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Recent surface faulting of the North Anatolian fault along the 1943 Ladik earthquake ruptures

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Abstract: We excavated the North Anatolian fault on the surface rupture of the 1943 Ladik earthquake in order to specify the recent faulting history of the segment. A trench was opened across the fault on an alluvial fan surface northwest of Havza. The sediments exposed on the trench walls consist of massive pebbly silt and gravel bearing pottery fragments of the Roman period. A few fault strands cut through these sediments. One strand of the faults cuts the sediments up to just below the ground surface. This strand was presumed to be formed during the last event of 1943.

We recognized at least three faulting events including the 1943 event. The radiocarbon ages of charcoal pieces and animal bones indicate that the penultimate event was likely to have occurred after the 11th century and before the 14th century. The estimated interval of 600 to 900 year recurrence time is much longer than the estimates from trench studies on the North Anatolian fault in Gerede and Erzincan are 280 km west and 380 km east of this site, respectively.

1. Introduction

The North Anatolian fault is a transform plate boundary between the Eurasian and Anatolian Plates on the north and south, respectively. The fault runs latitudinally across northern Turkey for over 1,200 kilometers with a consistent right-lateral strike-slip deformation. The fault is well known as the westward epicentral migration of large earthquakes that occurred in the 1939-1999 period. This series of earthquakes ruptured about a 900 km continuous portion of the fault between 29.5° E and 39.5° E (Fig. 1).

On November 26 1943, the Ladik earthquake (Ms= 7.3) hit north central Anatolia causing severe damage. A 265 km surface break from near Erbaa to Ilgaz appeared to be associated with the earthquake (Ambraseys, 1988). The maximum displacement along this surface break is 150 cm near Havza, close to the trench site (Ambraseys, 1970; 1988). According to Barka's (1996) compilation of the 20th century slip distributions along the surface break, an offset of 1 to 2 m horizontal slip is reported near Havza.

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2. Trench excavation

The trenching survey was carried out in October 1994. The trench site was located near the village of Arslançayırı (41.02° N, 35.64° E), 6 km northwest of Havza. We precisely investigated recent active fault traces around this site using aerial photographs taken by the General Directorate of Mineral Research and Exploration of Turkey (MTA) in the 1970's. The fault runs through a shallow rift valley dissecting gentle hills (Fig. 2). In this valley, small alluvial fans derived from the northern hills cover the valley floor. A sharp linear fault trace was observed cutting these alluvial fans from the aerial photographs. An exploratory trench was opened across the fault trace on the alluvial fan surface near the bottom of the valley (Fig. 3). There remains mole track topography on the fan surface. The trench was planned to cut into this mole track topography. The dimension of the trench is 10 m in length, 5 m in width, and 2.5 m in depth. The west and east walls of the trench are inclined 45° to 60°. The sediments exposed on the trench walls are composed of poorly sorted pebbly silt and gravel covering the pre-Quaternary bedrock. The logs of the trench walls are shown in Figs. 4 and 5.

Keywords: North Anatolian fault, Turkey, active fault, paleoseismology, trench, Ladik earthquake

