Nat. Hazards Earth Syst. Sci., 6, 999–1006, 2006
www.nat-hazards-earth-syst-sci.net/6/999/2006/

Natural Hazards and Earth System Sciences

Marmara Island earthquakes, of 1265 and 1935; Turkey

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Received: 27 September 2006 – Revised: 23 November 2006 – Accepted: 23 November 2006 – Published: 30 November 2006

Abstract. The long-term seismicity of the Marmara Sea region in northwestern Turkey is relatively well-recorded. Some large and some of the smaller events are clearly associated with fault zones known to be seismically active, which have distinct morphological expressions and have generated damaging earthquakes before and later. Some less common and moderate size earthquakes have occurred in the vicinity of the Marmara Islands in the west Marmara Sea. This paper presents an extended summary of the most important earthquakes that have occurred in 1265 and 1935 and have since been known as the Marmara Island earthquakes. The informative data and the approaches used have therefore the potential of documenting earthquake ruptures of fault segments and may extend the records kept on earthquakes far before known history, rock falls and abnormal sea waves observed during these events, thus improving hazard evaluations and the fundamental understanding of the process of an earthquake.

1 Introduction

The North Anatolian Fault (NAF) is a major right-lateral transform fault controlling the westward motion of the Anatolian Plate. It has shown cyclical seismic behavior, with century-long cycles beginning in the east and progressing westward. The northern branch of the NAF system in the Marmara Sea region, where it splays into two major fault branches about 100 km apart, has a very distinct morphological expression and is seismically active (Fig. 1). Most of the lateral motion is transferred obliquely from the southern to the northern branch, across the Marmara basin. The tectonic regimes and different structural models, which have been put forward for the NAF in the Marmara Sea region by various researchers, were discussed in Yaltırak (2002) in detail. Recently, Provost et al. (2003) through a 3-D mechanical modeling of the GPS velocity field, provided an estimate of the NAF slip rate in the Marmara Sea in the order of 17.5 mm/yr. Such a rate is very consistent with the long term slip rate estimates from geological reconstructions covering a period of 3–5 million years. Therefore, we may assume that the large earthquakes occurring along the NAF system and in the Marmara Sea region inherit a common systematic.

Apart from the systematic and large earthquakes, some others of moderate scale are known to have existed, possibly having occurred on other secondary faults, for example, on some diverse-sized strike-slip fault segments which take place along the southern margin of the Marmara Sea. Some of these occurred in and around the Marmara Islands which are located between the Kapıdağ Peninsula in the south and Şarköy in the SW margin of the Marmara Sea (Fig. 1). These earthquakes are classified as the Marmara Island earthquakes in this paper.

The Marmara Islands have always been on the nautical passageway between the countries of the Mediterranean and Black Sea. They are composed of three bigger (Marmara, Paalimanı, Ava) and many smaller islands (Ekinlik, Koyun, Hayırsız, Fener, Yer, Tavan and Mamalı). The Marmara Island, known as Proconnesus in classical times, is the biggest one with an area of 117 km^2. Thirteen shipwrecks have been identified around the islands since 1993 (PAP/RAC, 2005).

Our research has shown us that these earthquakes have some common characteristics. They usually are of shallow epicenters, and their effects are generally restricted to the west Marmara Sea. There are not many details on the literature on these earthquakes but there were records of tumbling boulders from steep precipices and of others causing abnormally destructive sea waves. In this study, the Marmara island earthquakes occurred in 1265 and 1935; associated tectonic setting and sea waves will be under focus.

2 Earthquakes in the region

Throughout history, earthquakes have been the most damaging natural disasters that have affected the study area (Ambraseys and Finkel, 1995; Ambraseys, 2000, 2002a; Pınar et al., 2003). They were strong and caused damage particularly in small villages on the islands, from where we have little

