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Palaeoseismological Investigations on the Karadere Segment, North Anatolian Fault Zone, Turkey

AYNUR DİKBAŞ[1,2] & HÜSNÜ SERDAR AKYÜZ[3]

[1] İstanbul Technical University, Eurasia Institute of Earth Sciences, Maslak, TR–34469, İstanbul, Turkey
[2] now at TÜBİTAK MAM, Earth and Marine Sciences Institute, Gebze, TR–41470 Kocaeli, Turkey
(E-mail: aynur.dikbas@mam.gov.tr)
[3] İstanbul Technical University, Faculty of Mines, Department of Geological Engineering, Maslak, TR–34469 İstanbul, Turkey

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Abstract: The Karadere segment of the North Anatolian Fault (NAF) is the easternmost part that ruptured during the 17 August 1999 İzmit earthquake (Mw 7.4). It has a different orientation, at N65°E to other segments which have a nearly E–W trend, and lesser dextral displacement, with maximum 2.3 m in contrast with 5.2 m in the ruptured neighbouring western segment. Two palaeoseismological trenches, at Kazimiye and Karadere sites, were excavated on the central part of the Karadere segment to determine the timing of past earthquakes.

Excavation of the Kazimiye site revealed the occurrence of five past events since the 4th century A.D., including the 1999 İzmit earthquake. The oldest event occurred after A.D. 231–407 and before A.D. 420–584 based on ^{14}C dating results. This event may correspond to either the A.D. 358 earthquake or the A.D. 554 historical earthquake. The younger three events predate 1999 and postdate A.D. 420–584. At the Karadere trench site, three past events, including the 1999 İzmit earthquake, were identified. The penultimate event was observed on the trench wall and dated to be after A.D. 1298–1370. The older event is dated as before A.D. 1150–1261, which may correspond to one of the determined events in the Kazimiye trench. In summary, palaeoseismological data provide evidence for at least five large earthquakes on the Karadere segment since A.D. 231–407, including the 1999 İzmit earthquake.

Key Words: North Anatolian Fault, earthquake, Karadere segment, palaeoseismology, 1999 İzmit earthquake

Karadere Segmenti Üzerinde Paleosismolojik Araştırmalar, Kuzey Anadolu Fay Zonu, Türkiye

Özet: 17 Ağustos 1999 İzmit depremi ile Kuzey Anadolu Fayı'nın (KAF) Marmara Bölgesindeki beş segmenti kırılmıştır. Bu segmentlerden en doğudaki Karadere segmentidir. Kırılan diğer segmentler yaklaşık doğu–batı konumlu iken Karadere segmenti hem K65°D doğrultusu ile hem de diğer segmentlerde ölçülen ötelenme değerlerinden daha düşük ötelenme değerleri ile farklılık gösterir. Karadere segmenti üzerinde meydana gelmiş eski depremleri belirleyebilmek amacıyla segmentin orta kesimlerinde iki farklı lokasyonda (Kazimiye ve Karadere lokasyonları) paleosismolojik hendek çalışmaları yapılmıştır.

Kazimiye hendeğinde 4.yy'dan sonra 1999 İzmit depremi dahil beş olay tespit edilmiştir. Karbon-14 tarihlendirmesine göre en eski olay M.S. 231–407'den sonra M.S. 420–584'den önce meydana gelmiştir. Bu olay seviyesi M.S. 358 veya M.S. 554 tarihsel depremlerinden birini temsil edebilir. Hendekte belirlenen daha genç üç olay seviyesi ise M.S. 420–584'den sonra 1999 tarihinden önce meydana gelmiştir. Karadere hendeğinde ise 1999 İzmit depremi dahil üç eski olay seviyesi belirlenmiştir. Bu seviyelere göre 1999 depreminden bir önceki olay M.S. 1298–1370'den sonra meydana gelmiştir. Daha yaşlı olan olay seviyesi ise M.S. 1150–1261'den önce meydana gelen bir depremi temsil etmektedir ve Kazimiye hendeğinde izlenen depremlerden biri ile deneştirilebilir. Palaeosismolojik veriler Karadere segmenti üzerinde M.S. 231–407'den sonra 1999 İzmit depremi dahil beş eski depremi işaret etmektedir.

Anahtar Sözcükler: Kuzey Anadolu Fayı, deprem, Karadere segmenti, paleosismoloji, 1999 İzmit depremi

Introduction

The North Anatolian Fault (NAF) is one of the major active faults on the earth, with an arcuate trend about 1400 km long across northern Turkey from eastern Anatolia to the northern Aegean Sea (Figure 1). The NAF was reactivated on 17 August (M_w= 7.4) and 12 November (M_w= 7.2) 1999 with two destructive earthquakes in the eastern Marmara region as a result

