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Araştırma / Research

Preliminary Observations and Assessment of Çanakkale-Ayvacık Earthquake Activity

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Abstract

A project was begun to monitor earthquake activity at the southwest branch of the Biga Peninsula in Ayvacık and close surroundings beginning on 14 January 2017 with Mw=4.6 and continuing through 6 February 2017 with Mw=5.5 (Mw=5.5 Kandilli Observatory and Earthquake Research Institute – KOERI - , Mw=5.3 AFAD, Mw=5.4 ÇOMÜ). The region has active seismicity and includes portions of the significant tectonic elements of the northwest Aegean region. Due to the continuation of earthquake activity, in addition to permanent stations linked to the national networks (KOERI and AFAD) in the region 10 continuous-form recording 3-component temporary stations were set up with the aim of observation for at least 1 year. The distances between these stations varied from 6 to 12 km. In addition to the intensity and continuity of microearthquake activity in the region, and the inclusion of geothermal fields in the region, the necessity to investigate the seismotectonic character of the region in detail came to the agenda. Together with permanent stations belonging to national observatories in the study area, the station density was insufficient to reveal these details. As a result, data from both national network and temporary stations will contribute to understanding the tectonic character of the region. When temporary stations at close proximity to the main shock and epicenter distribution are compared with the national network primary results indicate there were significant improvements in identifying microearthquakes especially and in determining their locations. Additionally, and in source mechanism solutions belonging to earthquake data with moderate magnitude, faulting with a dominantly NW-SE oriented normal offset component was observed. This study aims to reveal the time and spatial distribution, frequency content and source mechanisms for earthquakes occurring in the southwest of the Biga Peninsula near Ayvacık and surroundings, in addition to determining a detailed velocity model with local tomography.

Keywords: Ayvacık, earthquake, seismic network, seismotectonics

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Çanakkale-Ayvacık Deprem Etkinliği İlksel Gözlemleri ve Değerlendirmeleri

Özet

Biga Yarımadası'nın güneybatı ucunda Ayvacık ve yakın çevresinde 14 Ocak 2017 tarihinde Mw=4.6 ile başlayan 6 Şubat 2017 Mw=5.5, (Mw=5.5, Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü – KRDAE -, Mw=5.3, AFAD, Mw=5.4, ÇOMÜ) ile devam eden yoğun deprem aktivitesini izlemek üzere bir proje başlatılmıştır. Bölge aktif bir depremselliği içermekte ve Kuzeybatı Ege bölgesinin önemli tektonik unsurlarından bir kısmını barındırmaktadır. Deprem aktivitesinin devam etmesi nedeniyle, bölgede ulusal ağlara (KRDAE ve AFAD) bağlı sabit istasyonlara ek olarak, 10 adet sürekli formda kayıt alan 3-bileşen geçici istasyon en az 1 yıl süreyle gözlem yapmak amacı ile kurulmuştur. Bu istasyonların birbirlerine uzaklığı 6 ila 12 km arasında değişmektedir. Bölgedeki mikrodeprem aktivitesinin yoğunluğu ve sürekliliği yanında bölgenin jeotermal sahaları da kapsaması, bölgenin sismotektonik karakterinin incelenmesini ve detaylı olarak çalışılması gerekliliğini ön plana çıkarmaktadır. Çalışma alanında ulusal kurumlara ait sabit istasyonlar olmakla beraber istasyon yoğunluğu bu detayların ortaya çıkarılmasında yetersiz kalacaktır. Bu nedenle gerek ulusal sismik ağa gerekse geçici istasyonlara ait veri bölgenin tektonik niteliğinin anlaşılmasına katkılar sağlayacaktır. İlksel sonuçlar, ana şok ve episantr dağılımlarına göre yakın uzaklıklarda kurulan geçici istasyonların sabit ağlar ile karşılaştırıldığında özellikle mikrodepremlerin tespit edilmesi ve yerlerinin belirlenmesinde önemli iyileştirmeler sağladığını göstermektedir. Bunun yanında ve orta büyüklükteki deprem verisine ait kaynak mekanizması çözümlerinde, ağırlıklı olarak KB-GD yönlü normal atım bileşeni baskın faylanma gözlenmektedir. Çalışma başta Ayvacık ve yakın çevresi olmak üzere Biga Yarımadası güneybatı kesiminde meydana gelen depremlerin zaman ve uzaysal dağılımları, frekans içerikleri ve kaynak mekanizmalarını dağılımı yanında yerel tomografi ile ayrıntılı hız modelini çıkarmaya yöneliktir.

