Cappadocia Field Trip Guide

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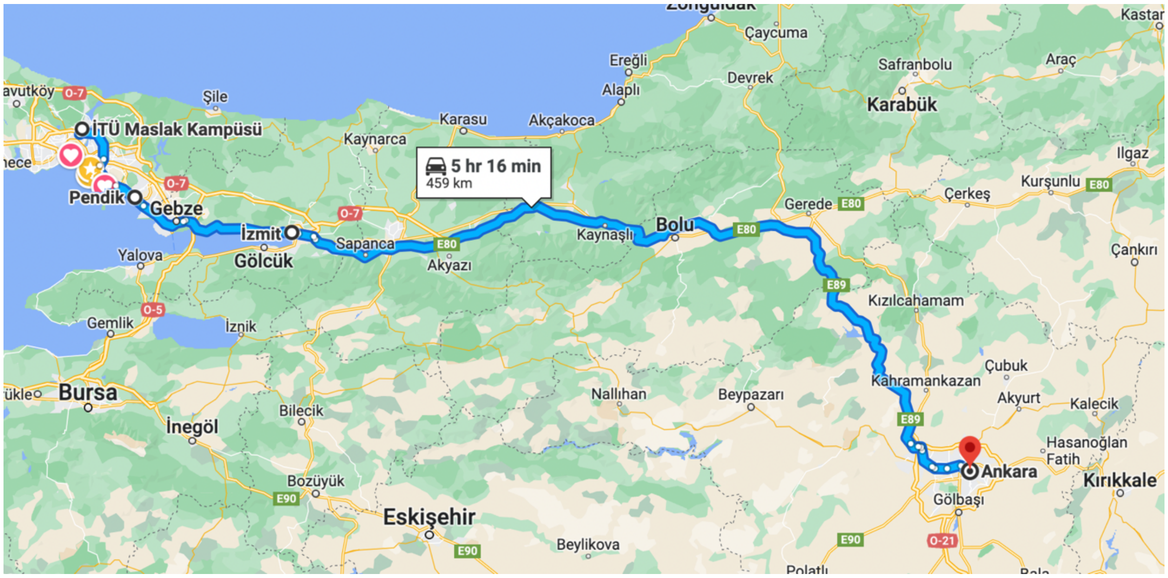
This four-day field trip will take place in Cappadocia, in the middle of the Central Anatolian Plateau (CAP), famous for its volcanism, unique landscape and unusual rock formations. The trip will start in İstanbul, and along the way to Ankara, we will observe the North Anatolian Fault. On the way to Cappadocia, we will also have the opportunity to visit the Tuz Gölü (Salt Lake) Fault and several other interesting geological formations beautifully exposed in the south of Ankara.

The development of the Cappadocia landscape dates back to the Late Miocene epoch (circa 10 million years) when volcanoes spread pyroclastic deposits over an area of 20.000 km^2. The volcanism continued for millions of years, laying down thick and colourful ignimbrite layers. The Cappadocian landscape's evolution starts with gently sloping plateaus, which are then dissected, usually along cooling fractures, to form mushroom-like structures known locally as "fairy chimneys". Humans used these volcanic formations for several millennia to build cave houses (troglodytes) and even underground cities. Kızılırmak River, the longest fluvial system of Turkey, also deposited numerous terraces because of the Anatolian Plateau's continuing uplift.

Several stops are planned to appreciate the beauty of the landscapes created by volcanoes. We also plan to visit the Taurus Mountain Range, only 100 km south of Cappadocia, and see glacial moraines and alluvial fans cut and offset by the Ecemiş Fault Zone. Cosmogenic surface dating of the alluvial fans allows for calculating slip rates and recurrence intervals of the Ecemiş Fault. Dating glacial moraines also gives insight into paleoclimate reconstructions since the Last Glacial Maximum, 20.000 years ago.

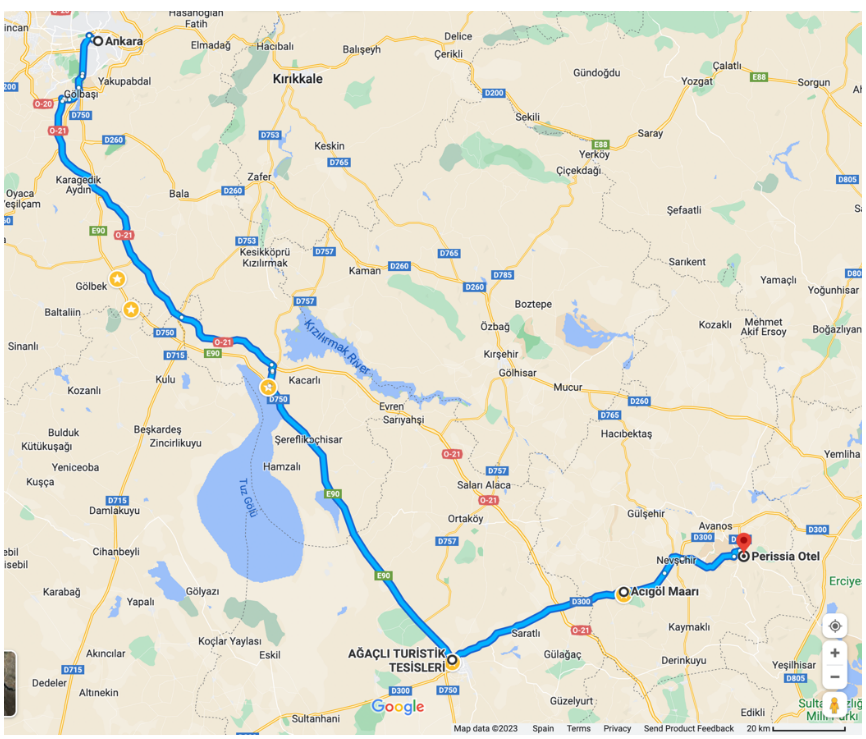
Day 1 (Thursday, 30 November 2023): Departure from the conference venue at ITU, Istanbul to Ankara at 09.30

- North Anatolian Fault along the road.
- Lunch stop on the road.
- Arrival at the hotel in Ankara around 20:00.
- Dinner at a nearby restaurant



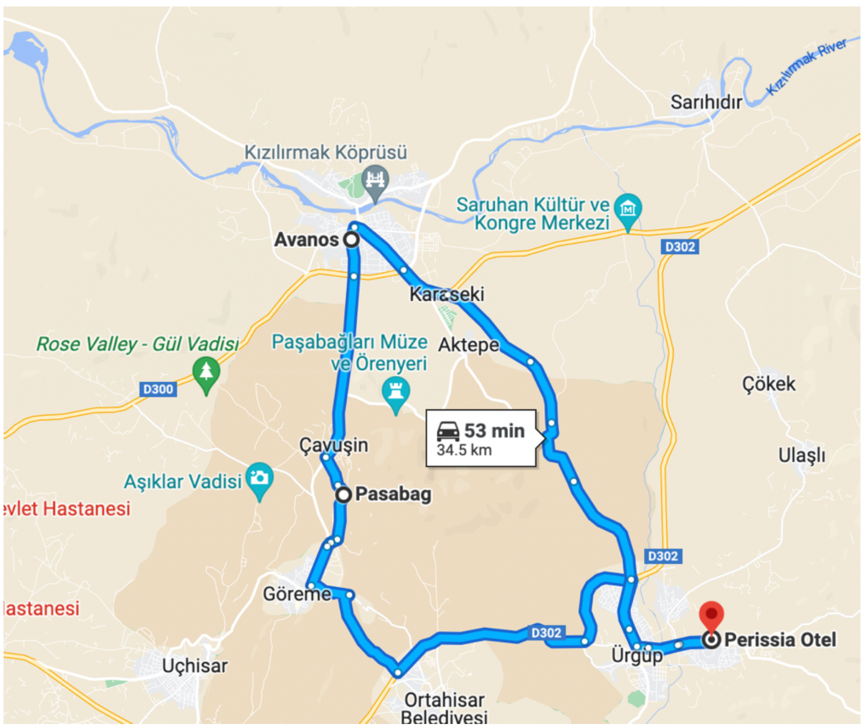
Day 2 (Friday, 01 December 203): Departure from Ankara to Cappadocia at 9:00

- Central Anatolia geology highlights: ophiolites, volcanics, continental red beds, and other sedimentary units.
- Tuz Gölü (Salt Lake) Fault Zone / Salt Lake geotouristic visit.
- Lunch at Orhan Ağaçlı Restaurant (Aksaray town).
- Cappadocia Volcanic Province volcanics (Hasandağ Volcano, monogenic volcanoes…)
- Arrival at Ürgüp (3-night stay at the hotel). Dinner at the hotel



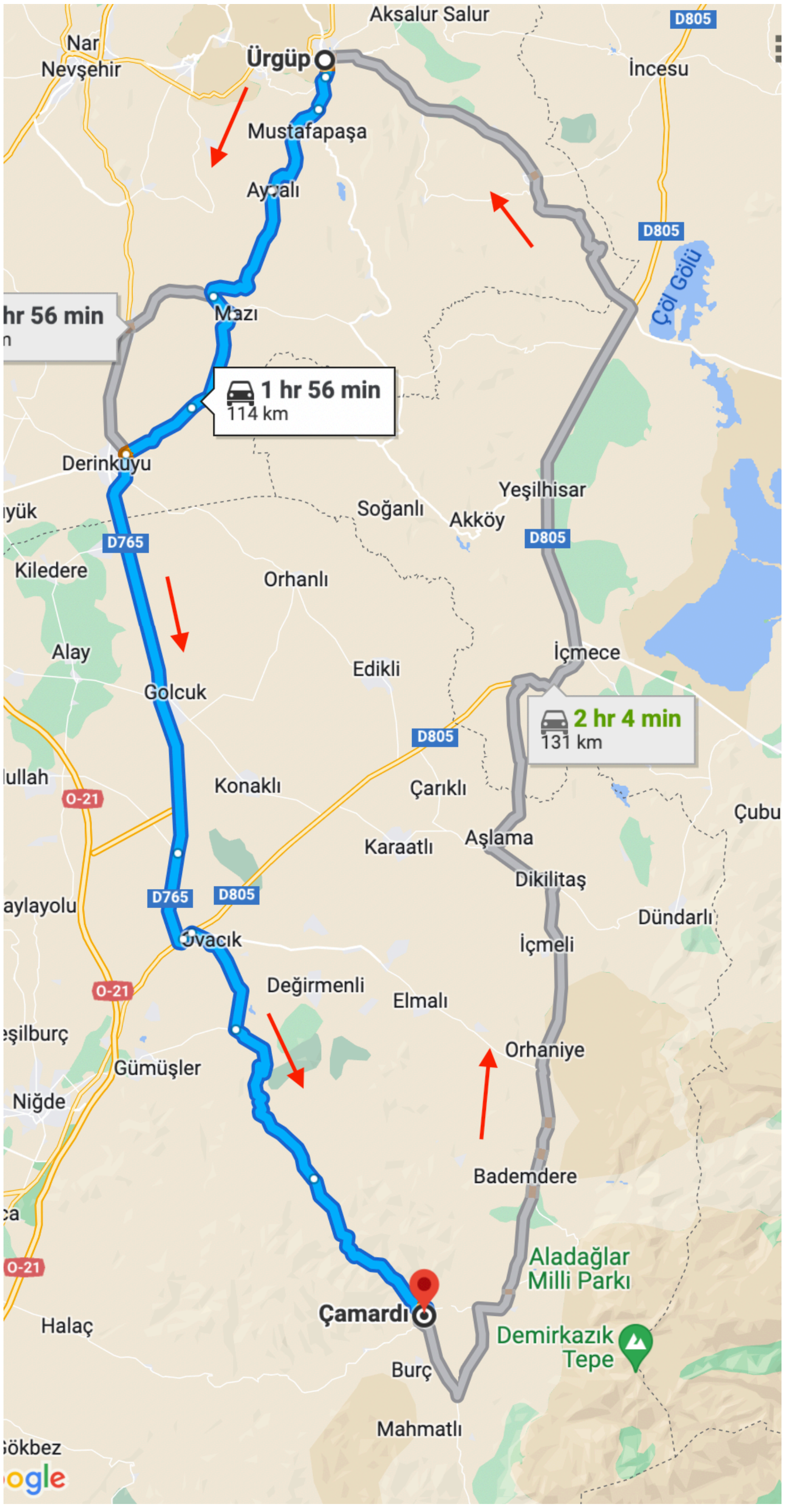
Day 3 (Saturday, 02 December 2023): Cappadocia geology

- Balloon flight (optional): very early morning departure at 5:30 and back at 9:00.
- Field trip departure at 10:00.
- Ürgüp fairy chimneys and Ignimbrite Stratigraphy at Red Valley.
- Uçhisar-Göreme towns (Lunch at Göreme)
- Kızılırmak River fluvial terraces and incision rates.
- Avanos and Pottery making shop visit.
- Zelve open-air museum.
- Paşabağ fairy chimney formation process and erosion rates.
- Dinner at the hotel.



Day 4 (Sunday, 03 December 2023): Mt Aladağlar

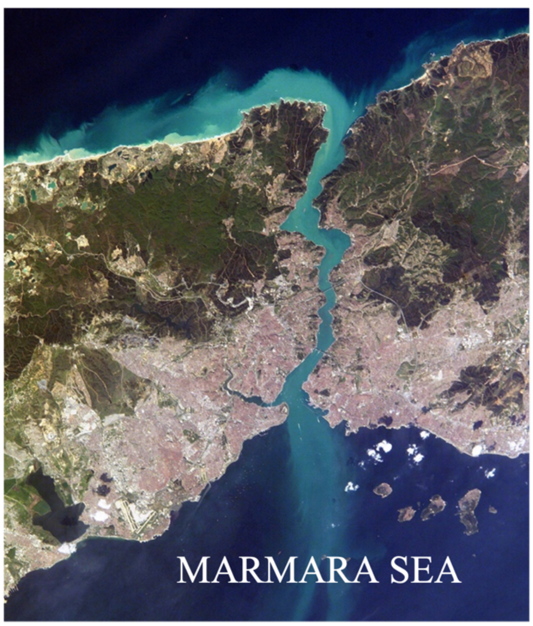
- Departure at 9:00.
- Derinkuyu underground city
- Derinkuyu-Çamardı (Mt. Aladağlar)
- Lunch at Alabalık (fish) Restaurant
- Ecemiş Fault
- Emli Valley (glacio/fluvial deposits)
- Back to Ürgüp & Dinner at the hotel.

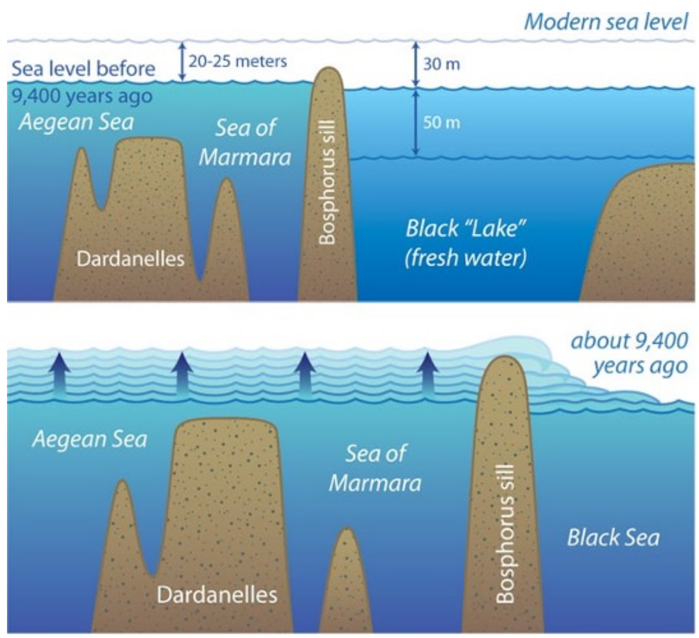


Day 5 (Monday, 04 December 2023): Individual departures from Ürgüp to Kayseri airport with shuttles.

