



States of local stresses in the Sea of Marmara through the analysis of large numbers of small earthquakes

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ABSTRACT

We invert the present day states of stresses for five apparent earthquake clusters in the Northern branch of the North Anatolian Fault in the Sea of Marmara. As the center of the Sea of Marmara is prone to a devastating earthquake within a seismic gap between these selected clusters, sensitive analyses of the understanding of the stress and strain characteristics of the region are all-important. We use high quality P and S phases, and P-wave first motion polarities from 398 earthquakes with $M_L \geq 1.5$ using at least 10 P-wave first motion polarities (FMPs), and a maximum of 1 inconsistent station, obtained from a total of 105 seismic stations, including 5 continuous OBSs. We report here on large numbers of simultaneously determined individual fault plane solutions (FPSs), and orientations of principal stress axes, which previously have not been determined with any confidence from the basins of the Sea of Marmara and prominent fault branches.

We find NE–SW trending transtensional stress structures, predominantly in the earthquake clusters of the Eastern Tekirdağ Basin, Eastern Çınarcık Basin, Yalova and Gemlik areas. We infer that a dextral strike-slip deformation exist in the Eastern Ganos Offshore cluster. Furthermore, we analyze FPSs of four $M_L \geq 4.0$ earthquakes, occurred in seismically quiet regions after 1999 Izmit earthquake. Stress tensor solutions from a cluster of small events that we have obtained, correlate with FPSs of these moderate size events as a demonstration of the effectiveness of the small earthquakes in the derivation of states of local stresses. Consequently, our analyses of seismicity and large numbers of FPSs using the densest seismic network of Turkey contribute to better understanding of the present states of the stresses and seismotectonics of the Sea of Marmara.

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1. Introduction

The relative motion between the Eurasia and Anatolia is accommodated by the North Anatolian Fault (NAF, Fig. 1) (Ketin, 1948), which is a dextral strike-slip fault system, starting from the Karlıova triple junction and terminating in the Aegean Sea. From east to west NAF follows roughly a small circle arc and at 32°E bifurcates into two branches, whose northern branch enters the Sea of Marmara at about 30°E longitude. In the Eastern Sea of Marmara a transition occurs from the right lateral strike-slip to the Aegean extension zone (AEZ, Fig. 1) (Armijo et al., 2005; Flerit et al., 2003).

The 1912 Mw7.4 Ganos (Aksoy et al., 2012) and 1999 Mw7.4 Izmit (Barka et al., 2002) earthquakes in both ends of the NAF in the Sea of Marmara are the latest devastating earthquakes of the region. There is much discussion about the extent of the 1999 Izmit rupture in the Sea of Marmara (e.g. Pınar et al., 2001), whether the rupture might be terminated to the south of the Princes' Islands (Bouchon et al., 2002;

Özalaybey et al., 2002) or to the Eastern Çınarcık Basin (Wright et al., 2001), although the segments between 1912 and 1999 earthquakes, which lies entirely within the Sea of Marmara, constitute a seismic gap (Ambraseys and Finkel, 1987; Barka et al., 2002; Geli et al., 2008; Hubert-Ferrari et al., 2000), and a large earthquake is expected here (Erdik, 2013; Erdik et al., 2004; King et al., 2001). Considering that the area is prone to a large earthquake within a 70–150 km long seismic gap, understanding of how the stress tensor varies and assessing the compatibility of structures with the overall stress regime are very important in both hazard and structural geology perspectives. The study of transient stress regime in the area can contribute to a better understanding of the fault zone evolution. Thus, we present the stress variation in the Sea of Marmara via higher resolution seismological data.

Recent studies have focused on the complex stress and strain conditions in the Sea of Marmara and its surroundings in order to obtain FPSs as well as principal stress axes (Bohnhoff et al., 2006; Gürbüz et al., 2000; Kiratzi, 2002; Örgülü, 2011; Pınar et al., 2003; Pınar et al., 2009; Polat et al., 2002), using P-wave first motion polarities (Gürbüz et al., 2000; Örgülü, 2011; Pınar et al., 2009; Polat et al., 2002) or moment tensor inversion techniques (Kiratzi, 2002; Pınar et al., 2003).

The regional stress field of the Sea of Marmara agrees with the coseismic stress field of the Izmit Earthquake (Bohnhoff et al., 2006).

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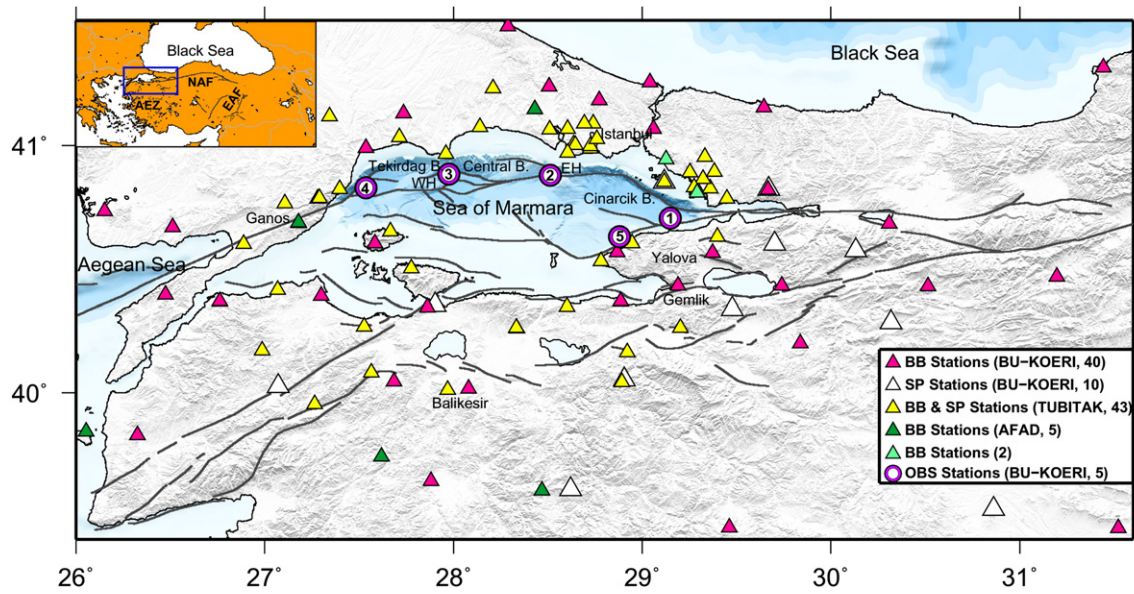