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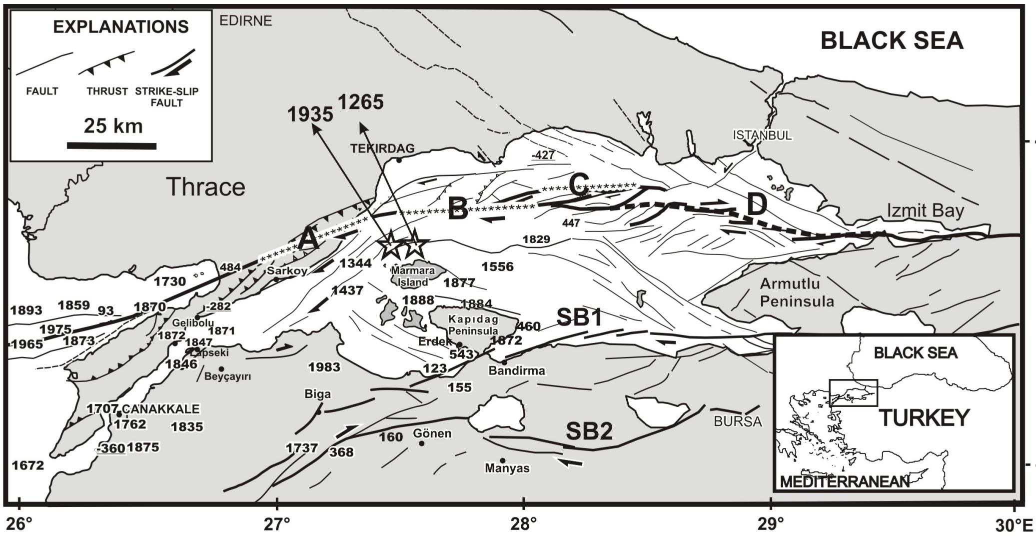

Fig. 1. Historical earthquakes (from 360 B.C. to present) of the Western Marmara Sea region (modified from Altınok et al., 2003). Marmara Island earthquakes are different from those occurred on the northern branch of the North Anatolian right-lateral strike-slip fault system (NAF) or on its Southern branches of SB1 and SB2. **(A)** 824, 1081 (?), 1354, 1659 1912; **(B)** 796, 1063, 1343, 1569, 1766-2; **(C)** 790, 1032, 1346, 1569, 1766-1 earthquakes. D (dashed line): probable rupture of the expected earthquake in the Marmara Sea.

information. Historical events (before 1900) are usually difficult to map out because their estimated epicenter locations usually coincide partially or wholly; therefore they are listed in Table 1.

Historical sources are rarely explicit enough to be definitive, especially for the Marmara Sea events with horizontal displacements on its strike slip faults. However, very little is known in detail about their effects in the rural areas of the Marmara Islands. It is therefore difficult to associate the earthquakes in Table 1 with a probable style of known Quaternary faulting.

Some important and well-documented data are as follows:

In 123, the flooding of the River Rhyndacus (Orhaneli River, a tributary of Kocasu River) is "prophesied"; "Cyzicus, dweller on the vine-clad Propontis, Rhyndacus shall dash his stream about thee in a swelling wave" (Guidoboni et al., 1994).

In 460, the city walls of Cyzicus in Kapıdağ Peninsula were partly collapsed (Guidoboni et al., 1994). Cyzicus was established by Dolions. The name of the city was taken from legend of the Argonauts and from king Kyzikos.

In the 543 earthquake, most of the city walls of Erdek (Artaki) were demolished. Seismic sea waves were reported. By the end of the earthquake the townsfolk had abandoned the city.

The earthquakes of June 1042 and September 1064 that occurred in the western part of Istanbul made the greatest damage in Iznik and the Kapıdağ Peninsula (Skylitzes age; Skylitzes Cont.; Glykas age).

On 13 October 1877, only 8 survived in the Marmara village out of 94 houses and 34 houses were destroyed at Paalimanı (Alonia) Island (Ambraseys, 2000). The shock was strong at Erdek and Çanakkale and was reported as being felt from Hisarlık, Ezine, Edirne and Istanbul. The tremors were followed by a few aftershocks.

The instrumental seismicity (1900–2006; ISC, NEIC, EMSC bulletins) shows a scatter of epicenters of moderate earthquakes around the northern branch of the NAF and on the NE margin of the Marmara Island (Fig. 2). The moment tensor solution of 22 events (Pınar et al., 2003), most of which took place following the 1999 Izmit earthquake (Mw=7.4), indicate normal faulting with oblique components stimulates most of the earthquakes to the north of the Marmara Islands, contrary to that of the main strike-slip fault in the north.

2.1 1265 Earthquake (10–12 August 1265)

This event is known as Proconnesus earthquake, occurred at 11 August, 40.7 N, 27.4 E, h=n, M=(6.6) (Papazachos and Papazachou, 1997).

