BİGA YARIMADASI ÜZERİNDE MEYDANA GELEN 2017 GÜLPINAR-AYVACIK DEPREMLERİNİN KAYNAK PARAMETRELERİ

SOURCE PARAMETERS OF 2017 GÜLPINAR-AYVACIK EARTHUAQKES ON THE BİGA PENINSULA

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Öz

Biga yarımadası üzerinde 2017'de meydana gelen Gülpınar-Ayvacık depremlerinin analizi bu çalışmanın amaçları arasında yer alır. Yığın şeklinde kümelenen bu aktivite anaşok ihtiva etmeden çok sayıda küçük ve orta ölçekli depreme neden olmuştur. 14 Ocak 2017 yılında orta büyüklükteki (M_w 4.4) bir depremle meydana gelen bu aktivite aralıklı olarak bir kaç ay devam etmiştir. Bu çalışma, deprem konumlarının güncellenmesine ve dalga biçimi modelleme tekniği kulllanılarak kaynak parametrelerinin elde edilmesine dayanmaktadır. Yeniden konumlandırılan depremlerin dağılımı, Tuzla fayına parallel 3km'lik bir zon içinde uzanan, KB-GD gidişli bir çizgiselliği işaret etmektedir. Basen içinde yer alan depremlerin kaynak derinlikleri GB yönüne doğru bir artış göstermektedir. Bu gözlemden yola çıkarak, Gülpınar-Ayvacık depremlerinin GB'ya eğimli olan Tuzla Fayı'nın Çamköy segmenti üzerinde meydana geldiğini söyleyebiliriz.

Anahtar Kelimeler: Gülpınar-Ayvacık, Çanakkale, deprem, sismisite, odak mekanizması.

Abstract

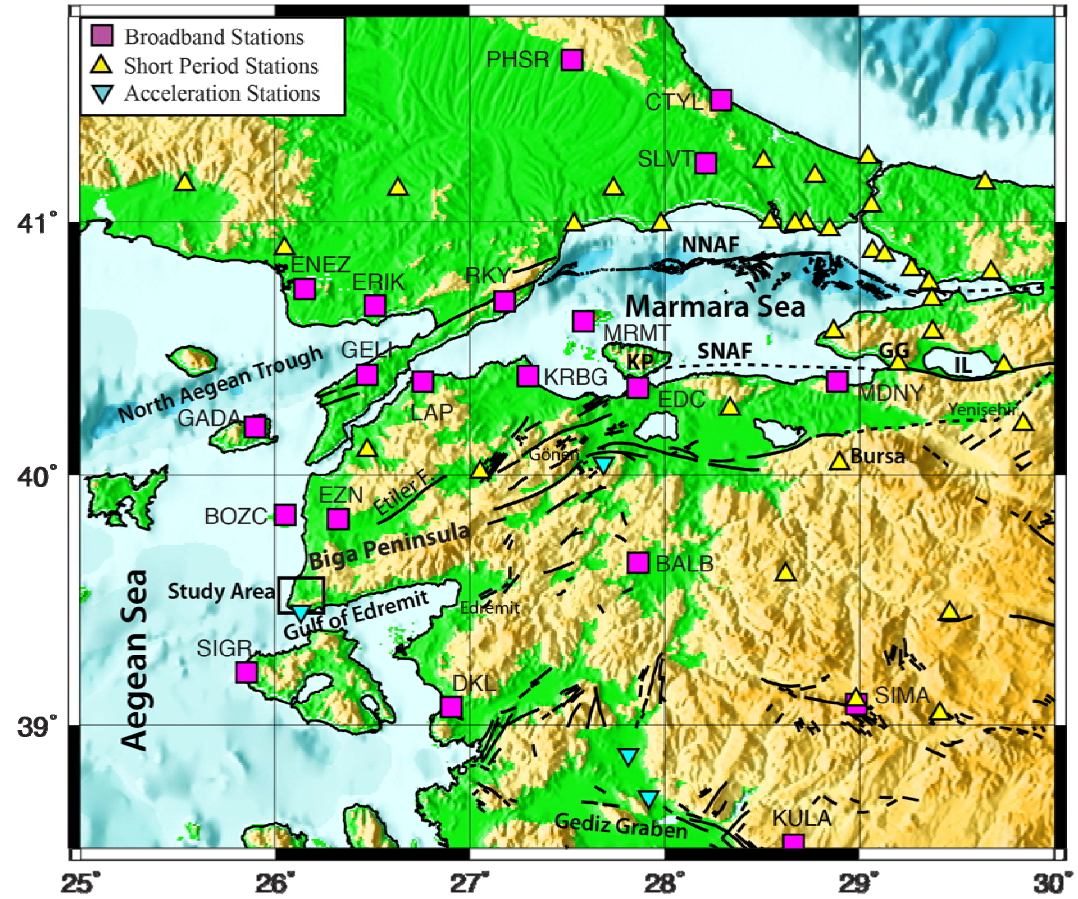
The purpose of this study is to analyze the Gülpınar-Ayvacık earthquakes occurring on the Biga Peninsula in NW Turkey in 2017. This activity in a swarm type causes a large number of earthquakes at small-to-moderate sizes without a mainshock. It has started on Jan 14 2017 with a moderate-size event (M_w 4.4), lasted intermittently. This study is based on the revision of earthquake locations and determination of source parameters from waveform modeling. Revised seismicity indicates an alignment with a NW-SE trend in a width of about 3km, parallel to the Çamköy Segment of the Tuzla Fault. Focal mechanisms indicate a pure normal fault with a NW-SE strike. Source depths of earthquakes of the aligned seismicity are increasing to the SW. This observation possibly infers that the Gülpınar-Ayvacık earthquakes have occurred on the Çamköy Segment of the Tuzla Fault, dipping to the SW.

