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RESEARCH ARTICLE

Investigation of active tectonics of Edremit Gulf, Western Anatolia (Turkey), using high-resolution multi-channel marine seismic data

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ABSTRACT

The Edremit Gulf is situated on the upper Miocene transtensional basin in the Western Anatolia and formed by the interaction between the North Anatolian Fault (NAF) and the N-S extensional tectonic regime of the Aegean domain. Our study is aimed to investigate the structural effects of these tectonic forces in the Gulf. Thus, approximately 300km. seismic data were collected within the Gulf area using the high-resolution seismic reflection method. The results indicated that the interpretation of the data, an E-W oriented, strike-slip fault system (Edremit Bay Fault - EBF) was identified in the Gulf as a possible continuation of the Havran - Balıkesir Fault Zone which can be followed on land. Likewise, a second strike-slip fault system (Edremit - Lesbos Fault; ELF) was observed which crosses the Gulf towards Lesbos Island in the NE-SW direction. This system was interpreted as the possible continuation of the Yenice - Gönen Fault Zone which is thought to be the branch of the North Anatolian Fault.

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Introduction

Edremit Gulf is a basin, located in the eastern Mediterranean, Aegean Sea, between the Biga Peninsula at the north, the Lesbos Island at the west and the Madra Mountains at the south. It is connected to the Aegean Sea by Müsellim Strait at the west and Dikili Strait (or Lesbos Strait) at the South (Figure 1). It has been shaped by both westward progression and N-S oriented extension of the Anatolian Plate (Dewey and Şengör, 1979; Barka and Reilinger, 1997; Yılmaz, 1997; Armijo, Meyer, Hubert and Barka, 1999; Yılmaz et al., 2000; Westaway, 2003) (Figure 2).

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A counter-clockwise rotation of the Aegean Region has proven by numerous studies, especially by GPS measurements (Le Pichon, Chamot-Rooke, Lallemant, Noomen and Veis, 1995; Oral et al., 1995; Yılmaz et al., 2000; Boztepe Güney et al., 2001) (Figure 2).

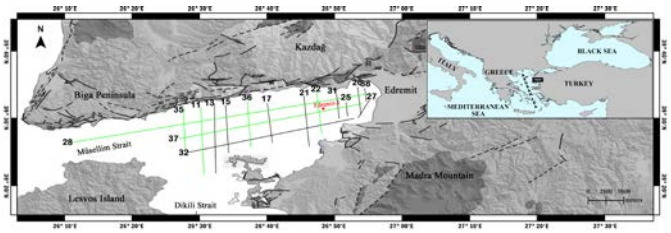

Figure 1. Location map of the research area and survey lines (green ones are presented in the paper) with Edremit-1 borehole location, compiled from (Boztepe Güney et al., 2001; Kurtuluş, Doğan, Sertçelik, Canbay and Küçük, 2009; Gürer et al., 2016).

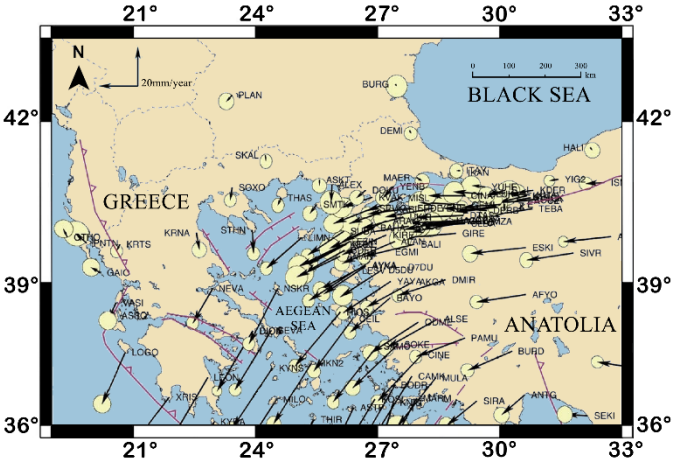

Figure 2. Western Anatolian speed vectors (Le Pichon et al., 1995; Oral et al., 1995; McClusky et al., 2000; Yılmaz et al., 2000; Boztepe Güney et al., 2001; Tur et al., 2015)