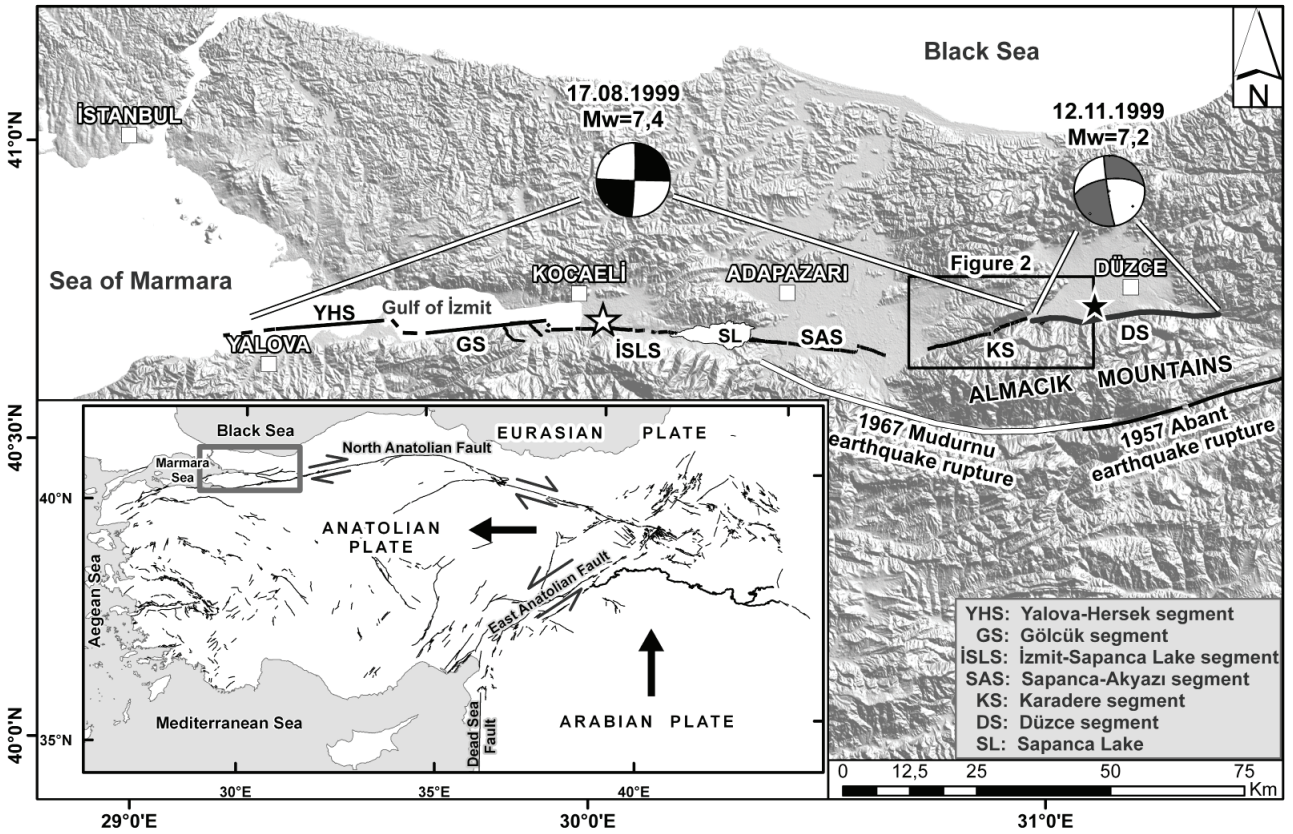

Figure 1. Simplified fault map of the eastern Marmara Region (modified from Barka *et al.* 2002). Inset fault map is taken from Şaroğlu *et al.* (1992).

of the westward migrating large earthquake series in the 20th century (Egeran & Lahn 1944; Ketin & Rösli 1953; Ambraseys 1970; Barka 1992, 1996; Stein *et al.* 1997). The 17 August 1999 İzmit earthquake was one of the most important and destructive earthquakes during the 20th century. It was strongly felt in northwestern Turkey and resulted in 18,000 deaths, 44,000 injured and 78,000 heavily damaged buildings especially in big industrial cities such as Kocaeli, Adapazarı, Yalova and İstanbul.

The 1999 İzmit earthquake ruptured approximately 150 km of the dextral NAF in 5 segments, named the Yalova-Hersek, Gölcük, İzmit-Sapanca Lake, Sapanca-Akyazı and Karadere segments from west to east respectively (Figure 1; Barka *et al.* 2002; Emre *et al.* 2003a). These segments and offset features were mapped and measured in detail by different groups and institutes (e.g., Barka *et al.* 2002; Hartleb *et al.* 2002; Langridge *et al.* 2002; Lettis *et al.* 2002; Rockwell *et al.* 2002; Duman *et al.* 2003; Emre *et al.* 2003a). The maximum dextral offset was measured as 5.2 m on the Sapanca-Akyazı segment (Barka *et al.* 2002). The Karadere segment is the easternmost of these 5 segments and differs in trending N65°E, rather than generally E–W like the others. Measured dextral displacements on the Karadere segment are lower than on the E–W-trending segments, with a maximum of 2.3 m (Duman *et al.* 2003). The Karadere segment forms the northwestern boundary of the Almacık Mountains. The cumulative dextral offset along the segment is measured at 10 km, based on the morphologic displacement of the northwestern part of the Almacık Mountains (Dikbaş *et al.* 2006, 2009).

Visible surface rupture on land after the 1999 earthquake gave an important opportunity to understand the fault geometry and segmentation

of the NAF. Although some palaeoseismological trenching studies have been conducted on the 1999 İzmit earthquake surface rupture, published papers are few. A palaeoseismological trench study was performed on the Gölcük normal fault which is located on a stepover zone between the Gölcük and İzmit-Sapanca Lake segments by Klinger *et al.* (2003). They identified the 1509 and 1719 earthquakes and proposed a 210–280 years recurrence period for large events. Trenching with a Ground Penetrating Radar (GPR) survey on the İzmit-Sapanca Lake segment was performed by Ferry *et al.* (2005). They observed 3 faulting events and a cumulative displacement of about 7 m since A.D. 1591 (date of a canal construction in Ottoman time). Pavlides *et al.* (2006) excavated some trenches on the Gölcük and İzmit-Sapanca Lake segments and obtained some results suggesting that the A.D. 554, A.D. 989 and A.D. 1509 events ruptured this part of the NAF.

Palaeoseismological studies were also conducted on the eastern neighbouring Düzce fault, which ruptured (M_w= 7.2) about three months later than the İzmit earthquake on 12 November 1999 (Figure 1). According to Emre *et al.* (2001, 2003b) and Sugai *et al.* (2001), the penultimate event on the Düzce segment can be correlated with the 1719 earthquake. Hitchcock *et al.* (2003) excavated the eastern part of the 1999 Düzce earthquake rupture and their results indicate that the penultimate event occurred about 300 years ago. They proposed at least four and possibly five earthquakes including the 1999 earthquake during the last 2100 years, with recurrence intervals ranging between 300 and 800 years. Pantosti *et al.* (2008) excavated trenches at five locations on the Düzce fault and recognized three past earthquakes which can be correlated with the A.D. 967, A.D. 1719 and A.D. 1878 historical earthquakes. The authors calculated an average recurrence interval of 330–430 years for the rupture of Düzce fault.

The Karadere segment may have a different history and kinematics due to its orientation. The aim of this paper is to present its general characteristics, palaeoseismicity and historical behaviour. These data will help understanding of the general characteristics of the NAF in the Marmara region and may contribute to seismic risk assessment for the expected Marmara earthquake.

General Characteristics of the Karadere Segment

The Karadere segment is the easternmost one of five segments that ruptured during the 17 August 1999 İzmit earthquake. It is 20 km long and trends N65°E. Its maximum dextral displacement is measured at 2.3 m towards its eastern end (Duman *et al.* 2003) (Figures 2 & 3). The slip distribution is non-uniform, and the offset amounts die out at both ends of the segment (Figure 3). The surface rupture of the 1999 earthquake appeared along linear valleys, offset hills, sag-ponds and pressure ridges along the Karadere segment (Figures 2, 4 & 5).

Palaeoseismological Studies of the Karadere Segment

The Karadere segment mostly follows a valley forming the northwestern boundary of Almacık Mountains. Two sites around the central part of the segment, about 500 metres apart and approximately 1 km southwest of Karadere village, were chosen for trenching; the Kazimiye site (KZM trench) and the Karadere site (KDR trench) from west to east respectively (Figure 6). Trenches perpendicular to the fault were excavated at both sites to identify past earthquakes on the segment. Dating of event horizons was based on ^{14}C (AMS) dating of charcoal samples collected from the trenches. The AMS results are calibrated in Oxcal 4.0 (Reimer *et al.* 2004; Bronk Ramsey 2007) and two sigma intervals are used to date the event horizons.