Key words: Gülpınar-Ayvacık, Çanakkale, earthquake, seismicity, focal mechanism

INTRODUCTION

Small-to-moderate sized earthquakes lasting for a few months are strongly felt by people living in the Biga Peninsula. This long-lasting seismic activity terrified the people and caused them to spend many nights outside, in tents. The largest event of this activity occurred at 03:51:40.7 (UT) on Feb 6 2017 with a moment magnitude of Mw=5.5. It damaged some houses in the villages of Taşağıl, Tuzla, Yukarıköy, Çamlık and Gülpınar and injured numerous people. This event was followed by two moderate-sized earthquakes; former (Mw 5.3) occurring at 02:24:03.7 (UT) on Feb 7 and latter (Mw 5.3) at 13:48:16.0 (UT) on Feb 12, 2017. In this study, we have analyzed the seismic activity between Jan 14 and Mar 2, 2017.

The North Anatolian Fault splays into two branches in NW Turkey: northern (NNAF) and southern (SNAF) strands (Figure 1). The southern branch is generally represented by short non-continuous fault segments due to an increasing component of the Aegean extensional system, compared to the single path of the northern branch in the northern Marmara Sea. A possible trend



Şekil 1. Gülpınar-Ayvacık depremlerini kayıt eden sismolojik istasyonların dağılımı. Sürekli çizgiler Maden Tetkik ve Arama (MTA) kurumu tarafından haritalanan aktif fayları gösterirken, kesikli çizgiler Kuzey Anadolu Fayının (NAF) güneydeki kollarına tekabül eden henüz haritalanmamış muhtemel fayları gösterir. Çalışma alanı dikdörtgen ile işaretlenmiştir. NNAF ve SNAF: Kuzey Anadolu Fayının kuzey ve güney kolları. GG: Gemlik Körfezi, IL: Iznik Gölü, KP: Kapıdağ yarımadası.

Figure 1. Distribution of seismic stations recording the Gülpınar-Ayvacık earthquakes. Solid lines shows active faults mapped from the General Directorate of Mineral Research and Exploration (MTA). Dashed lines indicate possible unmapped faults in NW Turkey, corresponding to the branches of the NAF in the south. The study area is marked by a small rectangle. NNAF and SNAF: Northern and southern branches of the North Anatolian Fault. GG: Gemlik Gulf, IL: Iznik Lake and KP: Kapıdağ Peninsula.

of the southern branch follows an east west trend to the Kapıdağ Peninsula by following the southern coastlines of the Iznik Lake and the Marmara Sea, then possibly changes main trend, turns SW and reaches to the Aegean Sea through the Biga Peninsula. Another possible branch of the SNAF passes through the Yenişehir, Bursa, Gönen and Edremit provinces and also reaches to the Aegean Sea.

The study area is located in the Marmara region, one of the most active seismic regions of Turkey. It produces many moderate- and large-size earthquakes (M>4). The region includes both historical and instrumental seismicity. The most damaging earthquake in the historical period occurred on March 7, 1867. This event affected the Lesvos island and caused tsunami. During the instrumental period, they are six major earthquakes (~M 7.0). They generally occurred along the fault segments of the NAFZ within the Marmara Sea and its surroundings. One of them is very close to the study area and it was located in the Gulf of Edremit on October 6, 1944 with magnitude (M6.8).

Seismological data were downloaded from database of the Regional Earthquake-Tsunami Monitoring Center (RETMC) of the Kandilli Observatory and Earthquake Research Institute (KOERI). Figure 1 shows study area and seismic stations recording this activity, operated by the KOERI. Phase readings of each earthquake were picked again in order to reduce uncertainties in earthquake location. Earthquakes were located using one-dimensional velocity model of Kalafat et al., 1987. A significant part of the Gülpınar-Ayvacık earthquakes occurred along the deformation zone of the Tuzla Fault. In this study we have revised this seismic activity in NW Turkey. Then, we have determined focal mechanisms of 18 earthquakes using a waveform modeling technique.