Anahtar Kelimeler: Ayvacık, deprem, sismik network, sismotektonik

1. Introduction

The North Anatolian Fault is one of the most active faults globally in terms of earthquake potential. With continuity in a zone between Karlıova and Sapanca both in terms of active tectonism and seismic activity, the North Anatolian Fault separates into three branches near the Sea of Marmara and surroundings at Mudurnu Valley. The north branch begins southeast of Lake Sapanca passes south of the Gulf of İzmit within the Sea of Marmara to the Gulf of Saros and then extends into the north Aegean (Şengör et al., 1985; Barka and Kadinsky-Cade, 1988; Barka, 1992; Armijo et al., 1999; Herece and Akay, 2003; Yılmaz and Koral, 2007). The central branch begins southeast of Lake Sapanca and runs south of Geyve, Pamukova and Lake İznik extending along the south coast of the Sea of Marmara until Kapıdağ Peninsula (Koçyiğit, 1988; Barka, 1997; Yılmaz and Koral, 2007). The south branch separates from the central branch near Pamukova and extends in SW-NE direction via Yenişehir, Bursa, Ulubat, Manyas, Gönen, and Yenice to the Gulf of Edremit (Herece, 1990; Yaltırak, 2002; Yılmaz and Koral, 2007). The Saroz-Gaziköy Fault, Etili Fault, Çan-Biga Fault Zone, Sarıköy Fault and Yenice – Gönen Fault in the Gallipoli and Biga Peninsulas are known active fault zones causing earthquakes. The Saroz-Gaziköy Fault strikes northeast-southwest with nearly 60 kilometer in length. This right-lateral strike-slip fault caused the 7.3 magnitude Şarköy earthquake in 1912. With nearly 15 km length within the provincial boundaries of Çanakkale, the Sarıköy Fault has nearly 60 kilometer length. Known to have caused the historical 1953 Yenice-Gönen earthquake with 7.2 magnitude, the Yenice – Gönen Fault Zone can be traced at the surface for nearly 50 kilometers (Herece, 1990).

1.1 Seismicity

The seismicity in the region may be said to be the result of two basic tectonic elements; faults with dominantly strike-slip character representing the south branch of the North Anatolian Fault Zone passing through the Biga Peninsula and faults with dominantly vertical slip character representing the Western Anatolian extensional regime. When records from the instrumental period in the last hundred years are examined, the 1912 Mürefte earthquake (Ms=7.3), 1953 Gönen earthquake (Ms=7.3), 1966 Gulf of Edremit earthquake (Ms=6.8) and 24 May 2014 Gökçeada earthquake (M_L=6.5) occurred in the north Aegean. Studies of the historical and instrumental period records show the northern branch of the North Anatolian Fault appears to be more active (Pınar and Lahn, 1952; Ambraseys and Finkel, 1991; Amraseys, 2002), while the earthquake recurrence periods are predicted to be mean 250 years (Ambraseys and Finkel, 1991; Rockwell et al., 2001; Özaksoy et al., 2010; Dikbaş and Akyüz, 2011). The earthquake recurrence periods for faults dominating the Biga Peninsula where the south branch passes were calculated to be longer than 600 years in paleoseismology studies (Kurçer et al., 2008; Sözbilir et al., 2016). Together with the irregularity of recurrence of large earthquakes, it is clear that microearthquake activity intensified in the Gulf of Saros, Ayvacık peninsula, Gulf of Edremit and around Gönen – Savaştape from earthquake catalogue information from the last hundred years (Kandilli Observatory and Earthquake Research Institute - KOERI - catalogue data 2016; National Disaster and Emergency Management Authority – AFAD - catalogue data, 2017) (Figure 1).