Besides, Paleomagnetic studies also prove that the Edremit Gulf region was affected by a counterclockwise rotation during the Pliocene-Quaternary times (İşseven et al., 1995; Orbay et al., 1999; Sözbilir, et al., 2016a). The gulf is affected by NE-SW trending fault zones such as Yenice – Gönen Fault Zone (YGFZ), Edremit Fault Zone (EFZ) and Havran – Balıkesir Fault Zone (HBFZ). The seismotectonic analysis shows that most of the faults of Edremit Gulf and surroundings are right lateral and strike-slip faults (Sözbilir et al., 2016b) (Figure 3b).

Paleostress studies done in the study area show that there is a dominant NE-SW opening regime that dominates the region. This model shows the main effects of the North Anatolian Fault System and the Aegean Region Extension System on the region (Gürer et al., 2016) (Figure 3b).

Despite many types of research in the region, most of all are focused on land and marine neotectonics studies are quite small in number. While Kurtuluş et al. (2009) evaluated 21 deep seismic profiles in the inner and middle parts of the Gulf of Edremit by 2009, Çiftçi, Temel and Terzioğlu (2004) demonstrated the Neogene stratigraphy in and around the gulf. The aim of this article is to contribute to such marine studies and to connect both the land and marine tectonic structures to better understand the regional tectonism.

Figure 3. Tectonic map of Anatolian Plate (EAF; East Anatolian Fault, NAF; North Anatolian Fault) (**a**) and North Western Anatolia (**b**) compiled from Kaymakçı, 2006; Özkaymak, 2015; Sözbilir et al., 2016a.

Regional Geology

Biga Peninsula consists of Paleozoic and Mesozoic metamorphic, ophiolitic and early Cenozoic plutonic rocks as the basement and late Cenozoic sedimentary and volcanic rocks lying on the basement. At the southern margin of the Biga Peninsula, there is a rise of the Kazdag Massif between Edremit Gulf and Yenice – Bayramic Basin with a lithology of marbles, amphibolites and Paleozoic-Triassic gneiss (Gürer et al., 2016) (Figure 4).

Magmatic rocks are quite common in the Biga Peninsula. They may be identified as Middle Eocene and Oligo-Miocene plutonic and volcanic rocks. The latest magmatic phase in the region is represented by the Late Miocene - Quaternary alkaline rocks (Genç, 1998; Yılmaz and Karacık, 2001; Beccaletto and Steiner, 2005; Gürer et al., 2016).

The sedimentary cover in the region is represented by Neogene-Quaternary units. The largest sedimentary rock formations in the southern part of the Biga Peninsula are the Lower-Middle Miocene Küçükkuyu, the Upper Miocene İlyasbaşı, and the Plio-Quaternary Bayramiç formations (Sengun et al., 2011).

Based on ~2800 m of drilling data shown in Figure 5 made by Turkish Petroleum Corporation (TPAO) in Edremit Gulf in

1998; approx. 23 m of unconsolidated sediment, 637 m of Plio quaternary, Bayramic formation (pebble stone and limestone), 200 m of Miocene Ilyasbasi formation (limestone, pebblestone, dolomite, and marl), 536 m of Miocene Küçükkuyu formation, Adatepe member (agglomerate and tuff) and 1324 m of Miocene Doyuran Volcanites lithology could have been collected.

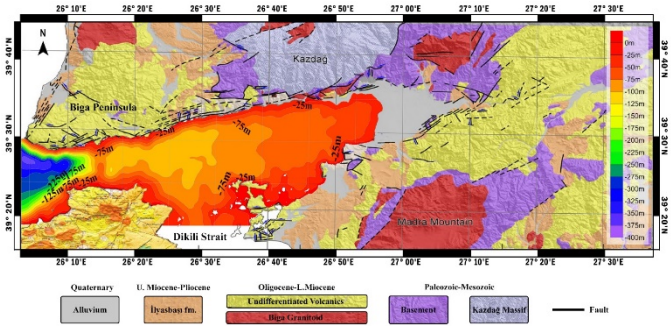

Figure 4. Regional geology and bathymetry of Edremit Gulf compiled from Gürer et al. (2016)

