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Paleoseismological Three Dimensional Virtual Photography Method; A Case Study: Bağlarkayası-2010 Trench, Tuz Gölü Fault Zone, Central Anatolia, Turkey

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Additional information is available at the end of the chapter

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1. Introduction

In order to make earthquake risk analysis in reliable manner in the regions carrying seismic risks, earthquake behavior of the active faults present in that region must be well determined. An active fault can be defined as a fault that produced earthquakes in Quaternary time associated with surface rupturing or deformation and has the potential to produce earthquakes in the future. The most important method which is accepted and commonly used at the present time to reveal earthquake behavior of active faults is paleoseismology. Paleoseismology is a method that tries to obtain information on the location, nature and date of historical earthquakes making use of geological and geomorphological data (McCalpin and Nelson, 2009).

Paleoseismic trenching is one of the methods that is frequently applied and provides noteworthy data in paleoseismology (Pantosti and Yeats, 1993; Demirtaş, 1997). In this method, geological evaluations are made according to the principles of sedimentology, stratigraphy and structural geology within trenches excavated perpendicular or parallel to the active fault trace depending on the faulting type. Appropriate samples collected from sediments are enable to date the historical earthquakes by suitable radiometric dating techniques.

Excavation types and dimensions of paleoseismological trenches can show variations according to the properties of the studied fault (faulting type, annual slip rate, earthquake recurrence interval, amount of displacement occurred in each earthquake, the elapse time from the last known historical earthquake until today, etc.), and the physical parameters of

the trench site (groundwater condition, stability of trench sediments, etc.). The paleoseismological excavations which are conducted in faults having relatively lower slip rate (< 1 mm / year) and in which dip slip is dominant, are made deeper and wider. In areas where the groundwater level is shallow or the trench walls are not stable, trenches are excavated benched and/or sloped for the sake of safety.

After the trench walls are cleaned, gridding is performed taking into consideration detailed geological features within the trench. In gridding, a grid interval of 1 m² is generally accepted as standard (McCalpin, 2009). After gridding the opposite walls in same scale the stratigraphic levels and displacement figures on the walls are visually recorded and photographed. Logging can be conducted based on two principles: subjective and objective (Hatheway and Leighton, 1979). In subjective logging, the logger reflects his personal point of view in the trench log. As for the objective logging, in that, all sorts of details observed on trench walls are tried to be reflected in the trench log rather than the personal point of view. Although objective logging is possible in theory, in practice its application is difficult and most of the time not fit for purpose. For this reason, the logger must transfer paleoseismological details on the trench walls with an objective point of view adding some subjective interpretation. Three methods are used in trench logging. These are: manual trench logging, electronic trench logging and photomosaic trench logging (McCalpin, 2009). These methods have numerous advantages and disadvantages compared to each other (for further detail, see McCalpin, 2009).

Trench logs are, after all, two dimensional figures that reflect the personal interpretation of the logger about that trench. In recent years, photomosaic trench logging technique started to be frequently applied in paleoseismology. Photomosaic trench logging technique is a fast and inexpensive method which minimizes the possible errors may be risen from drawing. However, this method remains inefficient in deep and benched trench excavations since it causes some image losts on photographs during stitching them together.

In this article, a new photographic method is suggested to be used for paleoseismological trench works and this method is named 'Paleoseismological Three Dimensional Virtual Photography Method'. This method has been applied for the first time in the paleoseismological study conducted on the Tuz Gölü Fault Zone (Central Anatolia, Turkey).

2. Tuz Gölü Fault Zone – Akhisar-Kılıç segment

The Tuz Gölü Fault Zone (TGFZ) is one of the most important intracontinental active fault zones of the Central Anatolian Region (Şaroğlu et al., 1992; Dirik and Göncüoğlu, 1996; Çemen et al., 1999; Koçyiğit, 2000) (Figure 1). When taken into account its morphotectonic features and the distribution of the epicenters of the earthquakes with magnitudes reaching up to 5, it can be said that TGFZ is still active (Dirik and Erol, 2000). TGFZ is a NW-SE trending, approximately 200 km long, oblique-slip normal fault zone with a right lateral strike-slip component. It extends from Tuz Gölü to the northwest and Kemerhisar (Niğde) to the southeast. This fault zone is at the same time a transition zone that separates the

region of normal component strike slip neotectonic regime to the east from the region of extensional neotectonic regime to the west (Koçyiğit and Özacar, 2003).

TGFZ is composed of fault segments parallel or subparallel to each other and with lengths varying between 4 and 33 km. Because of its geological fault length and morphotectonic features, the Akhisar-Kılıç Segment (AKS) constitutes one of the most important fault segments of TGFZ. AKS is a 25 km long, N25° - 30°W trending fault. It is located in the middle section of TGFZ and it extends between Akhisar Village and Hasandağ (Figure 2).

In Figure 3, a geologic map illustrates the region along the Akhisar-Kılıç Segment. According to this map, the Akhisar-Kılıç Segment cuts Lower Pliocene aged Kızılkaya ignimbrites in the vicinity of Akhisar village to the northwest. Between Akhisar and Yuva villages, it forms the boundary between Oligocene aged Yassipur formation and Quaternary aged alluvial fan deposits and in places it cuts these alluvial fan deposits. The Akhisar-Kılıç Segment cuts Hasandağ volcanites starting from the northwest of Yuva village. The fault segment which borders from the northeast the NW-SE trending area of depression with an ellipsoidal geometry, at the same time cuts Late Pleistocene-Holocene deposits in places. It again cuts Hasandağ volcanites in the section starting from the southeast of Helvadere to Kılıç Ridge and comes to an end at Kılıç Ridge locality. The Akhisar-Kılıç Segment is characterized by the alluvial fans arranged parallel to each other and the linear fault scarps between Akhisar and Yuva villages. A number of cold and brackish water springs are present along the fault trace in this area.

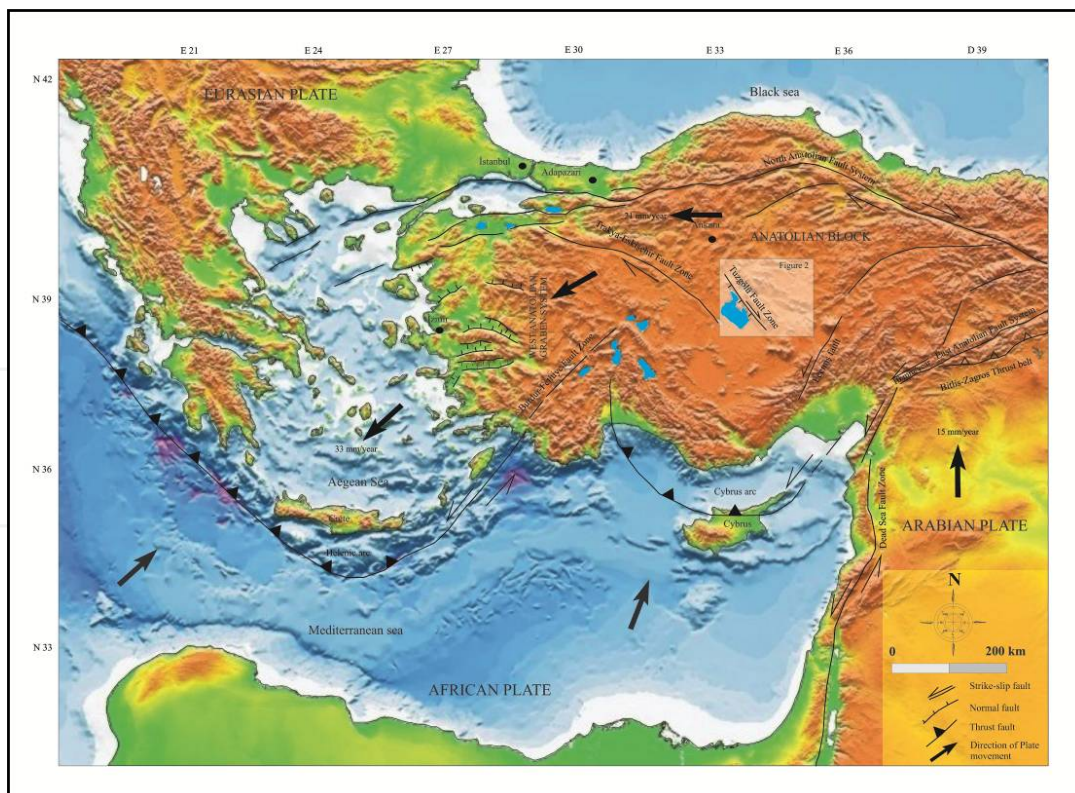


Figure 1. Main neotectonic elements of Eastern Mediterranean Region and Location of Tuz Gölü Fault Zone (Modified from Okay et al., 2000). Black arrows and corresponding number show GPS-derived plate velocities (mm-year) relative to Eurasia (Reilinger et al., 2006).