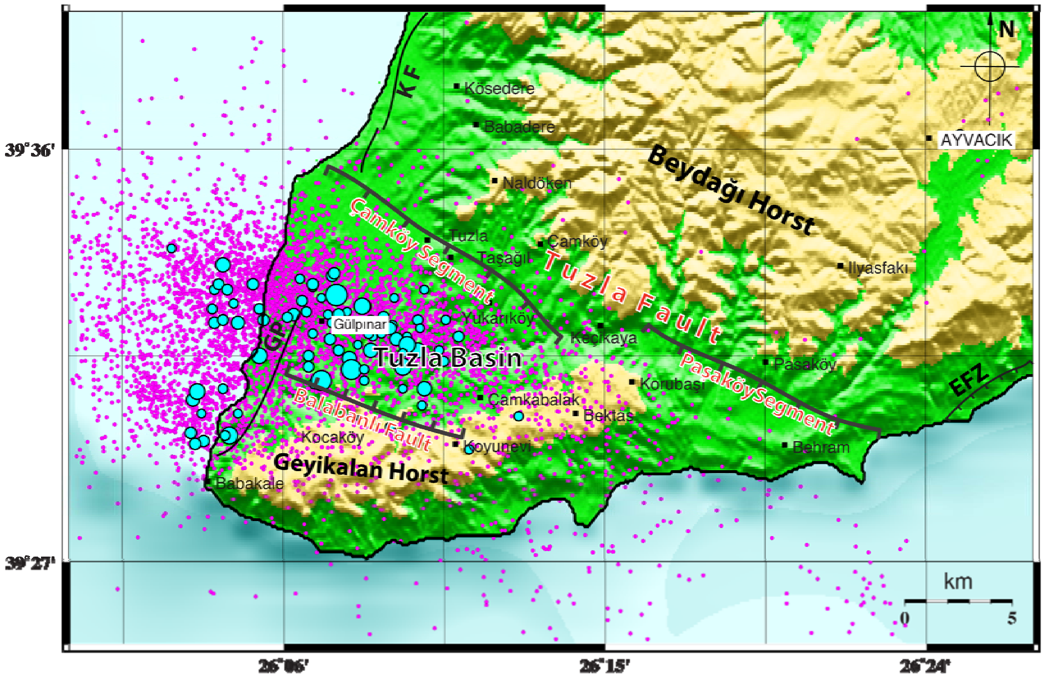
TECTONIC SETTING

Recent Gülpınar-Ayvacık earthquakes occurred on the Biga Peninsula (Figure 2) represented with a complex tectonic regime where strike-slip regime of the North Anatolian Fault Zone (NAFZ) and extensional regime of Aegean exist together (Dewey & Şengör 1979; Şengör et al. 1985; Smith et al. 1995). It accommodates conjugate faults with NE-SW (e.g., Kestanbol and Gülpınar) and NW-SE (e.g., Tuzla and Balabanlı) trending (Figure 2). Off these faults, Kestanbol is an active fault, and lies in the east of the Biga Peninsula. This fault is extending in the west of Tuzla province, parallel to the coast of the Aegean Sea. The Gülpınar Fault extends between Gülpınar and Babakale at the westernmost tip of the peninsula.

Following the Gülpınar-Ayvacık earthquakes, field observations have been performed by a group of earth scientists, closely recognizing the region (Sözbilir et al., 2017). Branches of the Tuzla Fault present a distribution of antithetic and synthetic faults along a zone with a width of 2 km (Sözbilir et al., 2017). With these properties of the fault branches seated at the north and south of the Tuzla, existence of a newly formed asymmetric depression area has been determined (Sözbilir et al., 2017). This depression is bounded by the Tuzla and Balabanlı Faults and referred to as Tuzla Basin seated between Beydağı and Geyikalan Horsts (Figure 2). The Tuzla Fault is splayed into two segments: Çamköy and Paşaköy. The former segment is extending from the coast at the northwest of the Tuzla province to the southeast and does not terminate on the coast and enters into the Aegean Sea. The latter one is seated to the southeast and combines with the Edremit Fault Zone, at the southern margin of the Biga Peninsula. The Balabanlı Fault, which is a normal fault with a NE dipping plane, delimits the southern margin of the Tuzla Basin.

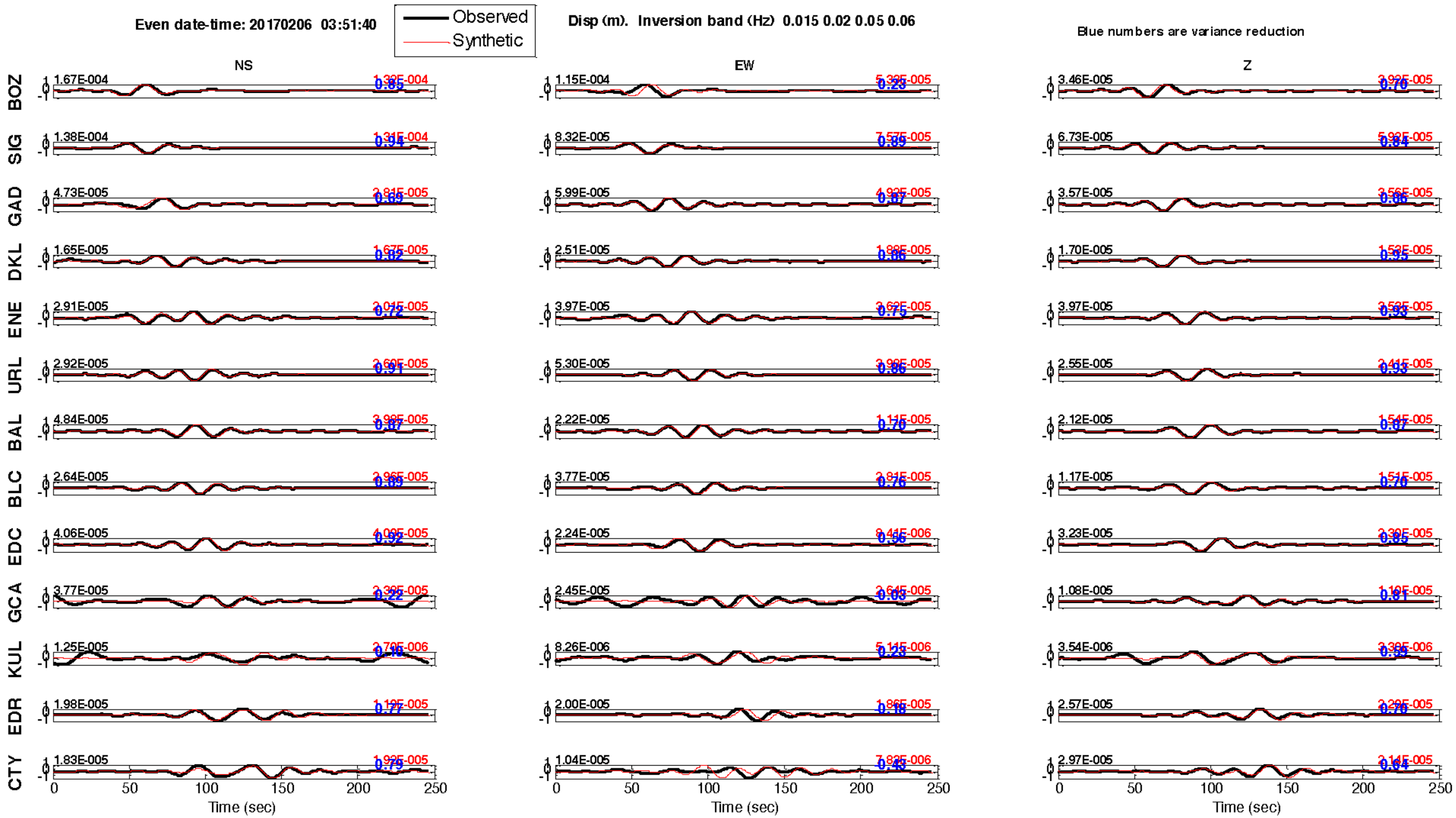
GÜLPINAR-AYVACIK SEISMICITY

The Gülpınar-Ayvacık earthquakes are recorded by stations of the Kandilli Observatory and Earthquake Research Institute (KOERI) – National Earthquake Monitoring Center (NEMC). Figure 1 shows these stations recording this activity.