ISTANBUL PENEPLAIN AND STRAIT (THE BOUNDRY OF ASIA & EUROPE)

Istanbul region suffered a long period of denudation between the Oligocene and the end of the late Miocene, which formed a regionwide peneplain. The N–S extensional regime followed this phase and began to produce a horst-graben system, and thus, fragmented the peneplain. The flat-lying erosional surfaces have been elevated above the horsts (Yılmaz et al., 2010).

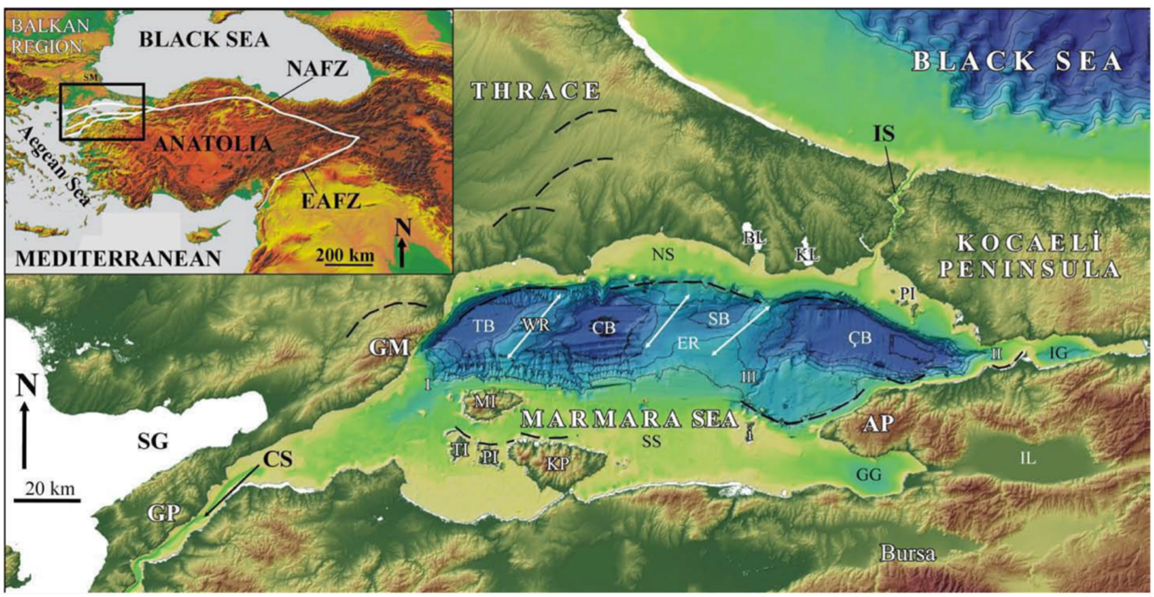




Ten thousand years ago, the Black Sea was an overflowing, fresh water lake. Then, its evaporation exceeded input, so that its level gradually lowered 90 m. Ancient shorelines show that it was a much smaller lake, occupying only the deep, southern basin of the Black Sea. Meanwhile, global sea level was rising. About 9400 years ago, it overtopped the Bosphorus and the ocean suddenly flowed into the sea, filling the deep basin and flooding over the broad shelves to the north. This event may have been the basis for the flood story found in ancient Phoenician writings and in the Gilgamesh epic, which in turn were precursors of the biblical story of Noah's flood (Ryan & Pittman, 1997). New studies claim that the Black Sea rose only 10 m (Illustration above by Jack Cook, Woods Hole Oceanographic Institution).

Later, the North Anatolia Fault Zone reached the Marmara Region. In the initial stage, it affected NW Anatolia extensively as a wide right-lateral shear regime. This has evolved, and through time the present narrow fault zone has developed (Yılmaz et al., 2010). The **North Anatolian Fault** (**NAF**) is an active right-lateral strike-slip fault in northern Anatolia, and is the transform boundary between the Eurasian Plate and the Anatolian Plate. The fault extends westward from a junction with the East Anatolian Fault at the Karliova Triple Junction in eastern Turkey, across northern Turkey and into the Aegean Sea for a length of 1200−1500 km. It runs about 20 km south of Istanbul.

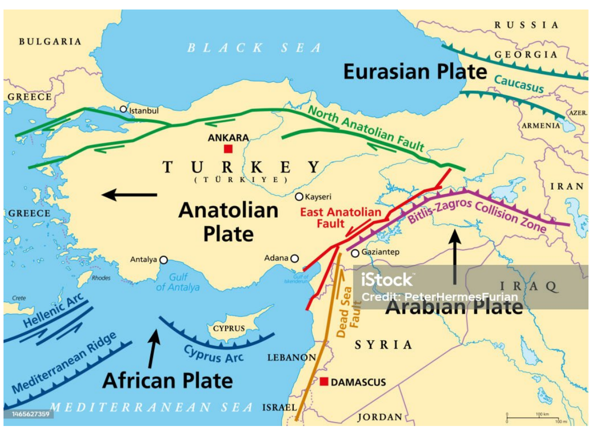
52 Y. Yılmaz et al. / Tectonophysics 488 (2010) 51–70

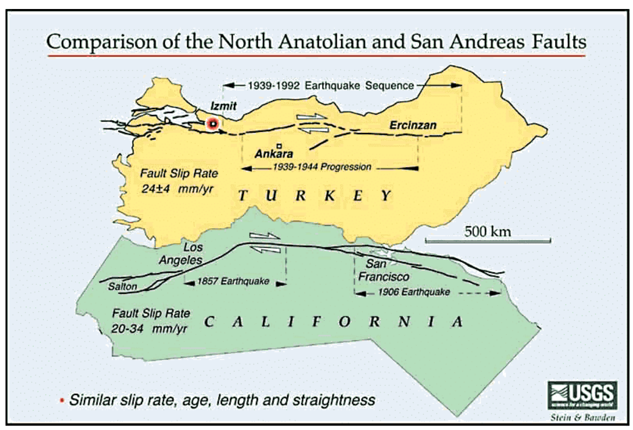


The NAF formed approximately 13 to 11 Ma ago in the east and propagated westward. It reached the Sea of Marmara no earlier than 200 ka ago, although shear-related deformation in a broad zone there had already commenced in the late Miocene. The fault zone has a very distinct morphological expression and is seismically active. Since the seventeenth century, it has shown cyclical seismic behavior, with century-long cycles beginning in the east and progressing westward. For earlier times, the record is less clear but does indicate a lively seismicity. The twentieth century record has been successfully interpreted in terms of a Coulomb failure model, whereby every earthquake concentrates the shear stress at the western tips of the broken segments leading to westward migration of large earthquakes.

The August 17 and November 12, 1999, events have loaded the Marmara segment of the fault. A major, M ≤ 7.6 event is expected in the next half century with an approximately 50% probability on this segment. Currently, the strain in the Sea of Marmara region is highly asymmetric, with greater strain to the south of the Northern Strand. This is conditioned by the geology, and it is believed that this is generally the case for the entire North Anatolian Fault Zone (Şengör et al. 2005).

1999 Earthquake displaced gas station (İzmit). Photo by Celal Şengör.



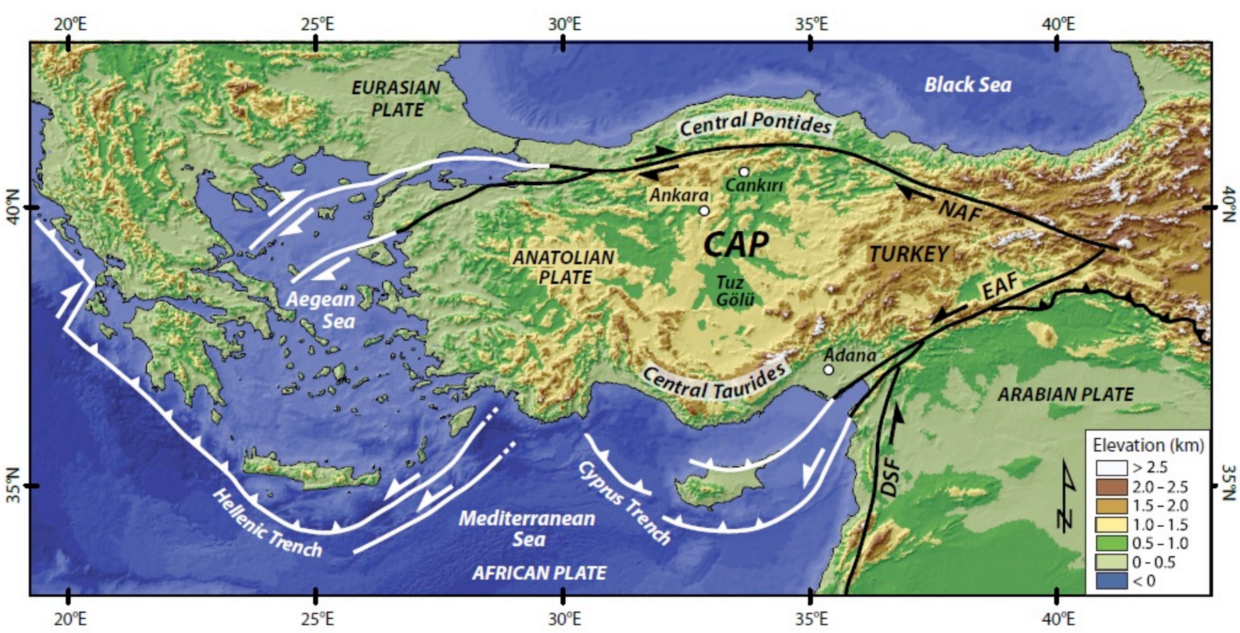


The North Anatolian Fault is similar in many ways to the San Andreas Fault in California. Both are continental transforms with similar lengths and slip rates. The Sea of Marmara near Istanbul is an extensional basin similar to the Salton Trough in California, where a releasing bend in the strike-slip system creates a pull-apart basin.

CENTRAL ANATOLIA PLATEAU (CAP)

Located between one of the world's most seismically active strike-slip faults (NAF), the Cyprus and Hellenic subduction margins to the south, the Aegean extensional zone to the west, and the Bitlis-Zagros collision zone to the east, the Central Anatolian Plateau (CAP) and its neighboring high-elevation regions constitute a relatively small orogenic plateau (Figure). Despite its modest average elevations between 1.2 and 1.5 km and low overall exhumation, the CAP is a first-order morphotectonic feature that has fundamentally impacted the geologic, geomorphic, and climatic evolution of the Eastern Mediterranean. Central Anatolia is the only orogenic plateau in the world today that appears to be in a nascent stage when compared to its much more extensive counterparts in the India-Eurasia collision zone, the non-collisional Andean Plateau, or the Colorado Plateau.

The northern and southern flanks of the plateau are bounded by the Pontide and Tauride mountains, which attain elevations in excess of 2000 m, posing significant barriers to modern precipitation. Between these 2 margins, the plateau interior comprises tectonic units assembled during Mesozoic to Tertiary orogenies. Related rocks are unconformably covered by extensive, thick successions of Miocene to Quaternary fluvio-lacustrine sediments and pyroclastic deposits at present separated by basement highs. The >1500 km^2 Tuz Gölü (Salt Lake) in the center of the plateau is only a remnant of these sedimentary systems. Lake sediments include a wide range of deposits and form well-preserved archives of plateau development that record tectonic deformation within the plateau and possibly tectonically driven climate change and fluvial adjustments, while the structures exposed at the basin margins and the plateau flanks record the deformation kinematics during plateau evolution.



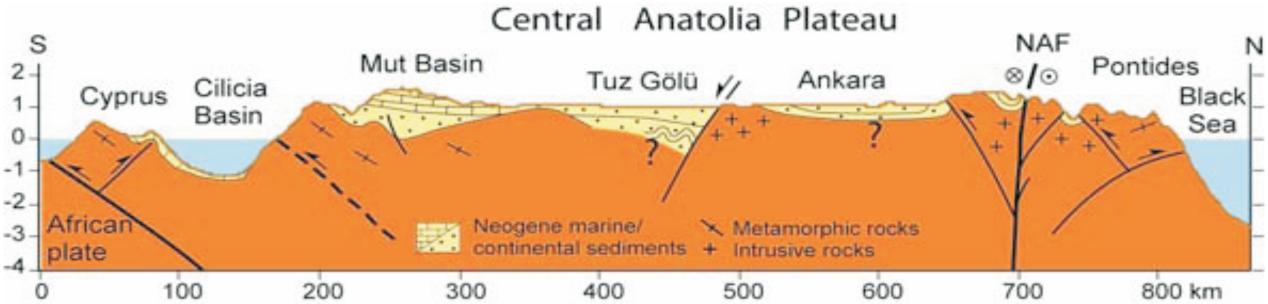
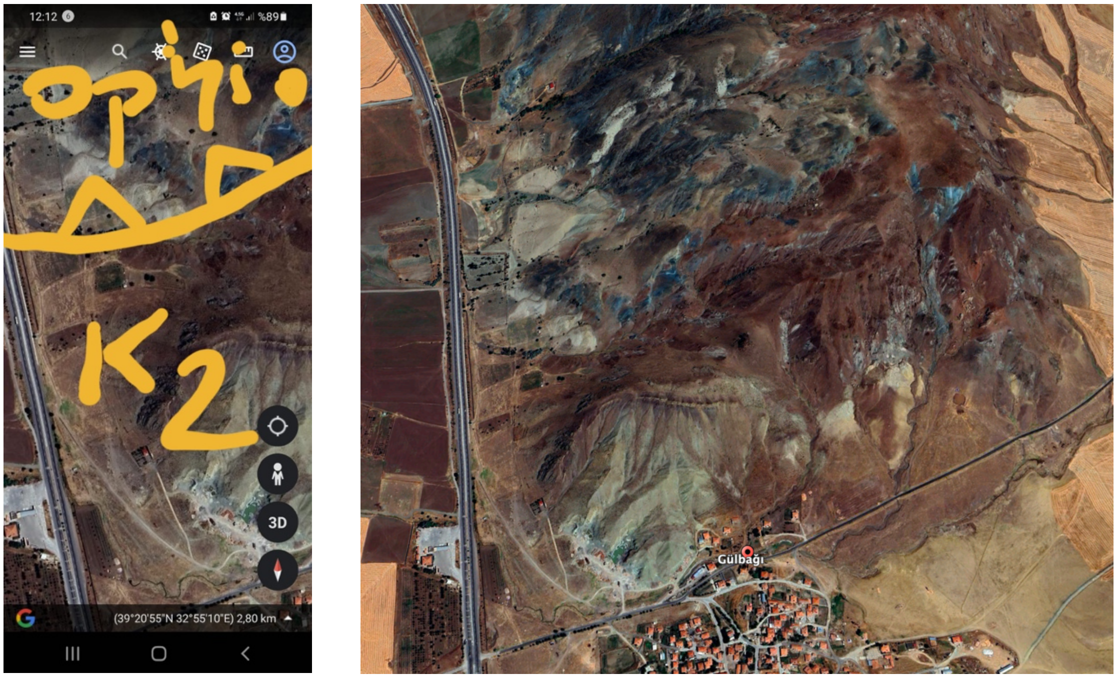
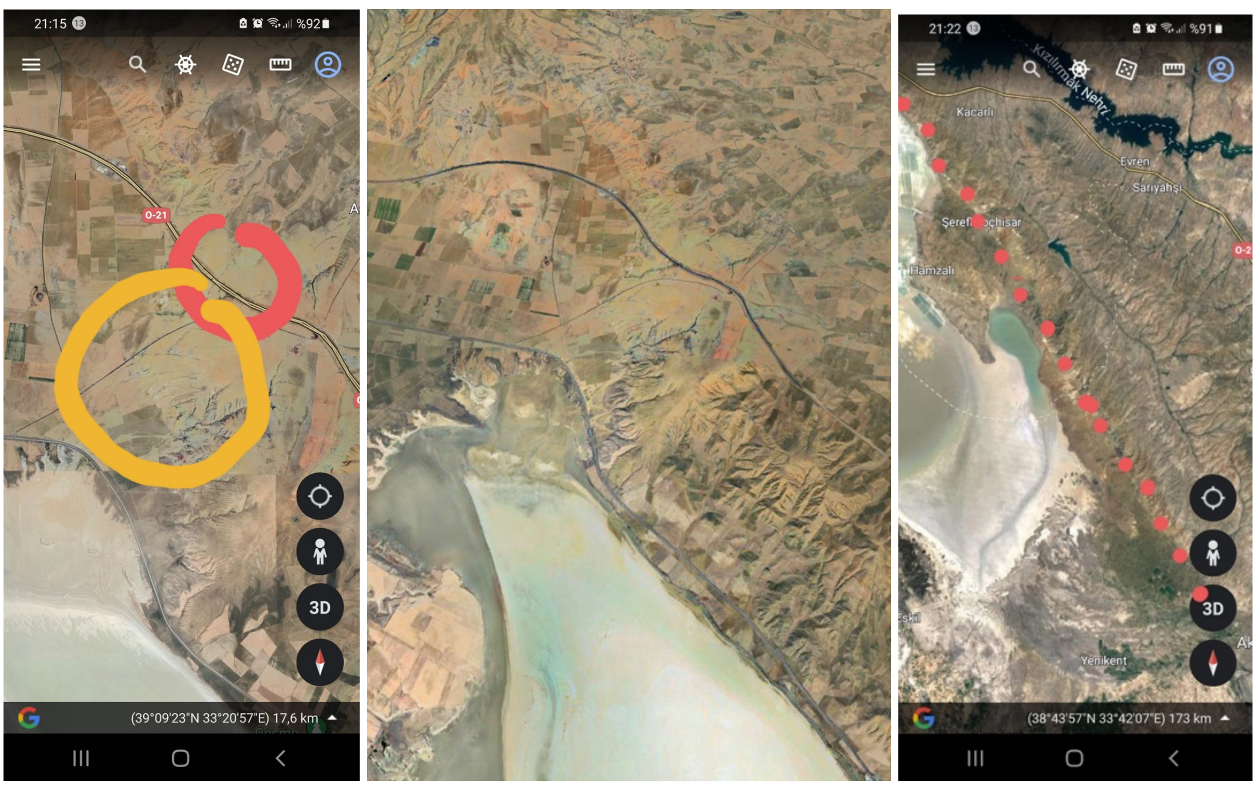


