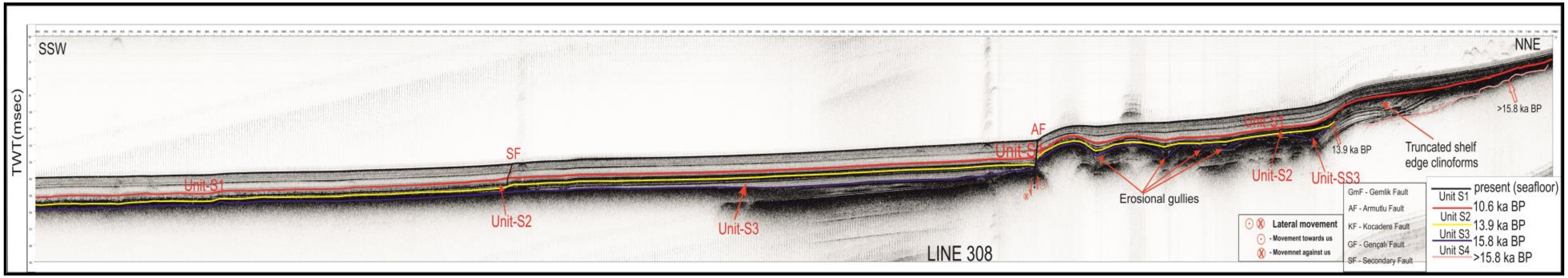
NNE
SW
GmF - Gemlik Fault
AF - Armutlu Fault
KF - Kocadere Fault
GF - Gençalı Fault
SF - Secondary Fault
Lateral movement
- Movement towards us
- Movemnet against us
TWT(msec)
AF
SF
Pressure ridge
Unit-S1
Unit-S1
Unit-S2
Unit-S3
Unit-S4
Unit-S4
Erosional gullies
LINE 348
Unit S1 present (seafloor)
10.6 ka BP
Unit S2 13.9 ka BP
Unit S3 15.8 ka BP
Unit S4 >15.8 ka BP

Appendix B

Appendix B1

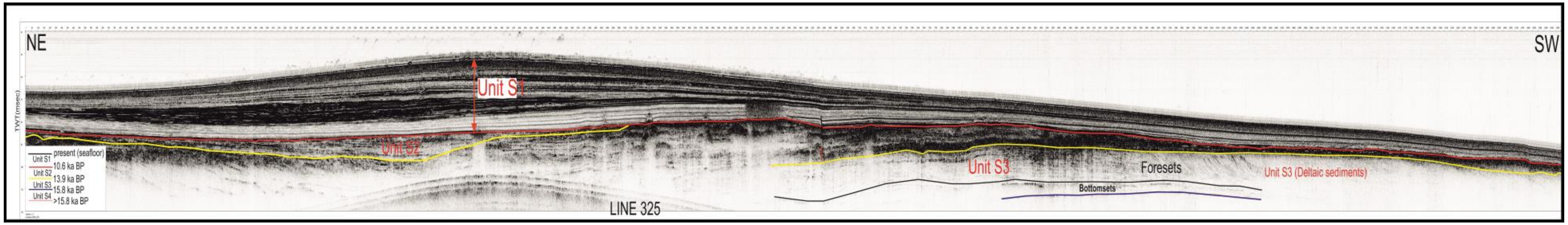


Appendix B2



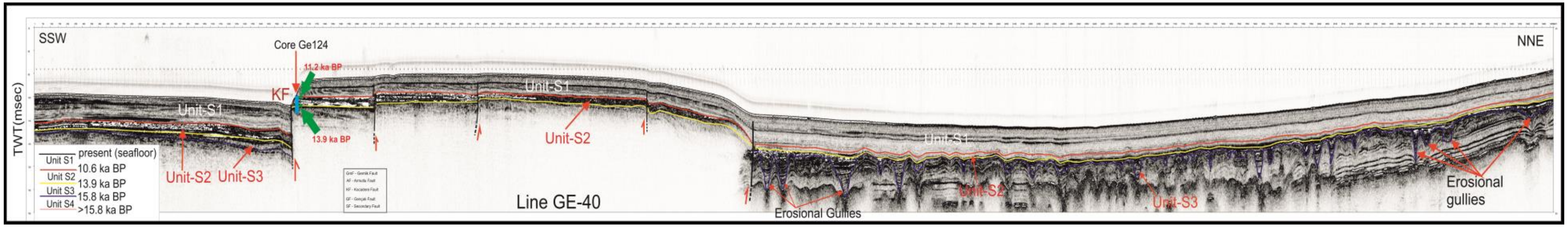
SSW
NNE
TWT(msec)
SF
AF
Unit-S1
Unit-S2
Unit-S3
Unit-SS3
Erosional gullies
13.9 ka BP
>15.8 ka BP
Truncated shelf
edge clinoforms
LINE 308
Lateral movement
- Movement towards us
- Movemnet against us
GmF - Gemlik Fault
AF - Armutlu Fault
KF - Kocadere Fault
GF - Gençalı Fault
SF - Secondary Fault
Unit S1
present (seafloor)
Unit S2
10.6 ka BP
Unit S3
13.9 ka BP
Unit S4
15.8 ka BP
>15.8 ka BP