The historian G. Pakhymeres himself, felt the earthquake and reported it (Pakhymeres, p. 377). Along with a committee of four people, Pakhymeres goes to pay a visit to the exiled patriarch Arsenios (Patriarch of Istanbul, 1255–1267) in order to tell him the decision of the emperor and the synods (Pakhymeres, p. 353). The committee leaves Istanbul on 25 July 1265 and arrives in the Marmara Island two days later, staying there for 15 days (Pakhymeres, p. 373; Failler, 1981). After their visit to Arsenios, upon their return, a terrible storm breaks out. The committee seeks refuge in the bay of Galenolimenas, NW of the island (Pakhymeres, pp. 373–375). In the middle of the night a strong earthquake occurs.

Table 1. The moderate to large earthquakes occurred in the region of the Marmara Islands.

No	Date	Lon Lat	Location	Intensity	Remarks
1	10 Oct 123		Erdek		Tsunami ?
2	7 April 460	(40.40 N 27.90 E)	Erdek	(VIII) M=(6.3)	
3	6 Sep 543	(40.35 N 27.80 E)	Erdek, Bandırma Kapıdağ Peninsula	IX M=(6.6)	Tsunami
4	June 1042		Iznik, Erdek		
5	Sep 1064	(40.40 N 28.00 E)	Iznik, Erdek	IX	
6	10–12 Aug 1265	(40.70 N 27.40 E)	Marmara Islands	M=(6.6)	Tsunami
7	10 May 1556	(40.30 N 28.00 E)	Edincik-Erdek	(IX) M=(7.0)	
8	12/13 Jan 1872 10:15	(40.40 N 27.80 E)	Erdek	VI M=4.9	
9	13 Oct 1877	(40.60 N 27.60 E) (40.50 N 27.50 E)	Marmara Islands	(VIII) M_s=5.5 M=6.1	
10	1 Nov 1877 08:35	(40.60 N 27.60 E)	Marmara Islands	(VI) M=4.9	
11	13 May 1884	(40.40 N 27.80 E)	Bandırma, Erdek, Balıkesir	(VII)	
12	6 April 1888		Erdek, Pasalimanı		
13	4 Jan 1935	(40.64 N, 27.51 E)	Marmara Islands	M_s=6.4	Tsunami

1 – Hasluck (1910); Doğancı (2001); This earthquake is dated 120/128 by Guidoboni et al. (1994). 2 – Ambraseys and Finkel (1991); Kılıç (2001); Guidoboni et al. (1994); Papazachos and Papazachou (1997). 3 – Malalas age; Soysal et al. (1981); Demirkent (2001); Ambraseys (2000); Guidoboni et al. (1994). 4 – Skylitzes age p. II, p. 532; Demirkent (2001). 5 – Demirkent (2001); Skylitzes Cont., p. 657; Glykas, age p. 605. 6 – Papazachos and Papazachou (1997); Ozansoy (2001); Ambraseys (2002). 7 – Ambraseys and Finkel (1995). 8 – Öcal (1968); Soysal et al. (1981). 9 – Soysal et al. (1981); Ambraseys (2000); Öcal (1968). 10 – Basiret (25 November 1877). 11 – Öcal (1968); Basiret (9 November 1877); Soysal et al. (1981). 12 – BOA Y.PRK.ASK. 54/16. 13 – Ambraseys (1988).

Upon its impact, a big piece of the mountain breaks off and tumbles into the sea, creating huge waves that hit the shore and swallow up the area. The committee members are terrified (Pakhymeres, p. 374–377).

The date of this earthquake is not clear. It might have happened between 10–12 August because the committee had a terrible trip back and were able to reach Istanbul on the 16th. All of this was interpreted as the result of not having had the Patriarch's blessing (Pakhymeres, p. 377).

There is no quantitative element about the earthquake. The high intensity of the earthquake implies that the epicenter should be very close to the hard metamorphic rocks that form the mountain ranges of Marmara Island, possibly even underwater (Ozansoy, 2001).

Some small sea waves were reported by eyewitnesses on Marmara Island. Ambraseys (2002b) believes that it was not of seismic origin, but was caused by the collapse of a rock mass from a mountain near Çınarlı. He defines the sea waves as spurious events. Even some false events can usually be assigned to historical earthquakes when they only consisted on storms, the sea waves occurred in this specific event are believed different from the storm waves occurred in the same period, as huge waves created were accompanied with the mountain break-off.