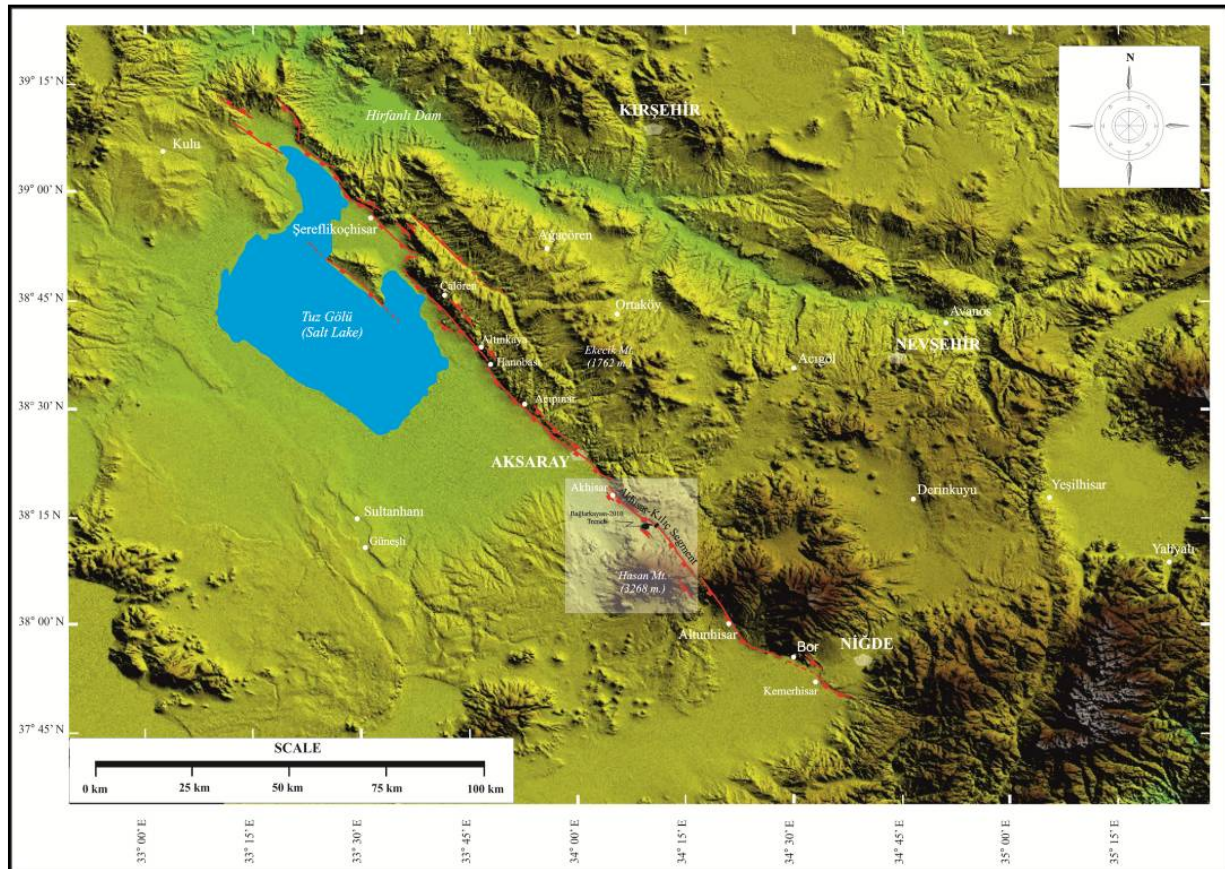


Figure 2. Segments of Tuz Gölü Fault Zone and setting of Akhisar-Kılıç Segment and Bağlarkayası-2010 Trench on the Digital Elevation Model of the region (Shuttle Radar Topography Mission-SRTM data were used for the Digital Elevation Model)

3. Bağlarkayası-2010 trench

Bağlarkayası-2010 Trench excavation is the first paleoseismological study carried out on the Tuz Gölü Fault Zone. The Trench is located in the middle part of the Akhisar-Kılıç Segment (See Figure 3, GPS Coordinates: 34.178505° E – 38.235561° N). The trench site is situated within the fault-controlled Quaternary area of depression to the southeast of Yuva village. In this depression area, Hasandağ volcanites were cut by the fault and obliquely displaced. Since the normal component of the fault was dominant, the hanging wall was tilted towards the fault and owing to this back-tilting a topographical saddle came into existence. Bağlarkayası-2010 Trench was excavated on this topographical saddle (Figure 4).

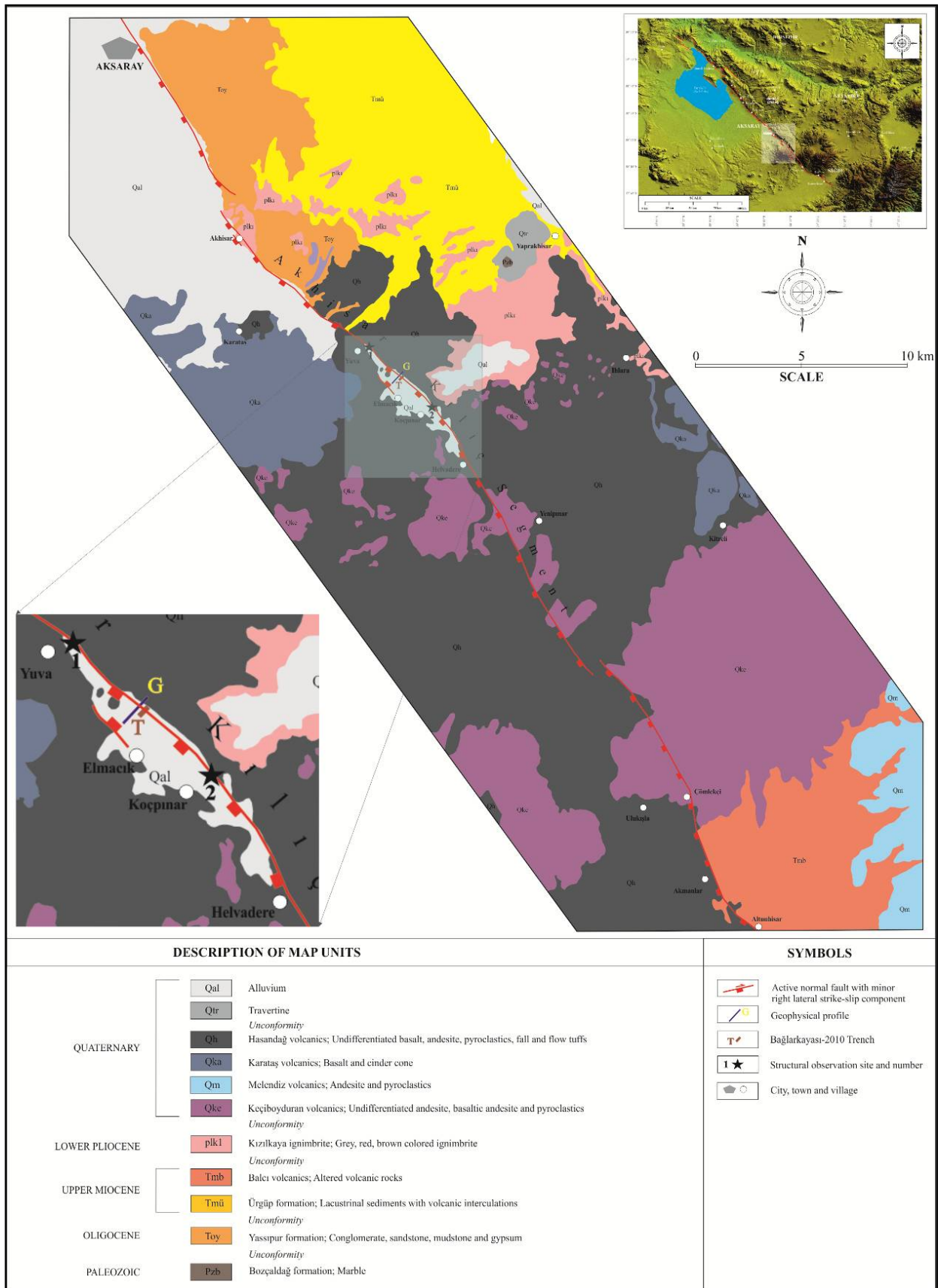


Figure 3. Geological map of Akhisar-Kılıç Segment and its vicinity (Modified from Dönmez et al., 2005).

