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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 ± 2 m left lateral and 31 ± 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 ± 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 ± 5.6 ka based on thirteen ^{36}Cl depth profile samples. Accordingly, we obtained a geologic fault slip-rate of 4.2 ± 1.9 mm a^{-1} horizontally and 0.8 ± 0.3 mm a^{-1} vertically for the time frame between 104.2 ± 16.5 ka and 64.5 ± 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 ± 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.

1. Introduction

Understanding the long- and short-term activity of intracontinental transcurrent faults may provide important information about the escape tectonics between plate boundaries. The Central Anatolian Fault Zone (CAFZ) as a transcurrent structure is an example of intracontinental deformation within the Anatolian microplate. The long-term activity of the CAFZ has been characterized by 75 km of total offset (Koçyiğit and Beyhan, 1998) that indicates a significant amount of deformation. Nevertheless, there has been an unclosed debate on the Quaternary activity of its southern segment, the Ecemiş Fault (EF) (Fig. 1a) (Jaffey and Robertson, 2001; Koçyiğit and Beyhan, 1998, 1999; Westaway, 1999, 2002). The discussion has been mainly because of the unproven sense and rate of active slip due to the constraints of explicitly dating offset markers along the fault line. The terrestrial cosmogenic nuclides (TCNs) now allow us to date these offset markers. Here, we focused on the excellent exposures of alluvial fans offset by the EF (Fig. 1b). Geomorphological evidence of recent motion of the fault is extremely clear, where the EF cuts (and buried by) across coalescent Quaternary alluvial fans originating from glaciated Aladağlar Mountains.

Alluvial fans form impressive landscapes especially in front of uplifting mountain belts. Their deposits not only constitute proxies for paleoclimate but also play a key role in the understanding of mechanisms and timing of the faulting that is often present, and in some cases are responsible for the fan growth, in such mountain fronts (Harvey et al., 2005). Several abandoned alluvial fan lobes that are cut by faults are recently described and TCN dated to estimate fault slip-rates, especially in semi-arid and desert environments such as in California (Frankel et al., 2007; Gold et al., 2013; Lee et al., 2009; Machette et al., 2008; Matmon et al., 2005), Morocco (Arboleya et al., 2008), Iran (Le Dortz et al., 2012) and Turkey (Kozacı et al., 2009; Sarıkaya et al., 2015).

EF cuts and offsets, for several meters, in time and space, numerous well-developed Quaternary alluvial fan lobe surfaces that are gently

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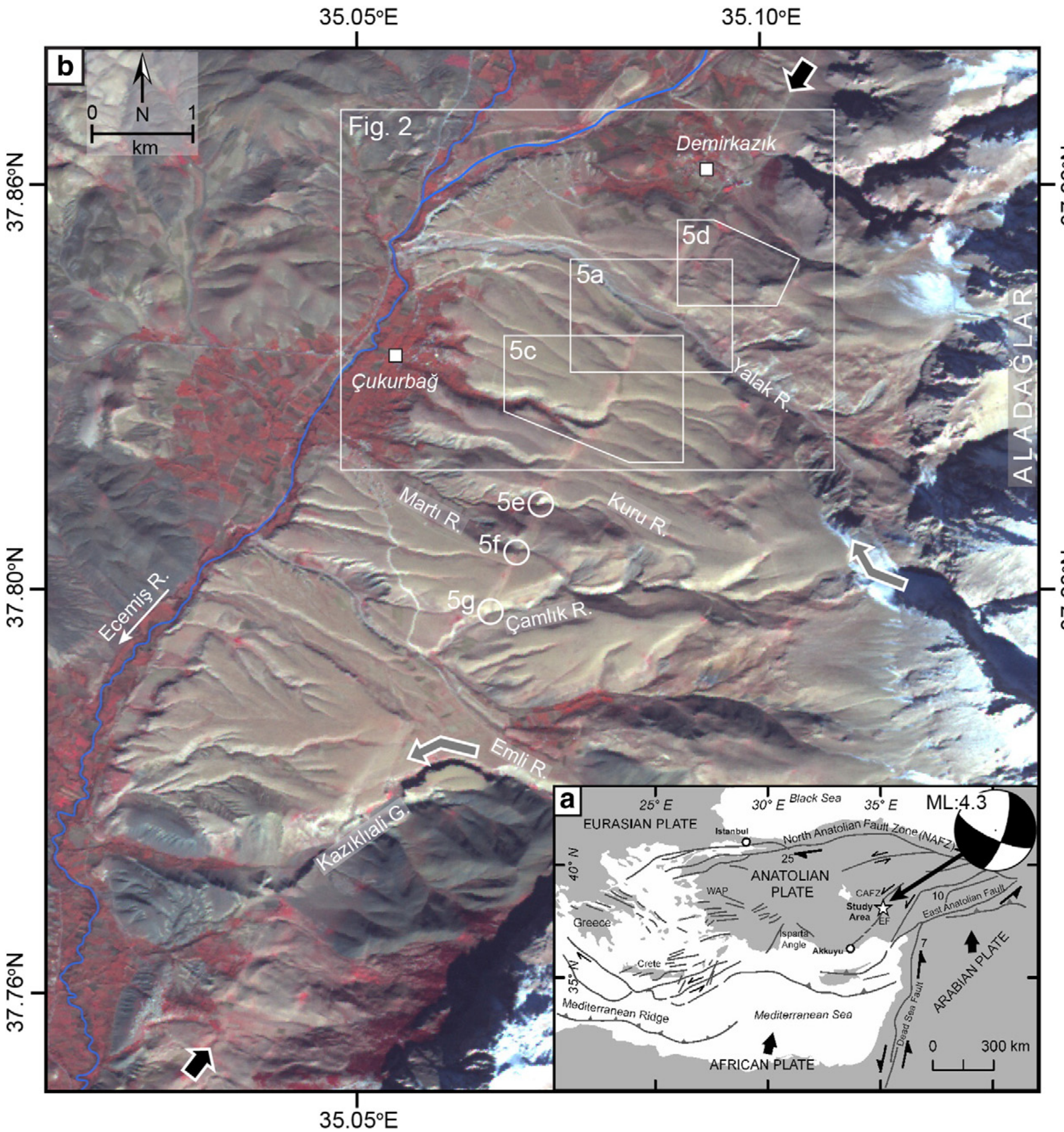

