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Source parameters of the 2005–2008 Balâ–Sırapınar (central Turkey) earthquakes: Implications for the internal deformation of the Anatolian plate

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ABSTRACT

Active tectonics of central Anatolia is mainly governed by the collision of the African, Arabian and Anatolian plates, which causes westward escape of Anatolia along the North and East Anatolian Fault zones, and the counterclockwise rotation of the Kırşehir block with insignificant internal deformation. The formation of the present-day tectonic processes in this region can be deduced from geophysical prospecting and seismological data. Although the seismicity in central Anatolia is distinctively lower than that in the northern and eastern parts of the Anatolian plate, small and moderate earthquakes ($2.5 \leq M_w \leq 6.0$) mostly occurred in the region in the past decades or so. For example, intense earthquake activity was observed in the Balâ–Afşar–Sırapınar (Ankara, central Anatolia) region in the period of 2005 to 2008 with destructive earthquakes of July 30, 2005 ($M_w = 5.2$); December 20, 2007 ($M_w = 5.7$) and December 26, 2007 ($M_w = 5.6$). Therefore, these earthquakes are crucial to analyze the shallow crustal deformation in the central Anatolian block. In the present study, we obtained source parameters of 2005–2008 earthquake sequence using the regional moment tensor (RMT) inversion method. We analyzed complete broad-band waveforms recorded at near-field distances ($0.45^\circ \leq \Delta \leq 3.6^\circ$). Our results reveal NW–SE directed right-lateral strike-slip faulting and NE–SW directed left-lateral strike-slip faulting mechanisms, which are clearly correlated with the conjugate fault systems in the Balâ–Afşar–Sırapınar region. However, some earthquakes also have E–W directed normal faulting components. We suggest that the major characteristics of 2005–2006 and 2007–2008 earthquake activity could have been dominantly associated with left-lateral and right-lateral strike-slip faulting mechanisms, respectively. The seismogenic depth is found to be about 8–10 km. This result implies that earthquakes in the study region occurred mostly in the upper crust, which accommodates the strain by brittle deformation. Furthermore, our results are consistent with neotectonic features and available geophysical data (e.g., gravity, aeromagnetic and paleomagnetic) reported by previous studies. It may be envisioned that the joint interpretation of earthquake source parameters with those observations will shed light into the complex deformation processes for future studies.

1. Introduction

The tectonic activity in central Anatolia is governed by the collision of African, Arabian and Anatolian plates, which causes westwards escape of Anatolia along the North Anatolian (NAF) and East Anatolian (EAF) intra-continental fault zones (Fichtner et al., 2013a,b; Fielding et al., 2013; McKenzie, 1972; Taymaz et al., 1990, 1991, 2004, 2007a,b; Vanacore et al., 2013; Yolsal-Çevikbilen and Taymaz, 2012; Yolsal-Çevikbilen et al., 2012; Yolsal-Çevikbilen, 2014). Due to the western escape of Anatolian plate, rotational wrench tectonic regime was developed in central Anatolia. Extrusion tectonics is also responsible for the counterclockwise (CCW) rotation of the Kırşehir block with slight internal deformation (Mantovani et al., 1993; McClusky et al., 2000, 2003; Şengör and Yılmaz, 1981), which plays an important role on the deformation characteristics of our study region. Thus, this region has undergone complex deformation since Late Miocene–Pliocene times (Dirik, 2001). The central Anatolian region is located between the İzmir–Ankara–Erzincan Suture Zone (IAESZ) in the north and the Inner-Tauride suture in the south (Çemen et al., 1999). The location of these major neotectonic structures is presented in a simplified tectonic map with a red rectangle presenting the study region (Fig. 1).