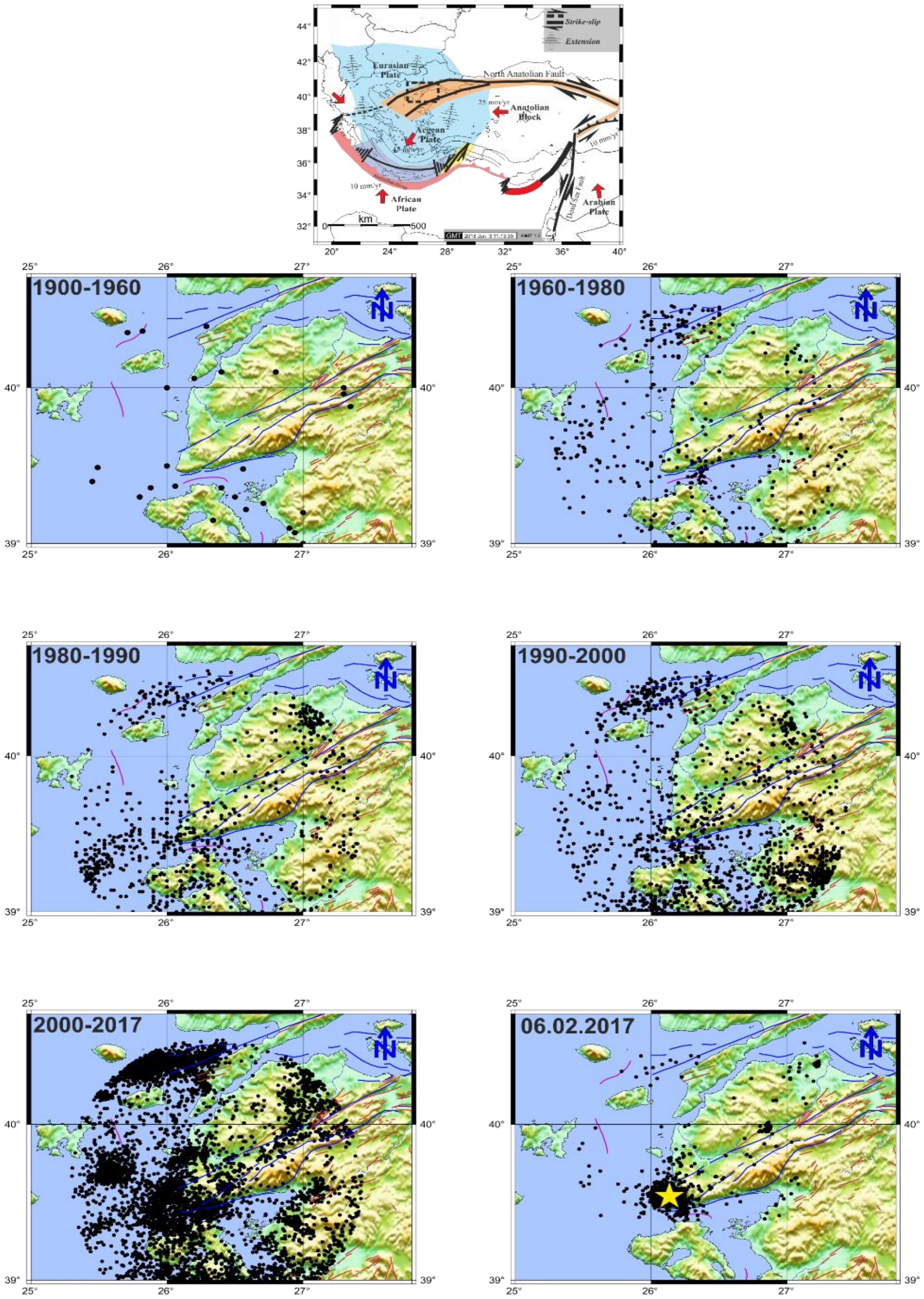

Figure 1. Distribution of earthquake activity for certain periods in the instrumental period in a circular area with 100 km radius around Ayvacık-Tuzla. Only lower left shows the 06.02.2017 earthquake and the occurred earthquakes (M>2) for the following month (KOERI, 2016).

Table 1. Ayvacık earthquakes (M≥4.0) from 14.01.2017 to 24.03.2017 and fault mechanism parameters.