Kazimiye (KZM) Trench Site

At the Kazimiye site, a dextral offset of 1.1 m was measured after the İzmit earthquake (Figure 7). The site is located on a fault-controlled morphological saddle that elongates nearly N75°E in the 'U'-shaped valley bounded by hills to the north and south. On the northern part of the trench site, Upper Cretaceous clastic carbonates (Yılmaz *et al.* 1982) crop out, overlain by Pleistocene and Holocene fluvial deposits (Emre *et al.* 1998; Ünay *et al.* 2001) (Figure 6). The southern hills are composed of pre-Devonian metamorphic rocks and Cenozoic igneous rocks (Abdüsselamoğlu 1959; Yılmaz *et al.* 1982; Herece & Akay 2003). A simple trench 13 m long and 2.5 m deep was dug. Distinguishable stratigraphic

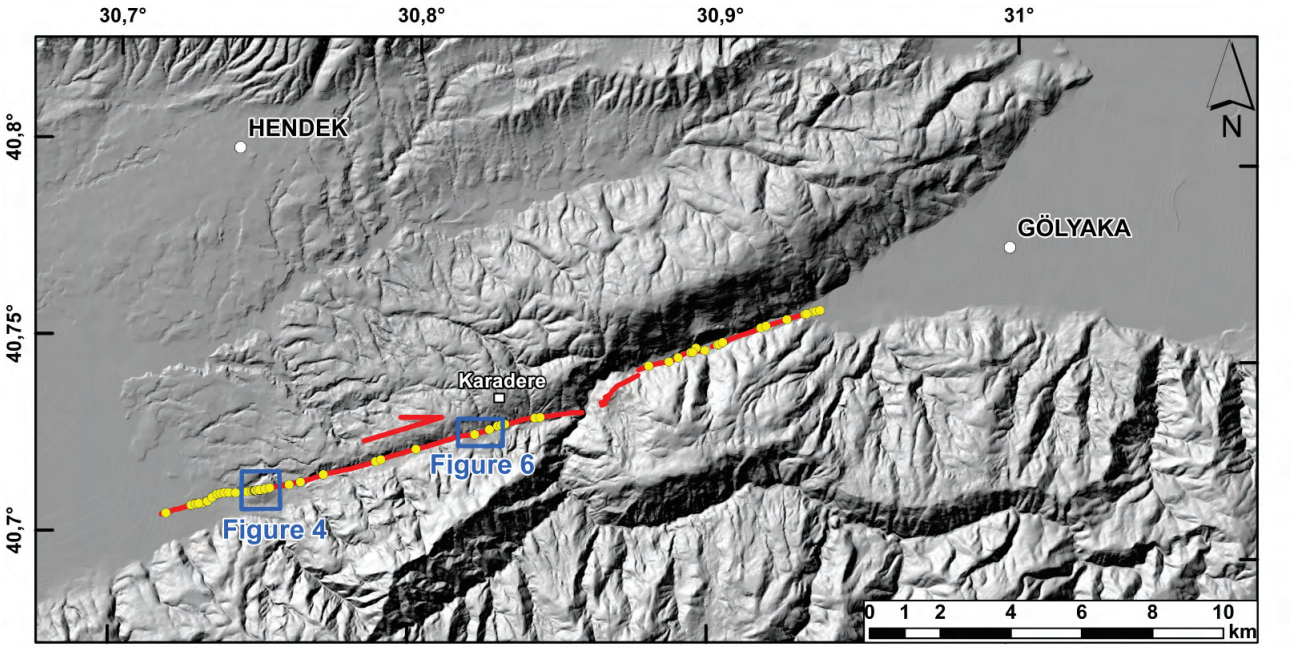

Figure 2. The 1999 İzmit earthquake surface rupture map of the Karadere segment (Barka *et al.* 2002; Hartleb *et al.* 2002). Yellow dots indicate measured offset sites (see Figure 1 for location).

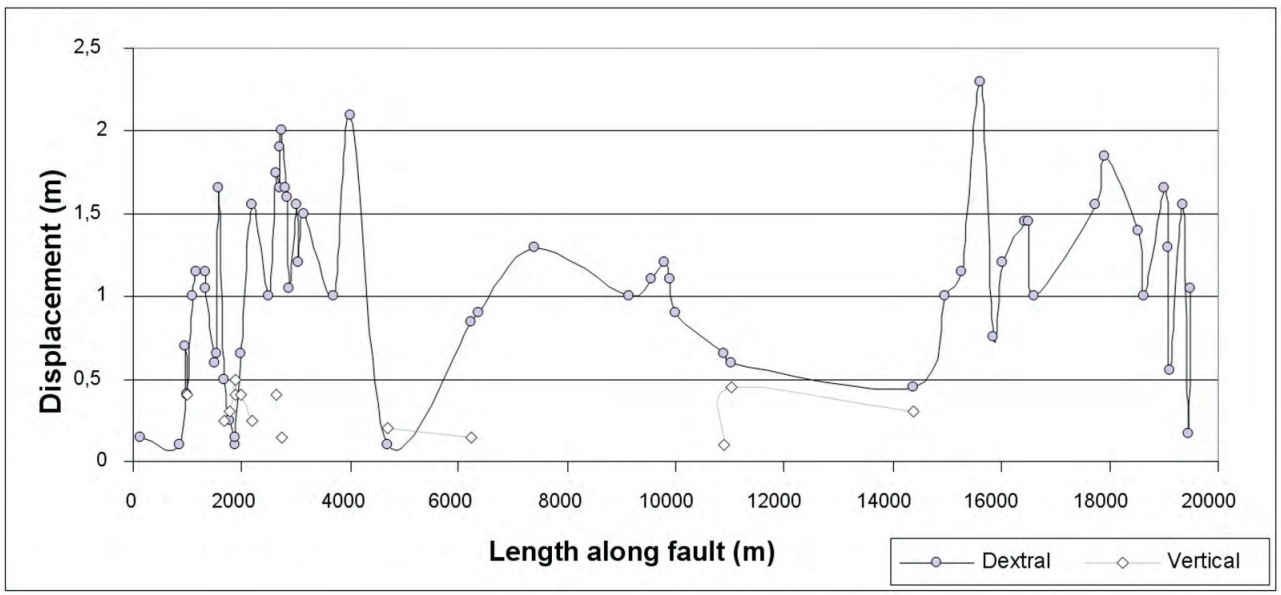

Figure 3. Slip distribution of the August 1999 earthquake on the Karadere segment compiled from Barka *et al.* (2002), Hartleb *et al.* (2002) and Duman *et al.* (2003).

layers, composed of fine-grained slope and colluvial deposits and buried channels, were observed on the trench wall (Figure 8, Table 1). The 1999 rupture zone cutting the ground surface is clearly seen between 2nd and 5th metres. Four past events were identified on the trench wall, based on stratigraphic and structural relationships. The event horizons are described below from the oldest (KZM-4) to the youngest (KZM-1).