Şekil 2. Biga yarımadası üzerindeki Gülpınar-Ayvacık depremlerinin dağılımı. Noktalar KOERI tarafından rapor edilen (Ocak 2017-Temmuz 2018) dönemine ait 1.5 yıllık sismisiteyi temsil ederken, içi dolu daireler bu çalışmada analiz edilen (14 Ocak-2 Mart 2017) arasındaki 1.5 aylık döneme ait 86 depremi temsil etmektedir. Yıldızlar ise bu aktiviteye ait en büyük üç depremi temsil ediyor (Tablo 1). Tektonik birimler şekil üzerinde haritalanmıştır. EFZ: Edremit Fay Zonu, KF: Kestanbol Fayı ve GF: Gülpınar Fayı

Figure 2. Distribution of the Gülpınar-Ayvacık earthquakes on the Biga Peninsula. Dots represent one and half year of seismic activity (Jan 2017 - Jul 2018) of the Gülpınar-Ayvacık earthquakes reported by the KOERI. Solid circles represent 86 earthquakes (Jan 14 to Mar 2, 2017) analyzed in this study. Stars represent three largest events of this activity, together with event numbers (see Table 1). Tectonic units have been also mapped in this figure. EFZ: Edremit Fault Zone, KF: Kestanbol Fault and GF: Gülpınar Fault.



Şekil 3. 6 Şubat 2017 tarihinde meydana gelen en büyük depremin (M 5.5) ters çözüm sonucuna ilişkin dalga formlarının karşılaştırılması. Değişim azalım değerleri sismogramın sağında tanımlanmıştır. Bu depreme ait tüm dalga formlarının karşılaştırılması sonucunda elde edilen değişim azalım değeri 0.77 olarak bulunmuştur.

Figure 3. Waveform comparison of the inversion solution of the largest event occurring on Feb 6, 2017 with a magnitude of 5.5. Variance reductions are defined at the right of each seismogram. Overall value for all waveform comparisons of this event is 0.77.

Waveform data are plotted by the Seismic Analysis Code (SAC), a software package mostly used by seismologists to study seismic events. Arrival times and phase identifications (such as being impulsive or emerge of phase onset, weighting) of P- and S- waves are marked on the waveform data. Then, this knowledge is extracted from waveform data to provide an input file to the "Hypocenter" earthquake location program (Lienert 1994). This program utilizes this input file with a velocity model (Kalafat et al., 1987) and produces three outputs. One of these outputs is used to evaluate location results. It shows hypocentral errors in origin time, latitude, longitude and depth. It also presents root mean square (rms) value of the location and residuals between observed and calculated arrival times of P- and S-waves for each station separately. If there is an error in phase reading or a timing problem for any of stations, the rms value may be greater than 1.0 and results in large residuals between observed and calculated arrival times. In this case, we iteratively check all P- and S-wave phase readings of stations resulting in large residuals. We attempt to decrease rms values either by visually checking/correcting phase readings or do not insert arrival times of those stations with larger residuals to the "hypocenter" program by assigning their weightings as 4. For each run, we look at residuals and decrease large residuals for each station as a function of distance. Consequently, we find an optimum final location of each event by revising the phase readings. The procedure mentioned above has been applied for each event and final earthquake locations have been revised for 86 events using the one-dimensional velocity model (Kalafat et al., 1987). Figure 2 shows the revised seismicity of the Gülpınar-Ayvacık earthquakes. The largest event [12] of this activity occurred at 03:51:40.7 (UT) on Feb 6 2017 with a moment magnitude of Mw=5.5. This event has been followed by two moderate-sized earthquakes (Mw 5.3); former [31] occurring at 02:24:03.7 (UT) on Feb 7 and latter [62] at 13:48:16.0 (UT) on Feb 12, 2017.

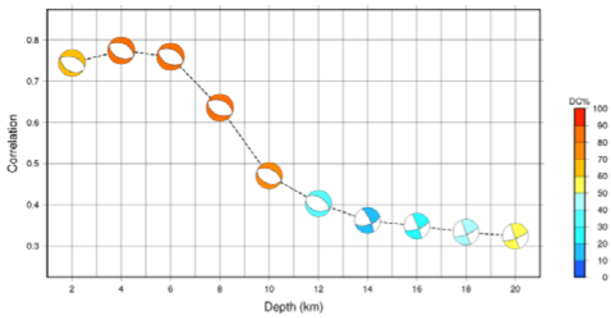
WAVEFORM MODELING

Originally, there are 86 earthquakes of revised seismicity in this study, but only 18 of them have magnitudes (M>4) and those are inverted by the ISOLA software (Sokos and Zahradnik, 2017) running on the MATLAB platform. The inversion procedure only requires waveform modeling of broadband stations. Thus, broadband stations of the KOERI network recording the Gülpınar-Ayvacık earthquakes are selected for the inversion. Distribution of these stations is shown in Figure 1.

Waveform modeling has the following data processing steps such as (1) preparation of pole-zero files to remove instrumental effect on the observed waveforms, (2) selection of broadband stations and crustal model, (3) preparation of waveform data for the inversion (e.g., resampling, DC offset and trend removal, conversion into displacement) (4) computation of Green's Functions which are elementary seismograms to compute synthetic seismograms and finally (5) application of the inversion process. On the inversion step, frequency band of filters are selected. This choice is generally done in terms of earthquake magnitude. For example, a band-pass filter is ranging from 0.02 to 0.05Hz for larger events (M>5). If the event is at moderate size, frequency range of the filter is selected between 0.05 and 0.08Hz. This filter is applied to both observed and synthetic seismograms.