#e/q	Origin Time	Lat°	Lon°	Depth (km)	M_L	M_w	1. Plane°			2. Plane°		
							Strike	Dip	Rake	Strike	Dip	Rake
1	24.03.2017 15:19:06	39.5432	26.1198	08	4.3	4.1	334	46	-95	160	44	-85
2	20.03.2017 07:00:18	39.5482	26.0980	06	4.3	4.1	198	50	-83	15	40	-92
3	28.02.2017 23:27:34	39.5082	26.0427	12	4.9	4.6	290	45	-92	113	45	-88
4	27.02.2017 22:52:23	39.5008	26.0508	13	4.1	4	316	50	-90	135	40	-90
5	23.02.2017 01:55:14	39.5642	26.0999	09	4.4	4.3	320	55	-102	160	37	-73
6	16.02.2017 00:19:00	39.5173	26.0597	14	4.8	4.5	289	35	-110	133	57	-77
7	12.02.2017 13:48:16	39.4988	26.1140	12	5.3	5.2	282	46	-83	92	44	-97
8	12.02.2017 12:14:50	39.5482	26.0600	12	4.0	4.1	300	54	-64	80	43	-121
9	10.02.2017 08:55:26	39.5165	26.1485	13	4.8	4.8	301	39	-87	117	51	-92
10	09.02.2017 10:13:10	39.5435	26.0557	13	4.3	4.1	327	50	-100	162	41	-78
11	08.02.2017 02:16:14	39.5375	26.1387	11	4.2	4.2	286	41	-78	90	50	-100
12	08.02.2017 01:38:04	39.5250	26.1408	12	4.7	4.6	272	48	-99	105	43	-80
13	07.02.2017 22:53:30	39.5167	26.0658	16	4.3	4.1	298	48	-72	92	45	-109
14	07.02.2017 21:35:00	39.5337	26.1412	10	4.3	4.2	348	45	-54	122	55	-120
15	07.02.2017 21:00:54	39.5290	26.1512	12	4.4	4.4	295	45	-51	66	56	-123
16	07.02.2017 05:17:09	39.5390	26.1562	06	4.6	4.2	266	69	-90	88	21	-89
17	07.02.2017 05:15:51	39.5255	26.1432	12	4.5	4.3	283	44	-92	106	46	-88
18	07.02.2017 02:24:04	39.5255	26.1238	14	5.3	5.2	286	31	-100	118	60	-84
19	06.02.2017 11:45:01	39.5293	26.0970	10	4.7	4.5	280	42	-110	126	51	-73
20	06.02.2017 10:58:02	39.5250	26.0992	15	5.3	5.2	288	49	-117	145	48	-63
21	06.02.2017 04:17:29	39.5422	26.1033	6	4.2	4.1	314	14	-105	150	76	-86
22	**06.02.2017 03:51:40**	**39.5460**	**26.1085**	**4**	**5.5**	**5.4**	**315**	**46**	**-92**	**137**	**44**	**-88**
23	15.01.2017 04:03:20	39.5478	26.1333	4	4.3	4.1	338	54	-99	172	37	-78
24	14.01.2017 22:38:59	39.5457	26.1310	2	4.8	4.6	310	36	-106	149	56	-79

2. Ayvacık Earthquakes and Temporary Seismic Network

The most recent example of microearthquake activity in the Ayvacık peninsula began on 14 January 2017 Mw=4.4 and 6 February 2017 Mw=5.4 with more than 6000 earthquakes ocurring (KOERI, AFAD and ÇOMÜ records). Source mechanism solutions for earthquakes with magnitude M≥4.0 show normal faulting with NW-SE strike in accordance with the characteristics of known active faults (Table 1 and Figure 2). A report prepared by Sözbilir et al. (2017) after the Ayvacık earthquakes observed parallel fault planes extending in N-S orientation especially in the Tuzla geothermal field. Faults dipping SW were observed that may be possible branches of the Tuzla fault or independent faults with similar character. It should not be forgotten that faults developing in this zone have the form of synthetic and antithetic faults. However, fault mechanism solutions support normal faulting geometry (Table 1). The mechanism solutions are very close to each other with NW-SE striking faulting causing the main shock and aftershocks and the main plane (fallen block) indicating SW dipping normal faulting. The revised active fault map of Turkey (Emre et al., 2011) shows the dominant faults on the Çanakkale sheet are the Kestanbol and the nearly NW-SE oriented Tuzla fault segment of this fault (Yılmaz and Karacık, 2001). This section is a pull-apart structure between two large right-lateral strike-slip faults segments of the south branch of the North Anatolian Fault in the Ayvacık peninsula and continuing under the north Aegean Sea (Utkucu et al., 2017) and a developing fault extends parallel to the normal faults bounding the east (Yaltırak et al., 2012) of the basin within this structure.