Figure: Top: East Mediterranean geodynamic setting. Bottom: Schematic profile across the CAP. NAF: North Anatolian Fault, EAF: East Anatolian Fault, DSF: Dead Sea Fault (Çiner et al., 2013).

Kulu Redbeds (Oligo Miocene continental clastics) on the road from Ankara to Tuz Gölü.



Gülbağı (Burhanlar Station): Upper Cretaceous Ophiolitic mélange thrusting over Upper Cretaceous red clastics and flysch sequence.



Quaternary fluvial terrace conglomerates (Red circle). Salt Lake was connected to Kızılırmak River (longest river in Turkey). We will see the river terraces in detail in Cappadocia. Salt domes (yellow circle). Tuz Gölü Fault Zone (red dots).

Central Anatolia is a continental, low-strain region characterized by low slip-rates along faults and large earthquake recurrence intervals.

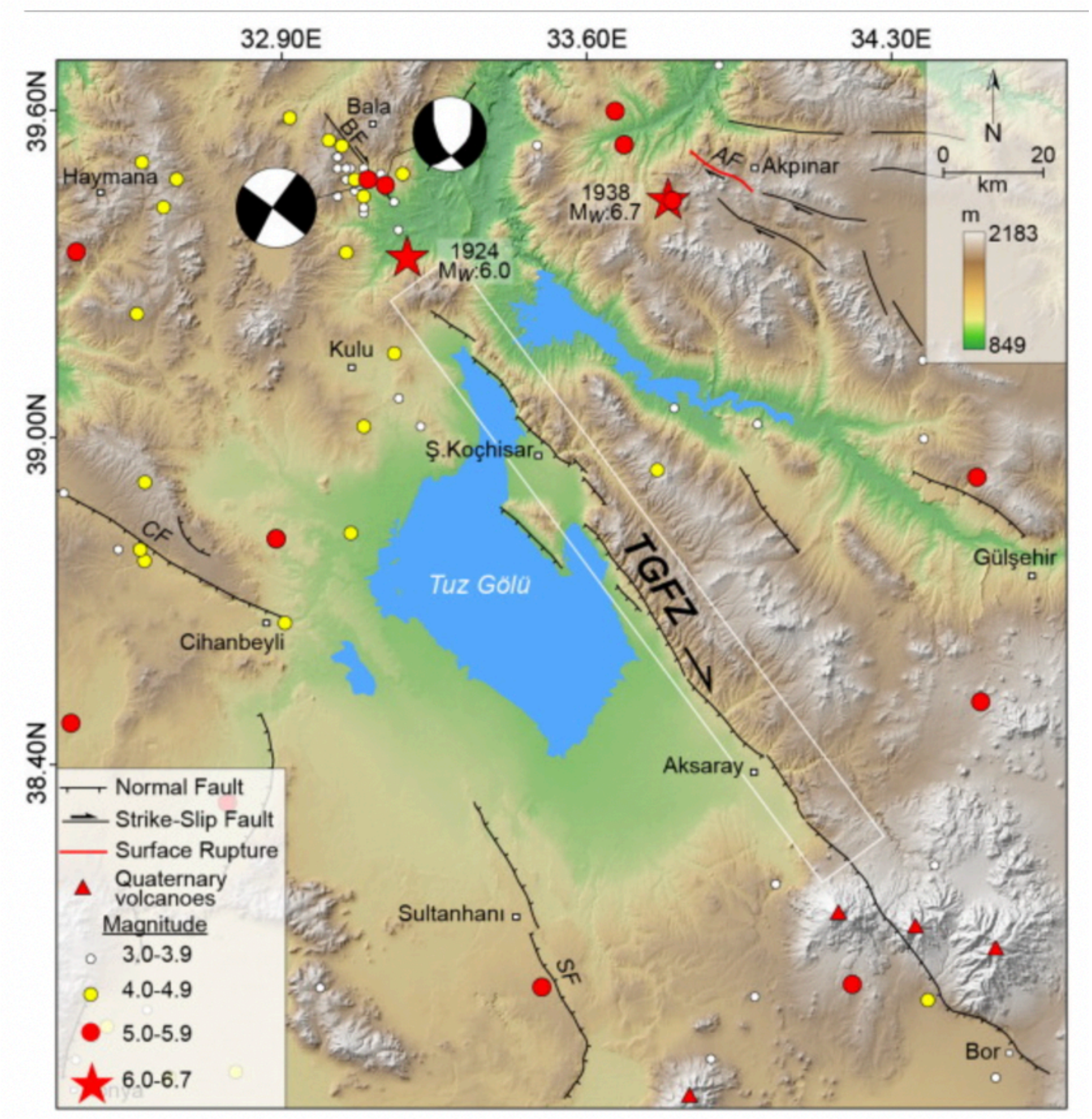


Figure: Seismotectonic map of Tuz Gölü. TGFZ: Tuz Gölü Fault Zone, SF: Sultanhanı Fault, CF: Cihanbeyli Fault (Özsayın et al. 2013).

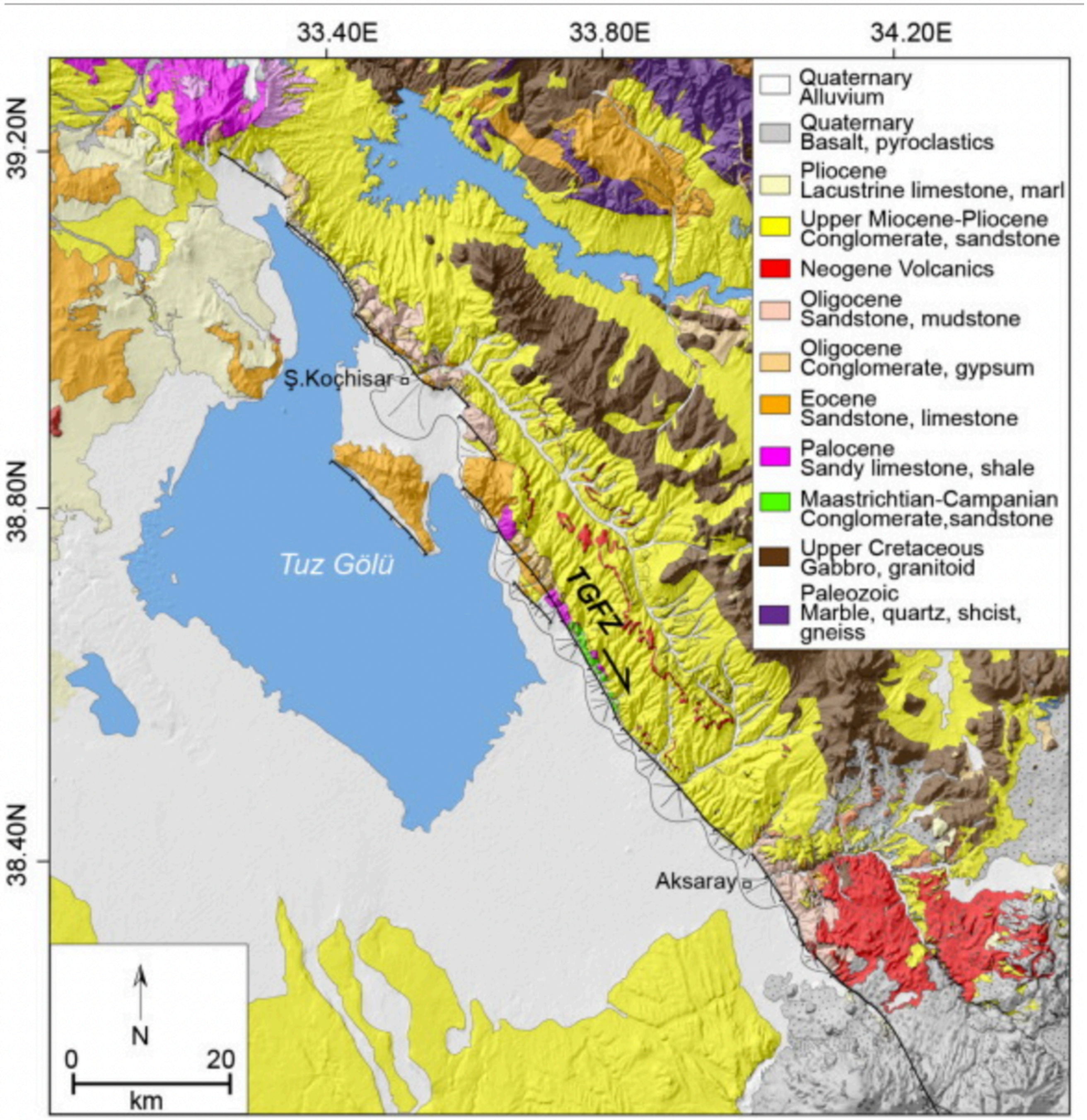


Figure: Geological map of Tuz Gölü area (Yıldırım, 2016).

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Plio-Quaternary extensional tectonics of the Central Anatolian Plateau: a case study from the Tuz Gölü Basin, Turkey

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Abstract: The Tuz Gölü Basin is the largest sedimentary depression located at the center of the Central Anatolian Plateau, an extensive, low-relief region with elevations of ca. 1 km located between the Pontide and Tauride mountains. Presently, the basin morphology and sedimentation processes are mainly controlled by the extensional Tuz Gölü Fault Zone in the east and the transtensional İnönü–Eskişehir Fault System in the west. The purpose of this study is to contribute to the understanding of the Plio-Quaternary deformation history and to refine the timing of the latest extensional phase of the Tuz Gölü Basin. Field observations, kinematic analyses, interpretations of seismic reflection lines, and $^{40}Ar/^{39}Ar$ dating of a key ignimbrite layer suggest that a regional phase of NNW–SSE to NE–SW contraction ended by 6.81 ± 0.24 Ma and was followed by N–S to NE–SW extension during the Pliocene–Quaternary periods. Based on sedimentological and chronostratigraphic markers, the average vertical displacement rates over the past 5 or 3 Ma with respect to the central part of Tuz Gölü Lake are 0.03 to 0.05 mm/year for the fault system at the western flank of the basin and 0.08 to 0.13 mm/year at the eastern flank. Paleo-shorelines of the Tuz Gölü Lake, vestiges of higher lake levels related to Quaternary climate change, are important strain markers and were formed during Last Glacial Maximum conditions as indicated by a radiocarbon age of 21.8 ± 0.4 ka BP obtained from a stromatolitic crust. Geomorphic observations and deformed lacustrine shorelines suggest that the main strand of the Tuz Gölü Fault Zone straddling the foothills of the Şereflikoçhisar–Aksaray range has not been active during the Holocene. Instead, deformation appears to have migrated towards the interior of the basin along an offshore fault that runs immediately west of Şereflikoçhisar Peninsula. This basinward migration of deformation is probably associated with various processes acting at the lithospheric scale, such as plateau uplift and/or microplate extrusion.

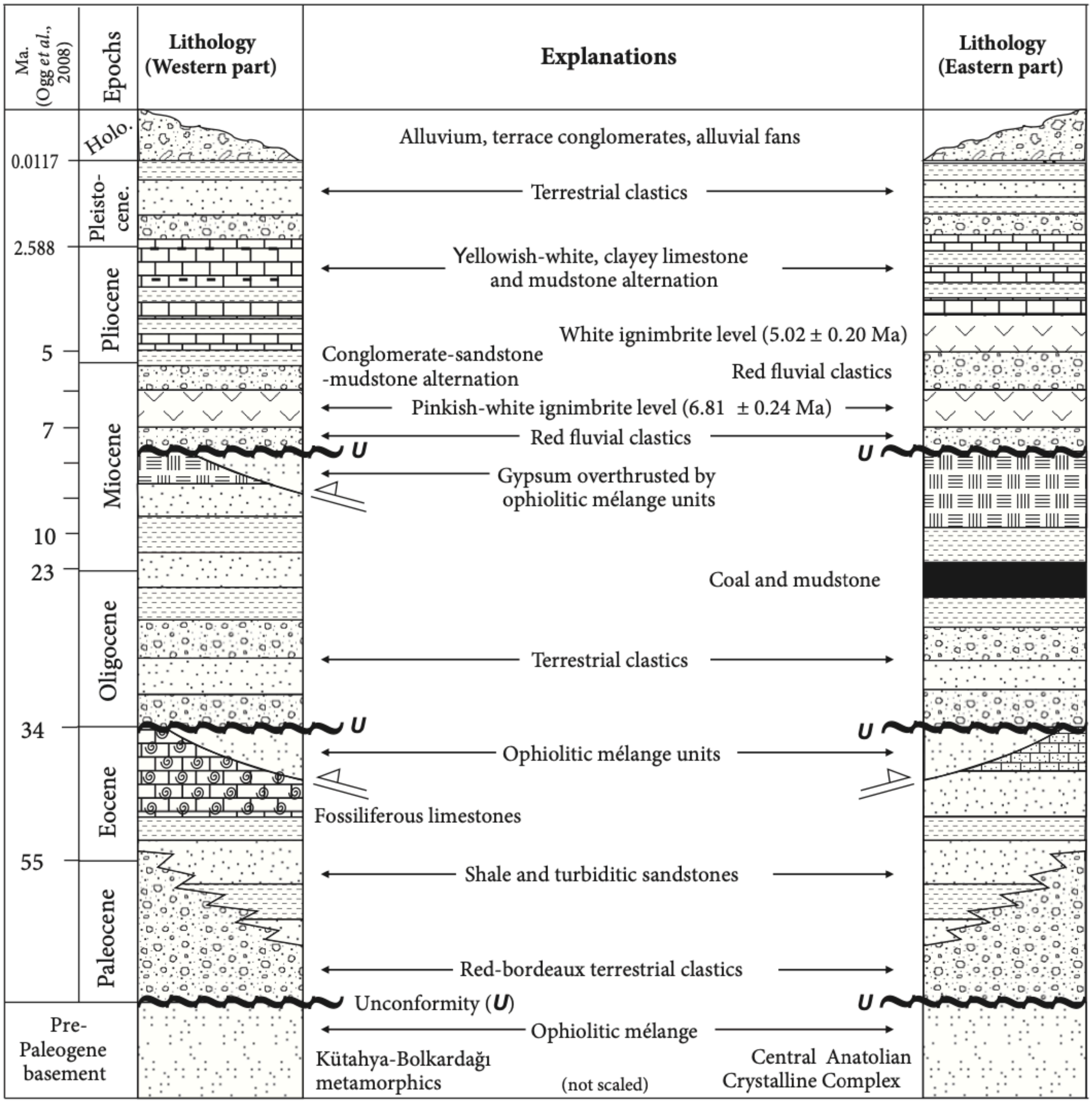

Figure 2. Tectono-stratigraphic section of the Tuz Gölü Basin.