IAESZ is composed of an ophiolitic mélange that represents a major remnant of the northern Neo-Tethyan oceanic crust. However, autochthonous Paleozoic sedimentary rocks and complex nappe structures characterize the Inner Tauride suture zone. The Central Anatolian Crystalline Complex (CACC) is another important structure that forms the eastern part of our study region (Fig. 2). The CACC exposes metamorphic rocks and magmatic intrusions, and it represents one of the most significant volcanic activity developed in Anatolia. The CACC has

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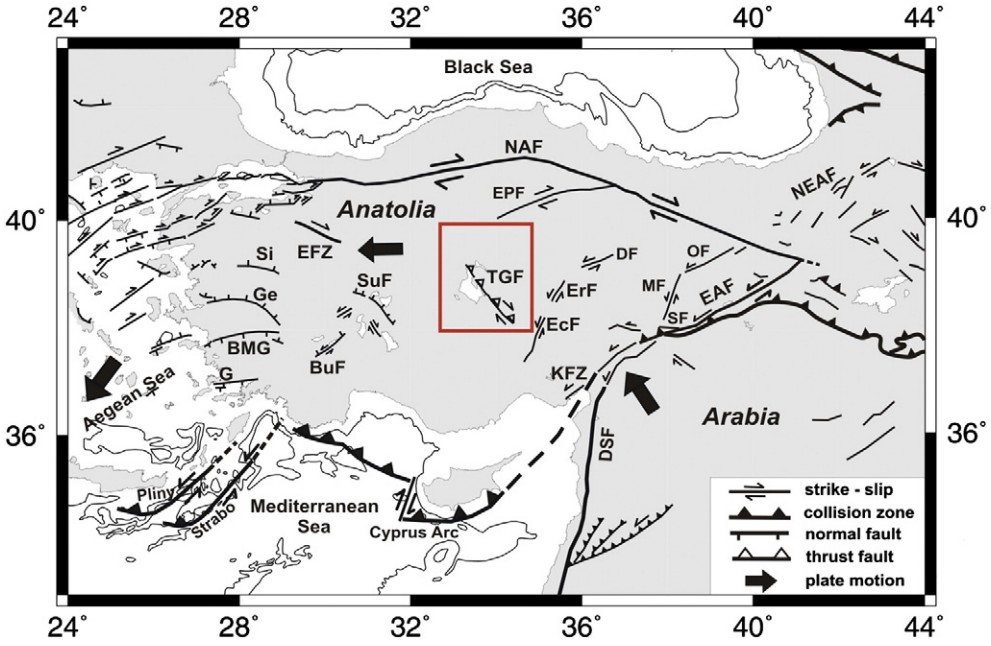

Fig. 1. Major tectonic units around the study area. See for details Taymaz et al. (1990, 1991, 2004, 2007a,b), Şaroğlu et al. (1992), Taymaz and Price (1992), Taymaz (1993, 1996), Bozkurt (2001), Poisson et al. (2003), Tan and Taymaz (2006), Yolsal et al., (2007), Yolsal (2008), Yolsal-Çevikbilen and Taymaz (2012), Yolsal-Çevikbilen et al. (2012, 2014), Yolsal-Çevikbilen (2014). Abbreviations: NAF: North Anatolian Fault, NEAF: North East Anatolian Fault, EAF: East Anatolian Fault, DSF: Dead Sea Transform Fault, BuF: Burdur Fault, DF: Deliler Fault, EFZ: Eskişehir Fault Zone, EcF: Ecemiş Fault, EPF: Ezine Pazarı Fault, ErF: Erciyes Fault, G: Gökova, Ge: Gediz Graben, KFZ: Karataş–Osmaniye Fault Zone, MF: Malatya Fault, OF: Ovacık Fault, Si: Simav Graben, SuF: Sultandağı Fault, TGF: Tuz Gölü Fault. Large black arrows exhibit relative plate motions with respect to Eurasia (McClusky et al., 2000, 2003; Reilinger et al., 2010). Bathymetric contours are shown at 1000 m, 1500 m and 2000 m, and were obtained from GEBCO-BODC (1997). Rectangular red box outlines the study area.

begun undergoing internal deformation in the Eocene due to the closure of the Tethyan basin (Kadıoğlu et al., 2006). It has a complex tectonic history involving obduction of ophiolitic nappes onto sedimentary units and intracontinental magmatism (Lefebvre, 2011). As a consequence of the volcanic activity of the CACC, the widespread magmatic intrusions and the largest metamorphic domain exposed in Turkey was generated (Floyd et al., 2000). The Paleogene cover sediments and volcanic rock features together with the central Anatolian intrusives surround the west and east of the Balâ–Sırapınar (Ankara) region, respectively (Lefebvre et al., 2013).