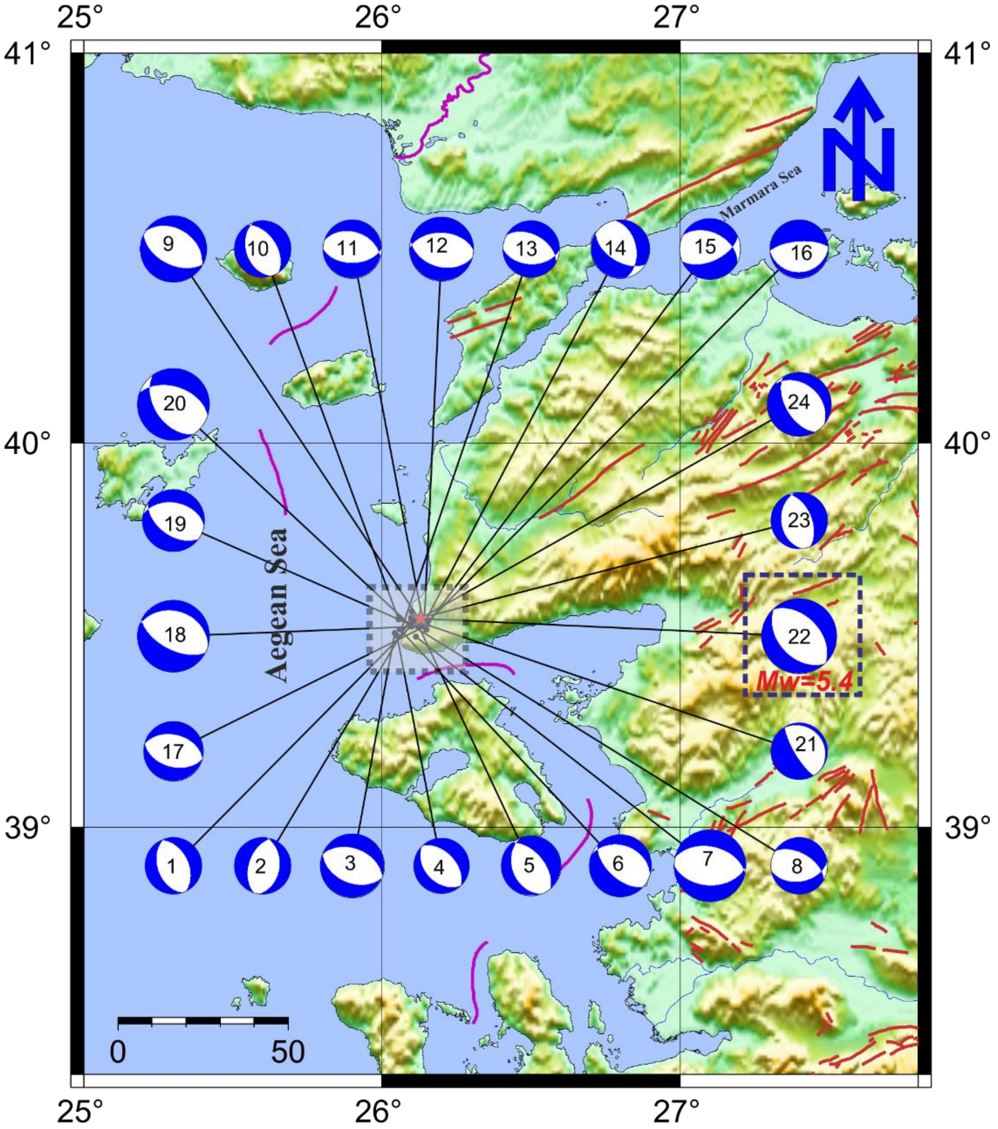

Figure 2. Solutions of fault mechanisms for the Ayvacık earthquakes (details are given at Table 1). Earthquake locations within dashed square (M≥4.0) are relocated events.