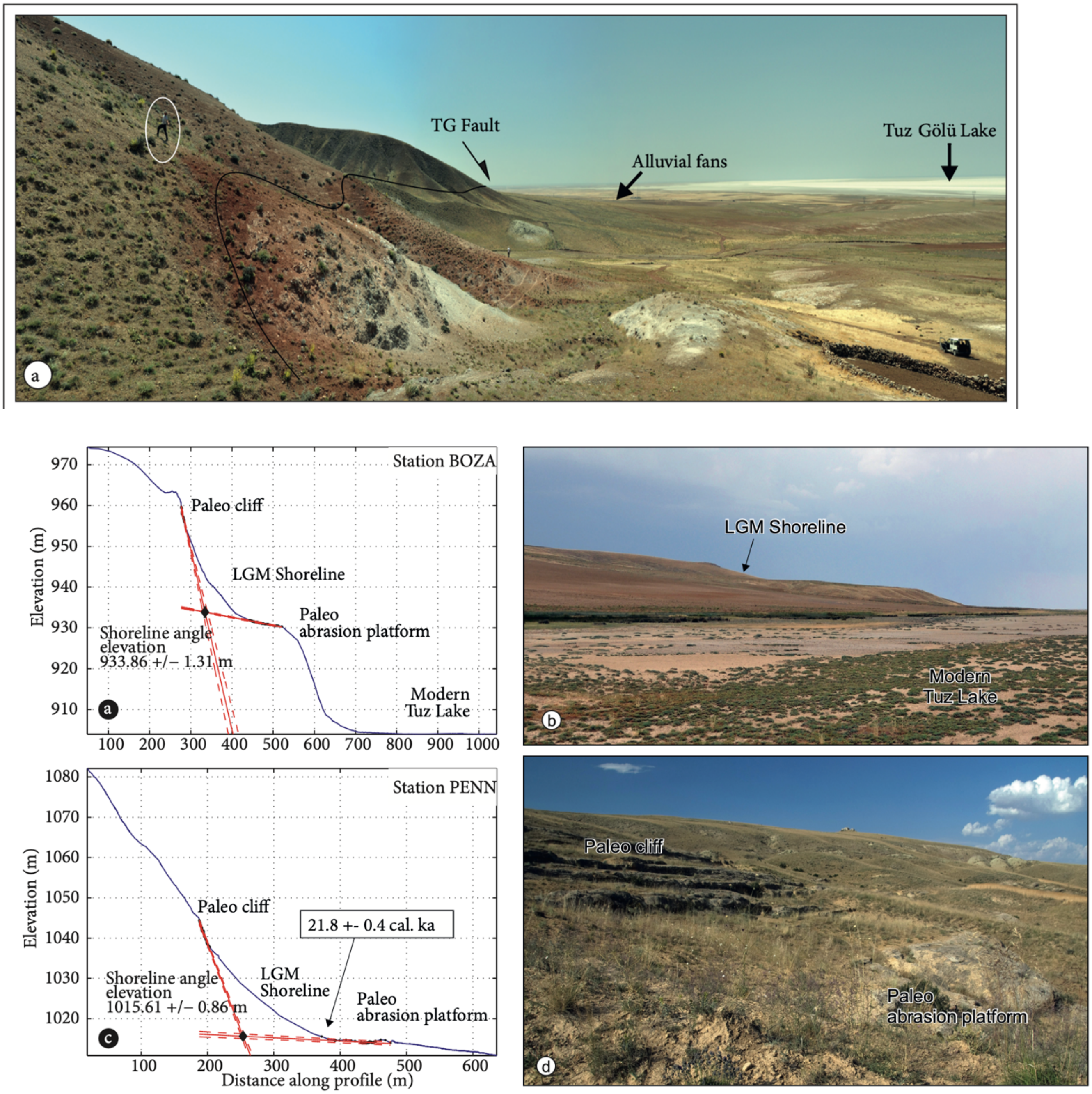

Figure 10. Examples of topographic profiles and field photos of Pleistocene shorelines of the Tuz Gölü Lake. (a & b) Site south of the town of Bozan. To determine the elevation of the shoreline angle, which is covered by colluvium, the outcropping parts of the paleocliff and abrasion platforms have been interpolated linearly. (c & d) Site at the Şereflikoçhisar Peninsula. The location of the sampled stromatolitic material and calibrated radiocarbon age is shown. See text for details.

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Cenozoic tectonics of the Tuz Gölü Basin (Central Anatolian Plateau, Turkey)

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Abstract: We present a new 3D geologic model for the architecture and Cenozoic tectonic evolution of the Tuz Gölü Basin, a major sedimentary basin in the Central Anatolian orogenic plateau. This model is grounded on 7 depth-converted seismic reflection profiles in combination with the analysis of backstripped subsidence curves, isochore maps, and a palinspastically restored cross-section. Two stages of basin formation are detected during Cenozoic times. During the Palaeogene, around 2 km of basement subsidence led to the development of a sag basin broader than the present basin in the absence of bounding faults. After a period of uplift and erosion, sedimentation restarted by Tortonian times. Up to 3.5 km of post-Palaeogene sediments were deposited in relation to this second regional subsidence phase, which continued possibly well into the Pliocene. During this time, the 2 main fault systems found in the area, the Tuz Gölü and the Sultanhanı faults, developed as south-west dipping, NW–SE striking, normal faults. At some time in the Late Miocene-Early Pliocene, during regional subsidence, a previously unreported phase of contraction occurred, which led to the development of a north-east–vergent thrust sheet, the culmination of which forms the morphologic ridge to the east of the Tuz Gölü Lake. This structure presently divides the previously continuous Tuz Gölü Basin. Finally, minor extensional reactivation occurred. At the regional scale, the pre-Late Miocene subsidence is coeval with the initiation of volcanism in the Central Anatolian Volcanic Province and marine carbonate deposition in southern Turkey, and the latest Miocene shortening is (partly) contemporaneous with the onset of uplift in the same region.

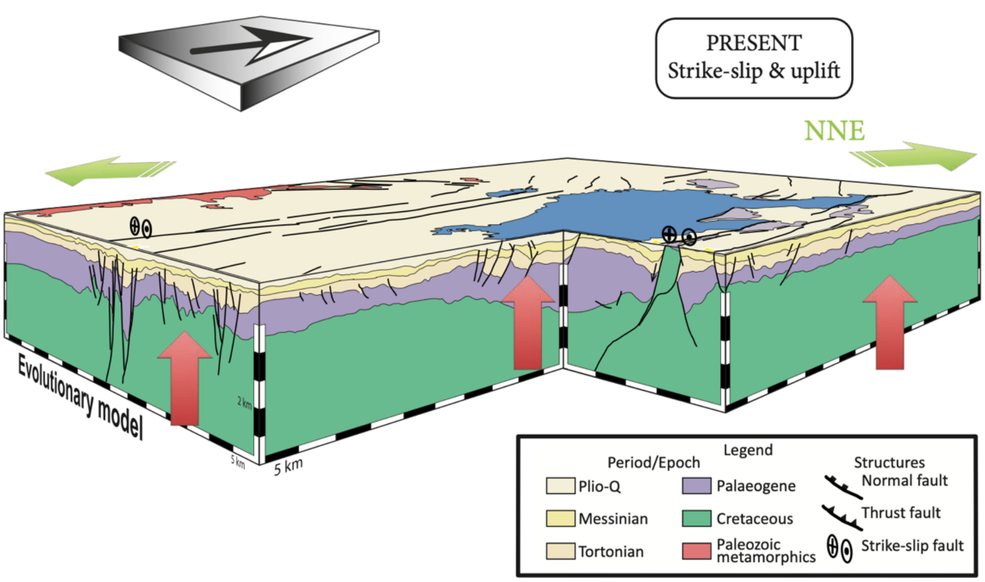

Figure 20. Real-scale box model (exaggerated 3 times in the vertical direction) showing the main tectonic structures and tectonic movements in present times. Arrows indicate the direction, type, and relative magnitude of the movements.

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Fairy chimney erosion rates on Cappadocia ignimbrites, Turkey: Insights from cosmogenic nuclides

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ABSTRACT

Cappadocia, in the Central Anatolian Plateau of Turkey, is famous for its unique landscape and unusual rock formations. The development of this landscape dates back to Late Miocene epoch (c. 10 million years) when volcanoes spread pyroclastic deposits over an area of about 20,000 km^2. The volcanism continued for several millions of years and laid down thick and colorful ignimbrite layers. The evolution of the Cappadocian landscape starts with nearly-horizontal plateaus, which are then dissected, usually along cooling fractures, to form mushroom-like structures (hoodoos) locally known as "fairy chimneys". Different layers of ignimbrites have different resistance to erosion: softer layers (necks) are easier to erode compared to the harder ignimbrites (caps). When the chimneys are isolated, the caps play an important role in slowing further erosion of softer layers. When the caps finally drop or completely erode away, the soft necks of the chimneys are quickly destroyed. Here, for the first time, we have determined the bedrock erosion rates at the three evolution stages of fairy chimneys using the cosmogenic chlorine-36 (^{36}Cl): the pre-chimney (plateaus) stage, the chimney stage and the post-chimney stage. The data show that the plateaus erode at a very low rate between 0.58 ± 0.02 cm/ky and 0.93 ± 0.05 cm/ky. When dissection of a plateau starts, the erosion rate increases to about 4.5 ± 0.6 cm/ky. The caps of chimneys have erosion rates between 3.21 ± 0.36 cm/ky and 3.39 ± 0.36 cm/ky. Once the chimneys disappear, erosion rates increase significantly to 28.0 ± 9.9 cm/ky.

Fig. 6. Field photographs of sample locations (e = erosion rates, T_{app} = apparent age).

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Quaternary uplift rates of the Central Anatolian Plateau, Turkey: insights from cosmogenic isochron-burial nuclide dating of the Kızılırmak River terraces

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A B S T R A C T

The Central Anatolian Plateau (CAP) in Turkey is a relatively small plateau (300 × 400 km) with moderate average elevations of ~1 km situated between the Pontide and Tauride orogenic mountain belts. Kızılırmak, which is the longest river (1355 km) within the borders of Turkey, flows within the CAP and slowly incises into lacustrine and volcaniclastic units before finally reaching the Black Sea. We dated the Cappadocia section of the Kızılırmak terraces in the CAP by using cosmogenic burial and isochron-burial dating methods with ^{10}Be and ^{26}Al as their absolute dating can provide insight into long-term incision rates, uplift and climatic changes. Terraces at 13, 20, 75 and 100 m above the current river indicate an average incision rate of 0.051 ± 0.01 mm/yr (51 ± 1 m/Ma) since ~1.9 Ma. Using the base of a basalt fill above the modern course of the Kızılırmak, we also calculated 0.05–0.06 mm/yr mean incision and hence rock uplift rate for the last 2 Ma. Although this rate might be underestimated due to normal faulting along the valley sides, it perfectly matches our results obtained from the Kızılırmak terraces. Although up to 5–10 times slower, the Quaternary uplift of the CAP is closely related to the uplift of the northern and southern plateau margins respectively.