Appendix B3

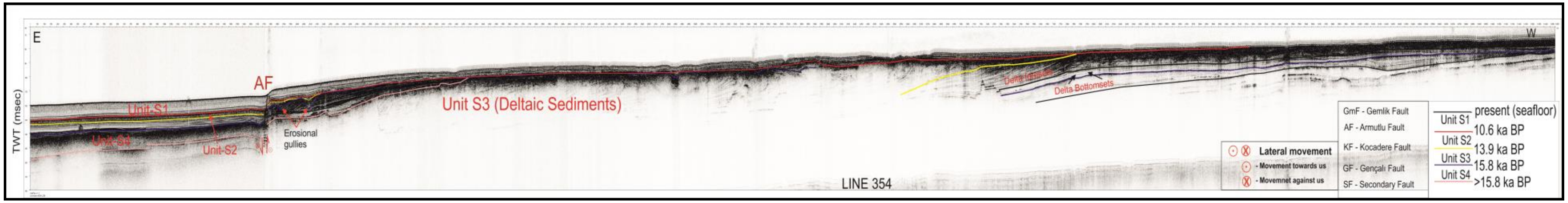

NE
SW
Unit S1
Unit S2
Unit S3
Foresets
Bottomsets
Unit S3 (Deltaic sediments)
LINE 325
TWT (msec)
Unit S1
Unit S2
Unit S3
Unit S4
present (seafloor)
10.6 ka BP
13.9 ka BP
15.8 ka BP
>15.8 ka BP