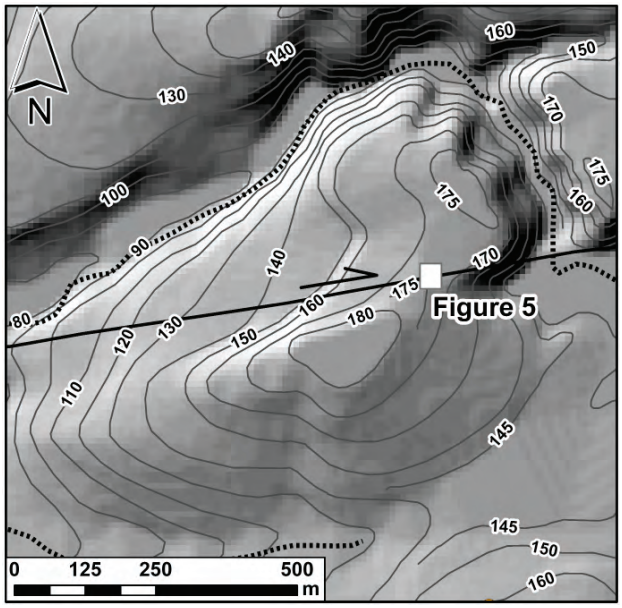

Figure 4. Cumulative right-lateral displacement of a hill on the western part of the Karadere segment (see Figure 2 for location).

The northern part of the trench wall reveals fine-grained deposits (unit B) which comprise different clay layers rich in organic material. In the southern part, slope deposits (unit F) were observed at the bottom of the trench, fed mainly by the metamorphic and igneous rocks forming the southern mountainous area. The grains become smaller towards the north and an erosion surface of unit F is overlain by fine grained deposits (unit C and B) and channel deposits (Unit H).

The oldest event (KZM-4) was observed in the southern part of the rupture zone, where two fault branches cut units F and G. Both branches are overlain by younger fine grained units (units C and E) (Figure 8).

The KZM-3 event was observed within unit C, where the coarse-grained unit F1 and fine-grained unit C3 are cut by a fault and overlain by unit C2.

The pre-penultimate event (KZM-2) was observed south of the rupture zone, where a sheared clay layer with randomly distributed pebbles (Shz4) is cut by a fault, covered with a pebbly clay layer within unit C1.

The penultimate event, KZM-1, was recognized within unit B in the northern part of the rupture zone

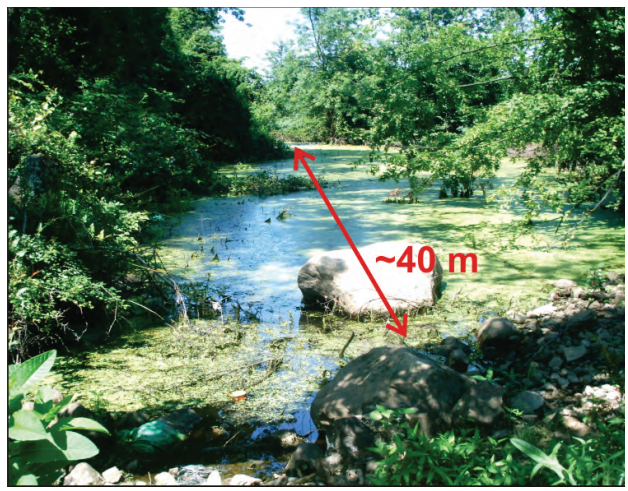

Figure 5. A sag-pond formed on the Karadere segment (see Figures 2 & 4 for location).

about 1 m below the surface (Figure 8). Different fine-grained units B5, B6 and B7 are cut and offset by two fault branches which are covered by unit B3.

Two charcoal samples, KZM-D5 and KZM-D2, constrain pre and post-dates of the oldest event horizon (KZM-4). According to the ^{14}C dating results of these two samples, the KZM-4 event occurred before A.D. 420–584 and after A.D. 231–407 (Table 2). Dating the KZM-D7 and KZM-D21 charcoal samples from units C1 and C3 on the southern part of the 1999 rupture zone produced ages of B.C. 17461–16581 and B.C. 7971–7586, respectively, which seem to be reworked. Although there are no reliable data for the KZM-1 and KZM-2 palaeo-events to date, it is appear that five large earthquakes including the 1999 event occurred after AD 231–407.

Karadere (KDR) Trench Site

The Karadere site is located at 1 km south of Karadere village and nearly 500 m east of the Kazimiye trench site (Figure 6). At this site, the 1999 İzmit earthquake surface rupture follows the southern slope of a pressure ridge and 1 m of right-lateral displacement was measured on an asphalt road which crosses it (Figures 6 & 9a). Along the road-cut, upper Pleistocene fluvial deposits faulted by secondary faults are exposed on the northern side of the 1999 earthquake surface rupture (Figure 9b). A simple trench 11 m long and 2.5 m deep was excavated