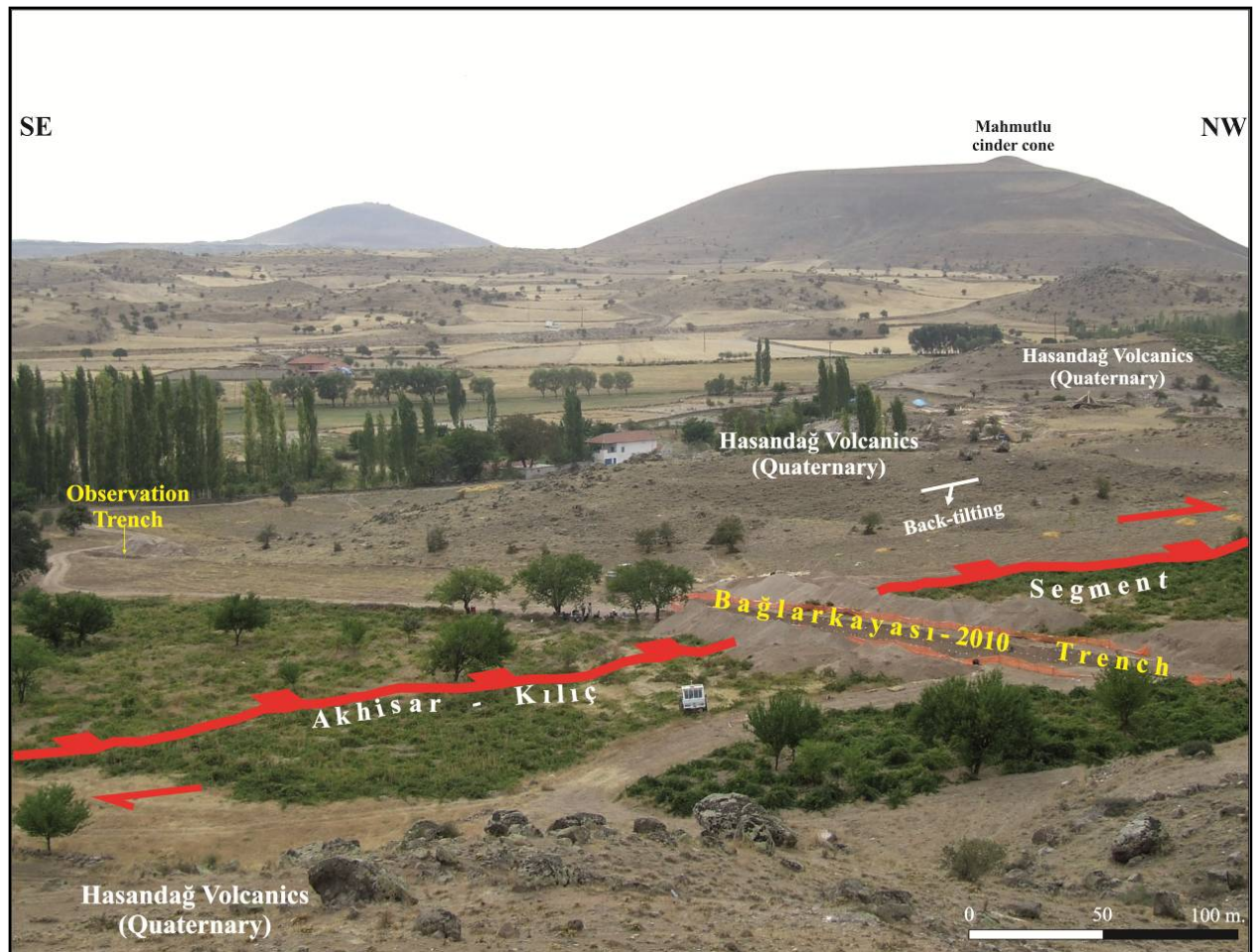


Figure 4. Panoramic view of Bağlarkayası-2010 Trench area (view from NE to SE)

In the selection of trench site, the fault plane outcrops existing in the near north and south of the trench area were made use of (See, points 1 and 2 in Figure 3 and Figure 5). In addition to this, 8 vertical electric soundings with intervals of 250 meters, along a line perpendicular to the fault trace were carried out in the area which was considered for the trench site. In these vertical electric soundings, data were gathered from a depth of approximately 2000 meters. A geoelectric cross section was generated making use of these data. On the generated geoelectric cross section, a fault that reached up to the surface was detected (Figure 6). The site of the trench was selected by integrating the fault data determined from the geoelectric cross section and structural observations with the geomorphology. The 1/500 scale microtopographical map of the Bağlarkayası-2010 Trench area is presented in Figure 7.

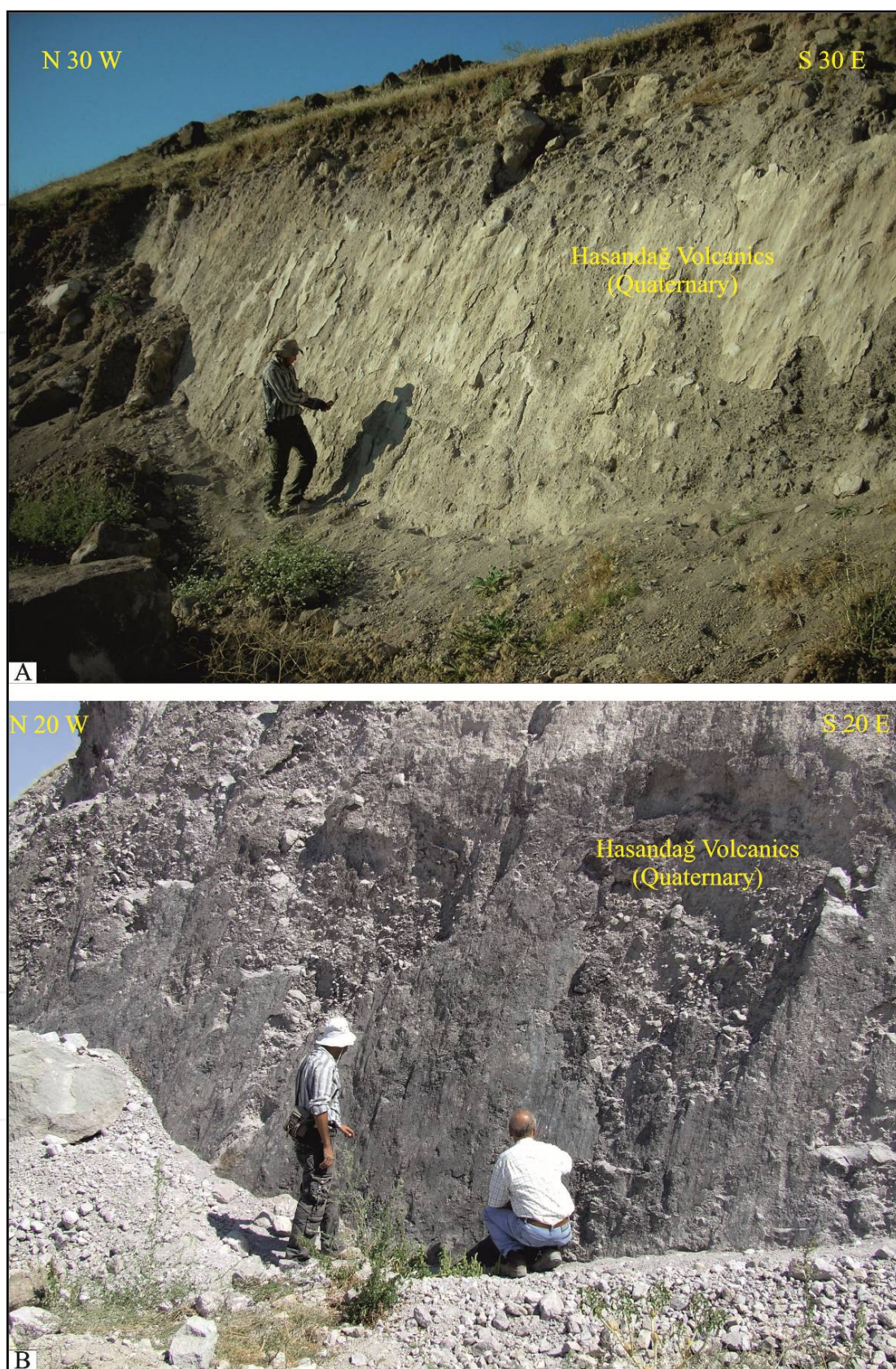


Figure 5. Fault planes belonging to Akhisar-Kılıç Segment that cuts Hasandağ volcanites A. SE of Yuva Village, B. NE of Koçpınar Village (see Figure 3 for Locations)

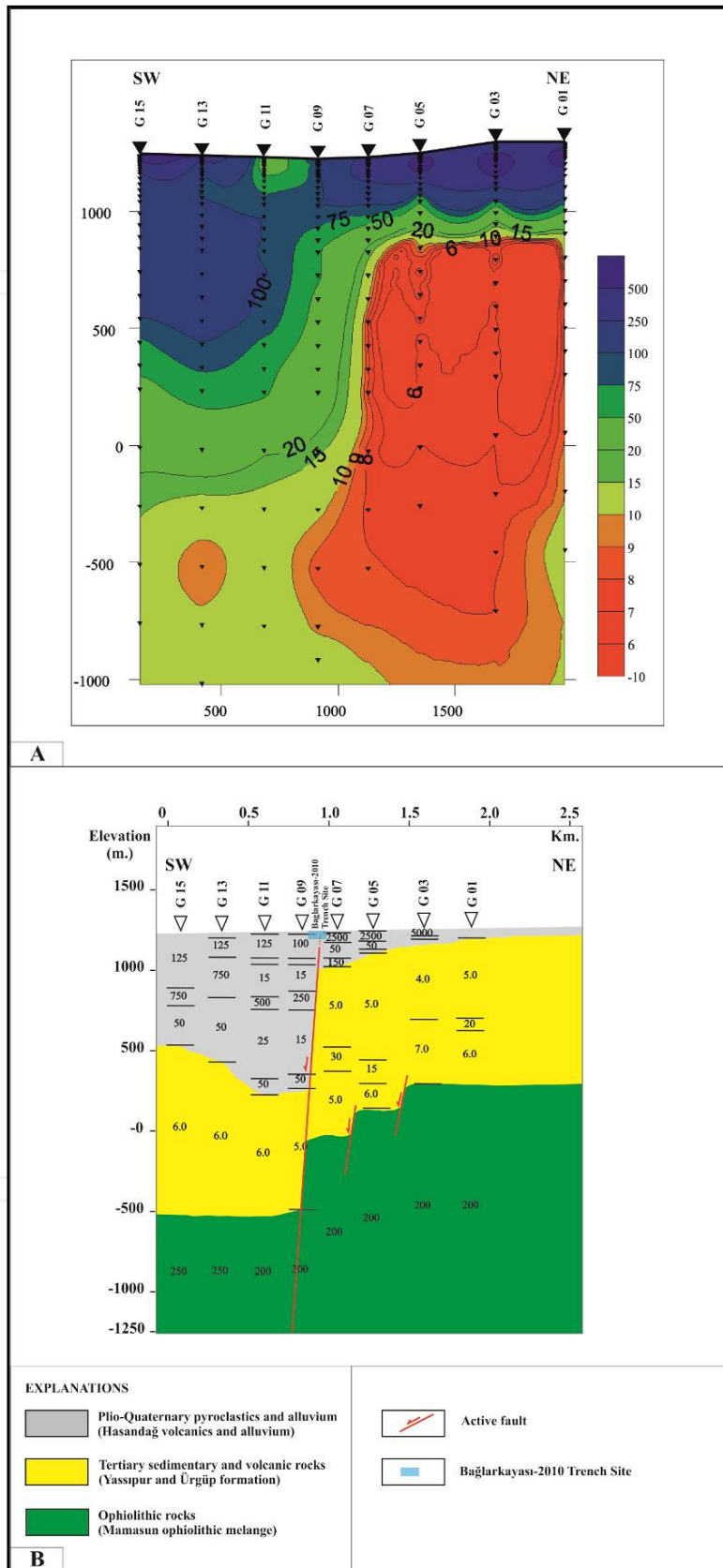


Figure 6. A. Apparent iso-resistivity cross section, B. Geoelectric cross section, generated from Vertical Electric Soundings (see Figure 3 for Profile Location)