Epicenters appear to cluster in a nearly 25 x 10 km area near Tuzla deformation and geothermal field, and close surroundings. Considering the distribution and incidence of activity, 10 temporary 3-component broad period seismometers (off-line) were set up close to the fault system controlling the region of the main shock and surrounding area. Together with these stations, 2 ÇOMÜ (Çanakkale Onsekiz Mart University) – KOERI (permanent and real time) continued to record continuously (Figure 3). Noting the number and local distribution of stations, the topic of the study in future periods is not just improving earthquake locations and kinematic parameters but to assess microearthquakes that are not recorded and/or defined by national organizations, and modeling regional velocity distribution appropriate to the horizontal and vertical variation of seismic velocities. According to the proximity to the epicenter of the main earthquake, in addition to national networks (KOERI and AFAD, temporary stations (T4 network) were set up in Taşağıl, Tamış, Babadere, Balabanlı, Babakale, Kocaköy, Karagömlek (Ezine), Kestanbol, Külcüler (Bayramiç) and Güre (Edremit). Additionally, ÇOMÜ and CANM stations are operated as ÇOMÜ-KOERI commonly installed (Figure 3).

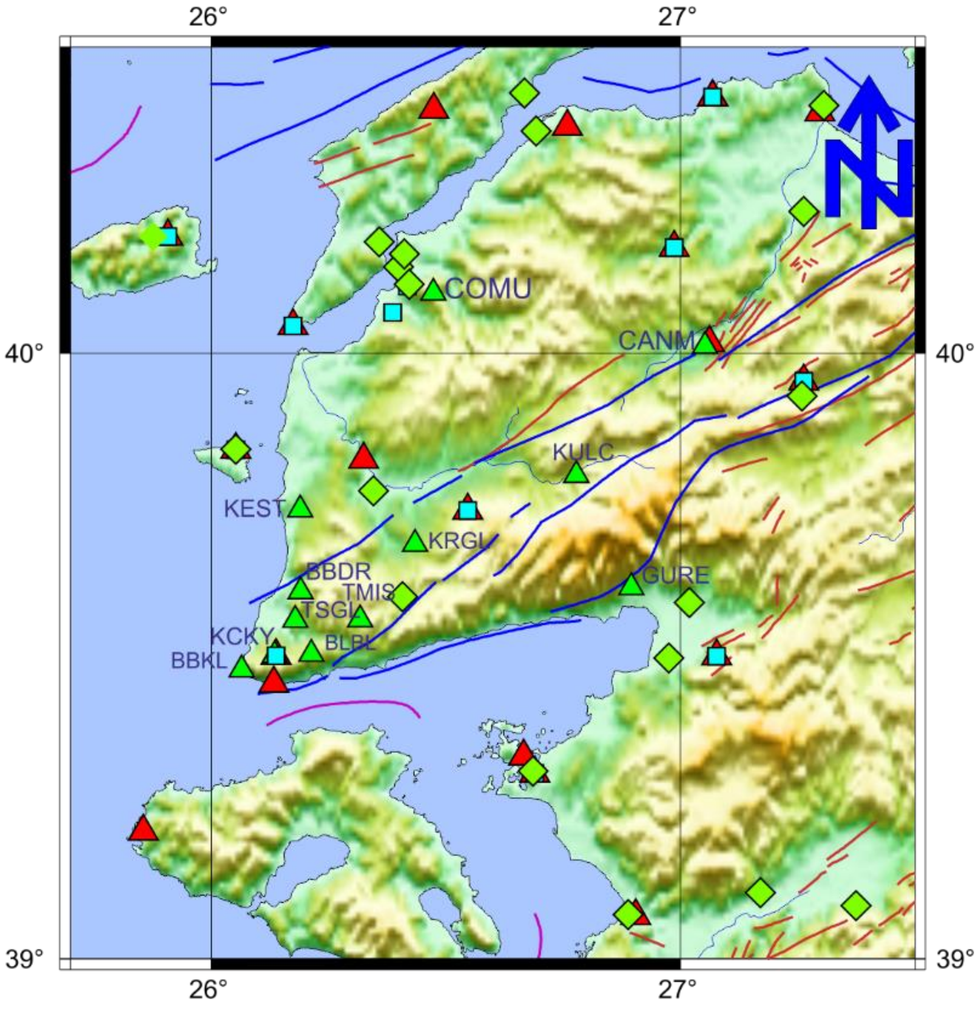

Figure 3. Locations of permanent and earthquake temporary installed stations. Triangles represent broadband stations governed by COMU.