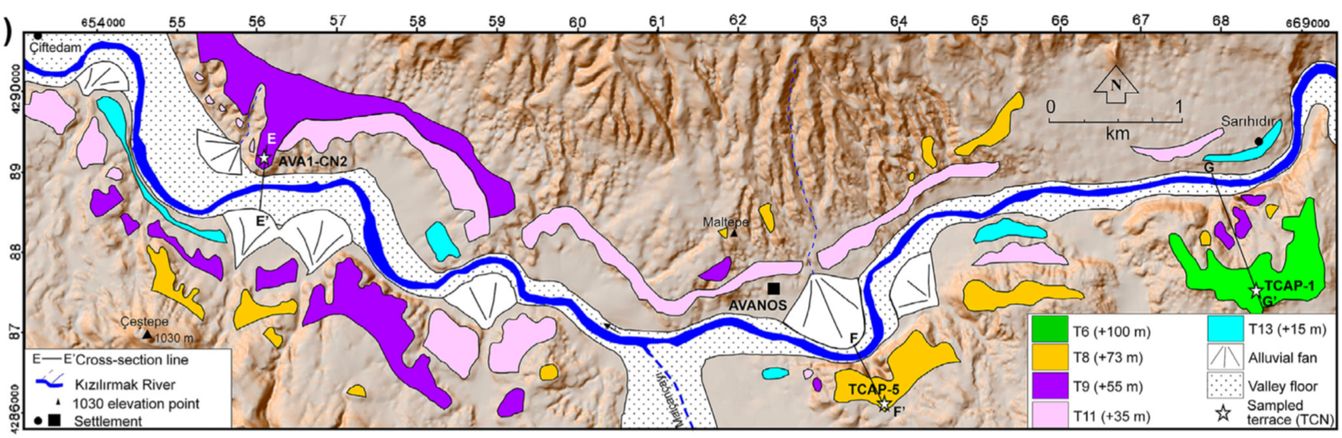


Figure: Geological map of the terraces observed around Avanos town

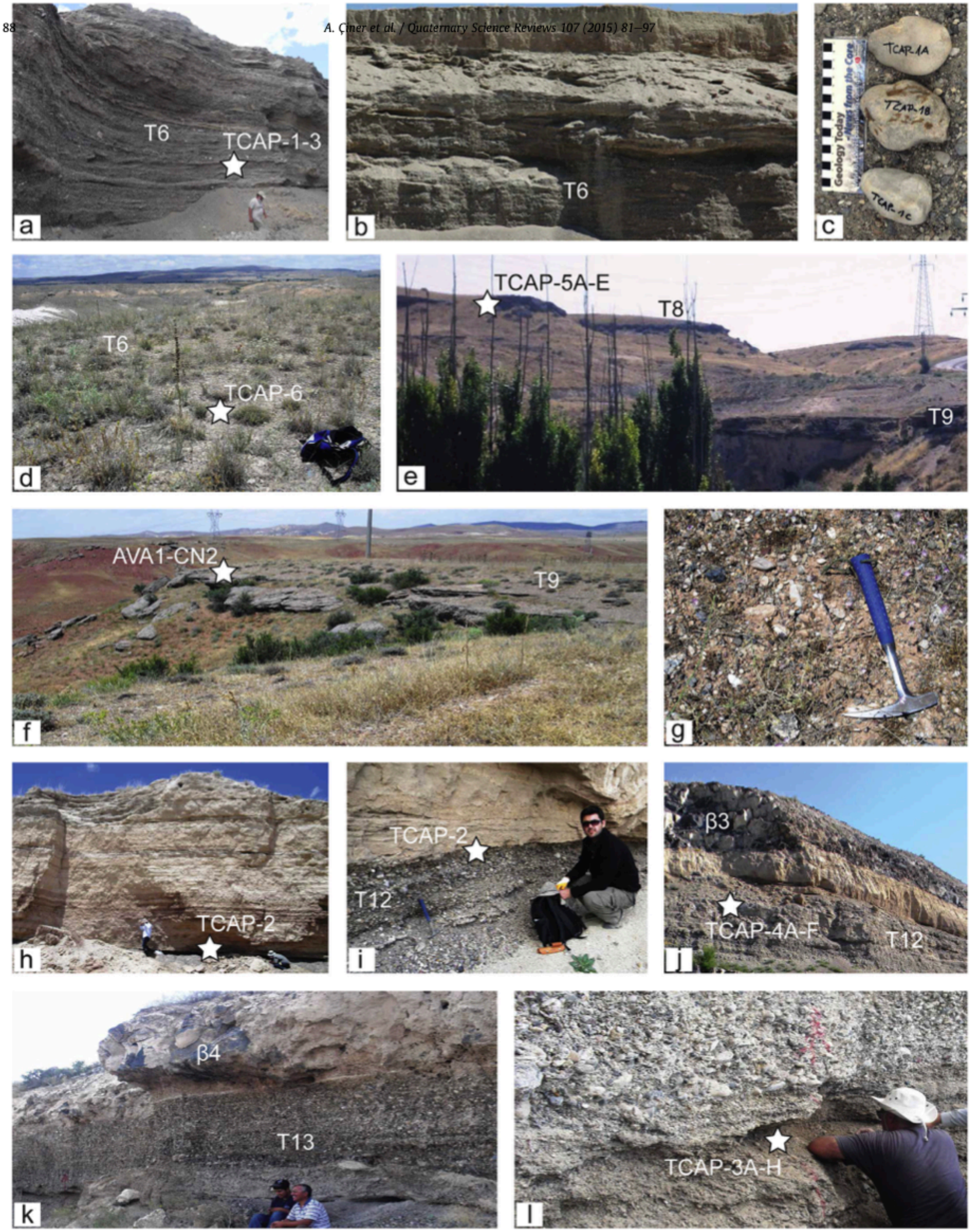


Fig. 4. Field pictures of the terraces (white stars indicate sampling sites and sample numbers): a) T6 at Sarıhıdır gravel quarry; b) cross-bedded conglomerates and overlying floodplain fine-grained sediments; c) quartz pebble samples (TCAP-1 to 3) collected from T6 for cosmogenic dating; d) T6 surface near Yüksekli village covered by cm size quartz pebbles; e) T8 and T9 near Avanos; f) T9 along Gülşehir-Avanos road; g) calcareous pebble samples collected for cosmogenic dating; h) T12 to NW of Gülşehir showing sampled conglomerates overlain by thick floodplain fine-grained sediments; i) close up view of T12 conglomerates and sample location; j) T12 near Gürüzlük Hill and fine-grained floodplain sediments and Tuzköy Basalt Plateau (β3) basalts; k) T13 with fine-grained quartz pebbles and Karnıyarık Hill Basalt (β4) on top; l) detail from the sampling site.

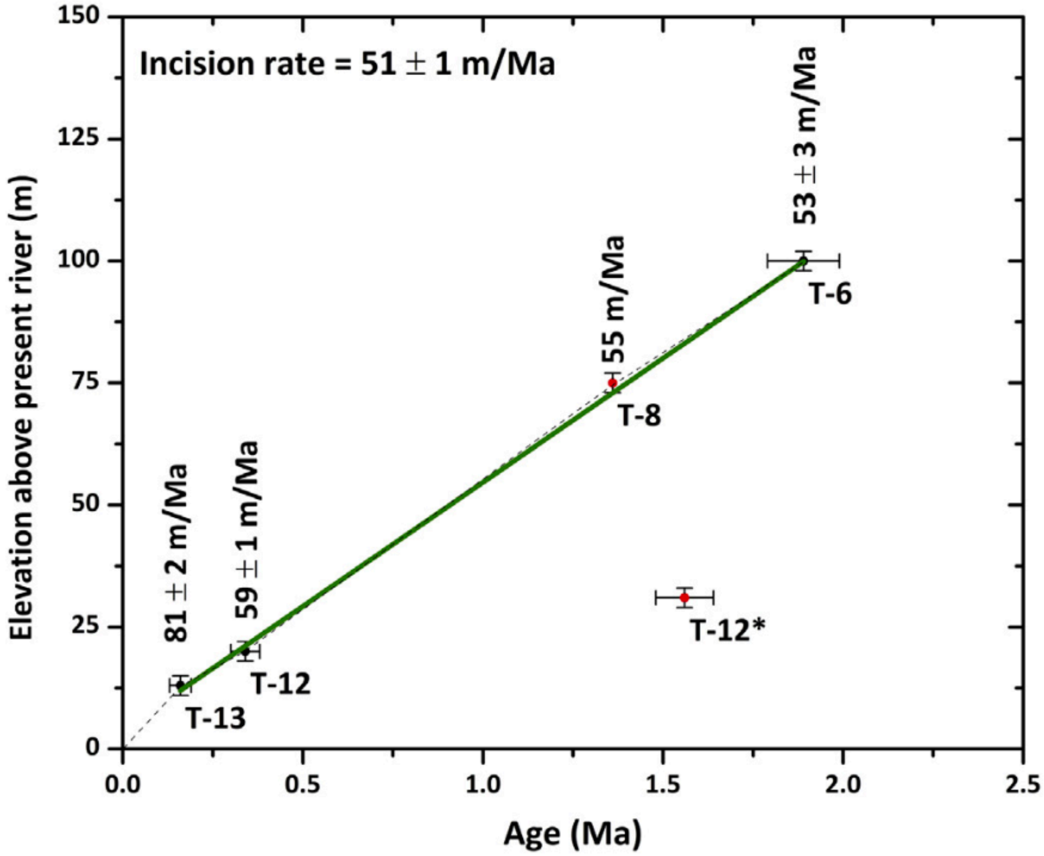
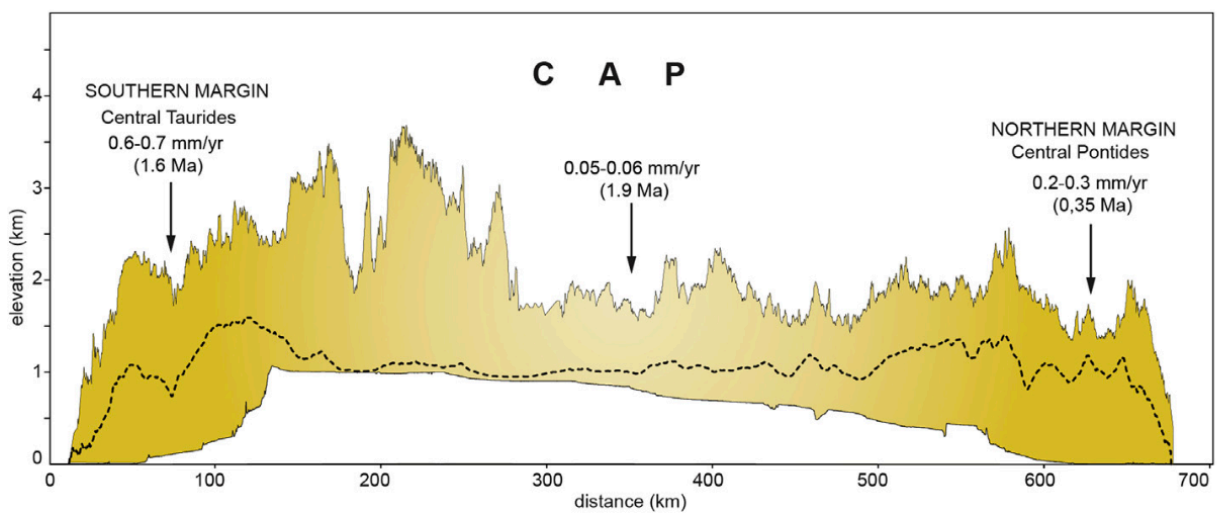


Fig. 6. TCAP average incision rate (51 ± 1 m/Ma).



8. Swath profile of the CAP. Dashed line indicates the mean elevation. Vertical exaggeration is ×100. See Fig. 1 for the swath section.

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Chlorine degassing constrained by cosmogenic ^{36}Cl and radiocarbon dating of early Holocene rhyodacitic lava domes on Erciyes stratovolcano, central Turkey

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ABSTRACT

The Erciyes stratovolcano in central Turkey has several young rhyodacite lava domes that show evidence of clear exposure histories but have hitherto unknown ages. We collected 27 surface samples from three volcanic domes namely Karagüllü, Perikartın and Dikkartın for cosmogenic ^{36}Cl dating. The Perikartın eruption generated a pyroclastic flow, which buried trees that were converted to charcoal. The radiocarbon (^{14}C) dating yielded an average age of 9728 ± 110 cal. years B.P. (calibrated using Calib 7.1). We analyzed the cosmogenic ^{36}Cl ages, however, were found that they were probably affected by Cl degassing of the magma. Our study suggests that the radiocarbon age indeed lies between the 0% Cl degassing (6.8 ± 0.5 ka, under nucleogenic ^{36}Cl equilibrium) and the 100% degassing conditions (9.9 ± 0.6 ka, under nucleogenic ^{36}Cl disequilibrium), which implies a partial Cl degassing (93%) during the eruption. This value is somewhat higher than earlier estimates and the difference may result from the miscalculated nucleogenic and/or low-energy neutron production of ^{36}Cl, uncertainties arising from the corrections due to hydrogen-rich cover (i.e., snow) of lava surfaces or due to unconsidered geological complications. Our findings provide a novel approach to estimate the Cl degassing on young lavas and deliver a new evidence of the Holocene volcano-chronology of the central Anatolia.

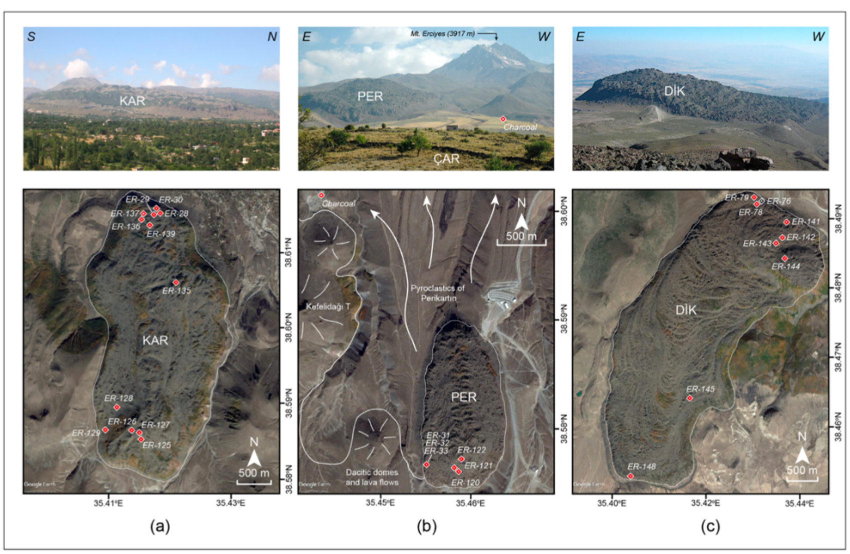

Fig. 3. Field pictures and Google Earth images with sample locations of the (a) Karagüllü (KAR), (b) Perikartın (PER) and (c) Dikkartın (DIK) lava domes. Pyroclastic deposits and flow directions of the Perikartın are shown on the middle lower panel. ÇAR: Çarık Tepe lava flow (80 ± 10 ka, Notsu et al., 1995).

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Glaciations and paleoclimate of Mount Erciyes, central Turkey, since the Last Glacial Maximum, inferred from ^{36}Cl cosmogenic dating and glacier modeling

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ABSTRACT

Forty-four boulders from moraines in two glacial valleys of Mount Erciyes (38.53°N, 35.45°E, 3917 m), central Turkey, dated with cosmogenic chlorine-36 (^{36}Cl), indicate four periods of glacial activity in the past 22 ka (1 ka = 1000 calendar years). Last Glacial Maximum (LGM) glaciers were the most extensive, reaching 6 km in length and descending to an altitude of 2150 m above sea level. These glaciers started retreating 21.3 ± 0.9 ka (1σ) ago. They readvanced and retreated by 14.6 ± 1.2 ka ago (Lateglacial), and again by 9.3 ± 0.5 ka ago (Early Holocene). The latest advance took place 3.8 ± 0.4 ka ago (Late Holocene). Using glacier modeling together with paleoclimate proxy data from the region, we reconstructed the paleoclimate at these four discrete times. The results show that LGM climate was 8–11 °C colder than today and moisture levels were somewhat similar to modern values, with a range between 20% more and 25% less than today. The analysis of Lateglacial advance suggests that the climate was colder by 4.5–6.4 °C based on up to 1.5 times wetter conditions. The Early Holocene was 2.1–4.9 °C colder and up to twice as wet as today, while the Late Holocene was 2.4–3 °C colder and its precipitation amounts approached to similar conditions as today. Our paleoclimate reconstructions show a general trend of warming for the last 22 ka, and an increase of moisture until Early Holocene, and a decrease after that time. The recent glacier terminates at 3450 m on the northwest side of the mountain. It is a remnant from the last advance (possibly during the Little Ice Age). Repeated measurements of glacier length between 1902 and 2008 reveal a retreat rate of 4.2 m per year, which corresponds to a warming rate of 0.9–1.2 °C per century.

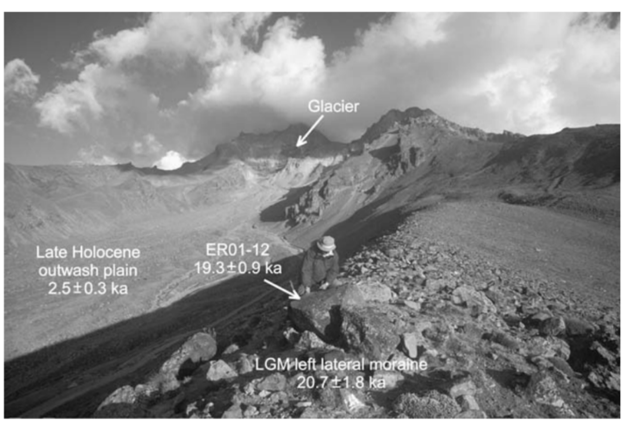

Fig. 2. Sample ER01-12 and the LGM left lateral moraine in the lower Aksu Valley. The Late Holocene outwash plain and the Erciyes glacier are on the left and in the background of the picture, respectively.