Fig. 1. a) Main tectonic structures of Turkey and surrounding region. Arrows indicate the movement of lithospheric plates. Numbers on main fault zones are slip-rates in mm a^{-1} from Reilinger et al. (2006) on NAFZ (North Anatolian Fault Zone), EAFZ (East Anatolian Fault Zone) and DSF (Dead Sea Fault). EF: Ecemiş Fault, CAFZ: Central Anatolian Fault Zone, WAP: Western Anatolia Province. The focal mechanism of the earthquake ML: 4.3 occurred on the EF on 30 September 2011 was given. b) ASTER satellite image of the study area and figure locations of Figs. 2 and 5. The thick arrows indicate the EF trace. The elbowed arrows are for the captured streams, and squares for the settlements.

sloped (~4°) and start at around 2300 m above sea level (a.s.l.) and reach down to 1450 m a.s.l. along the western border of Aladağlar (Yetiş, 1978; 1984; Erdağ, 2007; Erdağ et al., 2009). We identified four major fan surfaces originating from the Yalak River (Q_{AF}Y1 to Q_{AF}Y4). These fans have been successively incised to form multiple erosional terraces attributed to changing fluvio-glacial discharge (Jaffey and Robertson, 2001), possibly reflecting fluctuations in the Quaternary Aladağlar glaciations (Zreda et al., 2011). Offset features are widespread including beheaded and deflected stream courses, deflected terrace risers, fan edges and shutter ridges (Erdağ et al., 2009).

The scarcity of datable carbonaceous (^{14}C) and luminescence (OSL) materials, especially in arid climates, and their relatively limited age ranges, is a major problem in determining absolute age of the alluvial fans (Machette et al., 2008). Existing radiocarbon ages by Akyüz et al. (2004) and Çetin (2000) provide partial time control on the current activity of EF. They are rather limited to trench excavations over very small fault escarpments (<5 m) or to exposed soil horizons, and thus may not fully account for the long-term stress distributions. Besides, they may even represent paleoclimatic oscillations (Westaway, 2002). A fine age control of the offset markers should account for displacement across the entire fault zone. Our wide-aperture geomorphic measurements and cosmogenic age results constrain the timing of the development of the alluvial fans and the long-term slip-rate of EF. Continuous advances in TCN dating now allow dating of landforms like moraines, fluvial/marine terraces (Gosse and Phillips, 2001) or alluvial fans (Ivy-Ochs et al., 2013).

Understanding the slip-rate of a fault is critical not only for the understanding of the regional tectonic framework, but also for preventing and minimizing the damages for the habitations nearby. In this study, we aimed to resolve the unknown timing of the alluvial fan formations