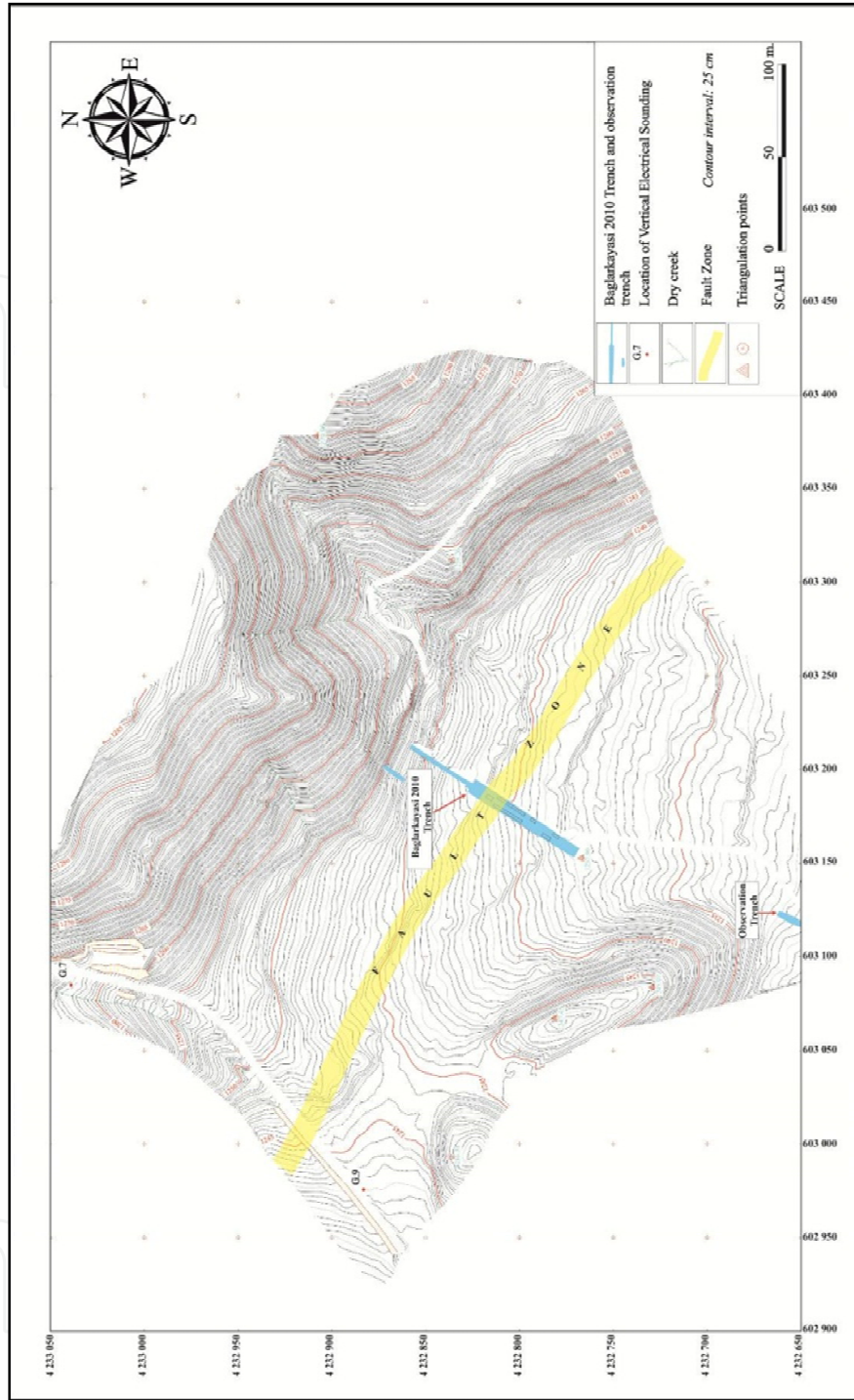


Figure 7. Microtopographic map of the Bađlarkayası 2010 Trench site

The Bađlarkayası-2010 Trench was excavated perpendicular to the fault. It has a length of 94 meters, a width of 5 meters and an average depth of 5 meters (maximum depth: 8.5 meters). While the northern 40-meter section of the trench was excavated as a single slot trench, the southern part of it was excavated as multi-bench trench (Figure 8). A gridding of 1 m² was applied in the trench. Manual trench logging method was applied for the entire trench, at a scale of 1/20. In Figure 9, the stages of the trench work are presented.



Figure 8. Aerial panoramic view of Bağlarkayası-2010 Trench, Photograph was taken from an altitude of 25 meters at inclined angle, from the fire tower (view from SW to NE)



Figure 9. The stages of the trench work A. Excavation and cleaning, B. Gridding, C. Manual logging D. Photographing

In Figures 10 and 11, wall logs belonging to Bağlarbaşı-2010 Trench are presented. Seven different microstratigraphic levels were identified within Bağlarbaşı-2010 Trench. The first two of these levels that are relatively older were interpreted as ash and block flows of Hasandağ volcanism. And the relatively younger units are deposits associated with plinian activity and fluvial processes. Three deformation zones were defined within the trench. These zones are main fault zone, synthetic faulting zone and antithetic faulting region. The photomosaic of the main fault zone on the NW wall of the trench is seen in Figure 12.

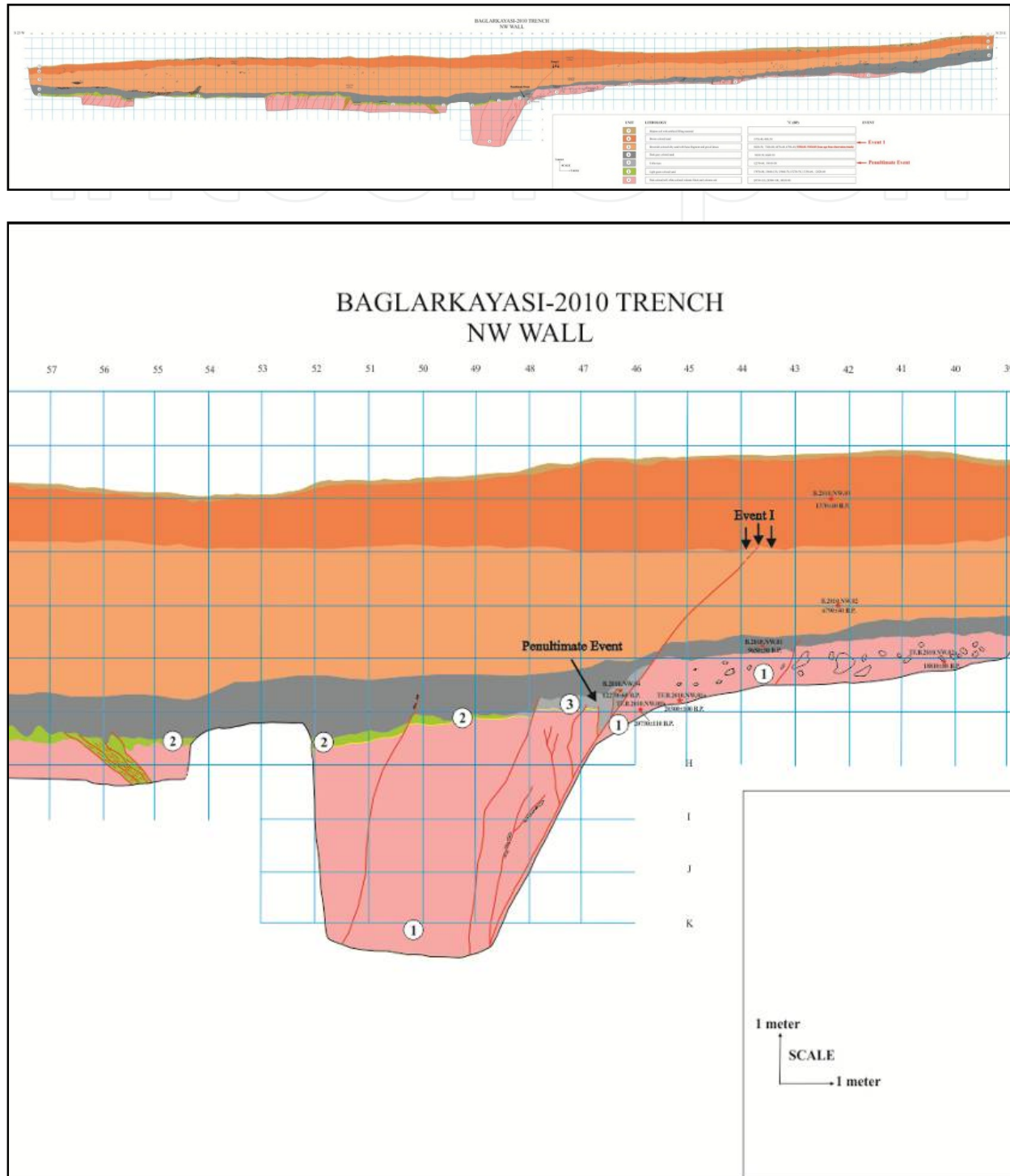


Figure 10. NW Wall Log of Bağlarkayası-2010 Trench (close shot of general log and main fault zone)