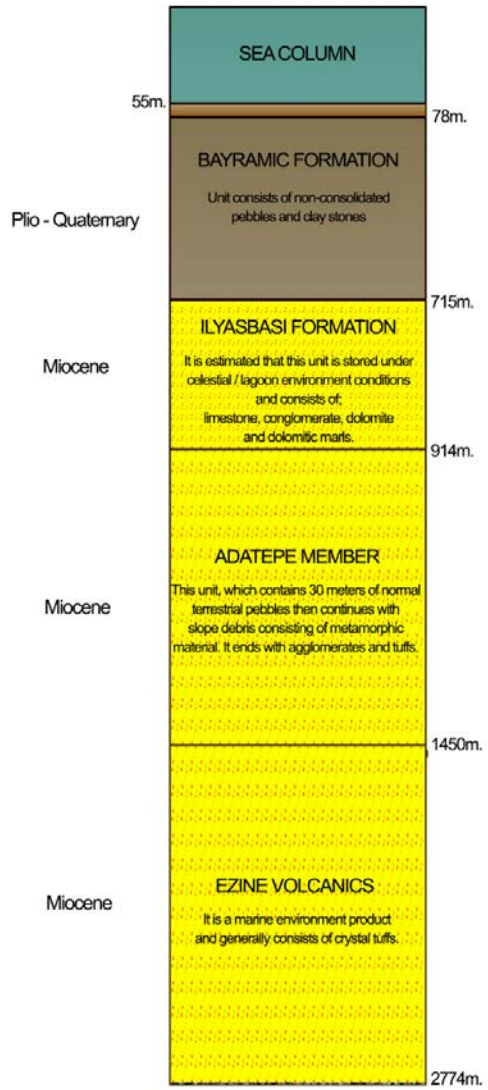

Figure 5. Drilling information chart of the TPAO Edremit-1 drill. Kılıç, O. (2018, October 12) Personal interview.

According to Çiftçi et al. (2004), plutonic and metamorphic rocks form the basement of the region. The Küçükkuyu Formation, which consists of Neogene sedimentary and volcanic units lie on the basement while Upper Miocene-Pliocene sediments of the fifth and sixth volcanism lie above the Küçükkuyu Formation with an angular unconformity, which is named as Mutlu or İlyasbaşı Formation by Siyako, Burkan and Okay (1989). The uppermost unit is considered as unconsolidated sediments.

Material and Methods

This study has been carried out in the inner and middle parts of the Edremit Gulf by using high-resolution seismic reflection method. Nearly 300 km of 2D multi-channel seismic data were collected using a 45+45 inch^3 GI gun by K. Piri Reis Research Vessel on 3 seismic lines along the NE-SW direction and 12 seismic lines in transverse N-S direction to define the inner gulf (Figure 1). Data were recorded by using a 192 channels streamer with a receiver group interval and shot interval of 6.25 m and 18.75 m, respectively. These parameters have provided 32-fold common-depth-point (CDP) data. Sampling interval and record length were selected as 1ms and 3000 ms, respectively.

Results

Since the sedimentary structure exhibits uniform stratification of reflectors close to each other, the sedimentary packages couldn't be separated. In this study, the boundaries of the strata, which could be followed, and show a slight impedance difference according to their surroundings have been determined and indicated with the letters A, B, and C in the sections.

A, B and C are seismic stratigraphic units that can be separated from each other by showing different impedance characteristics. Thin stratification in the geological structure of the seismic units A and B creates repetitive multiples which make stratigraphic interpretation difficult by obscures the actual signals.

Besides, with the undulations at the SW of the section formed by the E-W compression, some strike-slip faults reaching up to the seabed and the Edremit – Lesvos Fault (ELF) are also being observed. The Edremit Bay Fault (EBF) which is located in the central part of the section ends in Holocene sediments and does not give any surface fracture.

In Section 37, a normal fault at the northeast, and towards the SW, the ELF with some faults which end in sediments close to the seabed, are observed.