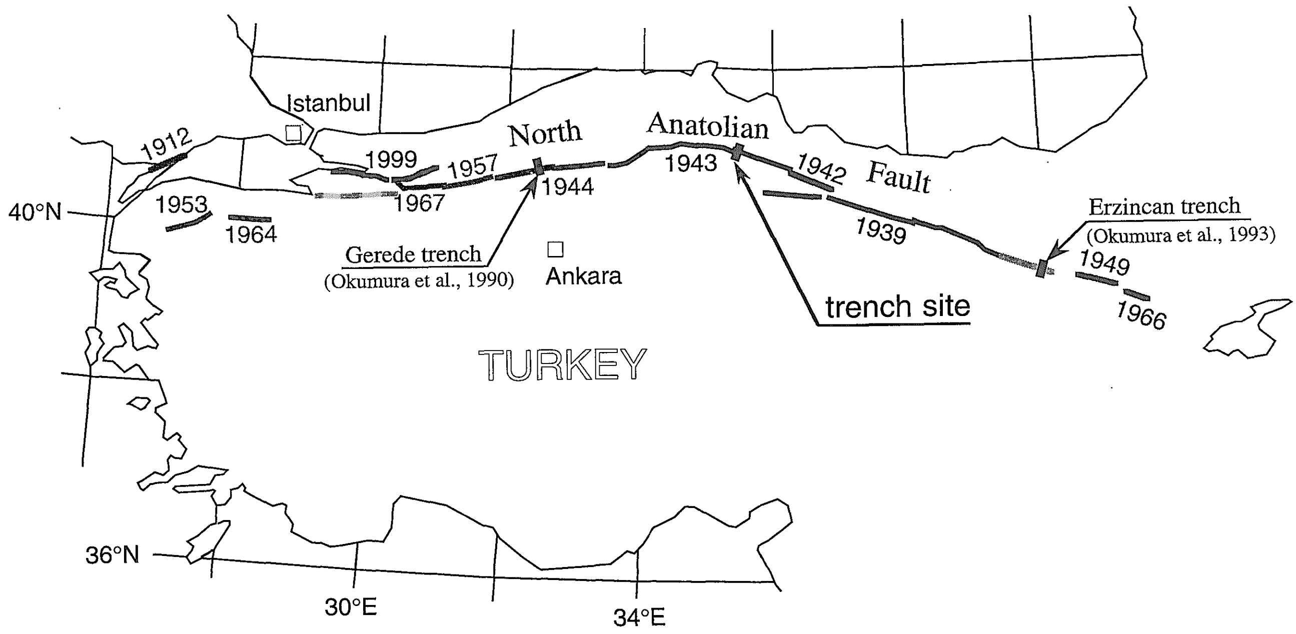

Fig. 1 Surface ruptures on the North Anatolian fault accompanied by the historical earthquakes during this century. Fault lines with light color are the unbroken part at least during this century. The trench site is located on the 1943 surface rupture.