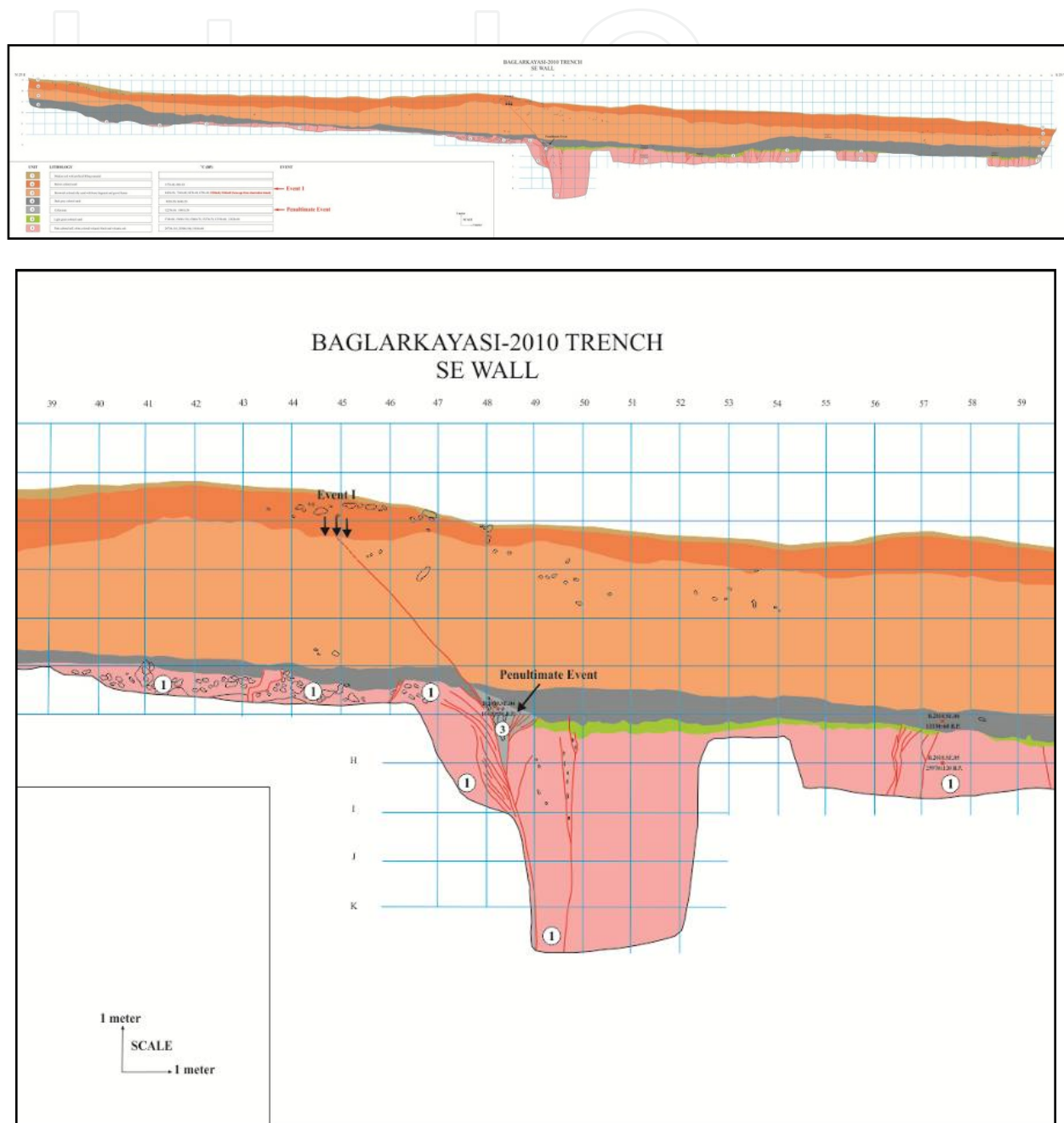


Figure 11. SE Wall Log of Bağlarkayası-2010 Trench (close shot of general log and main fault zone)

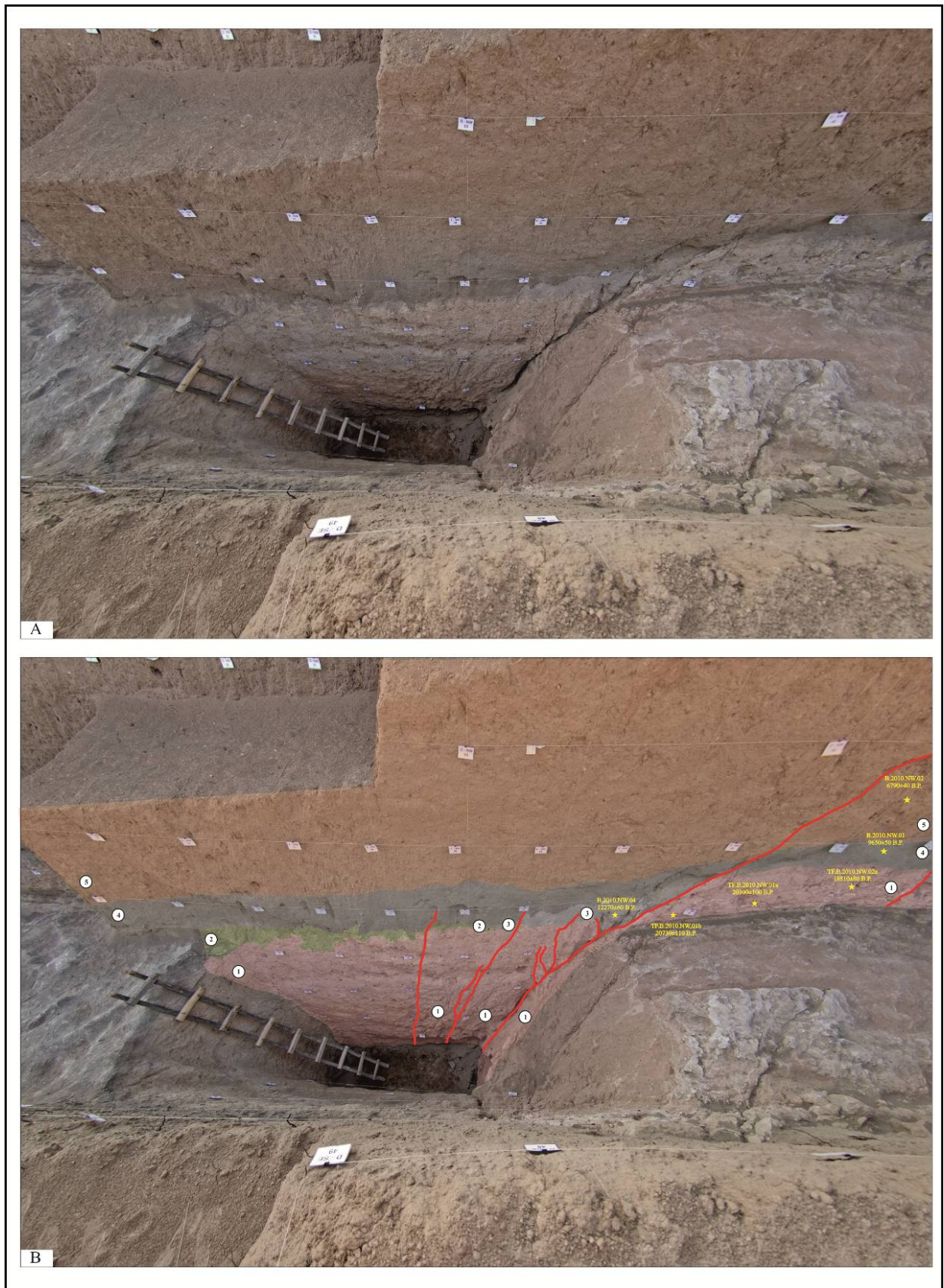


Figure 12. The photomosaic of the main fault zone on the NW wall of the trench; A : Uninterpreted B : Interpreted

Since carbon-rich material is limited within Bařlarkayası-2010 Trench, an supplementary trench was excavated approximately 100 meters SW of the trench (see Figure 4 and 7). In this trench, at a depth of 2 meters from the surface, some bones were encountered within a level that can be correlated with the unit 5 of Bařlarkayası-2010 Trench (Figure 13). According to the determination of Anthropologist Dr. Gerçek Saraç, these bones belong to a human.



Figure 13. Human bones detected within the supplementary trench

18 samples from Bařlarkayası-2010 Trench and 3 samples (2 of which were bones) from the Supplementary Trench were collected. The radiometric age determination (^{14}C -AMS) of the total 21 samples was carried out at BETA Analytical Lab (Table 1). The ^{14}C ages determined by BETA Analytical Laboratory were afterwards evaluated making use of Oxcal v3.10 calibration program developed by Ramsey (2001) (Figure 14).

