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Upper crust response to geodynamic processes beneath Isparta Angle, SW Turkey: Revealed by CMT solutions of earthquakes

Semir Över [a,*], Süha Özden [b], Züheyr Kamacı [c], Hüseyin Yılmaz [d], Ulvi Can Ünlügenç [e], Ali Pınar [f]

[a] Iskenderun Technical University, Department of Civil Engineering, 31200 Iskenderun, Turkey
[b] Çanakkale Onsekiz Mart University, Department of Geological Engineering, 17100 Çanakkale, Turkey
[c] Süleyman Demirel University, Department of Geophysical Engineering, 32260 Isparta, Turkey
[d] Cumhuriyet University, Department of Geophysical Engineering, 58140 Sivas, Turkey
[e] Çukurova University, Department of Geological Engineering, 01330 Adana, Turkey
[f] Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, 34684 İstanbul, Turkey

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ABSTRACT

The Isparta Angle is an important area of SW Anatolia where extensions in all directions (N-S, NE-SW, NW-SE and E-W) meet. These extensions were determined by normal faulting structures as well as by shallow earthquakes. All extensions, except the E-W one, were attributed to the deviatoric stresses in relation to slab forces and/or extrusion of Anatolia. The moment tensor inversion of 40 shallow earthquakes which occurred in the inner part of the Isparta Angle give focal mechanisms mostly indicating normal faulting. Inversion of all focal mechanisms of the earthquakes obtained from the moment tensor inversion yields normal faulting characterized by an approximately E-W (N268°E) σ_3 axis. The calculated stress ratio R is 0.6944 indicating a triaxial stress state. Commonly accepted geodynamic models for the eastern Mediterranean region do not include plate boundary forces acting in the east or west direction. Our hypothesis is that the cause of the E-W extension is the combined forces of Gravitational Potential Energy and the hot asthenosphere upwelling through a tear fault in the subducted African plate between the Hellenic and Cyprus arcs beneath the Isparta Angle.

1. Introduction

The western Anatolia-Aegean region is known as one of the world's complex and rapidly extending provinces (McKenzie, 1978; Le Pichon and Angelier, 1979; Dewey et al., 1986; Jackson and McKenzie, 1988; Taymaz et al., 1990, 1991; Ambraseys and Jackson, 1990; Goldsworthy et al., 2002; Nyst and Thatcher, 2004; Aktuğ et al., 2009; Le Pichon and Kreemer, 2010). The ongoing extensional period began in Miocene time creating dozens of basins with different directions and sizes: NW-SE, NE-SW, E-W (ENE-WSW to ESE-WNW) and N-S (NNE-SSW to NNW-SSW) (Fig. 1). The geological evidence collected in many papers show that this region has a tectonically complicated structure that can't be explained by a single model or approach. In the literature, three important models were proposed to explain the cause of the extension acting in western Anatolia: 1) the post-orogenic collapse model (Dewey, 1988; Seyitoğlu and Scott, 1991): The orogenic-collapse models suggest that the cause of the crustal extension is over-thickened crust due to the closure of the Neotethyan ocean along the Izmir–Ankara–Erzincan suture during latest Oligocene–Early Miocene. 2) The tectonic escape model (Dewey and Şengör, 1979): The authors proposed a model of extension caused by westward extrusion of Anatolia since the Late Serravalian. 3) Southward roll-back of the African slab or the back-arc spreading model (Le Pichon and Angelier, 1979): According to the authors' model, the crustal extension in Anatolia and Aegean regions is related to back-arc spreading accompanied by roll-back of the Mediterranean subducted slab along the Hellenic arc since late Serravalian (Mercier et al., 1989; Jackson and McKenzie, 1988) and along the Cyprus arc (Robertson et al., 1991; Över et al., 2002, 2010). These different models summarizing the causes of crustal extension in western Anatolia indicate the main forces of orogenic-collapse, southwestward extrusion of Anatolia and slab-pull of Africa's lithosphere beneath Anatolia. Moreover, several studies suggest that secondary driving forces associated with a combination of the main forces are also effective. The N-S extension is attributed to both orogenic-collapse and back-arc extension during Oligocene-Miocene (Bozkurt and Mittwede, 2005) and to the combined effect of the westward extrusion of Anatolia and roll-back process of Africa's lithosphere since Plio-Quaternary time (Över et al., 2010). A horst-graben morphology was formed across Western Anatolia under continuing N-S extension in Mio-Pliocene time (Bozkurt and Sözbilir, 2004) resulting in E-W Menderes Massif elevation of 200 m above sea level and Menderes graben floor near sea-level towards the coastal areas. It is claimed that the E-W basins are generated by N-S extension since Mio-Pliocene (Yılmaz

* Corresponding author.
E-mail address: semir.over@iste.edu.tr (S. Över).