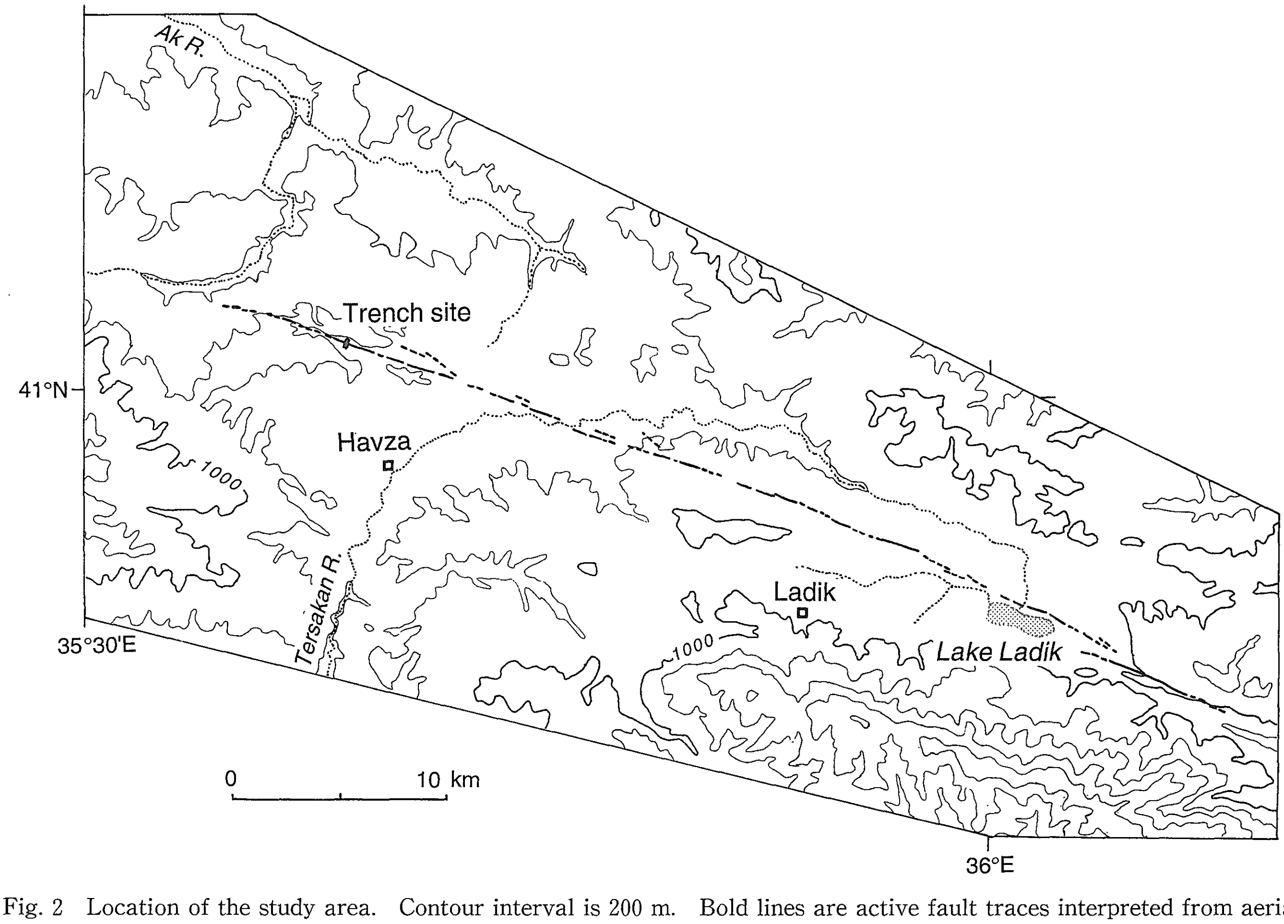

Fig. 2 Location of the study area. Contour interval is 200 m. Bold lines are active fault traces interpreted from aerial photographs. The dashed lines are inferred.