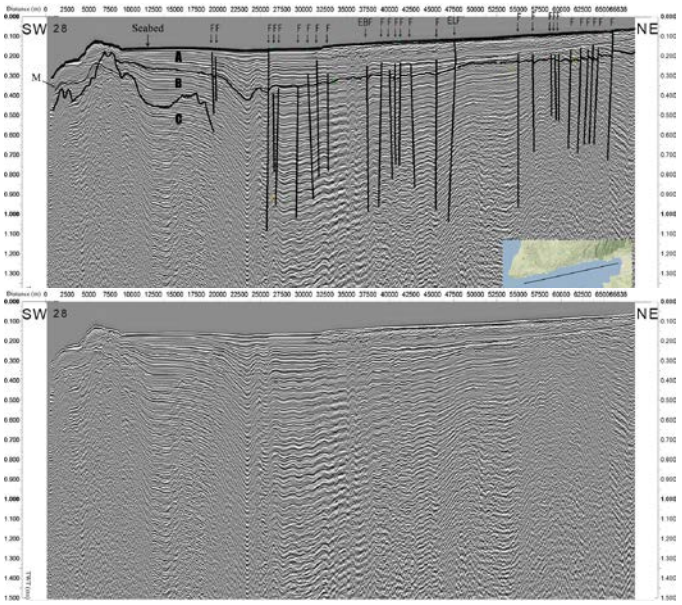

Figure 6. SW-NE directed seismic section 28. A, B and C; seismic units, F; fault, M; seabed multiples, ELF; Edremit – Lesvos Fault, EBF; Edremit Bay Fault

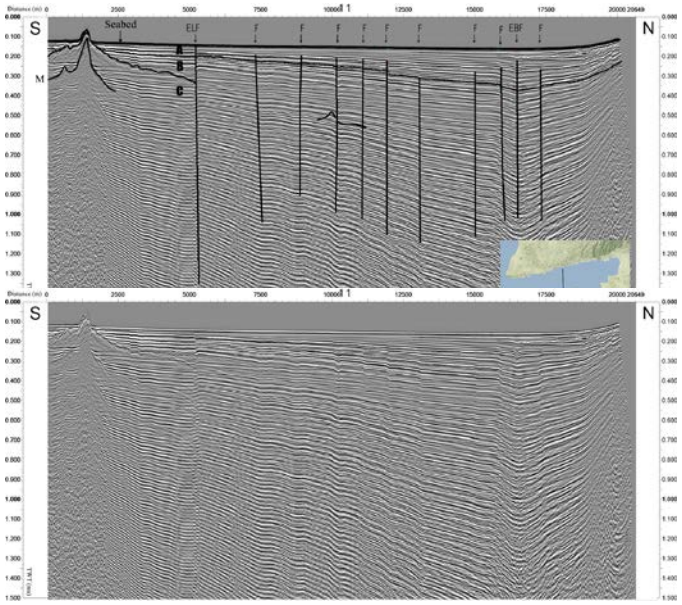

Figure 8. S-N directed seismic section 11. A, B and C; seismic units, F; fault, M; seabed multiples, ELF; Edremit – Lesvos Fault, EBF; Edremit Bay Fault

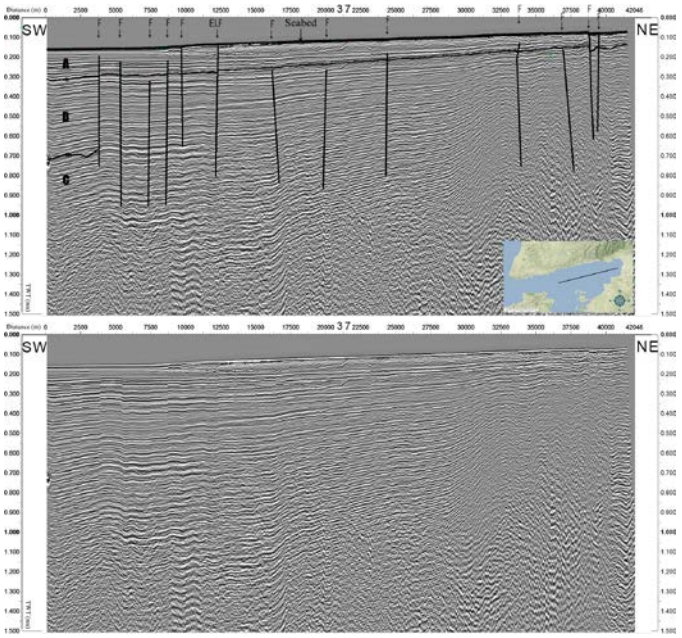

Figure 7. SW-NE directed seismic section 37. A, B and C; seismic units, F; fault, M; seabed multiples, ELF; Edremit – Lesvos Fault, EBF; Edremit Bay Fault