2.2 1935 Earthquake (16:41:29 local time, 4 January 1935)

This event is known as Erdek (Cyzicus) and Marmara Islands earthquake, occurred at 14:41:29, 40.64 N, 27.51 E (ISS), h=0–60 km (SEAP), M_s=6.4, I_o=IX (MSK) (Ambraseys, 1988).

Along with these heavily damaging earthquakes in the Marmara Islands and Erdek, three violent aftershocks also occurred (Pınar and Lahn, 1952). The quake was strongly felt also in Istanbul, Tekirdağ, Edirne, Izmir and Bursa (Cumhuriyet, 5 January 1935; Ulus, 5 January 1935). The villages of Gündoğdu, Çınarlı and Asmalı on Marmara Island were totally, and the center of the island was partially destroyed. In total, 922 houses were destroyed, along with 128 houses in the village of Türkeli on Avşa Island (Afisia), the whole villages of Asmalı and Yiğitler (Azaplar or Araplar), 100 houses in Gündoğdu, and 30 houses in Ekinlik (or Kutali) Island (Akşam, 9 January 1935; Kurun, 11 January 1935). As the earthquake took place during the day, there were not many human casualties except 5 dead and 30 people wounded. The largest aftershocks occurred within 2 h at 15:18:57 (M_s=4.6), 15:19:24 (M_s=4.5) and 16:20:05 (M_s=6.3) and continued until 7 March 1935 (Ayhan et al., 2000).

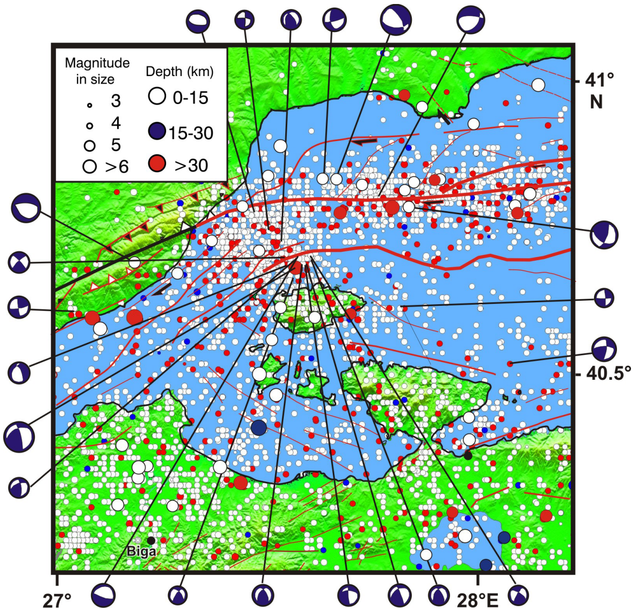

Fig. 2. Instrumental earthquakes occurred between 1900 and June 2006. Data is provided from the catalogues of Kandilli Observatory (KOERI). Geographic distribution of the 22 individual focal mechanism solutions obtained from Pinar et al. (2003) was superimposed. Circle size represents the magnitude of the earthquake, and ranges from 0 to 6.8. Figure was drawn using the GMT software (Wessel and Smith, 1998).

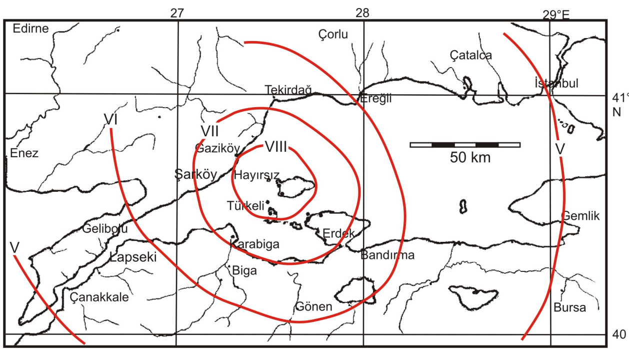

Fig. 3. Isoseismal map of the 1935 Marmara Island Earthquake (Ambraseys, 1988).

As the villages of Poyrazlar and Harmanlı on Paalimanı Island were totally destroyed, the villages of Çınarlı, Paalimanı and Balıklı took heavy damage. All wells dried up and landslides were reported on Marmara Island (Akşam, 9 January 1935). The maximum intensity of IX (MSK) was assigned by Ambraseys (1988) (Fig. 3).