Number of Sample	Unit	Number of Beta Lab.	Material	Measured age (B.P.)	13C/12C	2 Sigma Calibration
TF.B. 2010.NW.01a	1	291116	(organic sediment); acid washes	20300 +/- 100 BP	-20.1 o/oo	
TF.B. 2010.NW.01b	1	291118	(organic sediment); acid washes	20730 +/- 110 BP	-21.2 o/oo	
TF.B. 2010.NW.02a	1	291117	(organic sediment); acid washes	18810 +/- 80 BP	-22.2 o/oo	Cal BC 20560 to 20320 (Cal BP 22510 to 22270)
B.2010.NW.01	4	291093	(organic sediment); acid washes	9650 +/- 50 BP	-22.9 o/oo	Cal BC 9260 to 9120 (Cal BP 11210 to 11070), Cal BC 9010 to 8910 (Cal BP 10960 to 10860), Cal BC 8900 to 8860 (Cal BP 10840 to 10810)
B.2010.NW.02	5	291094	(organic sediment); acid washes	6790 +/- 40 BP	-23.5 o/oo	Cal BC 5740 to 5640 (Cal BP 7690 to 7580)
B.2010.NW.03	6	291095	(organic sediment); acid washes	1370 +/- 40 BP	-23.8 o/oo	Cal AD 600 to 680 (Cal BP 1350 to 1270)
B.2010.NW.04	3	291096	(organic sediment); acid washes	12270 +/- 60 BP	-22.8 o/oo	Cal BC 12470 to 12090 (Cal BP 14420 to 14040)
B.2010.NW.06	2	291098	(organic sediment); acid washes	17440 +/- 80 BP	-23.0 o/oo	Cal BC 18840 to 18470 (Cal BP 20790 to 20420)
B.2010.NW.07	2	291099	(organic sediment); acid washes	15060 +/- 70 BP	-23.5 o/oo	Cal BC 16690 to 16160 (Cal BP 18640 to 18100)
B.2010.NW.08	5	291100	(organic sediment); acid washes	8420 +/- 50 BP	-25.9 o/oo	Cal BC 7570 to 7420 (Cal BP 9520 to 9380), Cal BC 7420 to 7360 (Cal BP 9370 to 9310)
B.2010.NW.10	6	291101	(organic sediment); acid washes	480 +/- 30 BP	-25.3 o/oo	Cal AD 1410 to 1450 (Cal BP 540 to 500)
B.2010.NW.11	2	291102	(organic sediment); acid washes	15660 +/- 130 BP	-24.1 o/oo	Cal BC 17120 to 16810 (Cal BP 19070 to 18760)
B.2010.NW.15	5	291104	(organic sediment); acid washes	7360 +/- 40 BP	-23.3 o/oo	Cal BC 6380 to 6210 (Cal BP 8330 to 8160)
B.2010.SE.04	3	291105	(organic sediment); acid washes	10410 +/- 50 BP	-22.5 o/oo	Cal BC 10690 to 10190 (Cal BP 12640 to 12140)
B.2010.SE.06	2	291107	(organic sediment); acid washes	13330 +/- 60 BP	-23.2 o/oo	Cal BC 14070 to 13730 (Cal BP 16020 to 15680)
B.2010.SE.07	2	291108	(organic sediment); acid washes	12420 +/- 60 BP	-23.5 o/oo	Cal BC 12890 to 12220 (Cal BP 14840 to 14170)
B.2010.SE.10	5	291109	(organic sediment); acid washes	6870 +/- 40 BP	-23.7 o/oo	Cal BC 5850 to 5710 (Cal BP 7800 to 7660)
B.2010.SE.13	4	291111	(organic sediment); acid washes	8640 +/- 50 BP	-23.8 o/oo	Cal BC 7760 to 7580 (Cal BP 9710 to 9540)
BK.2010.SE.02	2	291113	(organic sediment); acid washes	15270 +/- 70 BP	-23.1 o/oo	Cal BC 16830 to 16650 (Cal BP 18780 to 18600)
BK.2010.SE.03	5	291114	(bone collagen); collagen extraction: with alkali	5590 +/- 40 BP	-18.8 o/oo	Cal BC 4610 to 4450 (Cal BP 6560 to 6400)
BK.2010.SE.04	5	291115	(bone collagen); collagen extraction: with alkali	5560 +/- 40 BP	-18.9 o/oo	Cal BC 4560 to 4440 (Cal BP 6500 to 6390), Cal BC 4420 to 4390 (Cal BP 6370 to 6340)

Table 1. Results of ¹⁴C Age Determination for the samples collected from Bağlarkayası-2010 Trench and Bağlarkayası Observation Trench

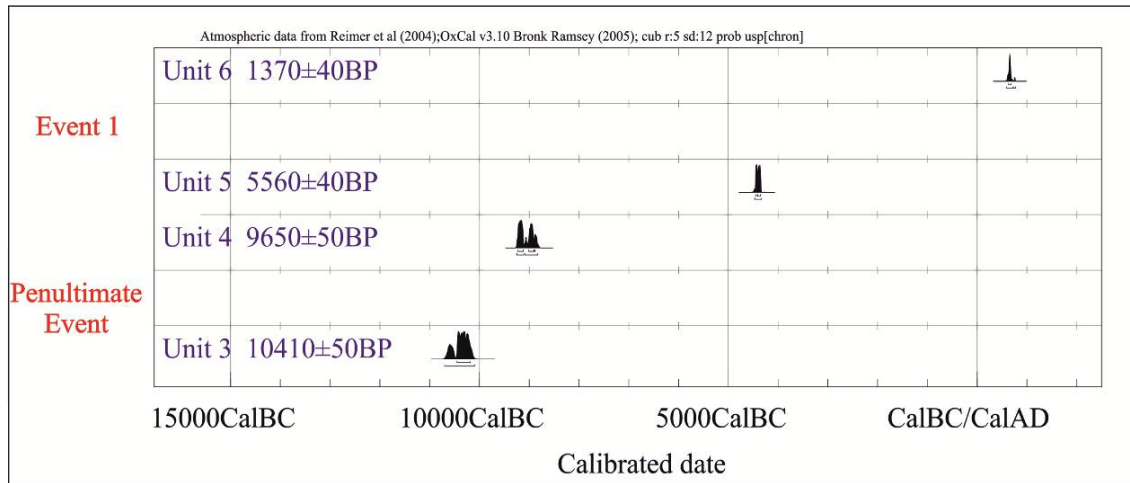


Figure 14. Radiocarbon ages calibrated making use of Oxcal v3.10 calibration program (Ramsey, 2001) of the samples collected from Bağlarkayası-2010 Trench and Bağlarkayası Observation Trench

As a result of the evaluation carried out making use of paleoseismological criteria such as trench microstratigraphy, geometry of fault colluvial wedge, upward termination of fault strands, and ^{14}C age data, two paleoseismic events were described within the Bağlarkayası-2010 Trench, which occurred during the last 10 500 years. The first of these earthquakes (penultimate event) occurred after the deposition of unit number 2 and as a result of it the colluvial wedge number 3 was developed (see Figures 10, 11 and 12). The youngest age obtained from the unit number 2 is $12\,420 \pm 60$ B.P. years. And the base age obtained from the unit number 4 that covers the colluvial wedge number 3 is 9650 ± 50 B.P. years. In addition to these, the ages obtained from the colluvial wedge number 3 are $12\,270 \pm 60$ B.P. and $10\,410 \pm 50$ B.P. years, respectively. Colluvial wedges can be directly used in paleoseismological studies as event horizons in dating of earthquakes. In the light of these data, the age of the first earthquake (penultimate event) defined in the Bağlarkayası-2010 Trench was determined between the years $10\,410 \pm 50$ B.P. and B.P. 9650 ± 50 B.P.

The second earthquake (Event 1) defined in the trench occurred after the deposition of the unit number 5. Faulting traces belonging to this earthquake can be traced within the unit number 5, but the faults do not cut the unit number 6 (see Figures 10, 11 and 12). The youngest age obtained from the unit number 5 of the trench is 6790 ± 40 B.P. years. In addition, the human bones discovered within the observation trench were collected from the unit number 5. The ages obtained from these bones were determined as 5590 ± 40 B.P. and 5560 ± 40 B.P. years, respectively. And the base age determined from the unit number 6 is 1370 ± 40 B.P. years. According to these age data the last earthquake took place between the years 5560 ± 40 B.P. and B.P. 1370 ± 40 B.P.

The amount of displacement occurred during the last earthquake (Event 1) was measured as 25 cm by taking the top of the unit 4 as reference plane (see Figure 12). Along the fault, the amount of displacement in the older units is 50 cm. This shows that these two earthquakes are of similar magnitude and an average displacement of 25 cm occurred in each earthquake. This data demonstrates that the Akhisar-Kılıç segment displayed characteristic earthquake behavior in Holocene.

On the other hand, it was determined that Kızılıkaya Ignimbrites was displaced 268 meters in the vertical direction by Tuz Gölü Fault Zone in the vicinity of Akhisar village (Figure 15). The age of Kızılıkaya Ignimbrites was determined by various researchers using different methods. For example, employing K/AR method, while Innocenti et al. (1975) obtained 5.4 ± 1.1 million years, Besang et al. (1977) 5.4 ± 1.1 million years, and Schumacher and Schumacher (1996) 4.3 ± 0.2 and 4.5 ± 0.2 million years of age for Kızılıkaya Ignimbrites. On the other hand, Aydar et al. (2012) obtained 5.19 ± 0.07 and 5.11 ± 0.37 million years of age employing the method of Ar/Ar. According to these age data, the age of the Kızılıkaya Ignimbrites is approximately 5 million years. Taking into account the radiometric age (5 million years) determined in previous studies and the measured total displacement (268 meter), the annual slip rate of Akhisar-Kılıç Segment of Tuz Gölü Fault Zone was calculated as 0.0536 mm starting from Early Pliocene.

Through the evaluation of the annual slip rate (0.0536 mm/ year) of the Akhisar-Kılıç Segment together with the amount of vertical displacement (25 cm), the average earthquake recurrence interval of the Akhisar-Kılıç Segment has been found as 4664 years. The age of the first earthquake (penultimate event) that occurred within the Bağlarkayası-2010 Trench was determined between $10\,410 \pm 50$ B.P. and $9650\,410 \pm 50$ B.P. years which can be accepted as 10000 years BP in average. After 4664 years from this earthquake, which is the average earthquake recurrence interval, the last earthquake (Event 1) must have been occurred. The age of this earthquake is approximately 5336 B.P. years. Consequently, the elapse time from the last earthquake to the present time is 5336 years. Since this value is greater than the average earthquake recurrence interval that is 4664 years, the Akhisar-Kılıç Segment could produce an earthquake at any moment. By taking into consider the annual slip rate and the elapse time from the last earthquake to the present time, the amount of average vertical displacement accumulated on the Akhisar-Kılıç Segment was calculated as 28.76 cm.