Appendix C

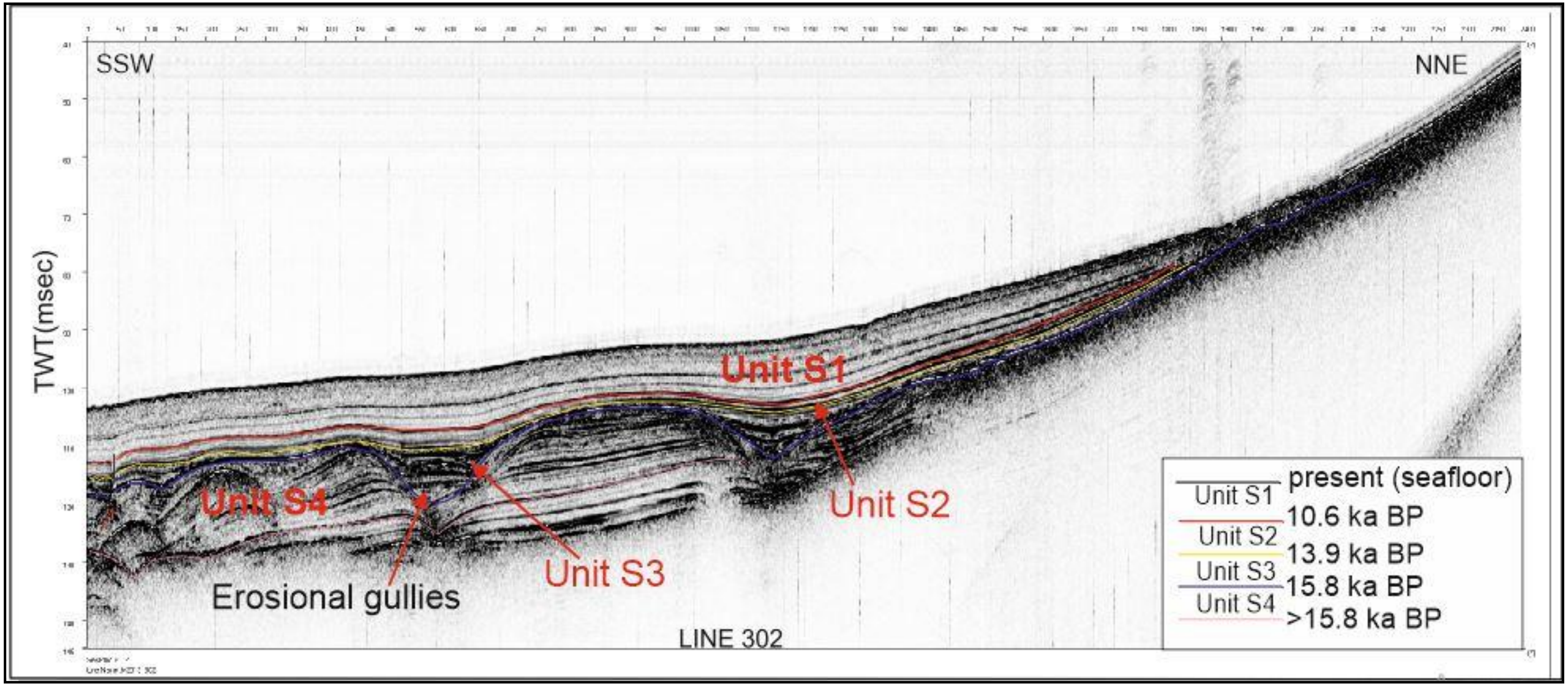
Appendix C1



Appendix C2

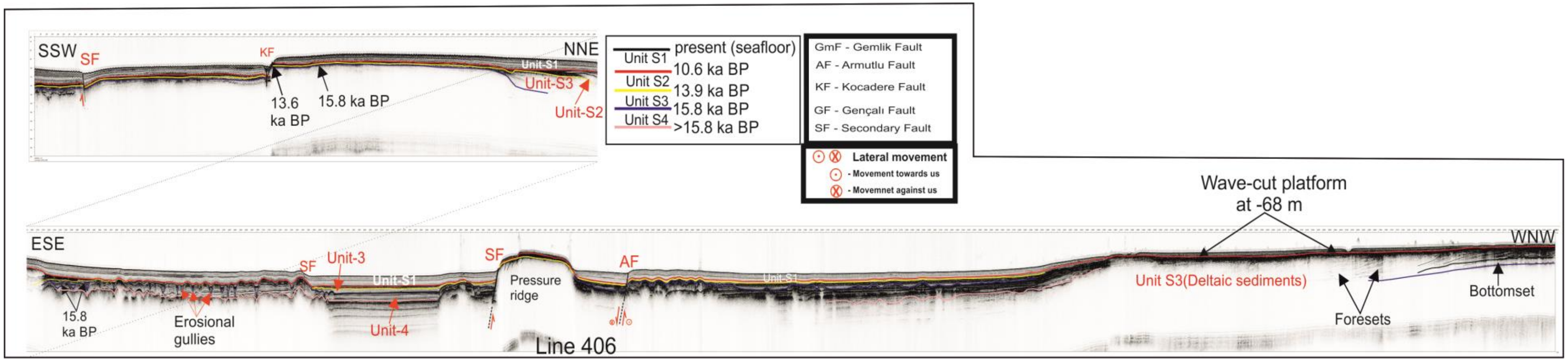

E
W
TWT (msec)
AF
Unit-S1
Unit-S2
Unit-S4
Erosional gullies
Unit S3 (Deltaic Sediments)
Delta Bottomsets
LINE 354
Lateral movement
- Movement towards us
- Movemnet against us
GmF - Gemlik Fault
AF - Armutlu Fault
KF - Kocadere Fault
GF - Gençalı Fault
SF - Secondary Fault
present (seafloor)
Unit S1
10.6 ka BP
Unit S2
13.9 ka BP
Unit S3
15.8 ka BP
Unit S4
>15.8 ka BP

Appendix D



SSW
NNE
TWT(msec)
Unit S1
Unit S2
Unit S3
Unit S4
Erosional gullies
LINE 302
Unit S1
Unit S2
Unit S3
Unit S4
present (seafloor)
10.6 ka BP
13.9 ka BP
15.8 ka BP
>15.8 ka BP

Appendix E



SSW
SF
KF
NNE
Unit-S1
Unit-S3
Unit-S2
13.6 ka BP
15.8 ka BP
Unit S1 present (seafloor)
Unit S2 10.6 ka BP
Unit S3 13.9 ka BP
Unit S4 15.8 ka BP
>15.8 ka BP
GmF - Gemlik Fault
AF - Armutlu Fault
KF - Kocadere Fault
GF - Gençalı Fault
SF - Secondary Fault
Lateral movement
- Movement towards us
- Movemnet against us
Wave-cut platform at -68 m
ESE
WNW
SF
Unit-3
Unit-S1
SF
Pressure ridge
AF
Unit-S1
Unit S3(Deltaic sediments)
15.8 ka BP
Erosional gullies
Unit-4
Line 406
Foresets
Bottomset

CURRICULUM VITAE (CV)

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