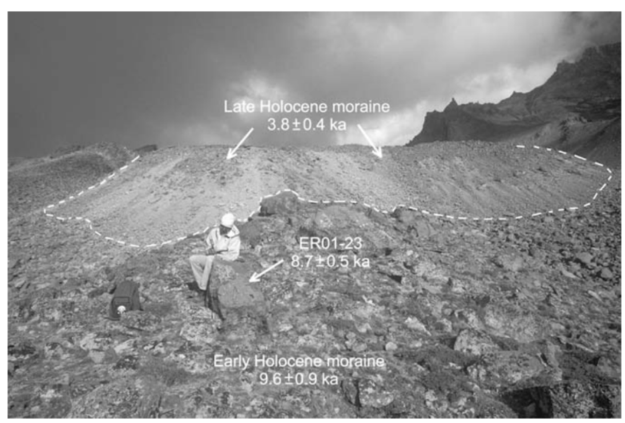

Fig. 3. Sample ER01-23 and the Early Holocene moraine overlain by the Late Holocene terminal moraine in the right tributary of the Aksu Valley.

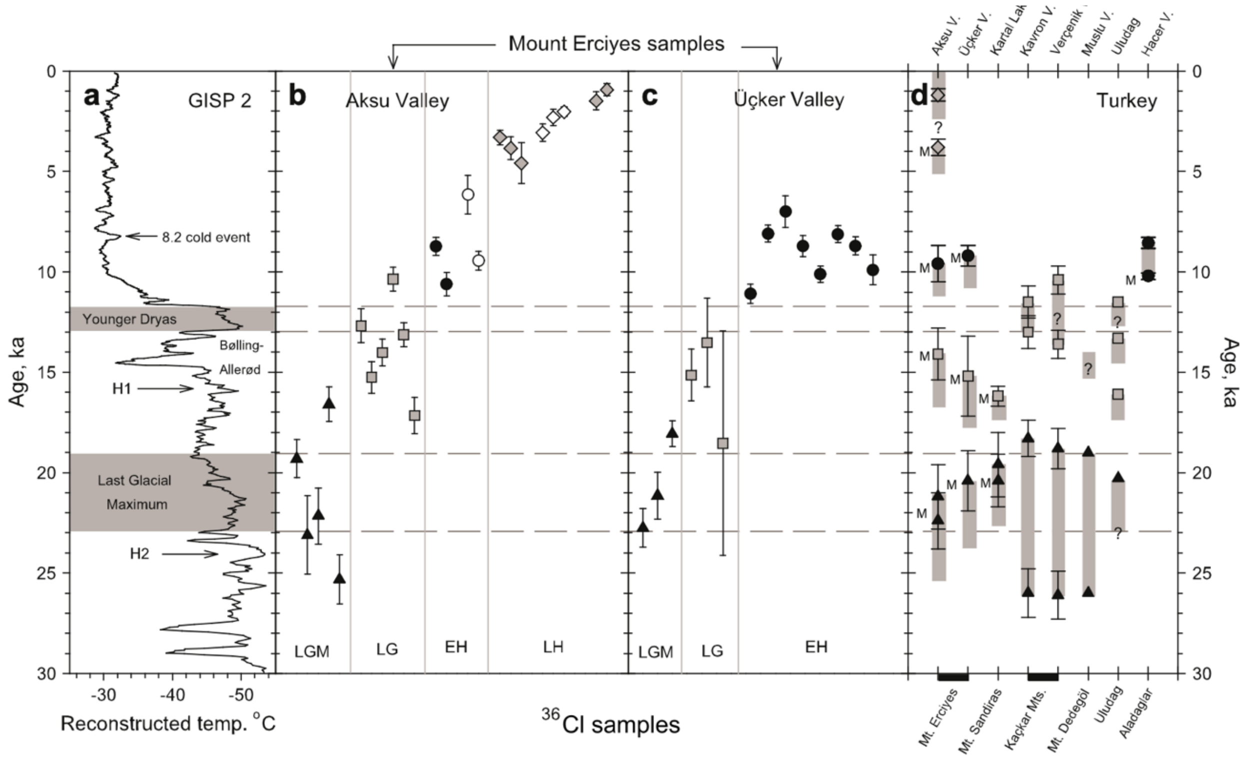

Fig. 4. (a) Reconstructed air temperatures from the GISP 2 ice core in Greenland (Alley, 2000) and comparison of cosmogenic exposure ages from the (b) Aksu and (c) Üçker Valleys of Mount Erciyes. Samples excluded from the moraine age calculations were not plotted. LGM: Last Glacial Maximum (triangles); LG: Late Glacial (squares); EH: Early Holocene (circles); LH: Late Holocene (diamonds). Open circles and diamonds indicate samples from outwash deposits of EH and LH, respectively. (d) Comparison of maximum extents of the Late Quaternary glaciations of Turkey. Timing of maximum glaciations is indicated as capital letter M, wherever possible. Vertical gray bars indicate possible range of ages from the Kartal Lake and Northwest Valleys of Mount Sandıras (Sarıkaya et al., 2008); the Kavron (Akçar et al., 2007) and Verçenik Valleys (Akçar et al., 2008) of the Kaçkarlar Mountains; the Muslu Valley of Mount Dedegöl (Zahno et al., 2006; 2007), Uludağ (Zahno et al., 2009) and the Hacer Valley of Aladağlar (Sarikaya, 2009).

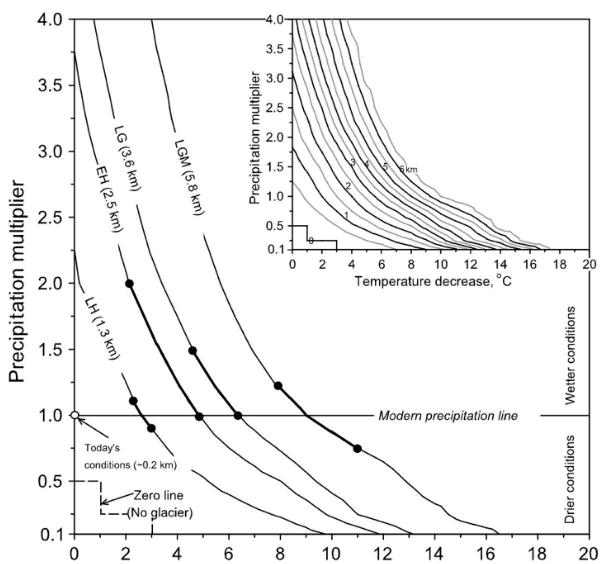

Fig. 5. Modeled length of the Aksu Valley glaciers during their maximum extents for Last Glacial Maximum (LGM), Lateglacial (LG), Early Holocene (EH) and Late Holocene (LH) as a function of temperature and precipitation changes from those of today. The thick lines with full circles, which indicate boundary conditions from the proxy data, show possible reconstructions of paleoclimate suggested by this study. Inset shows the full model results.

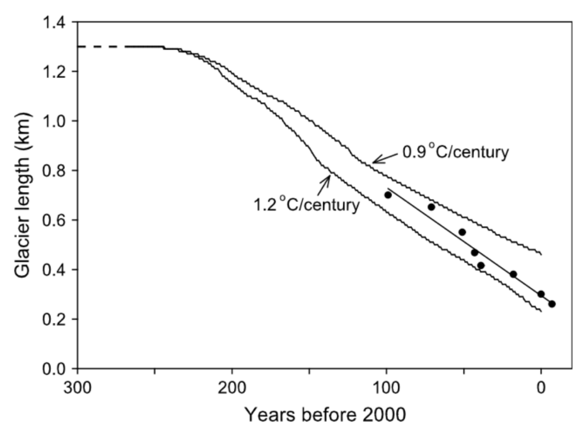

Fig. 8. Modeled retreat of the Erciyes glacier under constant warming rates. Dots are observation points (from Fig. 7) and their linear fit is shown by the straight line.

Contents lists available at ScienceDirect

Geomorphology

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Late Quaternary alluvial fans of Emli Valley in the Ecemiş Fault Zone, south central Turkey: Insights from cosmogenic nuclides

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ABSTRACT

Alluvial fans within the paraglacial Ecemiş River drainages on the Aladağlar Mountains in south central Turkey were studied using geomorphological, sedimentological, and chlorine-36 terrestrial cosmogenic nuclide (TCN) surface exposure dating methods to examine the timing of alluvial fan abandonment/incision, and to understand the role of climatic and tectonic processes in the region. These alluvial fan complexes are among the best-preserved succession of alluvial fans in Turkey and they were offset by the major strike-slip Ecemiş Fault of the Central Anatolian Fault Zone. The alluvial fans are mostly composed of well-lithified limestone cobbles (5 to 25 cm in size), and comprise crudely stratified thick beds with a total thickness reaching up to about 80 m. TCN surface exposure dating indicates that the oldest alluvial fan surface (Yalak Fan) was likely formed and subsequently abandoned latest by 136.0 ± 23.4 ka ago, largely on the transition of the Penultimate Glaciation (Marine Isotope Stage 6, MIS 6) to the Last Interglacial (MIS 5) (i.e. Termination II). The second set of alluvial fan (Emli Fan) was possibly developed during the Last Interglacial (MIS 5), and incised twice by between roughly 97.0 ± 13.8 and 81.2 ± 13.2 ka ago. A younger alluvial fan deposit placed on relatively older erosional terraces of the Emli Fan suggests that it may have been produced during the Last Glacial Cycle (MIS 2). These events are similar to findings from other fluvial and lacustrine deposits throughout central Anatolia. The incision times of the Ecemiş alluvial fan surfaces largely coincide with major climatic shifts from the cooler glacial periods to warmer interglacial/interstadial conditions. This indicates that alluvial fans were produced by outwash sediments of paleoglaciers during cooler conditions, and, later, when glaciers started to retreat due to a major warming event, the excess water released from the glaciers incised the pre-existing fan surfaces. An alluvial fan in the study area was also cut by the Ecemiş Fault, highlighting the influence of tectonics on fan development. It was offset vertically 35 ± 3 m since at least 97.0 ± 13.8 ka, which suggests a 0.36 ± 0.06 mm a^{-1} vertical slip-rate of the fault.

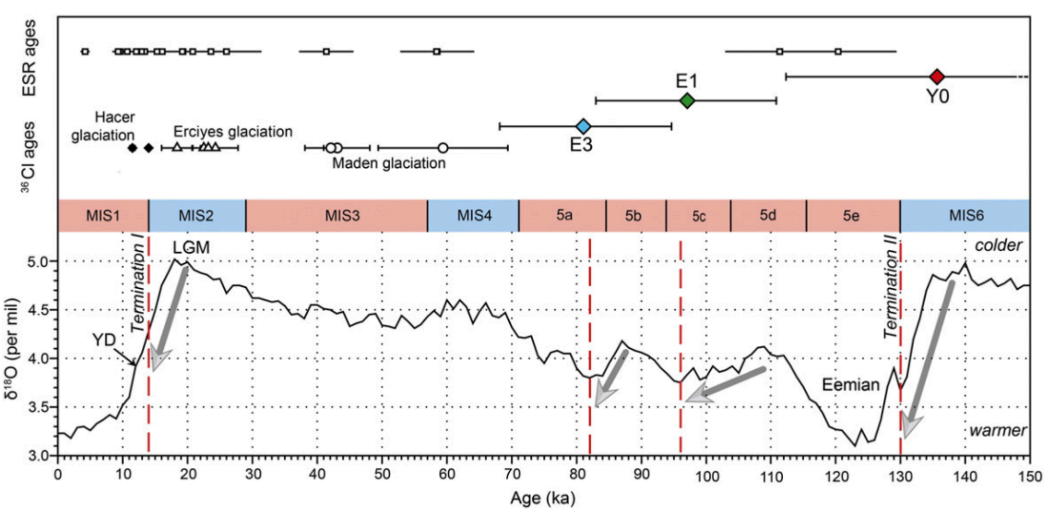

Fig. 7. Average globally distributed benthic marine $\partial^{18}O$ records of the LR04 stack (Lisiecki and Raymo, 2005) and MIS 1-6 series. Cosmogenic ^{36}Cl ages of alluvial fan samples (#1–6) and glaciation ages from Hacer (Zreda et al., 2011) and Maden Valleys of Aladağlar and from Mount Erciyes (Sarıkaya et al., 2009) were shown on the upper section along with ESR ages of speleothem from Aladağlar (Ulusoy et al., 2014). Vertical dotted red lines show the timing of the peak events of MIS 5a, 5c and Termination II from Lisiecki and Raymo (2005). Arrows indicate transition from cooler climates to warmer conditions (e.g. climatic shifts).

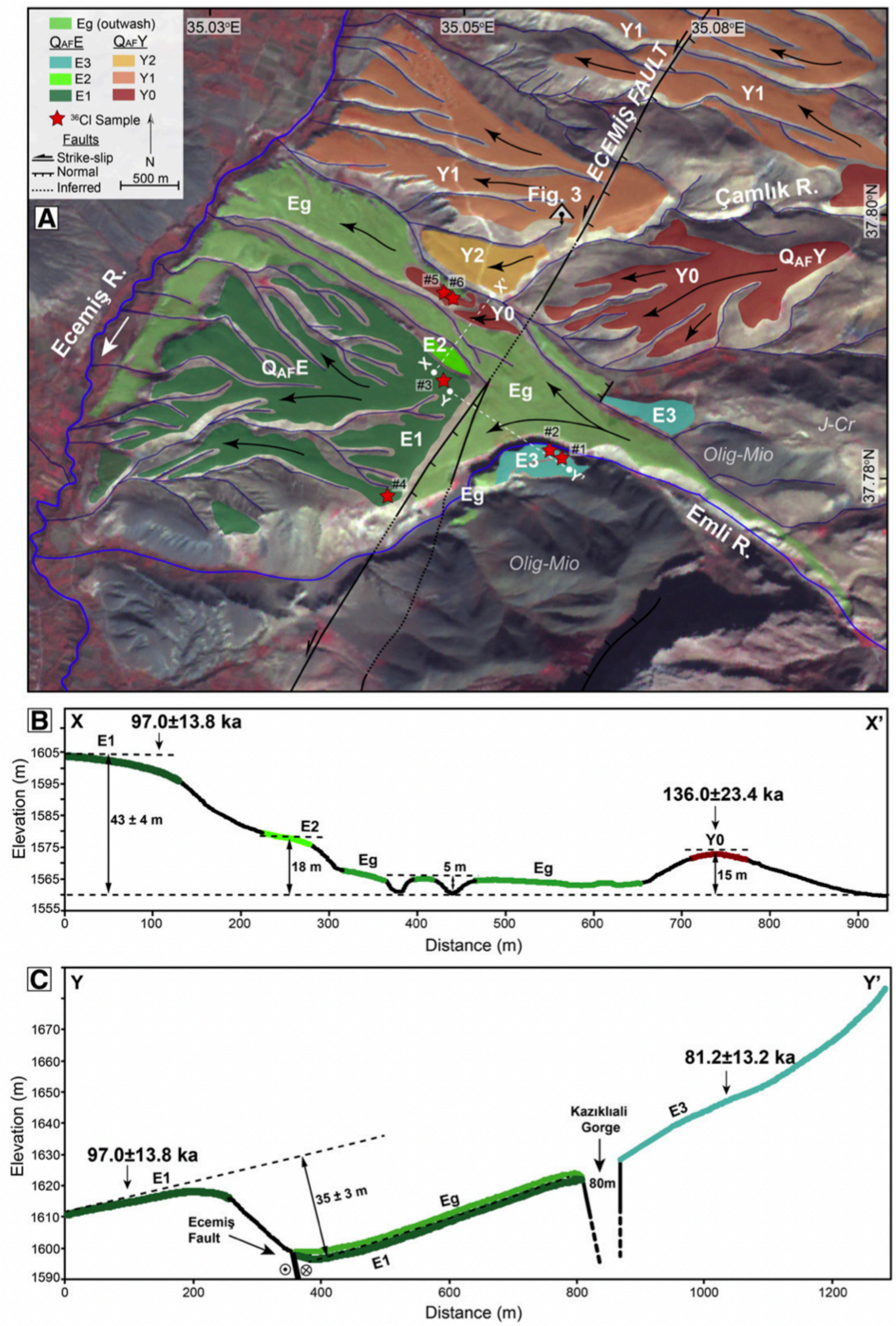

Fig. 2. Geomorphology of the study area. A) Map of the geomorphic surfaces of Emli Fan ($Q_{AF}E$) and Yalak Fan ($Q_{AF}Y$) emplaced on ASTER satellite image presented in Fig. 1B. Arrows show sediment transport directions of alluvial fans. Topographic cross-sections on X–X′ (B) and Y–Y′ (C) directions were obtained from GNSS measurements. Vertical exaggerations are 3.7 times and 4.8 times on X–X′ and Y–Y′ profiles, respectively.