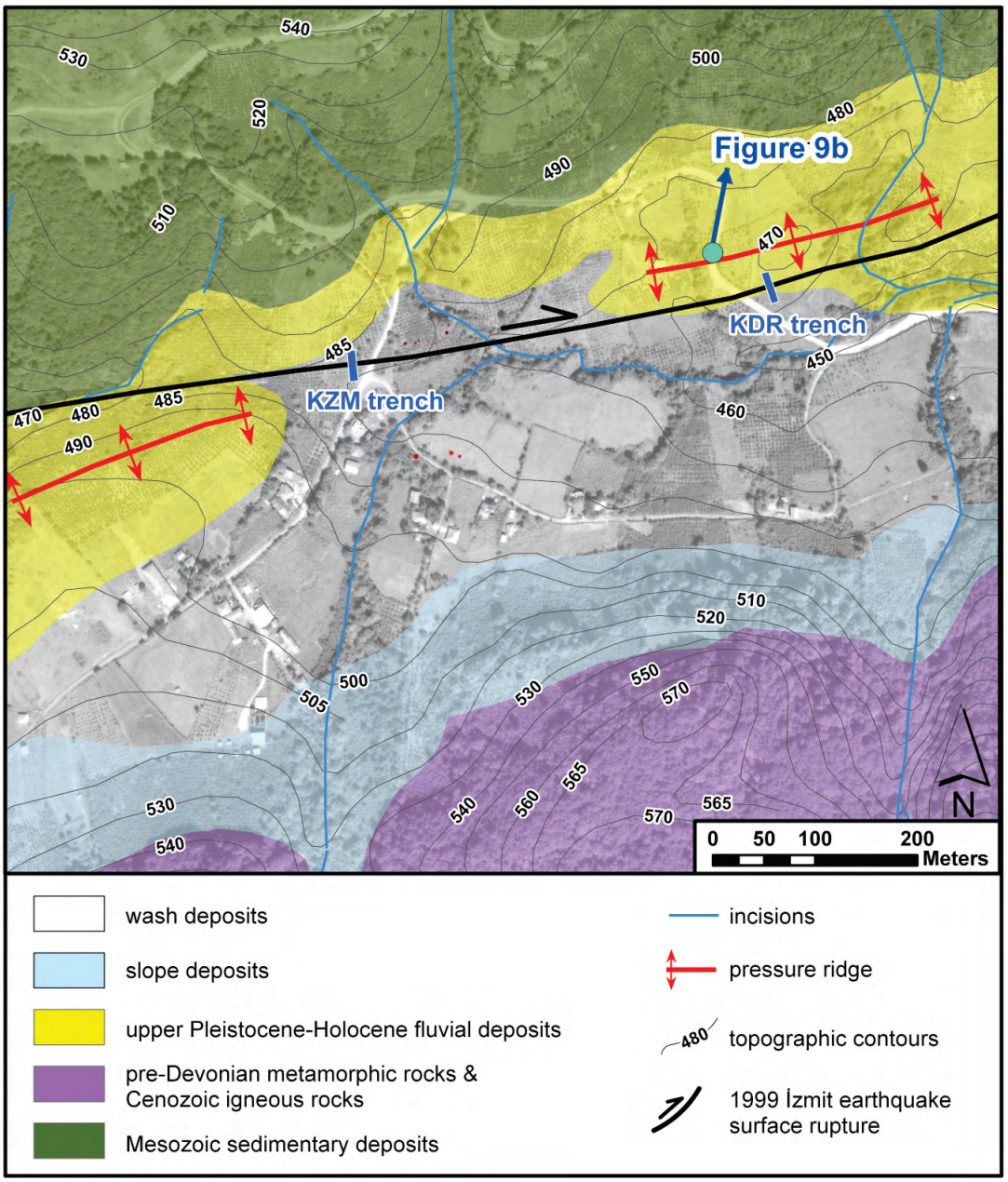

Figure 6. Surface geology and geomorphology map of trench sites in Kazimiye (KZM) and Karadere (KDR) (see Figure 2 for location).

perpendicular to the 1999 earthquake trace (Figure 10).

According to ^{14}C dating results, as mentioned later, the northernmost part of the recent rupture zone in the trench is Late Pleistocene in age (~15000 years) while southern part is Holocene. Holocene deposits are composed of mostly clay layers or clay-rich gravel, sand and silt layers. The 1999 earthquake rupture zone is clearly seen between the 3rd and 7th metres of vertical grid. We identified 3 past earthquakes, including the 1999 İzmit earthquake, based on structural and stratigraphic relationships (Figure 10).

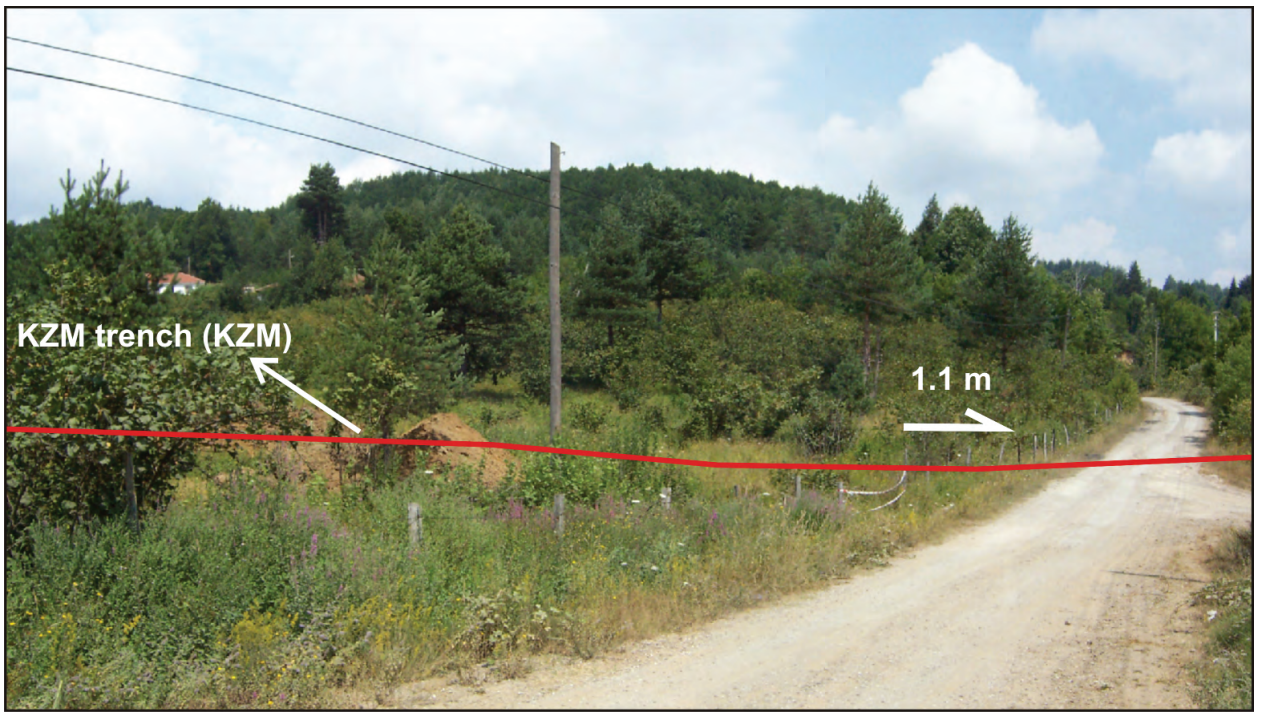

Figure 7. Kazimiye trench location and 1.1 m offset garden fence (view to north).

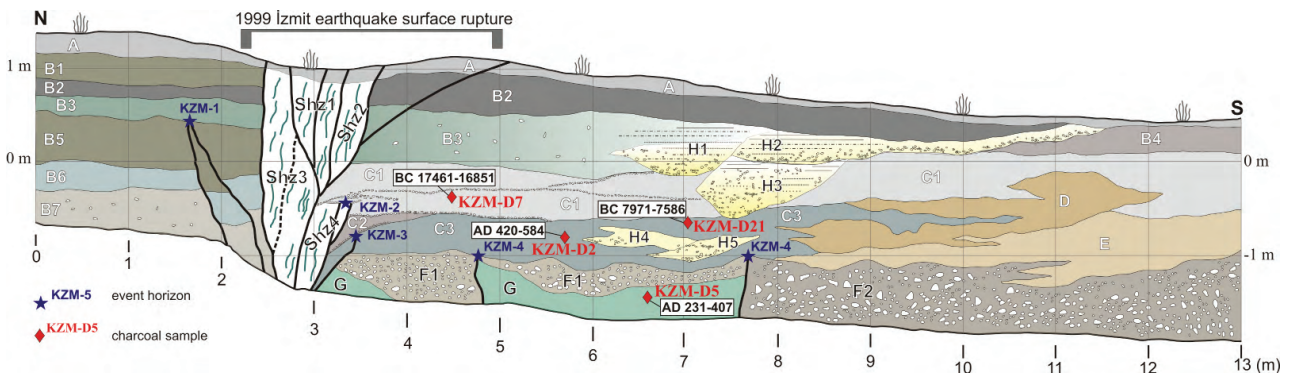

Figure 8. Log of Kazimiye trench, eastern wall.

The oldest event (KDR-2) on the trench wall was observed below unit C. In the southern part of the trench, units D and E are faulted along three different fault branches overlain by unit C (Figure 10). Just north of the recent rupture zone, units D and E are faulted and tilted southwards, and overlain by silty clay layers of unit C.