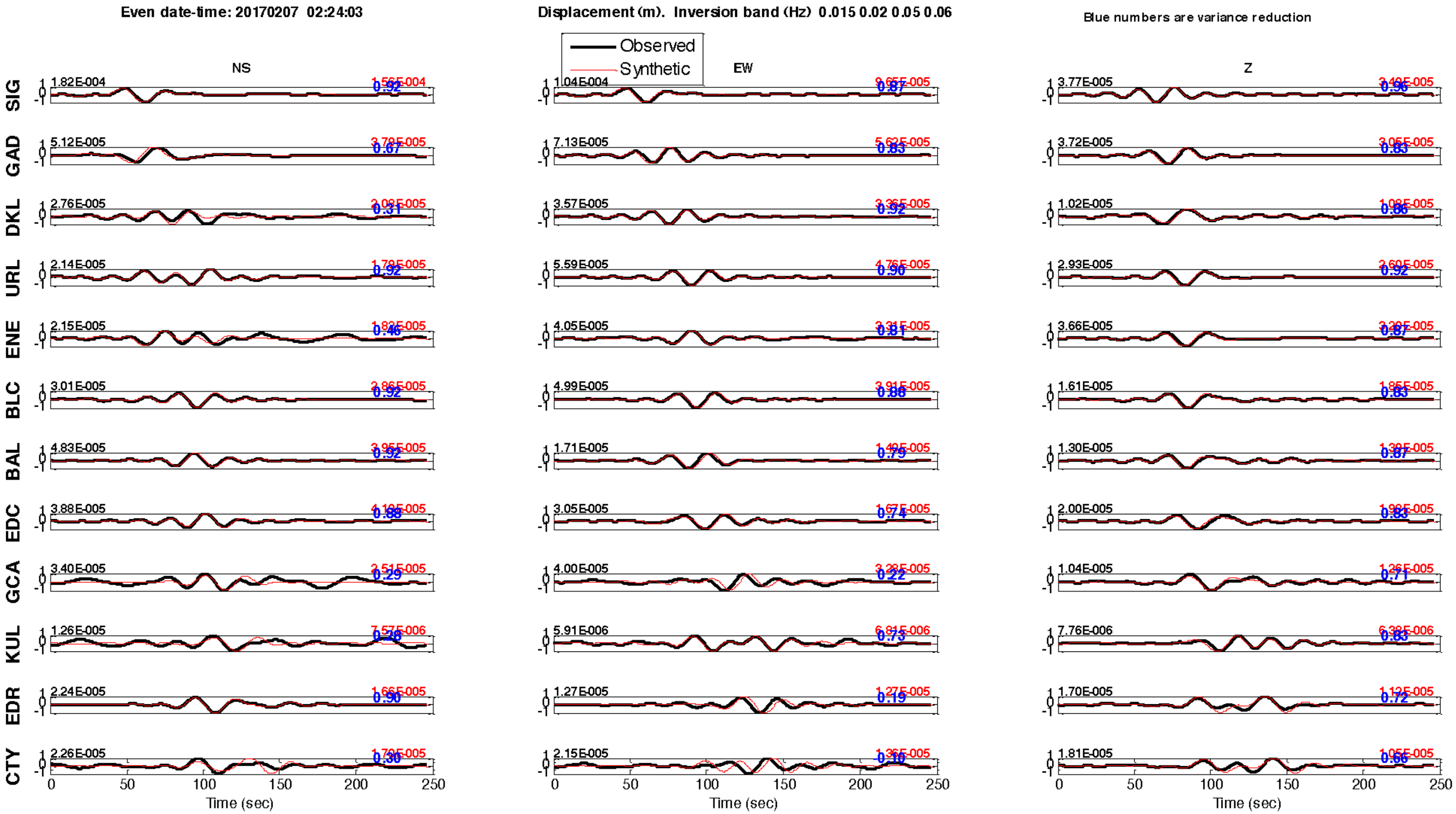
An example of the inversion results is presented for the largest earthquake (M 5.5) occurring at 03:51:40 on Feb 6, 2017. This event is inverted by thirteen broadband stations (see Figure 1). Figure 3 shows bandpass filtered observed and synthetic waveforms of this inversion. This comparison clearly shows that observed and synthetic seismograms are fitting well.

Fitting between observed and synthetic seismograms is given by a variance reduction ranging between 0 (bad fit) and 1 (good fit). This value of this event is found as 0.77 for a trial source depth at a depth of 4km. Figure 4 shows the variance reduction as a function of trial source depths. In this figure, focal mechanisms are colored as a function of double couple percentage. For this event double couple percentage is significantly high. This means it is originated from a double couple source, suggesting two couple of forces acting at the source region and this source is only subjected to the physical changes. This event gives a pure normal mechanism with a NW-SE strike dipping either to the NE or SW. Detailed information of its source parameters is given in Table 1.