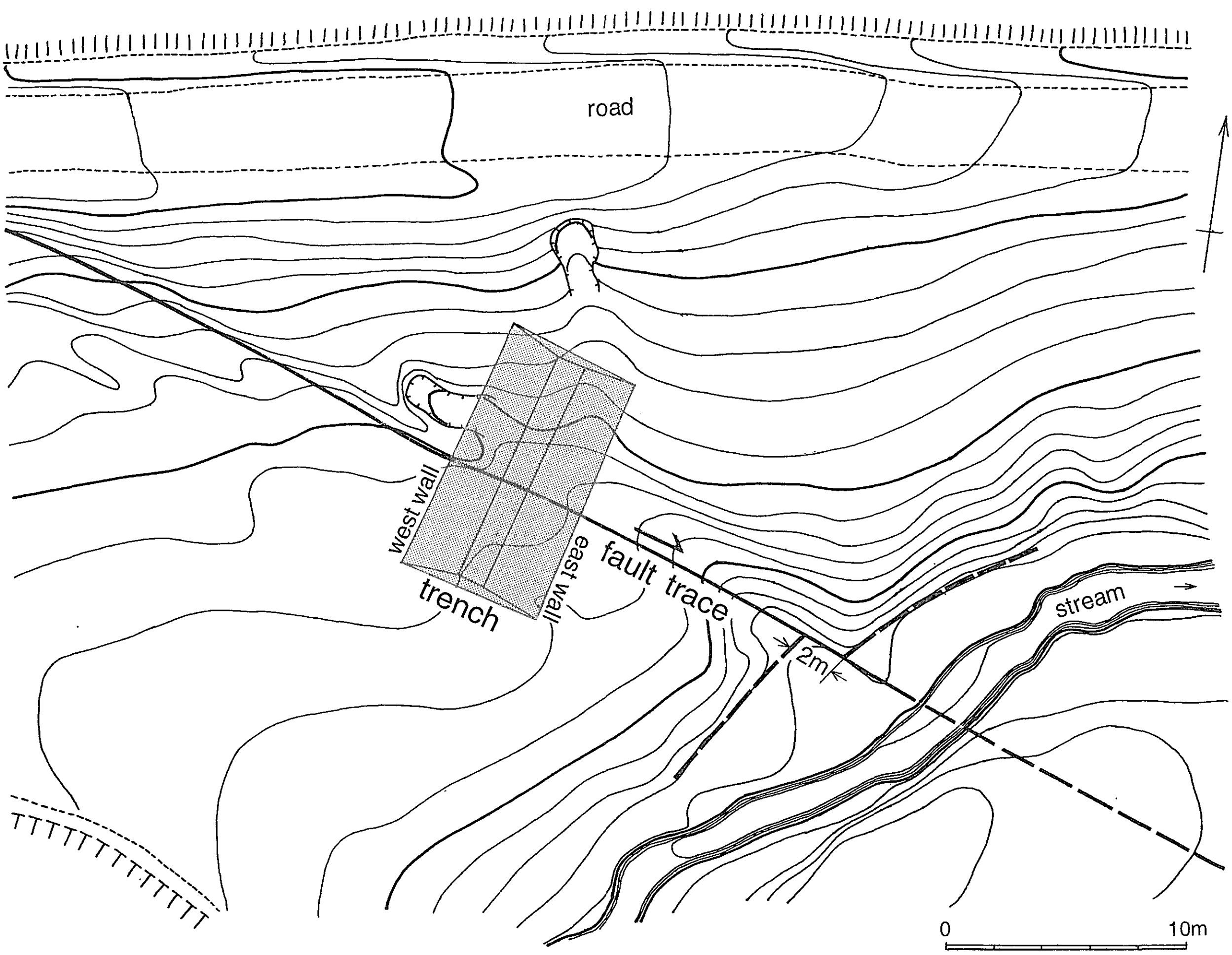

Fig. 3 Topography of the trench site. Contour interval is 20 cm.

A few fault strands cut through these sediments between horizontal grid 4 to 5 on the eastern wall and between horizontal grid 4 to 6 on the western wall. There is a minor fault at horizontal grid 7 on the eastern wall. The main fault strands on the eastern wall gather at the bottom of the trench to juxtapose the bedrock on the south and sediments on the north. The fault zone on the western wall is broader than that on the eastern wall. The fault planes, except for a minor fault, are almost vertical at the bottom of the trench.

We classified the exposed sediments into the following six sedimentary units, named unit 1 to 5 and N. Unit 1 appears only on the eastern wall and fills a shallow small channel covering the fault zone. This unit consists of sand and silty sand. Units 2 to 5 are distributed in only the south side of the fault zone. Unit 2 consists of rather well-sorted sandy silt. Unit 3 consists of black silt with a scattering ranging from pebbles to cobbles. The lower part of unit 3 is intercalating sand and gravel layers. Units 4 and 5 appear only on the west wall. Unit 4 is composed of black silt intercalating thin pebble layers. Unit 5 consists of unsorted sand and gravel. Unit N is distributed in only the north side of the fault zone. This unit consists of black pebbly silt and its upper part contains more pebbles to cobbles with a less silty matrix. This unit is dragged down toward the fault zone on both walls.

Pottery fragments of the Roman period, 1st century BC to 4th century AD, (Omura and Matsumura, personal communication) are scattered in unit 3 and the upper part of unit N. These sediments also contain many charcoal pieces and animal bones. One bone is sheared by a fault plane. These bones are identified as belonging to the Genus *Bos* (ox; Otsuka, personal communication).

3. Timing of faulting events

At least three faulting events are recognized on the trench walls, namely Events A, B and C from the youngest to the oldest.

Event A occurred before the deposition of unit 1 and after the deposition of unit 2. One fault strand cuts unit 2 and is covered by unit 1 on the eastern wall.