The public rumor is that Hayırsız Island (Gaidaura), west of Marmara Island, was literally divided into two parts from the middle. This is an interesting point and reflects the earthquake's intensity. More realistically, the fog horn building on top of the island was demolished and the cape part of the

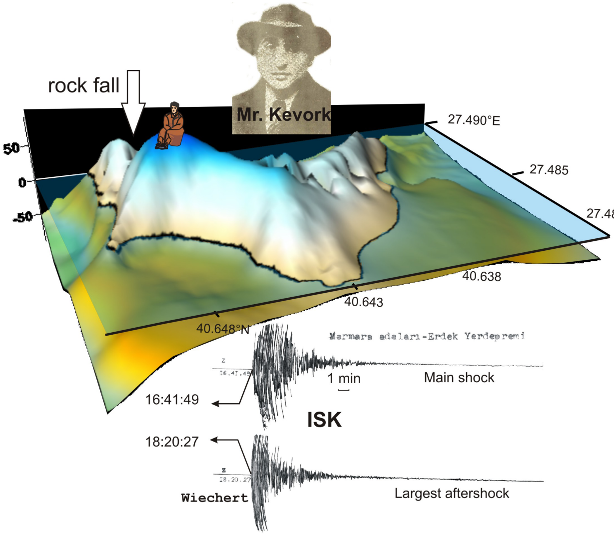

Fig. 4. Morphologic and bathymetric appearance supports extensive submergence along the northern margin of the Hayırsız Island during the 1935 event, as witnessed by Mr. Kevork. The data based upon the ISK (Istanbul) Wiechert seismograms are from "Legancy Data Rescue Project" (No: 05T204), Boğaziçi University.

island broke off and fell into the sea (Son Posta, 11 January 1935). The rocks at shore had fallen into the sea, three sides of the island were submerged and the sea had risen (Milliyet, 12 January 1935). A crack as long as 4 m had opened in front of the light house (Akşam, 17 January 1935). However, the telephone cable crossing the Marmara Sea, was still working.

Loud noises from underground were heard and the fountains at Narlı and Ocaklar villages on the Kapıdağ Peninsula and on Ava Island dried up. Sudden decreases of the groundwater levels were observed in some wells placed along the Dardanelles strait (e.g. Lapseki and Beyçayırı village) and fountains went dry (Son Posta, 20 January 1935). Such events should be related with some shallow deformations prior to and after the earthquake.

In the words of Mr. Kevork (Fig. 4): "*We were constructing a big foghorn for the lifeboat service at Hayırsız Island, right across Marmara Island. We had already placed the concrete foundations on top of the marble grounding and had almost completed the building up to its roof. We were to finish it up in a day or two. On Friday 4:45 (local time), the first tremors came. We were in the building then. The tremors lasted for 2 minutes. 15 minutes later a second, half an hour later, a third set of tremors followed. When the third came, I was outside, trying to gauge the damage done to the building. Suddenly I saw the ground move to and fro. I immediately sat down. Although from where I was sitting, normally the sea is not visible, somehow, I don't know how, I was able to see the sea. It was during this last tremor, when the whole building just collapsed.*" (Kurun, 10 January 1935).