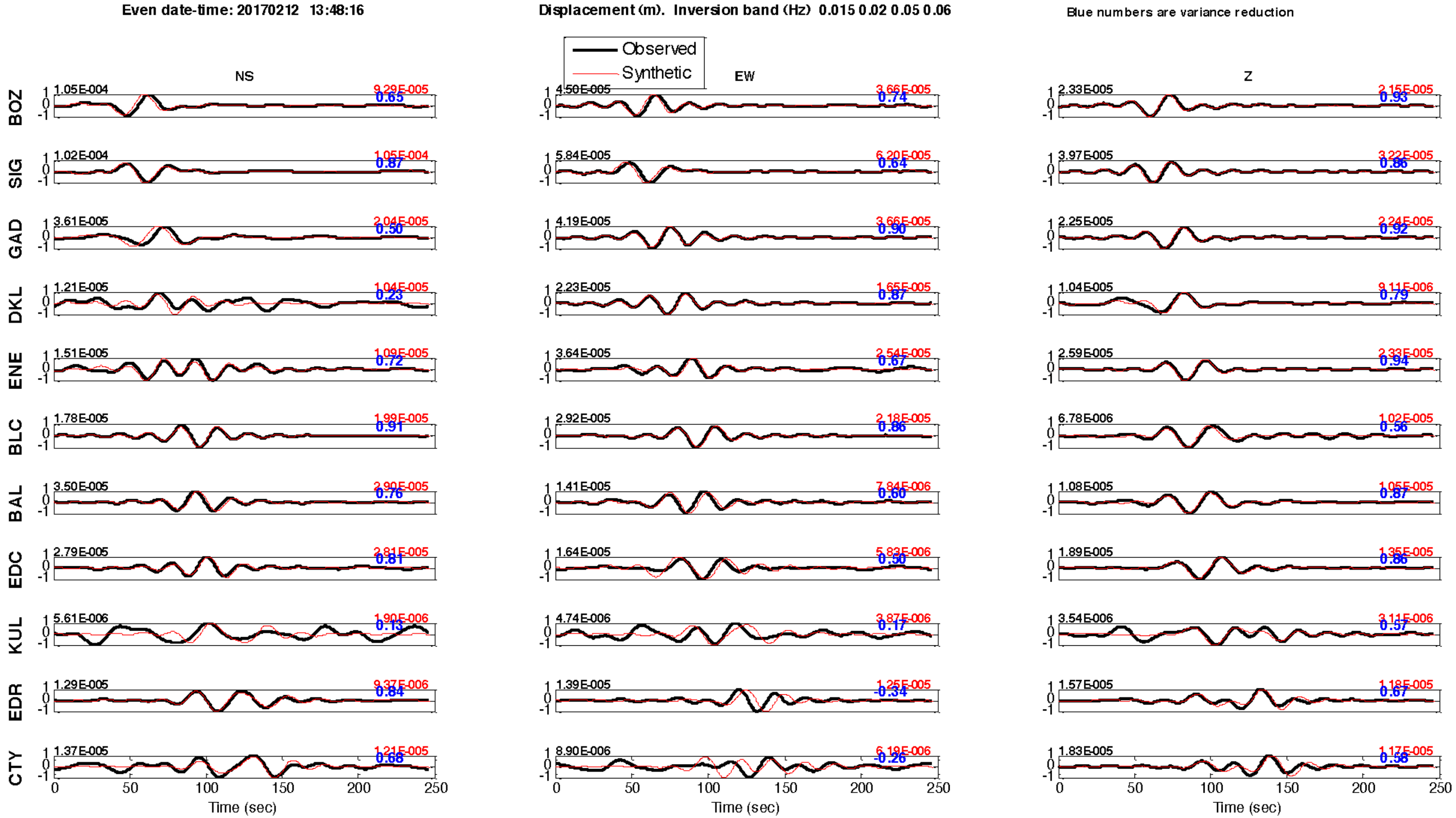


Şekil 4. En büyük depremin [12] değişim azalım değerinin test edilen kaynak derinliklerinin fonksiyonu olarak çizdirilmesi. Bu derinliklerde test edilen odak mekanizma çözümleri, odakta etki eden kuvvet çifti ile sembolize edilen double couple yüzdelerinin fonksiyonu olarak renklendirilmiştir.

Figure 4. Variance reduction of the largest event [12] is plotted as a function of trial source depths. Focal mechanisms at trial source depths are colored as a function of double couple percentage.



Şekil 5. İkinci büyük depremin [31] (Şubat 7, 2017 02:24:03 M5.3) dalga formlarının karşılaştırılması. Ters çözüm sonucu üzerindeki ayrıntılar için Şekil 3'e bakınız.
Figure 5. Waveform comparison of second largest event [31] (Feb 7, 2017 02:24:03 M5.3). See the Figure 3 for details of the inversion solution.