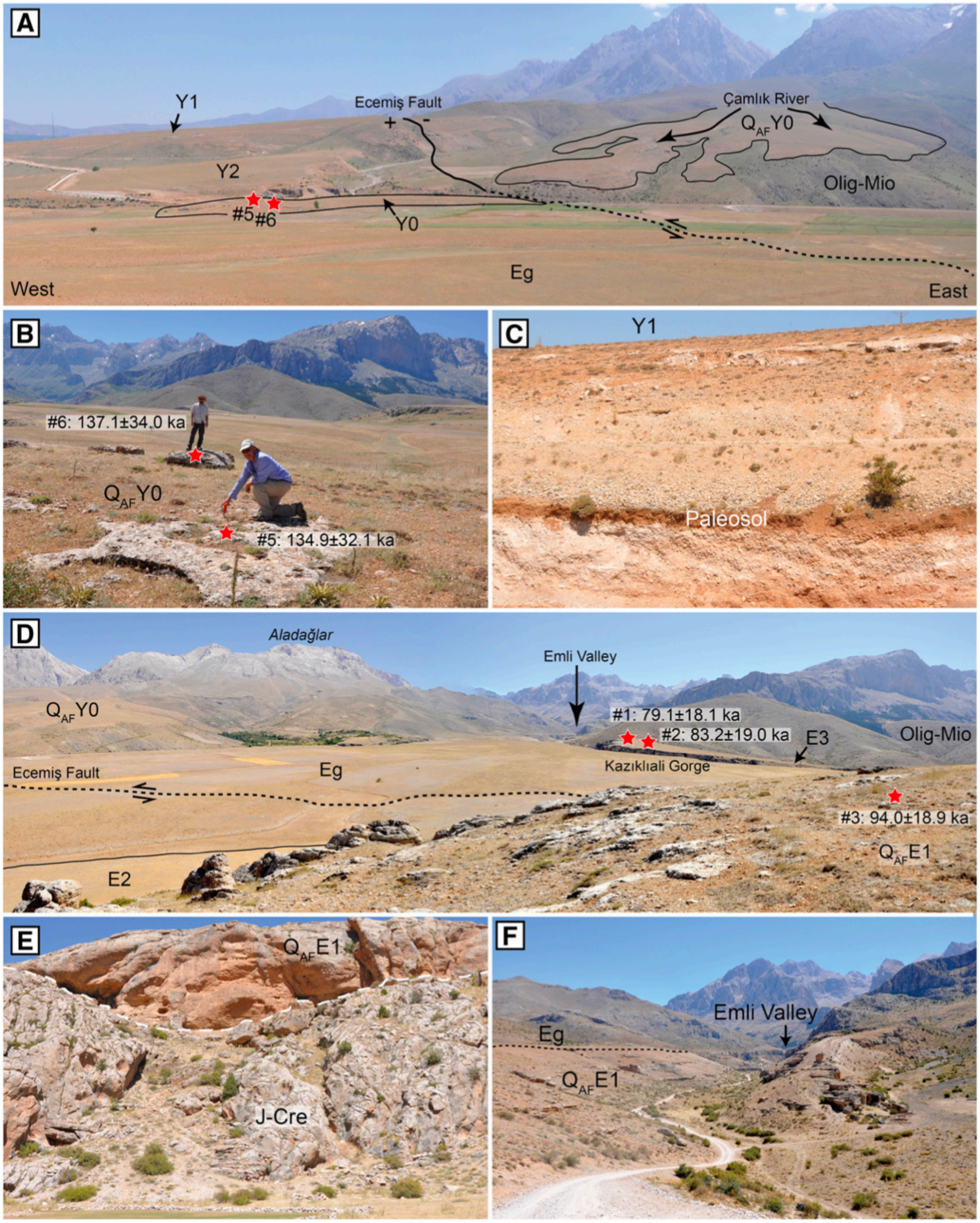

Fig. 4. A) General view of Yalak Fan and its surfaces from oldest (Y0) to youngest (Y2) and overlying glacial outwash fan (Eg). B) Samples #5 and #6 and their TCN ages. C) Y1 fan surface and a paleosol horizon. D) General view of Emli Fan and its surfaces from oldest (E1) to youngest (E3) and overlying glacial outwash fan (Eg). E) Angular unconformity observed between basement rocks and Emli alluvial fan conglomerates (E1). F) View of the Emli Valley, crudely stratified sediments of E1 and overlying glacial outwash (Eg).

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Tectonophysics

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No surface breaking on the Ecemiş Fault, central Turkey, since Late Pleistocene (~64.5 ka); new geomorphic and geochronologic data from cosmogenic dating of offset alluvial fans

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ABSTRACT

The Ecemiş Fault Zone (EF) has been recognized as a major left lateral strike-slip fault in the Central Anatolian Fault Zone (CAFZ) of Turkey. However, its Quaternary slip-rate has been challenging to determine due to the difficulty of dating offset markers. Using high-precision offset measurements and ^{36}Cl cosmogenic nuclide dating, we present the first geochronologically determined Late Quaternary slip-rate for the EF. Our study focuses on the excellent exposures of offset alluvial fan surfaces, originating from the Aladağlar, a Late Quaternary glaciated mountain. Analysis of airborne orthophotogrametry and GNSS (Global Navigation Satellite System) surveys indicates 168 $\pm$ 2 m left lateral and 31 $\pm$ 1 m vertical displacements. In-situ terrestrial cosmogenic ^{36}Cl geochronology obtained from eleven surface boulders provides a minimum abandonment/incision age of 104.2 $\pm$ 16.5 ka for the oldest offset alluvial fan surface. Our geomorphic observations together with Self-potential geophysical surveys revealed the presence of an unfaulted alluvial fan terrace, which allows us to constrain the timing of deformation. The abandonment/incision age of this fan is 64.5 $\pm$ 5.6 ka based on thirteen ^{36}Cl depth profile samples. Accordingly, we obtained a geologic fault slip-rate of 4.2 $\pm$ 1.9 mm a^{-1} horizontally and 0.8 $\pm$ 0.3 mm a^{-1} vertically for the time frame between 104.2 $\pm$ 16.5 ka and 64.5 $\pm$ 5.6 ka. Our analysis indicates that the EF has not been producing a major surface breaking earthquake on the main strand at least since 64.5 $\pm$ 5.6 ka (mid-Late Pleistocene). This could be the result of abandonment of the main strand and accommodation of deformation by other faults within the EF. Nevertheless, a recently occurred (30 September 2011) low magnitude (ML: 4.3) left lateral strike-slip earthquake indicates recent seismic activity of the EF. Comparison of the recent GPS velocity field with the longer slip history along the CAFZ indicates a constant but low strain release without surface breaking and very long large earthquake recurrence intervals.

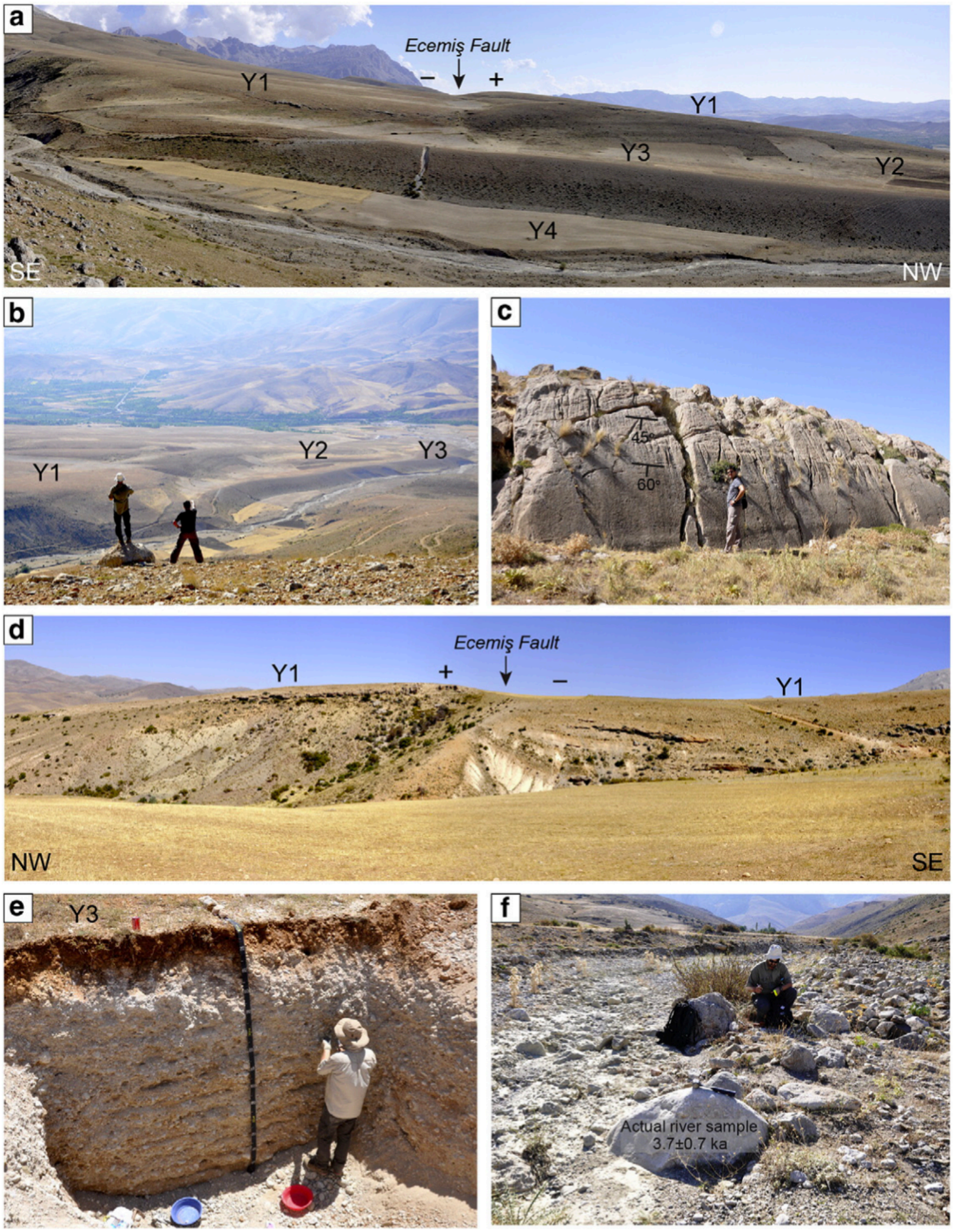
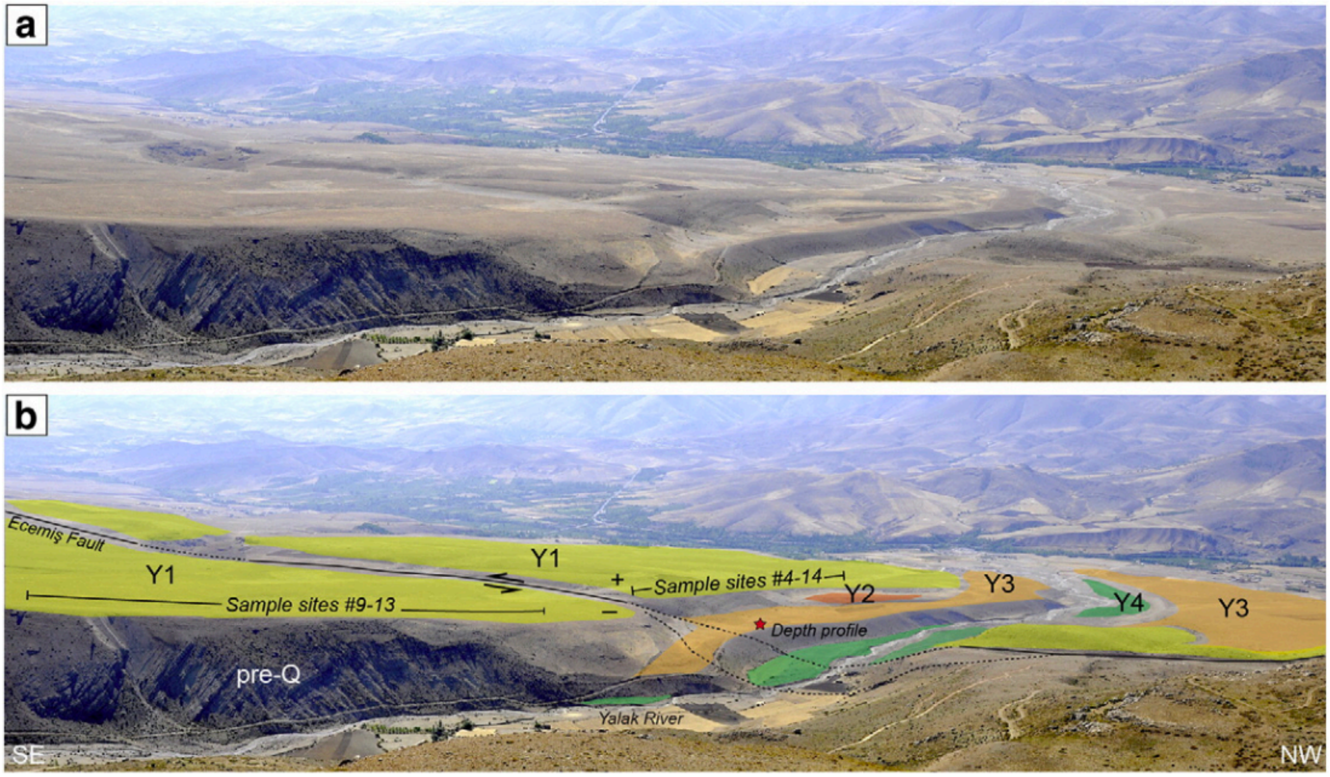


Fig. 3. Field pictures. a) Panoramic view of the EF with associated terrace surfaces of Yalak Fans. Note that the Y3 surface was not cut by the fault. b) View of Yalak River and terrace surfaces from Kartalkayası T. c) A fault plane located ~8 km NE of the study area. Note that the episodic movement of the fault is evident from the differential erosion of the fault plane. d) The trace of Ecemiş Fault near Kuru River. Note the tilted beds of the Çatalca formation in the center of the photo. e) The depth-profile site during the sampling campaign. f) Actual river sample from the Yalak River.