A joint interpretation of the neotectonic features and seismological data may contribute to gain understandings on complex deformation processes. Internal deformation of central Anatolia is complex (Tatar et al., 2000) and remains as tectonically poorly understood region (Yürür and Genç, 2006). The seismicity that took place in central Anatolia with $M \geq 4.0$ earthquakes is considerably lower than that in the northern, eastern and western parts of the Anatolia. Therefore, interpretation of seismotectonic pattern provided by the 2005–2008 Balâ–Afşar–Sırapınar (Ankara) earthquake sequences ($2.5 \leq M_w \leq 5.6$) has important implications for our understanding of rotational motion of the Anatolian plate. Seismicity maps show the regional earthquake distribution together with the location of important fault zones reported in the vicinity of the study area (Koçyiğit, 2009; Şaroğlu et al., 1992; Fig. 3).

The main tectonic framework of central Anatolia is driven by the right-lateral strike-slip North Anatolian Fault Zone (NAFZ) and its side-splay faults such as the Ezinepazarı and Almus fault zones in the north (EPF and AF; Gürsoy et al., 1997; Seyitoğlu et al., 2000) together with the NW–SE trending right-lateral strike-slip Tuzgölü Fault Zone (TGFZ) in the southeast. These fault zones have the capability to generate large and destructive earthquakes ($M_w > 6.0$) on a regional scale (Koçkar and Akgün, 2008). The Ecemiş (EcF) and Ezine Pazarı Faults (EPF) also with the Dodurga (DFZ) and Seyfe Fault Zones (SFZ) constitute other remarkable faults in the neighboring regions. On the other hand, the Ilıca (IFZ), Yeniceoba (YFZ) and Cihanbeyli Fault Zones (CFZ) define the northern, middle and southern branches of the NW–SE striking İnönü–Eskişehir Fault Zone (IEFZ, Özsayın and Dirik, 2011), and they contribute to the deformation processes in the W–SW part of the Balâ–Afşar–Sırapınar (Ankara) region. However, the 2005–2008 earthquake sequences mostly occurred along the Balâ, Balaban–Küredağ, Karakeçili, Kızılözü, Çatalören and Sırapınar Faults, which are known second-order faults in the vicinity of the study region.

There are several seismic, gravity and magnetic studies which have been carried out to acquire the physical properties of rocks and active tectonics of central Anatolia by the General Directorate of Mineral Research and Exploration of Turkey (MTA) and Turkish National Scientific and Technological Foundation (TUBITAK; Project No: 107Y288, 2011). The contour maps for the study region were plotted (Fig. 4a, b) using Bouguer gravity and magnetic data reported by Ateş et al. (1999, 2012).

The aim of this study is to determine source parameters of the Balâ–Afşar–Sırapınar (Ankara, central Anatolia) earthquakes that occurred during 2005 to 2008 using Regional Moment Tensor Inversion (RMT) algorithm and to reveal recent deformations and faulting geometries in the study region (Fig. 5). Then, we interpreted the outstanding results along with existing gravity, magnetic and paleomagnetic data and seismological observations.

2. Data

The seismic activity in the Balâ–Sırapınar (Ankara) region and neighboring regions is reported by Boğaziçi University—Kandilli Observatory and Earthquake Research Institute (KOERI) during 2005 to 2009. In this study, we used complete waveforms recorded at broadband stations operated by KOERI (Fig. 6). Hypocenter coordinates and various types of magnitudes of those earthquakes reported by different catalogs are summarized in Table 1.