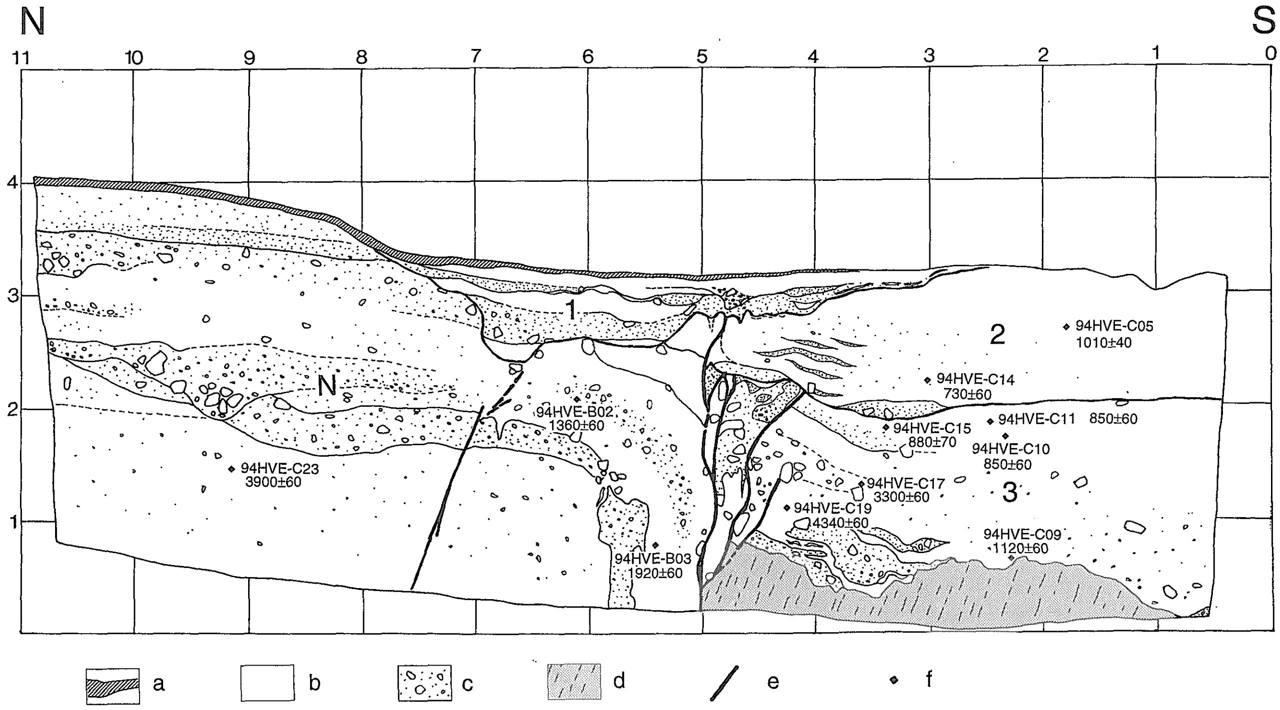

Fig. 4 Log of the east wall of the trench. Reference grid is 1 m square on the trench wall inclined at 45° to 60°. a: surface soil and fill-up, b: silt, c: sand and gravel, d: bedrock, e: fault, f: sample for radiocarbon dating. Uncalibrated radiocarbon ages in years BP. Bold letters indicate the sedimentary units.