Figure 15. Google earth image of Kızılıkaya Ignimbrites displaced by Tuz Gölü Fault, in the vicinity of Akhisar Village; the amount of vertical displacement between the points A and B is 268 meters.

Supposing that the whole of the Akhisar-Kılıç Segment, which has a length of 27 km, of Tuz Gölü Fault Zone was broken, the maximum earthquake magnitude that this segment can produce was calculated making use of the empirical equations proposed by Wells and Coppersmith (1994).

According to these equations, the magnitude of the maximum earthquake that the Akhisar-Kılıç segment could produce (M), the amount of maximum displacement (MD) and the amount of average displacement (AD) were computed as follows:

$$M = a + b \times \log (\text{SRL})$$

$$a = 4.86$$

$$b = 1.32$$

$$\text{SRL} = 27 \text{ km}$$

$$M = 4.86 + 1.32 \times \log (27)$$

and M was computed as $M = 6.74$.

$$\log (\text{MD}) = a + b \times M$$

$$M = 6.74$$

$$a = -5.90$$

$$b = 0.89$$

$$\log (\text{MD}) = 0.0986$$

and MD was computed as $\text{MD} = 1.25$ meters.

$$\log (\text{AD}) = a + b \times M$$

$$M = 6.74$$

$$a = -4.45$$

$$b = 0.63$$

$$\log (\text{AD}) = -0.2038$$

and MD was computed as $\text{MD} = 0.62$ meters.

The amount of the displacement measured for an earthquake in the Bağlarkayası- 2010 Trench is 25 cm. This value is smaller than the amount of average displacement computed employing the empirical equations proposed by Wells and Coppersmith (1994). There might be several reasons for this: 1) Since Akhisar- Kılıç Segment has a minor right lateral component, the amount of the measured normal displacement is smaller than the computed one 2) or the segment that has a length of 27 km was not entirely broken when the earthquake(s), during which a displacement of 25 cm occurred, took place.

By means of the evaluation made taking into account the second possibility, the magnitude (M) of the earthquake that should occur in order that an average displacement of 25 cm could take place and the length of the surface rupture (SRL) required for an earthquake with that magnitude to take place were computed as follows making use of the empirical equations proposed by Wells and Coppersmith (1994) :

$$\log (\text{AD}) = a + b \times M$$

$$\text{AD} = 0.25 \text{ cm}$$

$$a = -4.45$$

$$b = 0.63$$

$$-0.60205991 = -4.45 + 0.63 M$$

and M was computed as $M = 6.10$

$$\log(\text{SRL}) = a + b \times M$$

$$M = 6.10$$

$$a = -2.01$$

$$b = 0.50$$

$$\log(\text{SRL}) = 1.04$$

and SRL was computed as $\text{SRL} = 10.96 \text{ km}$.

4. Paleoseismological three dimensional virtual photography method; Bağlarkayaşı-2010 trench application

In recent years there have been significant developments in the applications related to the cameras that provide panoramic viewing, especially depending on the developments of image processing programs. Such cameras started to be widely used in various fields such as security, teleconference, publicity, virtual tour and robot navigation (Baştanlar and Yardımcı, 2005; Ergün and Şahin, 2009). Since the angle of sight of cameras is always smaller than that of human beings and the image of large objects cannot be pictured within a single photograph, a demand for the creation of a panorama arose just at the beginning of the photography (Parian, 2007). The efforts to obtain a photographic panorama were realized at the end of 1800s with joining together several photographs taken from different directions to form a full panorama (Baştanlar, 2005). 'Panorama' is a word that was formed by joining two Greek words together. 'Pan' means 'all', and 'orama' means 'sight' (Baştanlar, 2005). The difference between traditional photograph and panoramic photograph is similar to the difference between looking at a city from the window of a small office and from the roof of it (Kwiatek, 2005). One of the main objectives of Photogrammetry is, by carrying the real image into the virtual environment, to arouse the impression of 'really being there' in viewers and readers. In recent years, with the development of Internet and multimedia technologies, important developments were recorded in photogrammetry and the Three Dimensional Virtual Photography Technique started to be used in various fields. Although the method is frequently used in different sectors such as architecture, tourism and museum publicity; it has no application either in earth sciences or in paleoseismology. Paleoseismological Three Dimensional Virtual Photography Method has been applied for the first time in this study, in the paleoseismological studies conducted on the Tuz Gölü Fault Zone (Central Anatolia, Turkey).

The application area of the Earth Sciences is the Nature. The presentation of the studies, which are carried out in the Nature, to the readers without any loss of data and with high resolution is important. Paleoseismological trench works are comprehensive and high cost works. Trench works should be completed within a specified period of time and with specific standards. The specific physical conditions of the trench area (the state of groundwater, instability of trench sediments, etc.) in some cases complicate the trench works may sometimes and cause loss of life and property due to collapse and cave in. In order to eliminate

such drawbacks, trenches should be excavated as deep and wide as possible and the work should be completed in a manner as fast and qualified as possible.

Paleoseismological Three Dimensional Virtual Photography Method makes it possible the transfer of all details within the trench to the reader without any loss of data and with high resolution. In addition, as the reader can directly see the trench wall image, the method gives the reader the right to interpret. In the section that follows, the application of this method to a paleoseismological trench study (Bařlarkayası-2010 Trench) conducted in the middle part of the Tuz Gölü Fault Zone is explained.

Paleoseismological Three Dimensional Virtual Photography Method is mainly composed of four stages. These are :

1. Planning
2. Photographing
3. Stitching the photographs and forming scenes
4. Connecting the scenes and forming virtual tour

4.1. Planning

In order a trench work to be photographed in three dimensions, first of all, the number and locations of the points at which photographs are to be taken should be planned. In planning the number of points,

- Paleoseismological detail within the trench and
- Dimensions and excavation type of the trench

should be taken into consideration. In the determination of the locations of the point at which photographs are to be taken, care should be taken not to leave any blind spots. A virtual tour of the entire trench can be obtained only under these conditions.

Bařlarkayası-2010 Trench was excavated as 94 meters long, 5 meters wide and 5 meters deep on the average (Maximum depth: 8.5 meters). While the northern 40-meter section of the trench was excavated as a single slot trench, the southern part of it was excavated as multi-bench trench (Figure 8). A gridding of 1 m² was applied on the walls of the trench. Three deformation zones are present within the trench, which are main fault zone, synthetic faulting zone and antithetic faulting zone.

Before starting paleoseismological three dimensional virtual photographing, a general photograph should be taken which covers the entire trench and shows the points where the photographs are to be taken. This photograph can be taken, if possible, from above, at an inclined angle. The general trench photograph is to be used as the index photograph in the formation of the virtual tour in the final stage. In this study, the general photograph of the Bařlarkayası-2010 Trench was taken from the fire tower, at an elevation of 25 meters and at an inclined angle (Figure 16).

As a result of the evaluation made taking into account the form of the trench and the detailed paleoseismological features on the trench walls, it was decided to take photographs

at 15 points in the Bağlarkayası-2010 Trench (Figure 16). The points where photographs were taken were selected near the parts of the trench walls that contained fault. In order to trace the continuation of the fault on one wall of the trench, on the other wall, the floor of the trench should also be cleared and the fault traces should be made distinct at the floor as well.

