Earth and Planetary Science Letters 433 (2016) 89–98

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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Central and eastern Anatolian crustal deformation rate and velocity fields derived from GPS and earthquake data

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ARTICLE INFO

Article history:
Received 4 July 2015
Received in revised form 21 October 2015
Accepted 22 October 2015
Available online xxxx
Editor: P. Shearer

Keywords:
East Anatolian Fault
North Anatolian Fault
seismic hazard
strain-rate
Arabian–Anatolian convergence
seismotectonics of Anatolia

ABSTRACT

We present a new strain-rate and associated kinematic model for the eastern and central parts of Turkey. In the east, a quasi N-S compressional tectonic regime dominates the deformation field and is partitioned through the two major structural elements of the region, which are the conjugate dextral strike-slip North Anatolian Fault Zone (NAFZ) and the sinistral strike slip East Anatolian Fault Zone (EAFZ). The observed surface deformation is similar to that inferred by anisotropy studies which sampled the region of the mantle closer to the crust (i.e. the lithospheric mantle and the Moho), and is dependent on the presence or absence of a lithospheric mantle, and of the level of coupling between it and the overlaying crust. The areas of the central and eastern parts of Turkey which are deforming at elevated rates are situated above areas with strong gradients in crustal thickness. This seems to indicate that these transition zones, situated between thinner and thicker crusts, promote more deformation at the surface. The regions that reveal elevated strain-rate values are 1) the Elaziğ–Bingol segment of the EAFZ, 2) the region around the Karlıova triple-junction including the Yedisu segment and the Varto fault, 3) the section of the NAFZ that extends from the Erzincan province up to the NAFZ-Ezinepazarı fault junction, and 4) sections of the Tuz Gölü Fault Zone. Other regions like the Adana basin, a significant part of the Central Anatolian Fault Zone (CAFZ), the Aksaray and the Ankara provinces, are deforming at smaller but still considerable rates and therefore should be considered as areas well capable of producing damaging earthquakes (between *M*6 and 7). This study also reveals that the central part of Turkey is moving at a faster rate towards the west than the eastern part Turkey, and that the wedge region between the NAFZ and the EAFZ accounts for the majority of the counter clockwise rotation between the eastern and the central parts of Turkey. This change in movement rate and direction could be the cause of the extensional deformation and respective crustal thinning, with the resulting upwelling of warmer upper mantle observed in tomographic studies for the region between the Iskenderun bay and the CAFZ. The partitioning of deformation into an extensional regime could be the cause of the relatively low levels of strain-rate in the south-west part of the EAFZ and the northern part of the Dead Sea Fault Zone. Finally, using this new compilation of GPS data for the central-eastern part of Turkey, we obtained a new Anatolia–Eurasia rotation pole situated at 2.01°W and 31.94°N with a rotation rate of $1.053 \pm 0.015°$/Ma.

1. Introduction

An understanding of plate dynamics and the manner in which active faults form and respond to associated strain accumulation are among the most fundamental aspects of active tectonics. This is not only important for understanding long-term behavior of an active fault zone, but also for identifying faults and/or areas of elevated seismic hazard.

The deformation rates and kinematics in the western part of Anatolia, the Marmara and the Aegean Seas, have been thoroughly characterized (e.g., Aktuğ et al., 2009; Le Pichon and Kreemer, 2010; Pérouse et al., 2012; Reilinger et al., 2006) leaving its central and eastern parts kinematics well constrained (Aktuğ et al., 2013; Alchalbi et al., 2010; Mahmoud et al., 2013; Ozener et al., 2010; Reilinger et al., 2006; Tatar et al., 2012; Yavaşoğlu et al., 2011) albeit with few integrated deformation rate studies (Özeren and Holt, 2010; Walters et al., 2014). Here we present a new kinematic model of the eastern boundary and the central part of the Anatolian plate by interpolating published GPS velocities and seismicity data. Through this integrated approach we aim to clarify the tec-

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http://dx.doi.org/10.1016/j.epsl.2015.10.041