The penultimate event (KDR-1) was identified by the upward termination of fault branches which offset units older than unit B. More evidence for the KDR-1 event may be the amount of vertical displacement of unit B in the trench wall, which is larger than that of the previous event in the wall.

Five charcoal pieces dated by ^{14}C method yield ages from B.C. 15046–14265 to A.D. 645–724 (Table 2). The older dates (samples KDR-B2 and KDR-B6) are from the southern part of the trench wall where old fluvial units (units G and CH) were observed (Figure 10, Table 3). Samples KDR-B10 and KDR-B7 were obtained from clearly above the KDR-2 event horizon and their calendar ages are A.D. 645–724 and A.D. 1150–1261, respectively. According to

Table 1. Definition of units observed in the Kazimiye (KZM) trench. Shz– Shear zone.

Unit	Sub-unit	Description
A	A	top soil
B	B1	clay, rich in organic material, pale brown
	B2	sandy clay with rare gravel, brown
	B3	clay, green-grey in colour with thin brown clay strata
	B4	pale brown clay
	B5	clay, rich in organic material, pale brown
	B6	blue-grey clay, rich in organic material
	B7	clay, rare caliche gravels, blue-brown
C	C1	clay, rare gravels, rare caliche gravels, green-brown, oxidized -gravels, calishe in green clay
	C2	clay, rare gravels, pale brown
	C3	clay, grey-green
D	D	silt with gravel and sand, light brown
E	E	clay, rare pebbles, green-brown
F	F1	clay with gravels, brown
	F2	pebbles in sandy matrix
G	G	clay, green
H	H1	gravel-sand-silt, fining upwards, oxidized
	H2	gravel-sand-silt, fining upwards
	H3	pebble-gravel-sand-silt, coarsely sorted at the bottom fining upwards, oxidized
	H4	clay with gravel and silt, brown
	H5	clay with gravel, brown
Shz	Shz1	brown-green clay highly sheared
	Shz2	clay, highly sheared, rare pebbles, brown
	Shz3	clay, highly sheared, plenty of calishe gravels, pale brown
	Shz4	clay, lightly sheared, unordered pebbles, green

Table 2. Radiocarbon (AMS) dating results of charcoal samples derived from the Kazimiye (KZM) and Karadere (KDR) trenches.

Lab no	Sample no	Radiocarbon age (Before Present)	$\delta^{13}C$	Calibration (1σ)	Probability 68.2% (1σ)	Calibration (2σ)	Probability 95.4% (2σ)
AA74516	KZM D-2	1555±36	-25.6	A.D. 434–494	42.8	A.D. 420–584	95.4
				A.D. 506–548	25.4		
AA79262	KZM D-5	1731±37	-26.5	A.D. 253–347	64.5	A.D. 231–407	95.4
				A.D. 371–377	3.7		
AA74519	KZM D-7	15830±180	-27.3	B.C. 17260–16940	68.2	B.C. 17461–16851	95.4
AA74519	KZM D-21	8710±71	-25.9	B.C. 7818–7601	68.2	B.C. 8165–8136	1.3
						B.C. 7971–7586	94.1
AA74522	KDR-B2	13939±70	-27.9	B.C. 14874–14455	68.2	B.C. 15046–14265	95.4
AA74523	KDR B-3	585±33	-25.9	A.D. 1315–1356	48.6	A.D. 1298–1370	65.6
				A.D. 1389–1406	19.6	A.D. 1380–1416	29.8
AA74524	KDR-B6	966±29	-26.1	B.C. 1301–1192	57.9	B.C. 1380–1335	7.7
				B.C. 1176–1163	5.3	B.C. 1323–1118	87.7
				B.C. 1143–1132	5.0		
AA74525	KDR B-7	856±34	-26.8	A.D. 1155–1225	68.2	A.D. 1048–1087	11.0
						A.D. 1122–1139	3.3
						A.D. 1150–1261	81.0
AA74526	KDR B-10	1333±34	-26.1	A.D. 652–691	57.7	A.D. 645–724	76.4
				A.D. 750–763	10.5	A.D. 739–771	19.0

these results, the oldest event horizon predates A.D. 1150–1261. Sample KDR-B3, taken from a layer overlying unit G, gives a date of A.D. 1298–1370 for the penultimate event (event KDR-1). Thus, the penultimate event in KDR trench is dated to be after A.D. 1298–1370, and the pre-penultimate event must predate A.D. 1150–1261.

Discussion and Conclusions

The Marmara region has a long historical record due to the existence of major ancient cities in the region such as Constantinopolis (İstanbul), Nicomedia (modern Kocaeli), Hellenepolis (modern Hersek). Historical records provide reliable information about large earthquakes which caused serious damages in