2.1 Seismic Source Analysis

The spectral seismic source parameters for the 06 February 2017 Mw=5.4 Ayvacık earthquake were calculated using the spectral source model of Brune (1970,1971). As the temporary broad-band seismometers were very close to the source area causing saturation, the KOERI data distant stations were used. Based on the Brune source model, the source radius (r), seismic moment (M_0) and mean stress drop ($\Delta\sigma$) were calculated by determining the corner frequency, spectral level and maximum frequency on ground displacement spectra. The method followed for spectral assessment of earthquake source is that after high signal noise ratio and digital data tool effects are removed from 3-component data, they are transformed to radial and transverse components according to the azimuth angle of the earthquake. After determining the P and S phases and determining the window for the SH component (10 s for distant stations), the trend effect on the data is removed if present. To keep lateral release effects to a minimum level, after applying a cosine bell and truncated rectangular window (tukey), the spectral media (ground displacement) is calculated. To remove the regional absorption effect, assessment of acceleration reduction is used (Kurtulmuş and Akyol, 2013). In the ground displacement spectrum, as a result of calculating the low frequency level, corner frequency and slope, related empirical equations (Kumar et al., 2012) are used to calculate the source radius, seismic moment and mean stress drop. For the 06 February 2017 earthquake Mw=5.5, Mo= 2.1E17 Nm and mean $\Delta\sigma$= 12 Mpa were calculated. The stress drop value varies from lowest of 0.2 MPa to highest of 42 MPa. High stress drops are very close to the region of the Ayvacık earthquake. Using the stations set up close to the region and permanent stations, calculations continue to reveal the relations between the source parameters for small earthquakes.

Due to the location of Ayvacık and surroundings, in addition to being within the Biga Peninsula controlled by very active fault systems, it is an effective partner to the right lateral character of the North Anatolian Fault and the Aegean extensional system. This situation leads to regional stress. Loads above critical stress (1-5 bar) on the fault system affect ruptures in the brittle upper crust and displays as earthquake series (storm) on very close fault systems within this very active tectonic region. In this study the Coulomb stress variation causing the Ayvacık earthquake. In calculations the slip module (μ) $3x10^{10}$ Pa, Poisson ratio 0.25 and friction coefficient of 0.4 were used (Harris and Simpson, 1998). Additionally the fault plane parameters used in the calculations were obtained by the moment tensor inverse solution and results obtained in the study. On Coulomb stress variation maps, the areas shown as red represent areas with increased stress. The mean stress in a 12-16 km seismogenic zone affecting a southwest direction toward the Gulf of Edremit increased toward 0.5-0.6 bar. When the Coulomb stress variation is examined for the 4-20 depth interval, it is understood the intensity of aftershock earthquakes is in a very narrow zone and far from relative homogeneity. If it is considered that these faults were affected by a previous rupture but still did not rupture on a systematic plane, it is thought that these may be synthetic and shallow antithetic faulting in a very local area. The Coulomb stress variation models given in Figure 4 were calculated for depths of 4, 8, 12, 16 and 20 km, respectively, with red areas showing stress increase and blue areas stress drops. With the aim of understanding the current Coulomb stress situation in the region, using fault plane parameters belonging to 24 earthquakes with focal mechanism solutions and magnitudes, cumulative Coulomb stress variations (Figure 4) were investigated at 4 km depth intervals between 4 and 20 km. At depths of 8, 12 and 16 km, Coulomb stress is observed to increase in the southwest sections of the study area. When deeper sections are examined, it is noteworthy that this increase shows homogeneous low level distribution; together with the increase not exceeding 0.5 bar values in these sections, the number of aftershock locations in this section and at related depths in the study area is very low. The focal mechanism solutions belonging to earthquakes occurring in the study area show normal faulting character is dominant in the region. Though some solutions were observed to have low degree strike-slip component, it is considered the earthquakes with these solutions may have occurred due to the effect of complicated faulting in the region.