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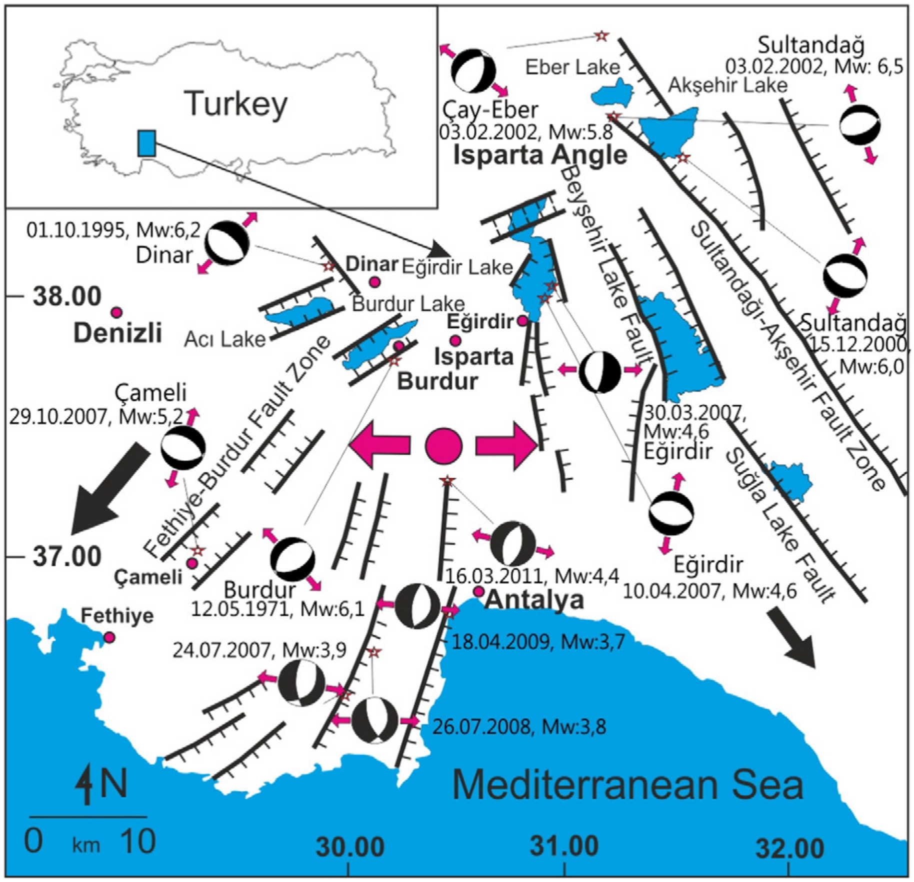

Fig. 1. The seismotectonic framework of the study area within Isparta Angle, Eastern Mediterranean region (modified from Bozkurt, 2001; Altuncu Poyraz et al., 2014). Red arrow represents E-W extensional direction; the thick black arrow indicates SW motion of the Anatolian block. Dashed thick green lines limit the Isparta Angle. The beach balls represent the focal mechanisms of the earthquakes.

et al., 2000; Bozkurt and Sözbilir, 2004) and actually this area is extending in a N-S direction at a rate of 14 mm/yr (Reilinger et al., 1997; McClusky et al., 2000). Across west and southwest Anatolia there are NE–SW trending faults and basins (e.g., Çameli, Burdur, Acıgöl, Çivril basins) and conjugated, approximately NW–SE trending basins and associated normal fault systems (e.g., Gediz, Denizli, Acıpayam and Dinar basins). The formation and development of these basins are attributed to the NW-SE and NE-SW extensions, respectively. The cause of the NW–SE extension is the slab-pull force due to the subduction process along the Cyprus arc, considered to be dominant up to the Plio-Quaternary. The NE–SW extension, dominant since the Plio-Quaternary, is related in particular to slab-pull force due to the subduction process along the Hellenic arc. The cause of the N-S extension is the combined force of the Anatolian extrusion and slab-pull force due to the subduction process along the Hellenic arc (Över et al., 2010).

The approximately N-S basins (i.e., Antalya, Eşençay, Gölova, Korkuteli, Eğirdir, Kovada and Şuhut basins) originated from E-W directed tensional forces in the apex region of the Isparta Angle, in the eastern part of western Anatolia (Yağmurlu and Şentürk, 2005; Koçyiğit and Deveci, 2007). The approximately N-S directed basins are also prominent in western Anatolia along with the other basins (e.g., E-W, NE-SW and NW-SE oriented basins). The models proposed have attempted to further explain the causes of the extensions in N-S, NW-SE and NE-SW directions; but none of the models explain the E-W extension at the geodynamical scale. What is the cause of the E-W extension? In this paper we propose an approach to explain the E-W extension acting within the Isparta Angle by using the CMT (centroid moment tensor) solutions of earthquakes occurring during the last decade within the Isparta Angle (IA) region to understand the deformation style and causes.

2. Regional geological setting

The regional geological pattern in the eastern Mediterranean region is dominated by the relative motions of the African, Arabian and Eurasian plates resulting in compression in eastern Turkey, extensional deformation in western Turkey and transform zones (i.e., North and East Anatolian Fault zones) connecting these areas with two different styles of deformation. The relative motions have led to west-southwest extrusion of the Anatolian block. The African plate's motion towards the Eurasian plate to the north results in oceanic subduction along the Hellenic arc and also a transitional zone of collision–oceanic subduction along the Cyprus arc (McKenzie, 1972; Le Pichon and Angelier, 1979; McClusky et al., 2000, 2003; Mart and Ryan, 2003). The subduction along the Hellenic arc is at a higher rate than the relative northward motion of the African plate along the Cyprus arc. This requires that the Hellenic trench move southwards relative to Eurasia as a consequence of the roll-back of the Mediterranean slab subducting beneath the Aegean Sea. This slab retreat has been attributed to the Mediterranean slab-pull force, which produces a decrease in the horizontal stresses in the overriding plate, i.e. widespread extensional tectonics in the Aegean domain and western Anatolia (e.g. Le Pichon and Angelier, 1979; Le Pichon, 1982; Mercier et al., 1989; Sorel et al., 1988). Similarly, the extensional tectonics observed in south-southeast Turkey i.e., Adana and Cilicia basins (Robertson, 1990; Robertson et al., 1991; Kempler and Garfunkel, 1994; Över et al., 2004a), in the Hatay region (Över et al., 2002,