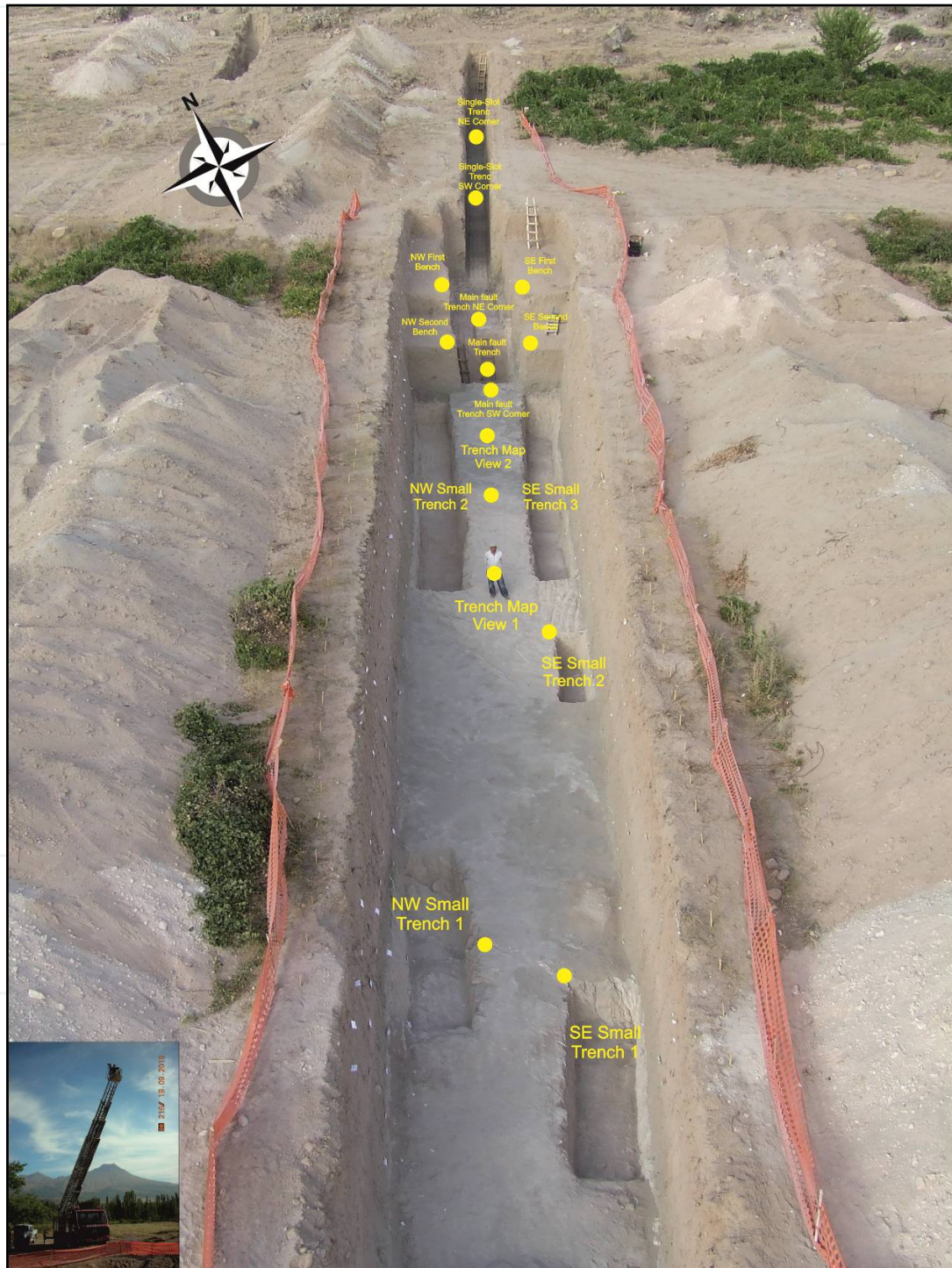


Figure 16. The general image of the Bağlarkayası-2010 Trench taken from the air at an inclined angle. Yellow circles represent the points where photographs were taken (look from SW to NE)

In the virtual tour to be obtained as a result of this method, the image should be as clear as possible. That's why, one day before photographing, the time and the angle at which sunlight comes to the trench walls should be controlled and recorded. Thus, it would be planned at which point, at which hour photographs be taken. Since 8 photographs are to be taken, an average of 15 minutes can be envisaged for taking photographs at each point.

4.2. Photographing

The hardware and software required for Paleoseismological Three Dimensional Virtual Photography are presented in Table 2.

Software	The aim of use	Hardware	The aim of use
Adope Photoshop CS5	Correction of color and light	Tripod	Photographing
PTGui Pro 9.0	Stitching	Digital camera	Photographing
Cubic Converter 2.2.1	Stitching and creating of stages	Pano Head	Photographing
PTLens 1.5.3	Correction of distortion	Fisheye Lens	Photographing
Panotour Pro 1.6.0	Cretating of Virtual tour	Computer	Office work
Web Browser	Internet Explorer, Google Chrome, Mozilla Firefox		

Table 2. The hardware and software required for Paleoseismological Three Dimensional Virtual Photography

In this study, Manfrotto 055x probe tripod, Nikon D200 Model and 10.2 megapixel Digital photo camera, Manfrotto sph 303 panoramic head and Nikkor fish-eye objective having 180° angle of sight were used.

At the stage of photographing, 8 photographs are taken at each point. Six of these photographs are taken at the horizontal plane using an angle of 60° and thus a horizontal image of 360° of that point is obtained. Afterwards, the sky and floor image of the same point are taken as two separate photographs and the image of that point at the vertical plane is obtained. In this manner, a total of 8 photographs, 6 of which at horizontal plane and 2 at vertical plane, of each point are taken.

4.3. Stitching photographs together and forming scenes

Paleoseismological Three Dimensional Virtual Photography Method is a method which is most of the time applied employing some computer programs. However, from time to time it requires some manual intervention. In order that the virtual tour to be produced from the photographs can be as realistic as possible, some corrections are needed to be made on the raw photographs.

At this stage, first of all, color and light corrections of 8 photographs taken at each point are made using Adobe Photoshop CS5 program. Following this, employing PTGui Pro 9.0

program, photographs are connected by stitching. At the first stage of the connection, 6 photographs taken at horizontal plane and the sky image taken at the vertical plane are used. During this process, from time to time manual corrections may be required when common parts of the photographs are overlapped. At the end of the first stage of the connection, all photographs, except the floor image, become stitched together.

These 7 stitched photographs are then transferred to Cubic Converter 2.2.1 program. Cubic Converter 2.2.1 program creates partial photographs by dividing the image composed of 7 stitched photographs into 6 parts in the form of cubes. One of these partial photographs is the floor photograph yet to be completed.

To complete the floor photograph, of the raw photographs taken at first, the one belonging to the floor is opened in the program PT lens 1.5.3. The image, which is obtained after its distortion correction is made in this program, is assembled with the partial photograph belonging to the floor. This assembled photograph is again transferred to the program Cubic Converter 2.2.1 and thus the floor photograph becomes completed. Lastly, the image of the whole scene is exported in TIFF format from the Cubic Converter 2.2.1 program. In Figure 17, the stitched and connected scene image belonging to the point 8 (see SE second bench in Figure 16) of Bağlarkayası-2010 Trench is presented.

By repeating these processes for all of the scenes, a total of 15 files were obtained.



Figure 17. The scene image obtained as a result of stitching and connecting the photographs belonging to the point 8 (see SE second bench in Figure 16) of Bağlarkayası-2010 Trench.

4.4. Connecting the scenes and forming the virtual tour

All of the scenes that are connected and recorded are opened in Panotour 1.6.0 program. Transition links are formed for the transition of the scenes with each other to be made. Afterwards, index photograph is imported into the program and transition links are added

to the index photograph as well. In this manner, the access to a desired scene is made possible both over the virtual tour and over the index photograph.

The completed virtual tour is recorded as MTML file. This file not only makes it possible the visual presentation of a trench study to the reader but also makes significant contributions especially at the stage of interpretation of the trench data

You can reach the virtual tour produced employing Paleoseismological Three Dimensional Virtual Photography Method developed in this study over the following link:

<https://hotfile.com/dl/155062161/c15656d/webquality.rar.html>

5. Results

In this study, a new photography method for paleoseismological studies was developed and named 'Paleoseismological Three Dimensional Virtual Photography Method'.

It was observed that this method could be successfully applied especially in deep and benched paleoseismological trench excavations.

The most important advantage of this method is that all the geologic detail within the trench can be transferred to the reader without any loss of data and with high resolution. In this manner, the reader is given the right to interpret.

Paleoseismological Three Dimensional Virtual Photography Method is mainly composed of four stages which are planning, photographing, forming scenes by stitching the photographs together and forming the virtual tour by connecting the scenes.

The virtual tour obtained as a result of this method enables the reader to make a tour, feeling as if he were really there.

The method has been applied for the first time in this study on the Akhisar-Kılıç Segment of the Tuz Gölü Fault zone which is one of the most important active fault zones of the Central Anatolia Region.

Tuz Gölü Fault Zone (TGFZ) is a NW-SE trending, dipping towards SW, active, right lateral strike slip component normal fault zone which extends between north of Tuz Gölü and Kemerhisar (Niğde) and has a length of 200 km.

TGFZ is composed of fault segments that have lengths varying between 4 and 33 km. The Akhisar-Kılıç Segment is one of the most important segments of this zone owing to its geological fault length and morphotectonic features.

The total amount of vertical displacement of the Akhisar-Kılıç Segment is 268 meters according to Lower Pliocene aged Kızılkaya Ignimbrites.

According to the calculation made taking into account the total amount of vertical displacement (268 meters) and the age of Kızılkaya Ignimbrites (5 million years), the slip rate of the Akhisar-Kılıç Segment during the period from Lower Pliocene to the present day is 0.0536 mm/year.

In this study, a paleoseismological trench study has been conducted on the Akhisar-Kılıç Segment of TGFZ for the first time and the trench has been named 'Bağlarkayası-2010 Trench'.

According to the paleoseismological findings obtained from Bağlarkayası-2010 Trench, two earthquakes that resulted in surface faulting occurred on the Akhisar-Kılıç Segment during the last 10 500 years. The first of these earthquakes occurred approximately in the year 10 000 B.P. and the second one took place in the year 5336 B.P. Consequently, the elapse time from the last earthquake up to the present is approximately 5336 years.

The amount of the average vertical displacement accumulated on the Akhisar-Kılıç Segment from the last earthquake to the present time was calculated making use of empirical equations (Wells and Coppersmith, 1994) as 28.76 cm.

An average displacement of 25 cm was measured in the earthquakes that were defined and dated within Bağlarkayası-2010 Trench. According to the evaluation made taking into consideration this value together with the slip rate (0.0536 mm/year), the earthquake recurrence interval for the Akhisar-Kılıç Segment was calculated as 4664 years.

The fact that the average earthquake recurrence interval (4664 years) is smaller than the elapse time from the last earthquake to the present day indicates that the Akhisar-Kılıç Segment has completed its average earthquake recurrence interval and could produce earthquake(s) at any moment.

The geologic fault length of the Akhisar-Kılıç Segment is 27 km. The moment magnitude of the maximum earthquake that this segment could produce in case the whole of it were to be broken was calculated as $M = 6.74$ making use of the empirical equations proposed by Wells and Coppersmith (1994).

According to the computations made using the other equations of the same study, the amount of the maximum displacement which could occur in an earthquake with the magnitude $M = 6.74$ is $MD = 1.25$ meters and the amount of the average displacement is $AD = 0.62$ meters.

A displacement of 25 cm was measured in both of the earthquakes defined by means of the paleoseismological excavation studies conducted in the trench. This value is smaller than the amount of the average displacement that a pure normal fault with a length of 27 km can produce. The reason for this difference may be the fact that the fault has a minor strike slip component. Or the whole of the segment that is 27 km long is not broken. In this case, in order for a displacement of 25 cm to occur, the moment magnitude of the fault is expected to be $M = 6.10$ and the required surface rupture length for an earthquake with the magnitude $M = 6.10$ to occur is expected to be $SRL = 10.96$ km.

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