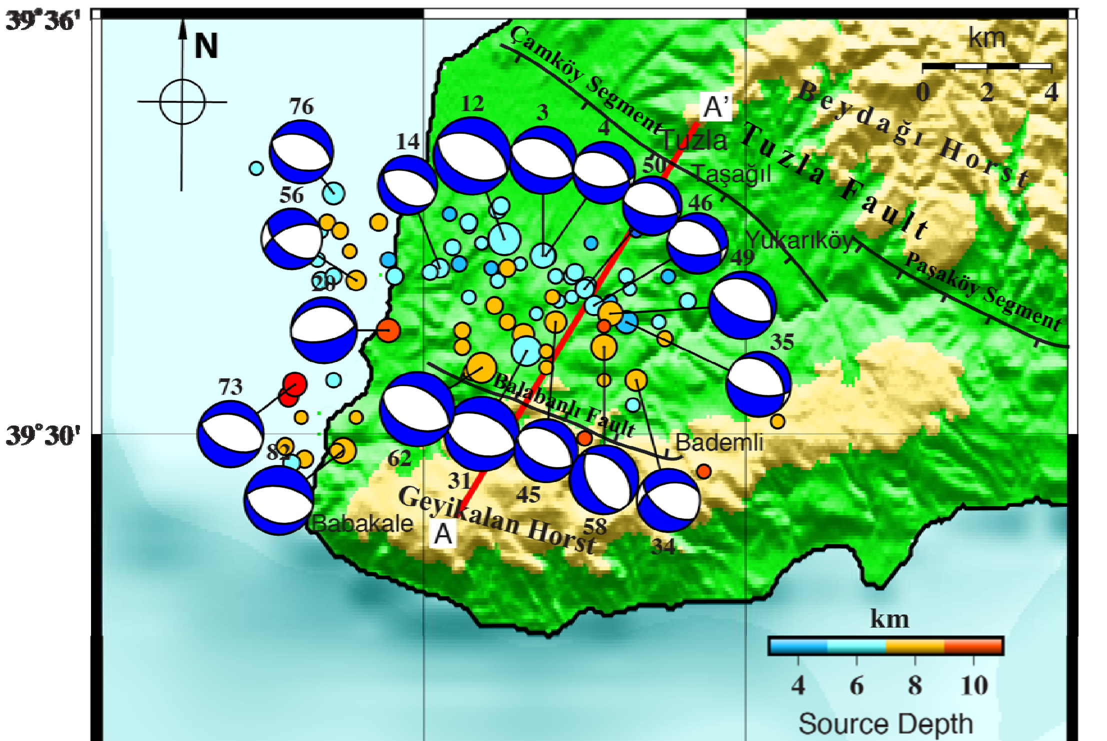


Şekil 6. Üçüncü büyük depremin [62] (Şubat 12, 2017 13:48:16 M5.3) dalga formlarının karşılaştırılması. Ters çözüm sonucu üzerindeki ayrıntılar için Şekil 3'e bakınız.
Figure 6. shows waveform comparison of third largest event [62] (Feb 12, 2017 13:48:16 M5.3). See the Figure 3 for details of the inversion solution.

Second large event [31] occurred at 02:24:03 on Feb 7, 2017. The inversion result based on waveform comparisons is given in Figure 5. This solution is obtained with 12 stations. It is located at 8 km depth with a high variance reduction of 0.81 and a high double couple percentage of 94%.

Third largest event [62] occurred on Feb 12, 2017 to the south of the Gülpınar causing a minor damage, but major panic among the locals since the region is seismically active with a series of earthquakes at variable sizes. According to the Kandilli Observatory, this event has occurred at a depth of 8.2 km at 13:48:16 (UTM). The inversion solution gave a similar depth such as 6 km with a high variance reduction of 0.74 and a high double couple percentage of 96% (Figure6). This event is characterized with a normal faulting with a strike of NW-SE.

Most of the events inverted in this study give pure normal mechanisms (Figure 7). The Gülpınar-Ayvacık earthquake activity shows a linear NW-SE trending tight cluster along the Tuzla Basin. We observe that all seismicity is located off from the mapped faults in the vicinity. Geological observations show that this basin has been formed due to existence of two margin faults; Tuzla and Balabanlı (Sözbilir et al., 2017). Revised seismicity in this figure is colored as a function of source depth. This illustration indicates that source depths of earthquakes are increasing to the SW. This observation infers that the Gülpınar-Ayvacık earthquakes are possibly related to the northern segment (Çamköy) of the Tuzla Fault. Events in the basin are possibly located off from this segment due to its slope. Figure 8 shows a cross section passing through from A to A'. This section clearly shows that earthquakes are aligned to the SW at depth.

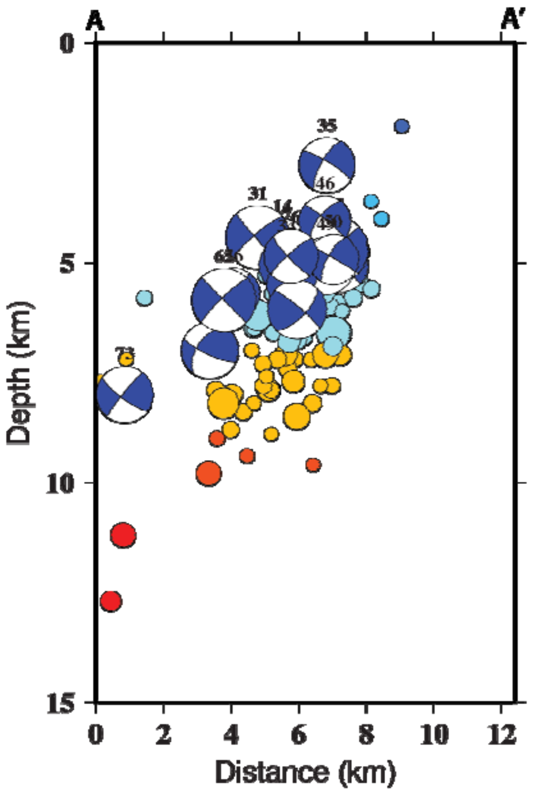


Şekil 7. Gülpınar-Ayvacık depremlerinin (M>4.0) odak mekanizma çözümleri. Depremler kaynak derinliğinin fonksiyonu olarak renklendirilmiştir.

Figure 7. Focal mechanism solutions of the Gülpınar-Ayvacık earthquakes (M>4.0). Earthquakes are colored as a function of source depth

CONCLUSION

In this study we have obtained revised seismicity of 86 earthquakes as well as focal mechanisms of 18 earthquakes near Gülpınar province on the Biga Peninsula, in NW Turkey. These events do not cause any loss of life, but they have caused significant damage in village houses, especially at the provinces on the falling block of the Çamlık Segment.



Şekil 8. Basen içindeki depremlerin KB-GD gidişli çizgiselliklerine dik alınan A-A' derinlik kesiti (kesitin konumu için Şekil 7'ye bakınız). Depremlerin GB'ya doğru bir eğime sahip olduklarını not edin. Bu bilgiden yola çıkarak, Gülpınar-Ayvacık depremlerinin Tuzla baseninin kuzey sınır fayı olan Tuzla Fayının kuzeydeki segmenti ile ilişkili olduğu sonucunu çıkarabiliriz.

Figure 8 A cross section through from A to A', perpendicular to the NW-SE alignment of earthquakes in the basin (see Figure 7 for the location of the section). Note that earthquakes have a slope to the SW, suggesting that the Gülpınar-Ayvacık earthquakes are possibly originated from northern segment of the Tuzla Fault, a northern boundary fault of the Tuzla Basin.

Sözbilir et al., 2017 state that the Tuzla Basin is a newly formed basin seated between the Beydağı and Geyikalan Horsts. This depression is mainly controlled by the Tuzla Fault to the north and Balabanlı fault to the south.