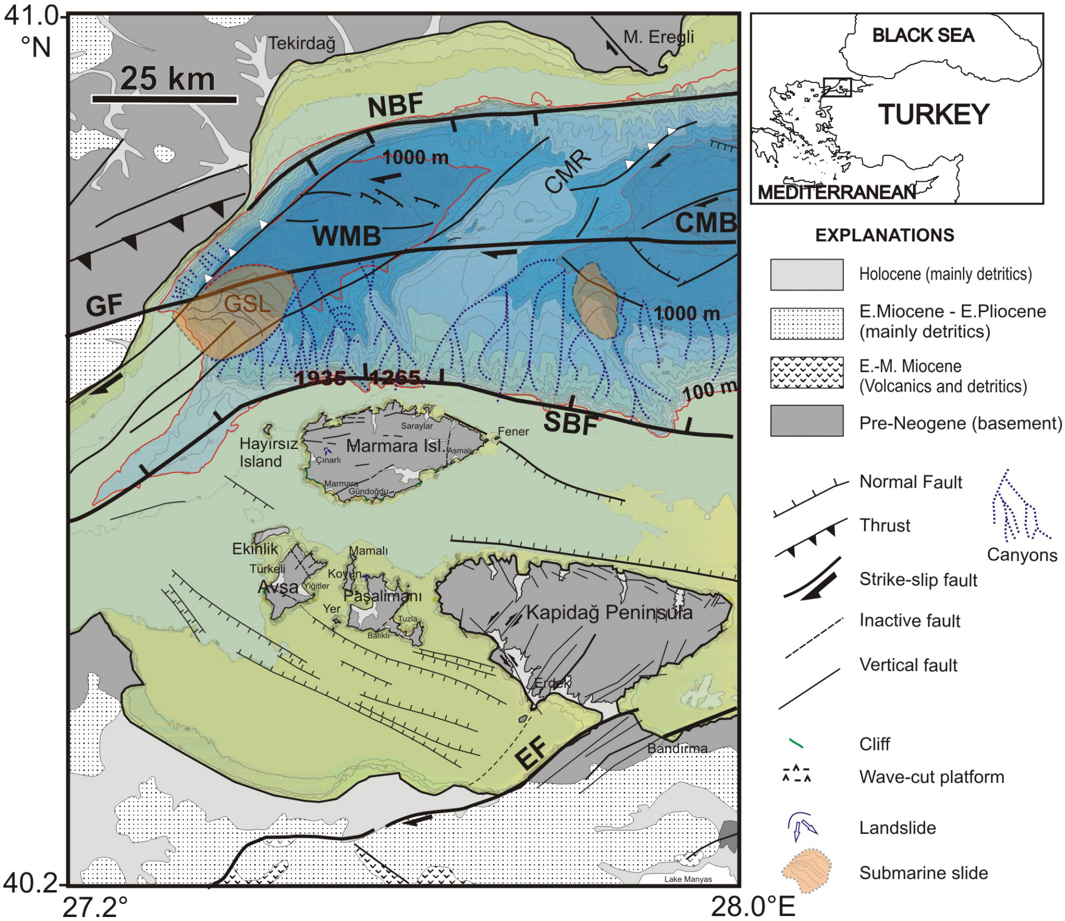

Fig. 5. Map showing the general tectonic features of the region of Marmara Islands such as simplified geology, active structures, submarine canyons and landslides. Compiled from Erentöz and Pamir (1964); Aksoy (1995); Yaltırak (2002); Yanmaz (2004); Karacık et al. (2004). WMB: Western Marmara (Tekirdağ) Basin, CMB: Central Marmara Basin, CMR: Central Marmara Ridge, GF: Ganos Fault, EF: Edincik Fault, SBF: Southern Boundary Fault, NBF: Northern Boundary fault of Northern Anatolian fault (NAF), GSL: Ganos Submarine Landslide.

The findings imply that the epicenter was located along the narrow northern shelf of the Marmara Island where faults with large normal components are dominant (Smith et al., 1995). Even no focal mechanism solutions are available, the isoseists which are almost circular between Gelibolu and Ereğli (Fig. 3) support normal-faulting mechanism in the northern margin of the Marmara Island. The earthquake caused rocks fall into the sea and three sides of the island were submerged. It is possible that the event may have produced some sea waves in and around Marmara Islands.

3 Discussion of the earthquake generating faults

The epicenters of the 1265 and 1935 earthquakes are not placed on the main fault zones in the Marmara Sea, e.g. Ganos fault zone or on the southern branch of NAF extending along the southern coast, but they occurred in the vicinity of the Marmara islands between these two main tectonic elements.

In geological and geomorphological sense, the Marmara islands are northward continuations of the Kapıdağ Peninsula (Fig. 5), on which Palaeozoic metamorphic schist and younger magmatic rocks are dominant (Aksoy, 1995). As joined to the mainland by a tombolo, this dome-shaped peninsula displays N–S oriented deep valleys and parallel mountain ridges as high as 800 m, and forming steep slopes along its northern and western shores. The northern shores are especially very indented. Quaternary alluvial plains, mainly made up of sand and gravel deposits with clay intercalations, are distributed along the short valleys in the north and southwest coasts. Similarly pre-Permian metamorphic units are widely distributed on the Marmara Island (Erentöz and Pamir, 1964). The granodioritic intrusions, however, form an E–W trending steep topography in the central part of the island which rose to prominence in the Roman period and retained its importance in the Byzantine and Ottoman periods. Its quarries supplied marble carried by ships for extravagant imperial building programs (Tunçdilek, 1987).