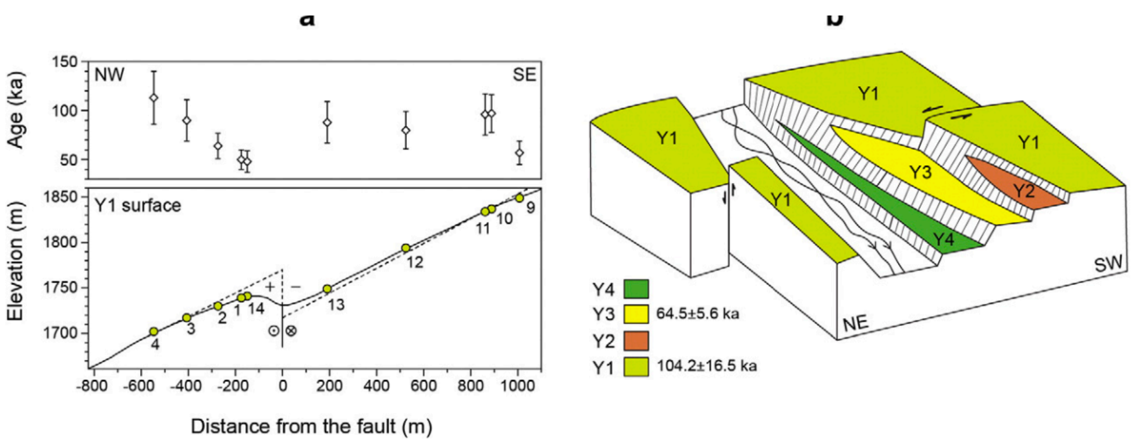


Fig. 8. a) Cosmogenic surface sample sites along a transect perpendicular to the fault. Upper panel shows the apparent ages of the surface boulders. Lower panel shows the topographic cross-section of the transect and sample locations on it. The dashed line is the initial topography of the faulted Y1 surface. It is exaggerated to show the sample locations. We think that the initial surface was diffused after the faulting and thus, samples #4 and #9 are the best representatives of the true abandonment age of the Y1 fan surface. b) Block diagram of the offset and non-offset alluvial fan terraces near the Yalak River.

Tectonics

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- Slip rate and extension rate of normal faults
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Late Pleistocene intraplate extension of the Central Anatolian Plateau, Turkey: Inferences from cosmogenic exposure dating of alluvial fan, landslide, and moraine surfaces along the Ecemiş Fault Zone

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Abstract Here we documented the vertical displacement, slip rate, extension rate, and geochronology of normal faults within a narrow strip along the main strand of the Ecemiş Fault Zone. The Kartal, Cevizlik, and Lorut Faults are normal faults that have evident surface expression within the strip. Terrestrial cosmogenic nuclide geochronology revealed that the Kartal Fault deformed the 104.2 ± 16.5 ka aged alluvial fan surface and the Cevizlik Fault deformed the 21.9 ± 1.8 ka old moraine and talus fan surfaces. Our topographic surveys indicated 120 ± 10 m and 13.1 ± 1.4 m surface-breaking vertical displacements along the Kartal and Cevizlik Faults, respectively. Accordingly, we suggest a 1.15 ± 0.21 mm a^{-1} slip rate and 0.66 ± 0.12 mm a^{-1} extension rate for the last 104.2 ± 16.5 ka on the Kartal Fault, and a 0.60 ± 0.08 mm a^{-1} slip rate and 0.35 ± 0.05 mm a^{-1} extension rate for the last 21.9 ± 1.8 ka on the Cevizlik Fault. We believe that these structures are an integral part of intraplate crustal deformation in the Central Anatolia. They imply that intraplate structures such as the Ecemiş Fault Zone may change their mode through time; presently, the Ecemiş Fault Zone has been deformed predominantly by normal faults. The presence of steep preserved fault scarps along the Kartal, Cevizlik, and Lorut Faults point to surface-breaking normal faulting away from the main strand and particularly signify that these structures need to be taken into account for regional seismic hazard assessments.

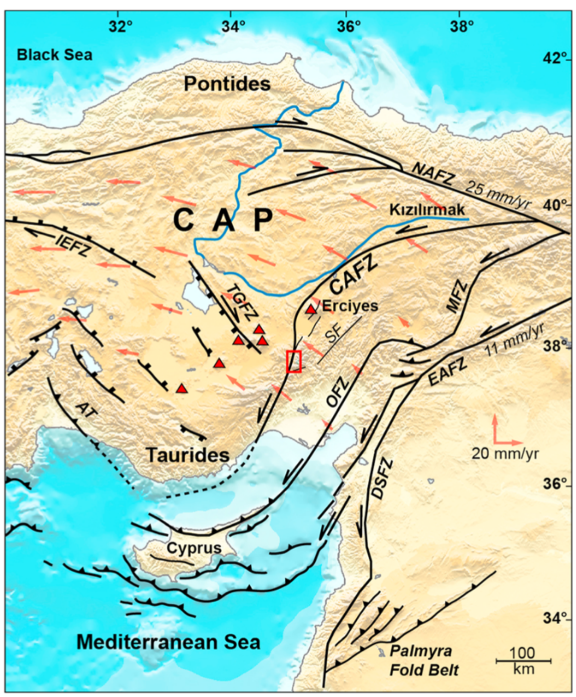

Figure 1. Simplified active tectonic map of the Eastern Mediterranean and Central Anatolia [*Şengör and Yılmaz*, 1981; *Barka and Reilinger*, 1997; *Koçyiğit and Beyhan*, 1998; *Reilinger et al.*, 2006; *Schildgen et al.*, 2014]. GPS vectors are from *Aktuğ et al.* [2013]. Red box indicates the study area, red triangles indicate volcanoes. AT: Aksu Thrust, CAP: Central Anatolian Plateau; CAFZ: Central Anatolia Fault Zone; DSFZ: Dead Sea Fault Zone, EAFZ: East Anatolia Fault Zone, EFZ: Ecemiş Fault Zone, IEFZ: İnönü-Eskişehir Fault Zone, MFZ: Malatya Fault Zone, NAFZ: North Anatolian Fault Zone, OFZ: Osmaniye Fault Zone, TGFZ: Tuz Gölü Fault Zone.

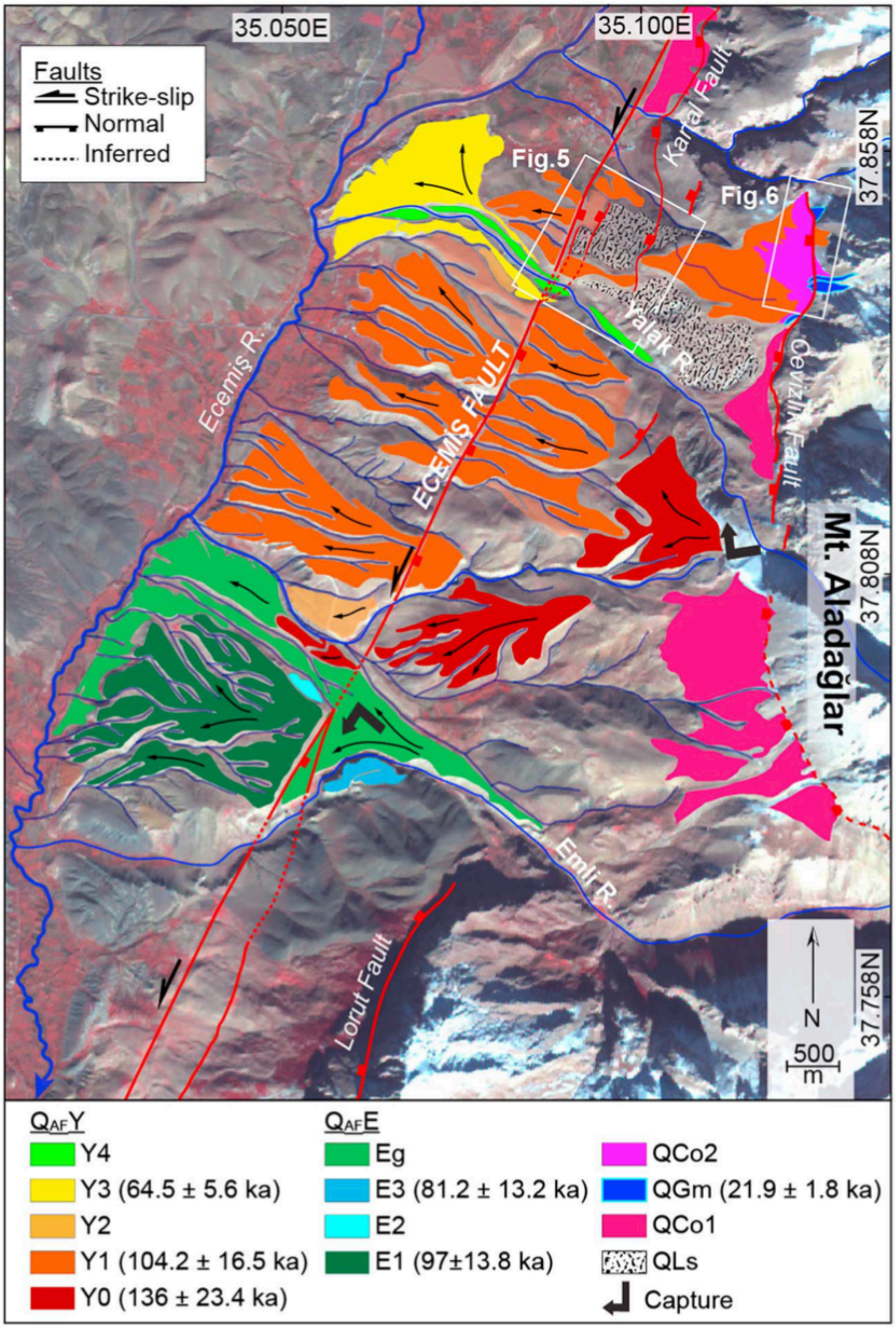

Figure 3. Geomorphological map of the study area (modified after *Sarıkaya et al*. [2015a, 2015b]). The background is an ASTER Satellite image (bands 4, 3, 2 for RGB, 70% transparent). Alluvial fan surfaces formed by the Yalak River are marked Q_{AF}Y and those formed by the Emli River are marked Q_{AF}E. Size of moraines is exaggerated for display purposes. CF: Cevizlik Fault, KF: Kartal Fault. Colluviums are marked Q_{Col}1 and Q_{Col}2, and moraines are marked Q_{Gm}.

Figure 4. (a) View of the Kartal Landslide (from west). The southern toe (right side) is longer than the northern toe. Blue circles indicate springs along the fault; (b) view of the Cevizlik Fault mountain front and landslides. Black triangles indicate trace of the fault, dashed lines outline hummocky topography of the landslide; (c) and (d) close-up view of the Cevizlik Fault scarp on moraines (see Figure 3 for their locations). Black triangles indicate trace of the fault. Q_{AF}Y1: alluvial fan; Q_{Col}1 and 2: colluviums; Q_{Gm}: moraines; Q_{Ls}: landslide.

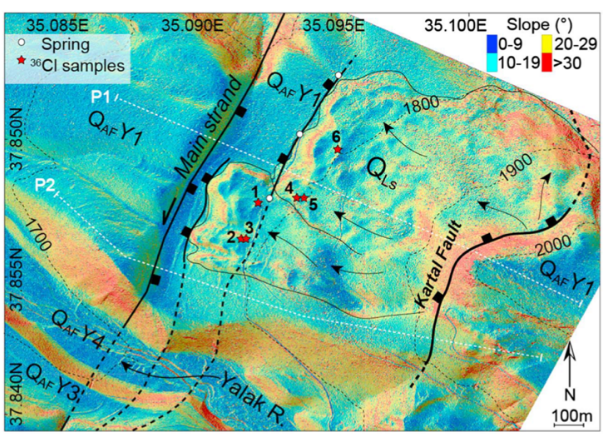

Figure 5. Hillslope map of the Kartal Landslide (see Figure 3 for location). Warmer colors indicate higher slope gradients. Black thin dashed lines indicate elevation contours, thin line indicates outline of the landslide. P1 and P2 indicate lines of profiles in Figure 7b; Numbers indicate sample numbers shown in the tables. Q_{AF}Y1: alluvial fan; Q_{Ls}: landslide.

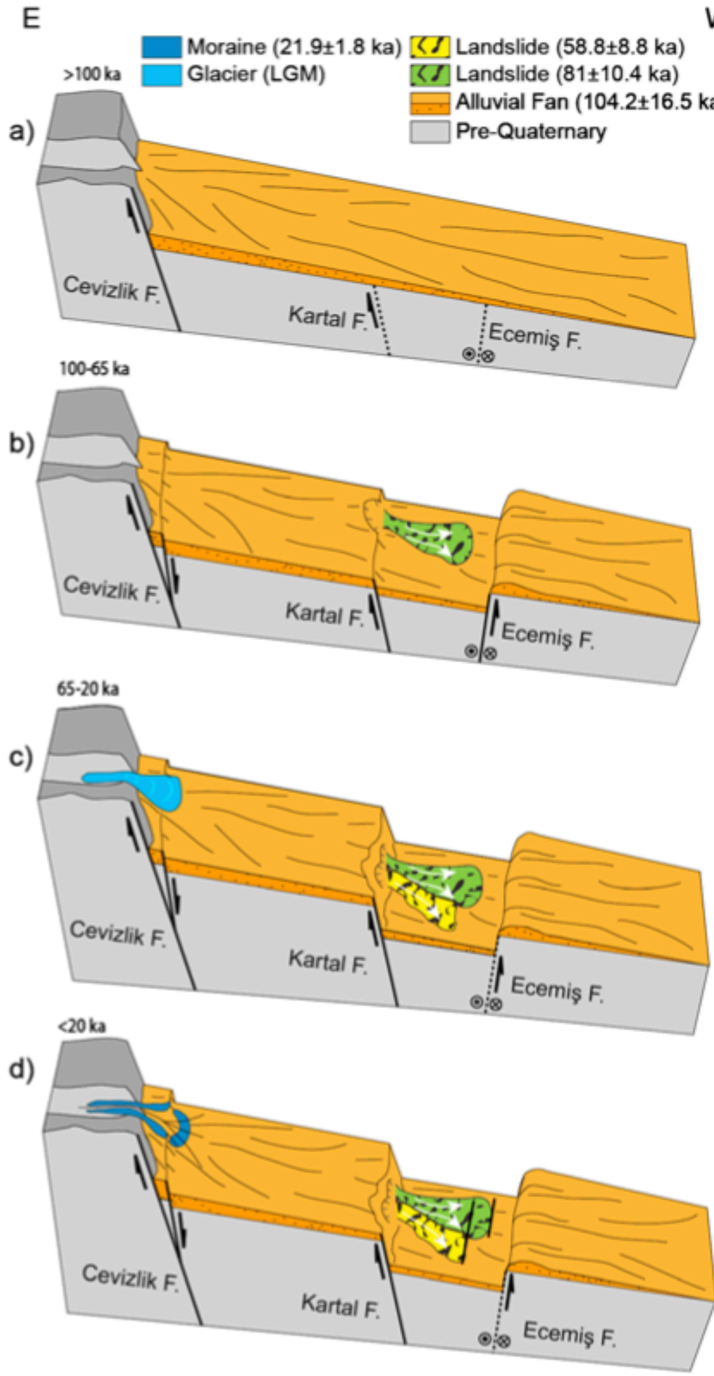

Figure 9. A conceptual model for the EFZ demonstrates seismic quiescence of the main strand and late Pleistocene activity on the main strand, Kartal, and Cevizlik Faults. (a) Growing of the mountain front along the Cevizlik Fault, formation of the $Q_{AF}Y1$ surface (>100 ka) and seismic quiescence of the Ecemiş and Kartal Faults; (b) seismic revival of the Ecemiş and Kartal Faults (100–65 ka), deformation of the $Q_{AF}Y1$ surface and occurrence of the first landslide; (c) seismic quiescence of the Ecemiş Fault, ongoing activity of the Kartal Fault, growing scarp of the Kartal Fault, and occurrence of the second landslide and glaciation on the Cevizlik Fault mountain front (65–20 ka); (d) seismic quiescence of the Ecemiş Fault continues, the Kartal and Cevizlik Faults continue their deformation, and the Cevizlik Fault deforms moraines (<20 ka).