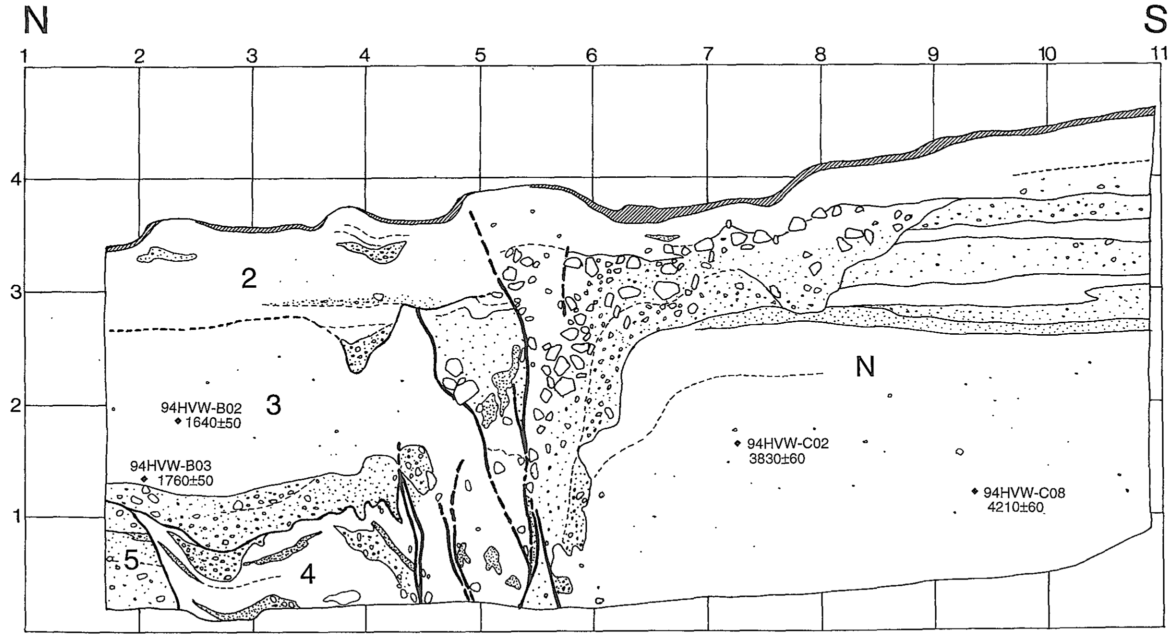

Fig. 5 Log of the west wall of the trench. Legend is the same as that in Fig. 4.

The fault plane cutting unit 2 is sharp and simple without any branches. This shows that only one faulting event occurred after the deposition of unit 2. This event is likely to be correlated with the 1943 Ladik earthquake.

Event B occurred before the deposition of unit 2 and after the deposition of unit 3. A pair of fault strands formed a wedge that cut unit 3 and truncated by unit 2.

Event C occurred during the deposition of unit 3. A

Table 1 Radiocarbon dates of the samples from the trenches. ^{14}C ages were corrected by $\delta^{13}C$ concentration and calculated using Libby's half-life of 5568 years. Calendar years are dendrochronologically calibrated probable age ranges with confidence levels of 68.3% (1σ). Calibration was carried out using CalibETH version 1.5b (Niklaus, 1991) with 93 TREE1.14C data sets. No adjustment for nonexistent 0 BC was made. AMS: accelerator mass spectrometry dating method.

sample no.	unit	material	method	^{14}C age (BP)	calender year (1σ)	prob.(%)
94HVE-C05	2	charcoal	AMS	1010±40	AD 986-1044	87.3
					AD 1103-1113	7.8
					AD 1146-1152	4.9
94HVE-C14	2	charcoal	AMS	730±60	AD 1233-1306	88.5
					AD 1363-1377	11.5
94HVE-C09	3	charcoal	AMS	1120±60	AD 883- 999	100.0
94HVE-C10	3	charcoal	AMS	850±60	AD 1066-1073	4.2
					AD 1127-1133	3.6
					AD 1159-1275	92.2
94HVE-C11	3	wood	AMS	850±60	AD 1066-1073	4.2
					AD 1127-1133	3.6
					AD 1159-1275	92.2
94HVE-C15	3	charcoal	AMS	880±70	AD 1047-1096	29.7
					AD 1116-1144	17.2
					AD 1153-1229	53.1
94HVE-C17	3	C incl. silt	AMS	3300±60	BC 1672-1659	7.0
					BC 1641-1513	93.0
94HVE-C19	3	C incl. silt	AMS	4340±60	BC 3031-2963	53.1
					BC 2947-2889	46.9
94HVW-B02	3	bone	AMS	1640±50	AD 381- 461	66.7
					AD 477- 532	33.3
94HVW-B03	3	bone	AMS	1760±50	AD 235- 347	90.7
					AD 359- 374	9.3
94HVE-B02	N	bone	AMS	1360±60	AD 635- 718	82.9
					AD 741- 764	17.1
94HVE-B03	N	bone	AMS	1920±60	AD 19 - 146	90.8
					AD 175- 194	9.2
94HVE-C23	N	charcoal	AMS	3900±60	BC 2461-2297	100.0
94HVW-C02	N	charcoal	AMS	3830±60	BC 2397-2378	8.0
					BC 2349-2189	85.0
					BC 2161-2145	6.9
94HVW-C08	N	charcoal	AMS	4210±60	BC 2888-2858	18.8
					BC 2816-2693	76.7
					BC 2677-2668	4.4

branch of the fault cuts the lower part of unit 3 and is covered by the upper part of unit 3 on the east wall. A similar relationship between faults and sediments was observed on the west wall.