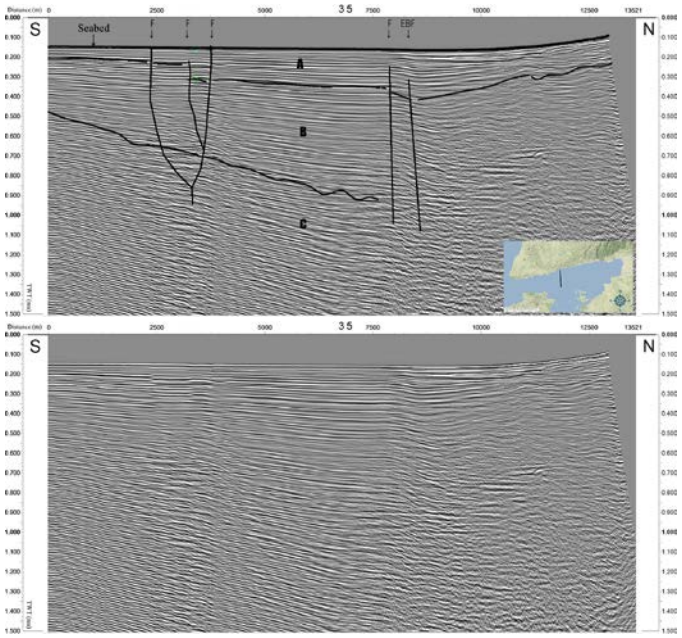

Figure 9. S-N directed seismic section 35. A, B and C; seismic units, F; fault, M; seabed multiples, EBF; Edremit Bay Fault

In some sections (11, 35, 36) (Figures 8, 9, 10) crossing the Edremit Gulf in the N-S direction, the seismic A, B, and C units are thickened towards the middle of the gulf. The acoustic basement forming the C unit approaches to the seabed in the sections towards the North and South shores of the Gulf. EBF and ELF systems also can be observed in these sections.

Discussion

The Edremit Gulf began to open under the control of low-angle NW–SE trending faults that developed after the compression of western Anatolia in an E–W direction in the early Neogene. Subsequently, regional N–S extensional stress formed the Aegean type basin system from the Neogene to Holocene (Kurtuluş et al., 2009).

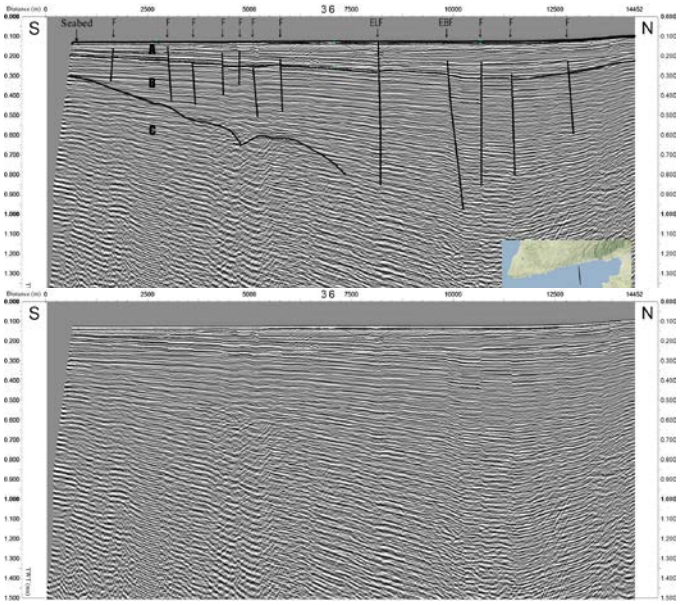

Figure 10. S-N directed seismic section 36. A, B and C; seismic units, F; fault, M; seabed multiples, ELF; Edremit – Lesvos Fault, EBF; Edremit Bay Fault