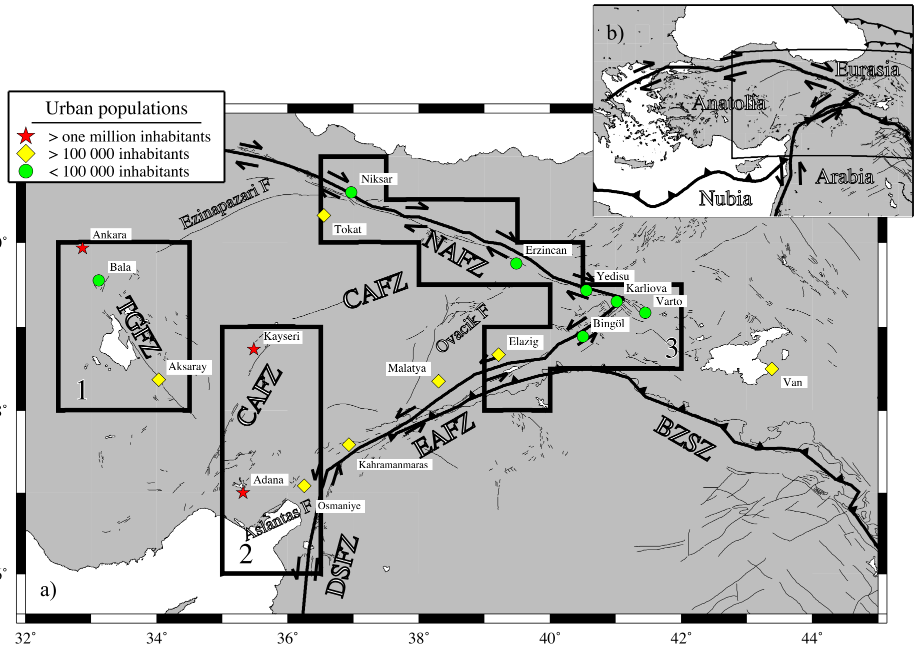

Fig. 1. a) Tectonic map of the central and eastern regions of Anatolia. Bold numbered blocks represent the areas of focus in this study. b) Tectonic setting of the north-eastern part of the Mediterranean region showing the northward movement of both the Nubia and Arabia plates towards Anatolia and Eurasia.

tonic regimes and to provide insights into the earthquake hazard for the region.

2. Tectonic setting

Turkey's complex tectonic setting is predominantly the result of the continental collision of the Arabian and Eurasian plates in the east, and the convergence of the Nubian and Anatolian plates in the south. The Arabian plate is moving in a north-northeast direction in relation to Eurasia at a rate of approximately 15 mm/yr, while the Nubian plate is moving in a northerly direction at a rate of around 10 mm/yr relative to Eurasia (Le Pichon and Kreemer, 2010; Reilinger et al., 2006; Walters et al., 2014). The differential motion between Nubia and Arabia is mostly accommodated by the left-lateral motion of the Dead Sea Fault Zone (DSFZ) (Fig. 1). The northward motion of Arabia results in the continental collision along the Bitlis–Zagros Suture Zone (BZSZ), and Nubia's northward motion results in the plunge of oceanic lithosphere under the Anatolian plate along the Aegean–Cyprean Arc.

Analysis of seismic data from several studies revealed that the crustal thickening in eastern Turkey was less than expected from the magnitude of the uplift of the plateau north of the BZSZ. *Pn* and *Sn* velocity anomalies studies lead to the conclusion that such a crustal lid is not present and that the elevation is a result of mantle temperatures typical at least of those of the asthenosphere. This resulted in a hypothesis that envisages a hot mantle plume under the plateau that supports the existing high elevation in the region (Gök et al., 2007; Şengör et al., 2003).

The continuous northward motion of Arabia results in the westward extrusion of the Anatolian block between two conjugate major transform faults, the dextral North Anatolian Fault Zone (NAFZ) and the sinistral Eastern Anatolian Fault Zone (EAFZ) (Fig. 1). The NAFZ is a 1200 km-long fault zone that runs along the northern part of Turkey, roughly parallel to the Black Sea from Karlıova in the east to the Gulf of Saros in the west, connecting the East Anatolian compressional region to the Aegean extensional region. The EAFZ is a 550 km-long fault zone extending between Karlıova (triple junction with the NAFZ) in the north-east and the city of Kahraman Maras in the south-west, where it meets the DSFZ. It is roughly a north-east trending, sinistral strike-slip fault zone (Fig. 1) which comprises a series of faults arranged in parallel, each with a different amount of slip, sub parallel or oblique to the general trend. The EAFZ and its adjacent section of the NAFZ have been relatively active in the last century (Ambraseys and Jackson, 1998; Nalbant et al., 2002, 2005) and this activity provides additional evidence to data from seismic studies which show that significant stress builds in sections of the fault zone. In fact, Nalbant et al. (2002) underlined two highly stressed segments along the EAFZ, a segment extending from south of the city of Kahraman Maras to south of the city of Malatya, and the sector between the east of the city of Elaziğ and the north east of the city of Bingol. The latter ruptured with an *Mw* 6.1 earthquake in 2011, validating the forecast. The same study also indicated that the other section could accommodate a larger $Mw > 7.0$ earthquake in the future, highlighting the importance of understanding the long-term strain accumulation and active tectonics within this area. GPS observations over the last two decades, however, reveal that slab pull along the Hellenic trench is now more important than the push from the collision in eastern Turkey (Le Pichon and Kreemer, 2010; Pérouse et al., 2012; Reilinger et al., 2006; Vernant et al., 2014).

3. Data and methodology

Employing the method of Haines and Holt (1993) we derived continuous velocity and strain-rate fields, without the need to previously define the geometry of the rigid blocks, through interpolation of published GPS velocities and seismicity data. We paid particular attention to interactions between the conjugate NAFZ and EAFZ, extending this region to the east, and west to the Tuz Gölü Lake.

The existing, large dataset with its broad spatial coverage, permitted us to reliably derive strain-rate fields and their correspondent velocity fields between plate motions and, as in our case, between slowly deforming regions (Pérouse et al., 2012; Reilinger et al., 2006). We used GPS velocity vectors from Reilinger et al. (2006), to which we added the velocity vectors published by Aktuğ et al. (2013), Alchalbi et al. (2010), Mahmoud et al. (2013), Ozener et al. (2010), Tatar et al. (2012) and