The radiocarbon ages from charcoal, animal bones and other organic materials in the sediments are shown in Table 1. These ages are dispersive because some dated materials may have been reworked from older sediments. The ages of three samples (94HVE-C10, C11, and C15) from the uppermost part of unit 3 indicate the 11th to 13th century with a good concordance. One of the age of unit 2 shows the 13th to 14th century AD. This means the penultimate event B is likely to have occurred after the 11th century and before the 14th century. The interval between the event A and B is estimated to be 600 to 900 years. The age of the event C is uncertain because of the wide range in the radiocarbon ages. The age of pottery fragments indicates that event C occurred in the Roman Period or later. The chronological diagram of sedimentary units and faulting events is shown in Fig. 6.

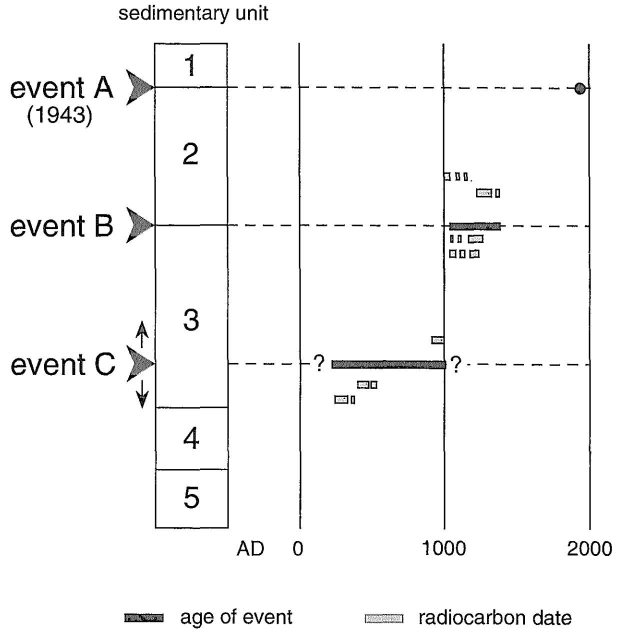

Fig. 6 Chronological diagram of sedimentary units and faulting events.

The 2 m offset of the stream bank east of the trench (shown in Fig. 3) is likely to show right lateral displacement during the 1943 earthquake. This amount is comparable to the horizontal slip reported by Ambraseys (1970, 1988) and Barka (1996). This is much smaller than the slip along the surface ruptures associated with the 1939 and 1944 earthquakes.

4. Conclusion

The trench excavation revealed that the penultimate event on the 1943 rupture had occurred after the 11th century and before the 14th century. The interval between event A and B is estimated to be 600 to 900 years. On the other hand, the trenching study in Gerede (Okumura et al., 1994) on the 1944 rupture, 280 km west of this trench site (Fig. 1), and Erzincan (Okumura et al., 1993), near the end of the 1939 rupture, 380 km southeast of this trench site (Fig. 1), indicate the recurrence interval of 200 to 300 years (Okumura et al., 1994). The interval estimated from this trenching study is much longer than those results. The 2 m horizontal slip is much smaller than those connecting to the 1939 and 1944 surface breaks. There are two possibilities. One is there was less activity of this fault segment than the 1939 and 1944 segments, and the other is the existence of unknown fault traces except for the surveyed trace. More trenching surveys and further investigations are required to solve these discrepancies.

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トルコ，北アナトリア断層，1943年Ladik地震断層の最近の活動

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要　旨

トルコ北部を東西に横断する北アナトリア断層の中部にあたる，1943年Ladik地震の地震断層においてトレンチ発掘調査を実施した．壁面に露出した地層と断層の関係から，この地点では1943年の地震を含め少なくとも過去3回の断層活動があったことが判明した．堆積物に含まれる木片や動物の骨の年代測定の結果，1943年の活動に先立つ活動は11世紀以降14世紀までの間にあったものと推定された．したがって，最新活動とそれに先立つ活動との時間間隔は600-900年となり，これは，北アナトリア断層の他の地点（ゲレデ及びエルジンジャン）における平均再来間隔より有意に長いものである．