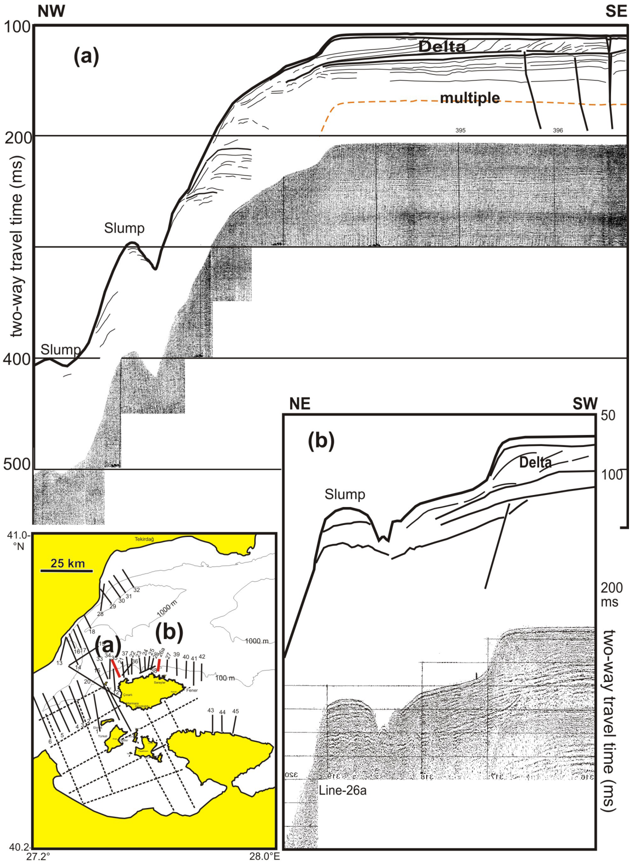

Fig. 6. Slumps at various depths can be seen off the shelf break to the north of the Marmara Islands.

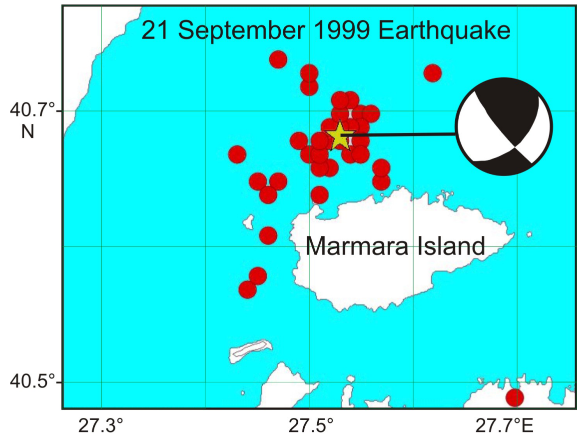

Fig. 7. Focal mechanism solution of the 21 September 1999 earthquake and its aftershock distribution (data from KOERI).

The metamorphic and magmatic complexes observed on the Kapıdağ Peninsula and Marmara islands were bounded by tectonic elements in the north and south. The most important faults in the region are the NE–SW trended Edincik fault (northernmost rupture of the Bandırma-Gönen bend system), and other underwater faults bordering the Kapıdağ peninsula and Marmara Island in the north (Fig. 1) (Yaltırak, 2002; Karacık et al., 2004). In order to document the processes associated with underwater ruptures (homogenites, mass wasting, liquefaction, fluid seepages); high-resolution shallow (Beller, 1994; Domaç, 1994; Smith et al., 1995; Altınok et al., 2003) and multichannel seismic data (Smith et al., 1995; Adatepe et al., 2002; Ateş et al., 2003; Parke et al., 2003) were combined and reinterpreted (Fig. 5). A modified structural map was superimposed on the bathymetry map (1:250 000) compiled by Yanmaz (2004). The depth contours were produced from a data grid of 25 to 50 m intervals obtained from (a) regular investigations of the Marine Research Division by R/V MTA Sismik-1 from 1995 to 2003 using Atlas Deso echo-sounder and Seisnet Integrated Navigation Systems (DGPS), (b) multibeam data collected by Department of Navigation, Hydrography and Oceanography (SHODB), (c) the data of projects Marmara-2000 (R/V Le Suroit and R/V Odin Finder) and Marmara-2001 (R/V Urania). The data gaps especially for near shore areas were supplemented by the navigation charts of SHODB.

Seismic data reveal that the metamorphic core of the Marmara Island is uplifted as a footwall in the south of the southern boundary normal fault (Ateş et al., 2003) EW extending in the Marmara Sea. To the north of this fault, syn-tectonic growth strata submerge along this fault as a hanging wall. Positive Bouguer gravity anomalies over the Marmara Island and Kapıdağ Peninsula, contrary to negative anomalies over the deep Marmara troughs, are due to intrusions of the high-density upper mantle (Adatepe et al., 2002), and this supports the uplift of the Marmara Island which is made up of felsic (igneous) rocks.