Although there are many opinions about the formation mechanism of the stress regime in Western Anatolia, the most accepted view is the collision of the African and Arabian Plates of different velocities with the Anatolian Microplate and forcing it to escape to the west by using the two important transform faults; the left-lateral East Anatolian Fault (EAF) and the right-lateral North Anatolian Fault (NAF) (Dewey and Şengör, 1979; Mantovani et al., 2000). The North Anatolian Fault System (NAFS) is exposed to the SW-NE rotation and is divided into three main branches as a result of the blockage of the Greek Plate in the east of the Marmara Sea (Jackson and McKenzie, 1988; Barka and Reilinger, 1997; Yaltırak, Alpar and Yüce, 1998; Yaltırak, 2002; Reilinger et al., 2006). The southernmost branch is re-divided into branches on the Biga Peninsula and continues as a zone. One of these branches, the Edremit Fault, formes the northern boundary fault of the Edremit Gulf (Yılmaz et al., 2000; Kurtuluş et al., 2009; Sözbilir et al., 2016a), while the other branch formes the Yenice-Gönen Fault Zone (Barka and Kadinsky-Cade, 1988). The study conducted by Yılmaz and Karacık (2001) propose that the southern strand of the NAFZ deviates toward the SW at the town of Gönen, continues on the same trend of YGFZ and reaches Edremit Gulf near Altınoluk.

Our data reveal that the YFGZ observed on land enters to the sea between Küçükkuyu and Akçay, and extends in Edremit Bay in segments, towards the Lesvos Island, compliance with the geology of Lesvos proposed by Lekkas et al. (2017) and the morphotectonic map of Lesvos Island proposed by Chatzipetros et al. (2013) (Figure 11b). We also infer that the HBFZ, which is described as a Holocene fault zone by Sözbilir et al., 2007 and consists of many strike-slip segments, extends from Balıkesir to the eastern end of the Gulf. The system continues in two segments to the west of the study area and shared by the ELF whilst forming a step over in the middle of the Gulf (Figure 11a).

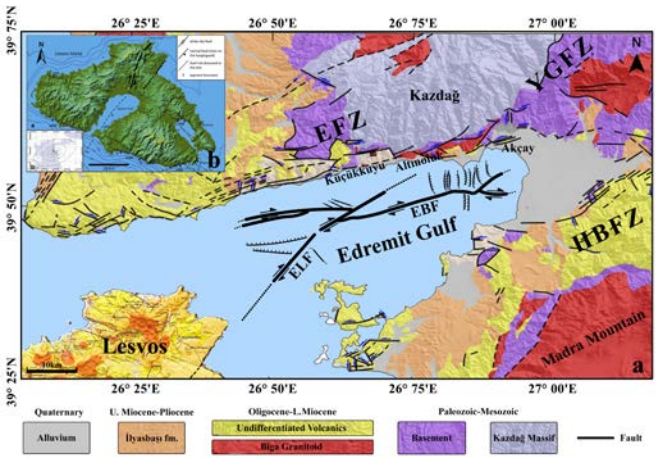

Figure 11. Interpreted ELF and EBF on the base map compiled from Gürer et al. (2016) (**a**), The ELF shows compliance with the morphotectonism of Lesvos Island (**b**) (Chatzipetros et al., 2013). (HBFZ; Havran – Balikesir Fault Zone, YGFZ; Yenice – Gonen Fault Zone, EFZ; Edremit Fault Zone).

Conclusion

The interpretations of seismic reflection profiles indicates both the continuation of the southern strand of the NAF, the Yenice-Gönen Fault, within the Gulf, towards Lesvos Island, in the NE-SW direction, and the effect of the E-W oriented Balıkesir-Havran Fault, which formed during the N-S extension system. Due to the fact of the existence of these faults, we also infer a seismic hazard in the Gulf and surroundings.

Conflict of Interest

The authors declare that there is no conflict of interest.

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