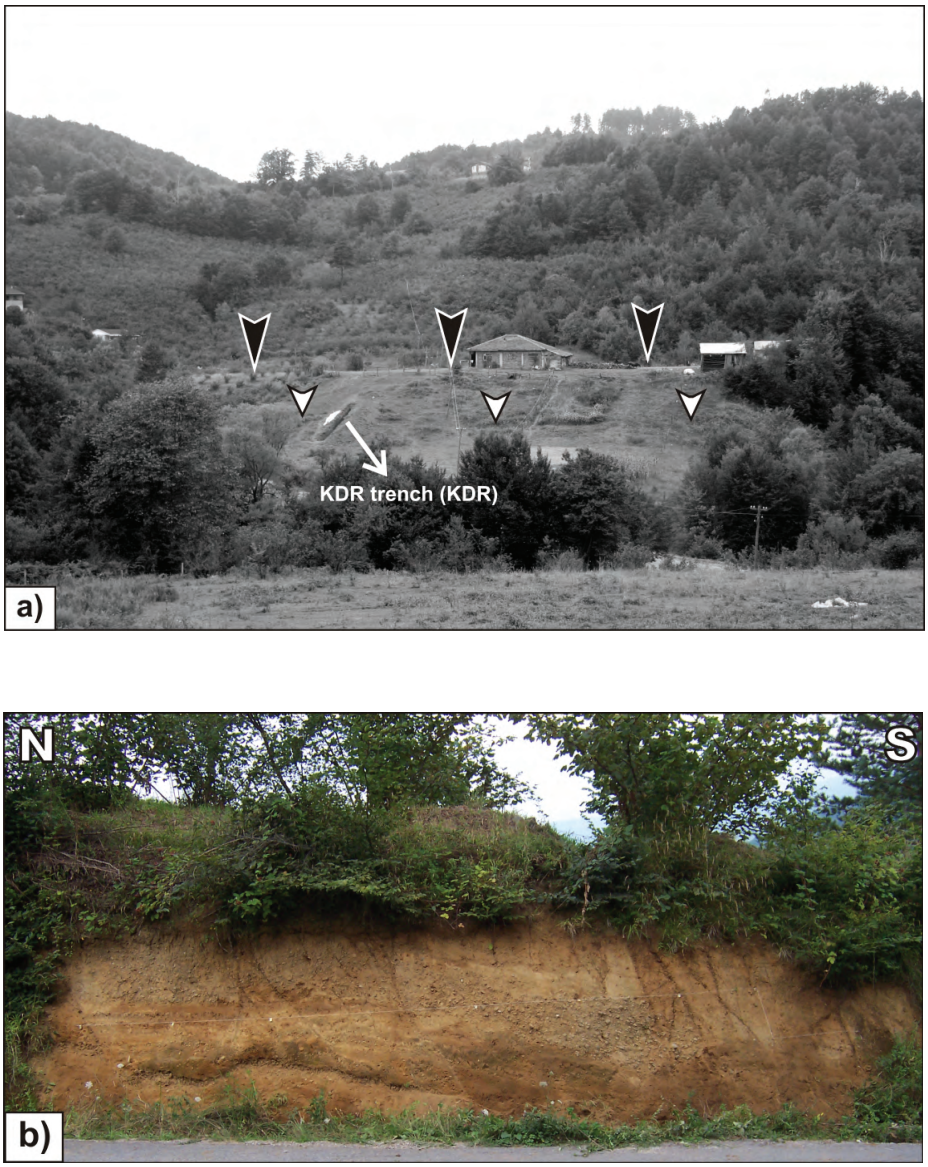

Figure 9. **(a)** Photo of the Karadere trench site. White arrows indicate the 1999 August earthquake surface rupture and black arrows show the peak points of the pressure ridge (view to northwest). **(b)** Faulted Pleistocene deposits on a roadcut northwest of the Karadere trench site (view to east).

those cities. As briefly explained below, dating results for the event horizons compiled from trenches can possibly be correlated with recorded historical earthquakes in the last millennia (Table 2, Figure 11).

The event horizons in the KZM trench can be well distinguished by both stratigraphic and structural features. Based on ^{14}C dating, the KZM-4 event horizon can be constrained to a specific time period that occurred after A.D. 231–407 and before A.D. 420–584, and so can represent the A.D. 358 historical earthquake (Guidoboni *et al.* 1994, and references therein) which was strongly felt in the eastern Marmara region, and caused serious damage to Nicomedia (modern Kocaeli) and the surrounding areas (Öztüre 1969; Guidoboni *et al.* 1994 and references therein). The A.D. 358 earthquake is likely to equate with event KZM-4 (Figure 11).

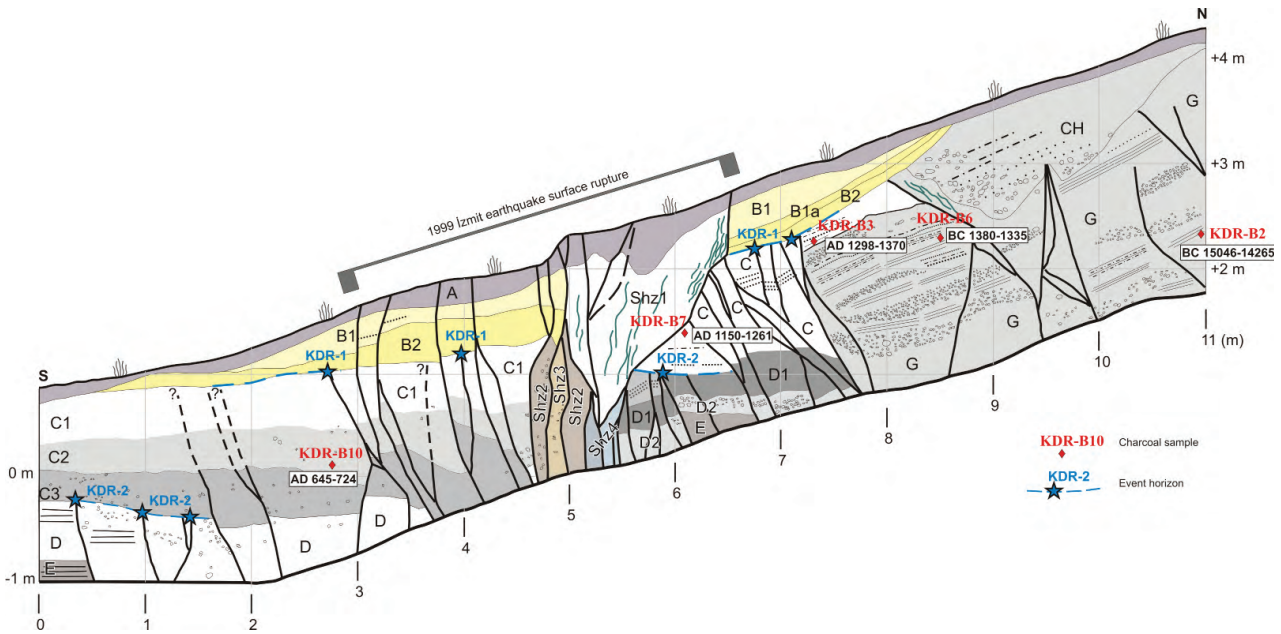

Figure 10. Log of the Karadere trench, western wall.

Table 3. Definition of units observed in the Karadere (KDR) trench. Shz– Shear zone.

Unit	Sub-unit	Description
A	A	top soil
B	B1	sand-coarse sand in clay matrix, grey
	B1a	sandy silt, pale yellow
	B2	clayey silt, grey
C	C1	clay, thin sand-coarse sand layers
	C2	sandy clay, rare gravel, grey
	C3	clay, rare gravels, brown
D	D1	sandy,silty clay
	D2	silty clay, silt and rare gravel layers in clay matrix
E	E	silty-sandy clay with rare gravel, green-grey
Shz	Shz 1	highly sheared clay layers
	Shz 2	clayey silt with caotic gravels
	Shz 3	silty clay, brown
	Shz 4	sheared clay, green-grey-blue
CH	CH	channel deposits
G	G	Holocene and Pleistocene fluvial deposits