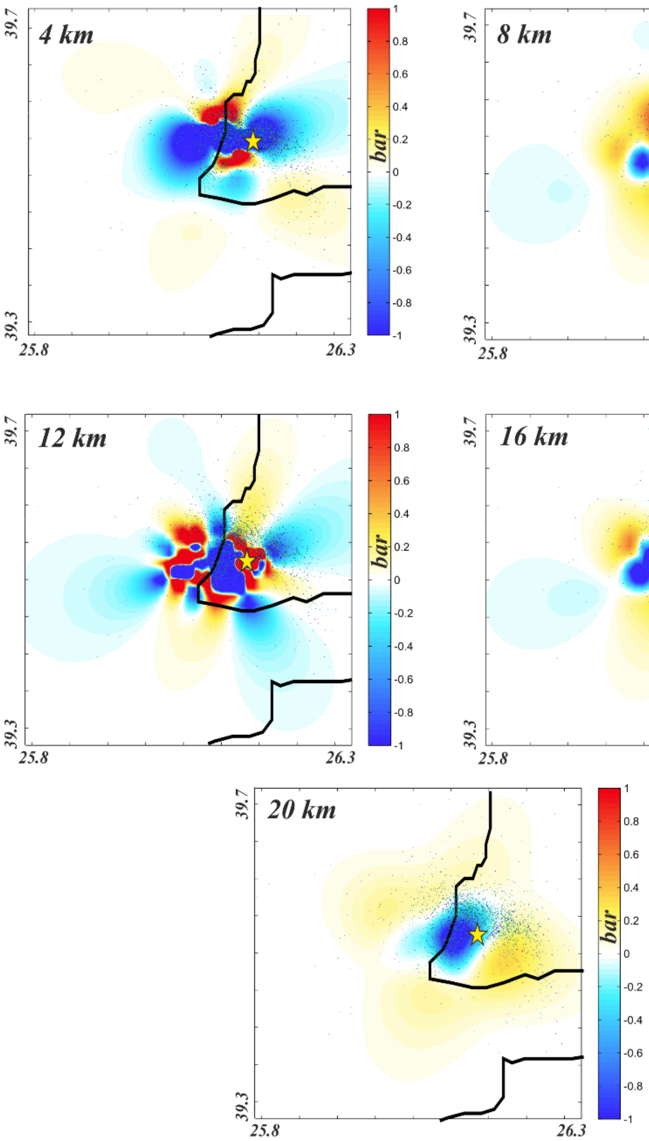

Figure 4. Coulomb stress variations calculated at different depths for 06 February 2007 (Mw=5.4) and aftershocks (Mw>4 on Table 1). Star shows main shock and dots indicate the aftershocks.

2. Results and Discussion

After the February 6, 2017 (03:51 UT) Mw=5.4 magnitude earthquake many researchers began studies revealing the character of the earthquake and its aftershocks. These studies were mainly seismologic studies based on field observations and databases offered by national seismic networks. This study partly uses these databases and began due to the very close proximity of fault segments in the region and the excessive earthquake production potential of these faults with very similar kinematic and involved setting up new earthquake stations to observe microearthquakes and more local scale seismological studies. The study has not been completed yet, with data collection and assessment continuing. Accordingly the preliminary results are as follows;

- Source mechanism solutions in the region show NW-SE and nearly SW dipping normal faulting in accordance with field observations.
- The stress increase due to the main earthquake is considered to have caused intensification of aftershock distribution in the region.
- As a result, in these areas with stress increase, relatively small magnitude earthquakes occurred along present faulting or zones of weakness. The aftershock earthquake activity lasing for longer durations than normal in the region is associated with the complicated faulting and intense geothermal activity in the region.
- The spectral source parameters of microearthquakes and the relations between these parameters will be studied within this scope.
- Due to the geothermal resources in the study region (Tuzla, Kestanbol, Külcüler, Güre), phase reading and calculations based on these will be performed to improve the locations of microearthquakes and to define earthquakes not identified by national networks.
- The lack of a velocity model for both the Biga Peninsula and the northwest Aegean region reveals the importance of the database in this study once more. In this context, the clearest target of this study is local earthquake tomography.

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