Fig. 1. The seismic station distribution of the study. BB (40) and SP (10) stations of KOERI are indicated by pink and white triangles, respectively. BB and SP (43 in total) stations of TUBITAK are shown by yellow triangles. BB (5) stations of AFAD and BB (2) stations of other constitutions are demonstrated by dark and light green triangles, respectively. Purple circles with numbers are from the OBS system of KOERI consisting of 5 real-time continuous observation points. The fault traces on the main figure are from Armijo et al., 2002, while the ones on the legend are from Şaroğlu et al. 1992. Topographic data are from Reuter et al., 2007 and bathymetry data are from Le Pichon et al., 2001.

On the other hand, both strain partitioning, and stress rotations are clearly visible in the direction of local stress fields subsequent to the Izmit mainshock. Moreover, due to the western termination of the Izmit event, strain accumulation is less in the Eastern Sea of Marmara comparing with the central part (Ergintav et al., 2007). Also, Çınarcık area is famous for its geothermal springs which gives an indication of a weak fault plane and low coefficient of friction that is proportional to the rate of the shear and normal stresses (Pinar et al., 2009; Twiss and Moores, 1992). As a result of analyses of aftershocks of the 1999 Izmit Earthquake, Çınarcık Basin displays strike-slip (Özalaybey et al., 2002) and/or compressional movements (Pinar et al., 2009).

Nevertheless, recent studies represent normal and oblique structures in the Yalova area from the analyses of individual FPSs (Karabulut et al., 2002; Karabulut et al., 2011; Korkusuz, 2012; Örgülü and Aktar, 2001; Özalaybey et al., 2002; Tunç et al., 2011), and composite FPSs (Bulut et al., 2009; Sato et al., 2004).

In this study, we investigate the FPSs and microseismicity with the purpose of understanding the spatial variation of the stress tensor and its relation with the seismotectonic features of the Sea of Marmara and its surroundings. Assuming a homogeneous stress state, we reduce the elasticity tensor to a single (Young's) modulus. Therefore, the relation between the stress and strain becomes linear. We compare our

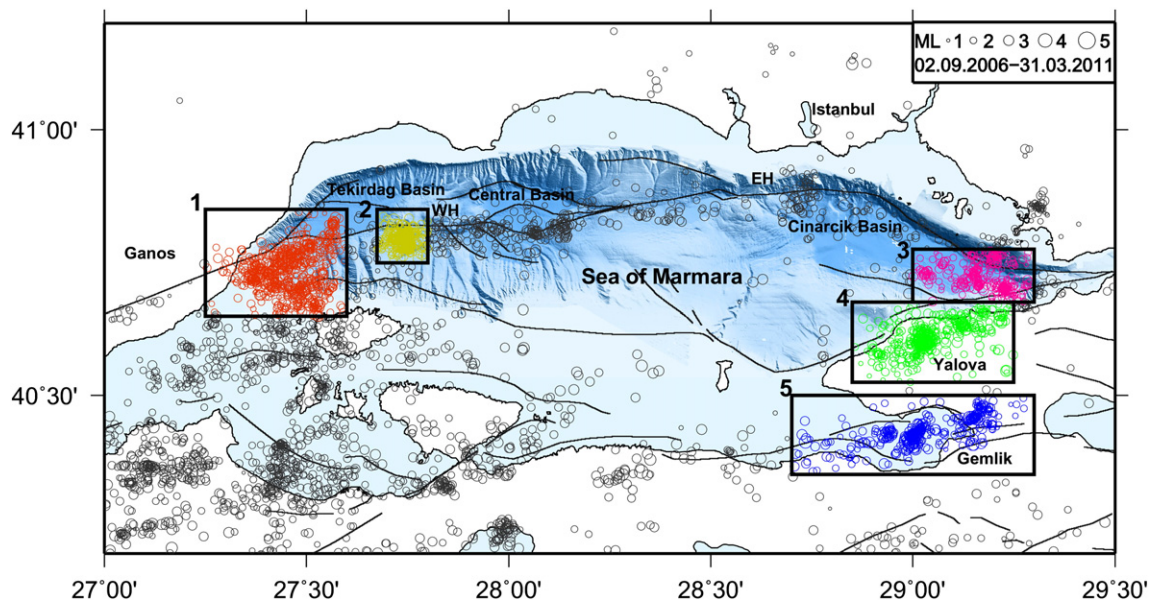


Fig. 2. Recent seismic activity of the Marmara Region for a time period between 02.09.2006 and 31.03.2011 from the earthquake catalog of TUBITAK-MRC. All circles are events with $ML \geq 1.0$. Black rectangles including colored circles are selected earthquake clusters; Eastern Ganos Offshore (1, orange), Eastern Tekirdag Basin (2, yellow), Eastern Çınarcık Basin (3, pink), Yalova (4, green) and Gemlik clusters (5, blue). Fault traces are from Armijo et al., 2002, and bathymetry data are from Rangin et al., 2001.

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