Revised seismicity indicates that Gülpınar-Ayvacık earthquakes are aligned parallel to the Çamköy segment of the Tuzla Fault, characterized by a normal faulting in a NW-SE trend. Focal mechanism solutions from waveform modeling only indicate existence of a normal fault with a trend of NW-SE extending along the basin. Both revised seismicity and focal mechanism solutions suggest that the Gülpınar Ayvacık earthquakes are possibly associated with the Çamköy Segment of the Tuzla Fault.

Tablo 1. Gülpınar Ayvacık- depremleri moment tensor çözümlerine ait kaynak parametreleri
Table 1. Source parameters from moment tensor inversions of the Gülpınar-Ayvacık earthquakes

No	Date (mm/dd/year)	Time (UTC)	Lon. (E)	Lat. (N)	$D_{(HYP)}$ (km)	$D_{(INV)}$ (km)	M_D	M_w	M_o (Nm)	Strike/Dip/Rake	VR/DC
03	01/14/2017	22:38:59	39.543	26.137	6.6	6.0	4.8	4.3	3.312E+15	108/49/-96	0.69/88
04	01/15/2017	04:03:20	39.543	26.138	7.1	6.0	4.4	3.9	8.763E+14	93 /49/-111	0.66/93
12	02/06/2017	03:51:40	39.547	26.125	6.6	4.0	5.5	5.0	4.700E+16	117/44/-88	0.77/90
14	02/06/2017	04:17:29	39.540	26.105	6.4	8.0	4.2	3.8	5.326E+14	127/40/-75	0.57/58
20	02/06/2017	11:45:01	39.525	26.089	9.8	8.0	4.7	4.1	1.587E+15	78/61/-96	0.66/99
31	02/07/2017	02:24:04	39.520	26.132	6.2	8.0	5.3	5.1	6.363E+16	106/42/-96	0.80/94
34	02/07/2017	05:15:51	39.513	26.166	7.1	6.0	4.5	4.0	1.108E+15	121/55/-62	0.59/98
35	02/07/2017	05:17:09	39.527	26.163	4.6	4.0	3.9	4.1	1.919E+15	102/62/-109	0.51/97
45	02/07/2017	21:00:34	39.527	26.141	7.7	6.0	4.5	4.1	1.566E+15	115/50/-99	0.54/91
46	02/07/2017	21:34:59	39.531	26.153	5.7	4.0	4.3	3.8	5.682E+14	94/54/-114	0.55/98
49	02/08/2017	01:38:04	39.529	26.158	7.1	4.0	4.8	4.4	4.884E+15	116/62/-95	0.71/95
50	02/08/2017	02:16:14	39.535	26.150	6.9	4.0	4.2	3.7	4.164E+14	101/62/-103	0.65/32
56	02/09/2017	10:13:10	39.537	26.079	8.0	6.0	4.3	3.7	4.096E+14	128/52/-40	0.62/90
58	02/10/2017	08:55:26	39.521	26.156	8.5	6.0	4.9	4.4	5.076E+15	153/50/-77	0.80/97
62	02/12/2017	13:48:16	39.516	26.118	8.2	6.0	5.3	5.0	3.898E+16	111/45/-97	0.75/96
73	02/16/2017	00:19:01	39.512	26.060	11.2	10.0	4.7	4.3	4.211E+15	115/51/-81	0.79/91
76	02/23/2017	01:55:14	39.558	26.072	6.8	6.0	4.5	4.0	1.285E+15	109/43/-91	0.77/82
82	02/28/2017	23:27:31	39.496	26.075	8.8	8.0	4.9	4.5	6.165E+15	108/34/-80	0.81/94

ÖZET

Çanakkale'nin Ayvacık ilçesine bağlı Gülpınar beldesi etrafında, 2017 yılının başlarında çok sayıda deprem meydana gelmiştir. Gülpınar beldesi, Tuzla baseni olarak bilinen volkanik bir basen üzerinde kurulmuştur. Gözlemlenen sismik aktivitenin çoğu bu basen içinde yer almaktadır. Basenin kuzeyini ve güneyini sınırlayan faylar, kuzeyde Tuzla ve güneyde Balabanlı faylarıdır.

14 Ocak 2017 ile 02 Mart 2017 arasındaki depremlerin konumlarını yeniden tespit etmek için, bu depremlere ait tüm sayısal kayıtlar incelendi ve faz okumaları yeniden yapıldı. Elde edilen faz okumaları kullanılarak bu depremlerin konumları "Hypocenter" programı (Lienert 1994) ile yeniden tespit edildi. Tespit edilen deprem konumları harita üzerinde çizdirildiğinde depremlerin KB-GD yönlü bir yönelime sahip olduğunu gözlemledik.

Çalışmanın ikinci adımında dalga biçimi modelleme tekniği (Sokos and Zahradnik, 2017) kullanılarak depremlerin odak mekanizma çözümleri hesaplandı. Odak mekanizma çözümlerinin neredeyse hepsi KB-GD gidişli normal faylanma ilişkili bir mekanizma ile sonuçlandı. Bu sonuç, bu depremlerin sınır fayları ile ilişkili olabileceğini göstermektedir. Depremlerin hangi sınır fayı ile ilişkili olabileceğini anlamak için KB-GD gidişli çizgiselliğe dik olacak şekilde bir derinlik kesiti aldık. Derinlik kesitine baktığımızda depremlerin GB'ya doğru derine doğru bir çizgisellik gösterdiği, bu sonucunda Gülpınar-Ayvacık depremlerinin Tuzla baseninin kuzey sınır fayı olan Tuzla fayının kuzey segmenti (Çamlık) ile ilişkili olabileceğini göstermektedir. Sonuç olarak, Gülpınar-Ayvacık depremleri tektonik kökenli depremlerdir ve bölgedeki jeotermal kaynaklarla ilişkili değildir.

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