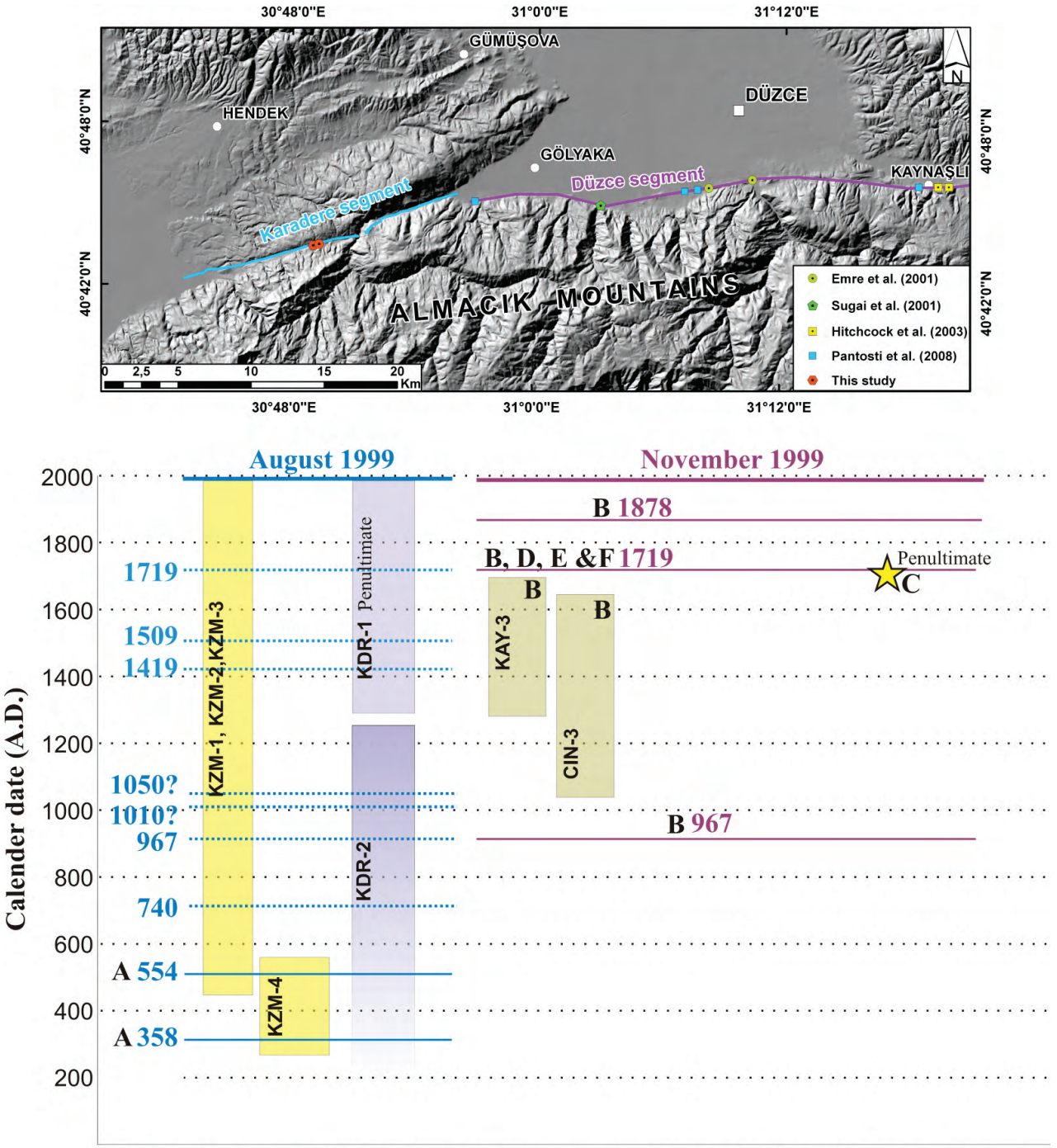

Figure 11. Compiled palaeoseismological results from trenches excavated on the northern boundary of the Almacık Mountains. Dashed blue lines indicate the possible historical earthquakes that had ruptured the Karadere segment. Blue and purple solid lines represent the palaeoseismologically defined historical earthquakes. A– this study, B– Pantosti *et al.* (2008), C– Hitchcock *et al.* (2003), D– Emre *et al.* (2001), E– Emre *et al.* (2003b), F– Sugai *et al.* (2001).

The age of sample KZM-D2 suggests that the KZM-3 event should be around A.D. 420–584. Examination of historical records shows that an earthquake occurred in 554 A.D., which mainly affected Adapazarı and Kocaeli cities in the eastern Marmara region. The earthquake was also felt in İstanbul and İznik (Öztüre 1969; Guidoboni *et al.* 1994 and references therein). Considering its damage distribution, the 15 August 554 earthquake can be correlated with event KZM-3.

Historical documents tell about some well-defined earthquakes (Guidoboni *et al.* 1994 and references therein) which affected the Marmara region and the surrounding areas, circa A.D. 1000. The next large earthquake in historical documents was on 25 May 1419 (Guidoboni & Comastri 2005 and references therein), felt in the eastern parts of the gulf of İzmit, and in the east of the Düzce region (Sakin 2002 and references therein). This earthquake could have ruptured one of the segments in the east Marmara region, based on the damage it caused.

The known big earthquakes in the last 5 centuries in the region are the A.D. 1509 and A.D. 1719 earthquakes. It is well documented that (e.g., Ambraseys 2002) the A.D. 1509 event occurred in the western part of the study area. The A.D. 1719 event also affected the eastern Marmara region (Ambraseys & Finkel 1995).

In the light of historical records, previous studies on neighbouring segments and our findings, a palaeoseismic scenario may be established for the seismic history of the Karadere segment. The A.D. 554 and A.D. 358 earthquakes are well defined by examining the structural and temporal relationships between the KZM and KDR trenches. The A.D. 554 event was also recognized in the trenching study in the Karamürsel-Gölcük segment by Pavlides *et al.* (2006). Combining their results with results of this study, the 15 August 554 earthquake seems to have been very similar to the August 1999 earthquake, if it had ruptured the NAF at least from the İzmit Gulf to the Karadere region. The events recorded in historical documents reveal that the A.D. 358 earthquake ruptured the segments close to the gulf of İzmit. Defining this earthquake in the Karadere segment shows a similar scenario to the A.D. 554 earthquake and this one also seems to have ruptured the same segments as the 1999 earthquake did.

The event horizons KAY-3 and CIN-3 in Pantosti *et al.* (2008) are dated to have occurred between A.D. 1035 and A.D. 1640, and between A.D. 1280 and A.D. 1700, respectively. These two events, observed in two different sites, may represent the 25 May 1419 earthquake (Figure 11). Considering that the 1419 event caused heavy damage east of Düzce, it is possible that the rupture of the 1419 earthquake continued along the Düzce fault, east of the Karadere segment. Ambraseys & Finkel (1991) located this earthquake on the Mudurnu fault which bounds the Almacık Mountains to the south. However, the relationship between the ^{14}C dating result and recorded events in historical documents indicates that the 1419 earthquake possibly ruptured the segments bounding the northern side of the Almacık Mountains.

Pantosti *et al.* (2008) mentioned two earthquakes during this time interval rupturing the neighbouring Düzce fault to the east and correlated them with A.D. 1719 and A.D. 1878 historical earthquakes (Figure 11). Hitchcock *et al.* (2003) realized that the last earthquake on the Düzce fault was about 300 years ago, namely the early 18th century. Emre *et al.* (2001, 2003b) and Sugai *et al.* (2001) recognized the penultimate event on the Düzce segment as the A.D. 1719 earthquake. Trenching studies performed by Klinger *et al.* (2003) in the Gölcük segment provided evidence for the A.D. 1719 event. The existence of evidence from both the Gölcük and Düzce segments suggests that the rupture for the 1719 event extended at least from the gulf of İzmit in the west to the Düzce region in the east, including the Karadere segment.

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