The seismic sparker data collected by Smith et al. (1995) on the northern shelf of the Marmara Island and south of the western Marmara basin show clear offsets in the buried sediments (Fig. 6). The siliciclastic mud deposits, with parallel reflections forming a 5–6 m thick drape over the delta progradation, are dominant around the shelves of the Marmara Islands. As inferred from the ^{14}C dating, the sedimentation rate is estimated 40–45 cm/1000 years (Çağatay et al., 1996). Sand and gravel-rich sediments are locally exposed near the coastal areas.

The Marmara Sea presents an interesting setting for landslide tsunamis. In the present-day seafloor setting along the northern slope of the Marmara islands, sedimentary bodies from submarine landslides are abundant at various depths in front of the progressive delta deposits. We interpret these features as morphological records of repeated slope failures and slump generated massive debris flows which may help to document syn-sedimentary tectonic movements. The sediments, however, are highly deformed, possibly due to the deformation associated with the tectonic regime. This area is defined as a zone of intense deformation by Parke et al. (2002). On 21 September 1999 a Mw 5.3 earthquake

(KOERI: 40.69° N 27.58° E, local time 00:27:59, M_d 5.0, 16.4 km deep; USGS: M_b 4.5) occurred close to Marmara Island. Although the location of the earthquake may be within a 10-km-error range, in the absence of a reliable local seismic monitoring network in the region at that time, the epicenters of the main and following aftershocks were located near the western tip of the Marmara Island fault, suggesting this as a likely source (Fig. 7).

Zitter et al. (2006) defines some deep canyons in the southern Marmara slope off the Marmara Island. These canyons are organized in a network with large spaces between them and might be closely associated with previously active mass movements and underwater slides from the canyons' walls (Fig. 5). Frequent earthquake activity in the region sheds sediments from the flanks and contributes sediment on to the basin floor. At the southwestern margin of the Western Marmara Basin, a rough and hummocky topography can be observed over an oval area more than 75 km^2 and several imbricated scars on it indicate multiple events of underwater failures.

4 Conclusions

Earthquakes in the Marmara Island region have some common characteristics. They are usually shallow earthquakes whose effects are generally restricted to the west Marmara Sea. Narrow and steep-sloped rock cliffs with small pockets of sediment which occur sporadically within indentations along the coast are dominant along the northern margin of the Marmara islands. Tumbling boulders detached from these steep precipices have been observed and reported. Abnormal sea waves have also been observed.

It is presumed that these earthquakes were triggered by the fault line running north of the Marmara Island. During the 1265 earthquake, the mountain in the region of Çınarlı village, west of Marmara Island toppled into the sea after the violent tremors. In 1935, a similar event took place on Hayırsız Island. This sort of phenomena takes place on shores that are by nature rocky or with steep precipices, caught between beach-type sandy areas. Hayırsız and Marmara Island, with coasts that have a strong foundation, precipices looming in the foreground and rocky debris on the coastline may be evidence left behind by these earthquakes.

During the 1265 and 1935 earthquakes, sea waves were created in and around Marmara Island. The place where Mr. Kevork sat was approximately 100 m above sea level. From this position, he was able to see the sea momentarily, which was normally invisible. However, there are no records that indicate any effect these sea waves have had on the Marmara Island coastline. No slide or slump-like structures were observed on the seismic sections recorded on the shelf zones. In addition, the slump structures observed on the slopes beyond the shelf edge do not appear to be related to the earthquakes of 1265 and 1935, since their tsunami would have been moderately high and observed by many witnesses living along many coastal cities of the Marmara Sea. The results indicate that the sea waves observed during the Marmara Island earthquakes were caused by the massive boulders that tumbled into the sea, or the collapsing of Hayırsız Island on three sides. The generated sea waves should be local and hardly noticeable from populated places at the northern or southern coasts of the Marmara Sea.

Acknowledgements. Funding was partly allocated by the research fund of the Istanbul University; under project UDP-680/08022006, and European project FP6-037058, Transfer. The authors thank N. Özer, N. Özel and C. Yaltırak for providing recent and historical earthquake data and seismic profiles.

Edited by: E. Pelinovsky
Reviewed by: two referees

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