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Seismic velocity and Poisson's ratio tomography of the crust beneath East Anatolia

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ABSTRACT

Eastern Anatolia is a region in the early stages of continent–continent collision and so provides a unique opportunity to study the early development of continental plateau. Located within the Alpine–Himalayan fold-thrust fault belt, the Anatolian plateau is geologically very complex, with over half of the surface area covered with late Cenozoic volcanics of diverse composition. The plateau is also seismically active and is dissected by numerous seismogenic faults predominantly of strike-slip motion. In this study, we determine 3-D tomographic images of the crust beneath eastern Anatolia by inverting a large number of arrival time data of *P*- and *S*-waves. From the obtained *P*- and *S*-wave velocity models, we estimated the Poisson's ratio structures for a more reliable interpretation of the obtained velocity anomalies. Our tomographic results are generally consistent with the major tectonic features of the region. High *P*- and *S*-wave velocity anomalies are recognized near the surface, while at deeper crustal layers, low seismic wave velocities are widely distributed. Poisson's ratio exhibits significant structural heterogeneities compared to the imaged velocity structure. The seismic activity is intense along highly heterogeneous zones and is closely associated with pre-existing faults in the central and western parts of the study area. Results of the checkerboard resolution test indicate that the imaged anomalies are reliable features down to a depth of about 40 km. The low-velocity/high Poisson's ratio zones in the middle to lower crust are consistent with many geophysical observations such as strong *Sn* attenuation, low *Pn* and *Sn* velocity, and the absence of mantle lid, implying the presence of partial melt in the uppermost mantle.

1. Introduction

Turkey and its surrounding region are considered as an 'excellent natural laboratory' to study a variety of seismotectonic processes such as post-collisional intracontinental convergence, tectonic escape-related deformation, and the consequent structures that include fold and thrust belts, suture zones, active strike-slip faulting, active normal faulting and the associated basin formation (Kalyoncuoglu, 2007). The study of its neotectonic features and the current active tectonics are a key for the understanding of the entire eastern Mediterranean region (Fig. 1). Plate tectonic models (DeMets et al., 1990; Jestin et al., 1994; McClusky et al., 2000) based on analysis of global seafloor spreading, fault systems, and earthquake slip vectors indicate that the Arabian plate is moving in a north–northeast direction relative to Eurasia at a rate of 18–25 mm/yr, averaged over about 3 Myr. These models also indicate that the African plate is moving in a northerly direction relative to Eurasia at a rate of about 10 mm/yr. Differential motion between Africa and Arabia (~10–15 mm/yr) is accommodated predominantly by left-lateral motion along the Dead Sea Fault Zone (DSFZ). This northward motion results in continental collision along the Bitlis–Zagros fold and thrust belt (Fig. 1), intense earthquake activity (Fig. 2), high topography in eastern Turkey and the Caucasus Mountains, and the westward extrusion of the Anatolian plate. Three major structures, thus, control the tectonics of Turkey; they are the dextral North Anatolian Fault Zone (NAFZ), sinistral East Anatolian Fault Zone (EAFZ) and the Aegean–Cyprean Arc (Fig. 1). The Anatolian wedge between the NAFZ and EAFZ moves westward away from eastern Anatolia because of the collision zone between the Arabian and the Eurasian plates. Ongoing deformation along, and mutual interaction among them have resulted in four distinct neotectonic provinces, namely, the East Anatolian contractional, the North Anatolian, the Central Anatolian *Ova* and the West Anatolian extensional provinces (Fig. 1). Each province is characterized by its unique structural elements and presents a typical region to study active strike-slip, normal and reverse faulting and the associated basin formation (Bozkurt, 2001).

The westward extrusion of the Anatolian wedge, initiated in the early Pliocene (e.g., Dhont et al., 1998; Kocyiğit and Beyhan, 1998; Platzman et al., 1998; Armijo et al., 1999; Barka et al., 2000), is

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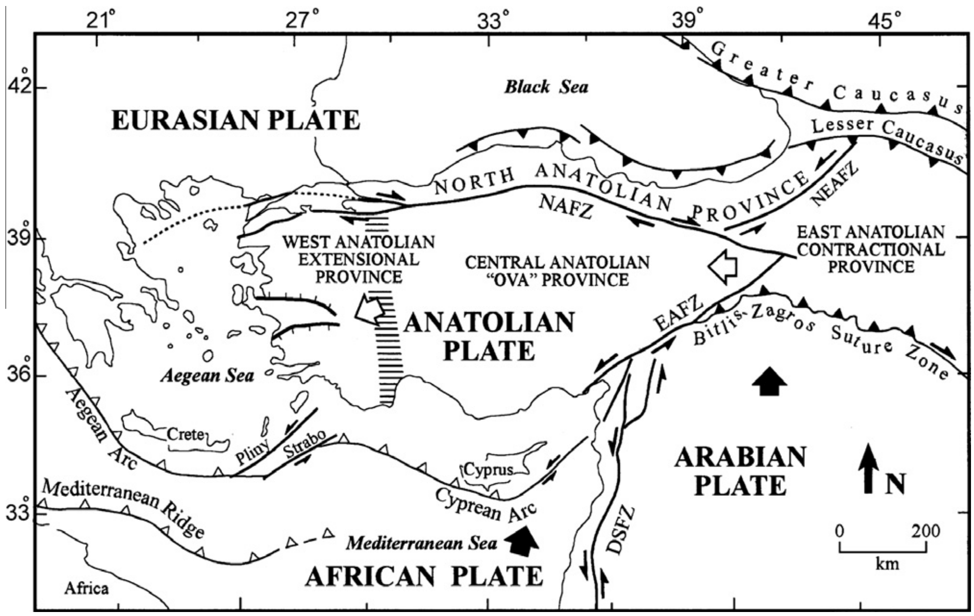

Fig. 1. Simplified tectonic map of eastern Turkey showing major structures and neotectonic provinces (from Şengör et al., 1985; Barka, 1992). DSFZ – Dead Sea Fault Zone, EAFZ – East Anatolian Fault Zone, NAFZ – North Anatolian Fault Zone, NEAFZ – Northeast Anatolian Fault Zone.

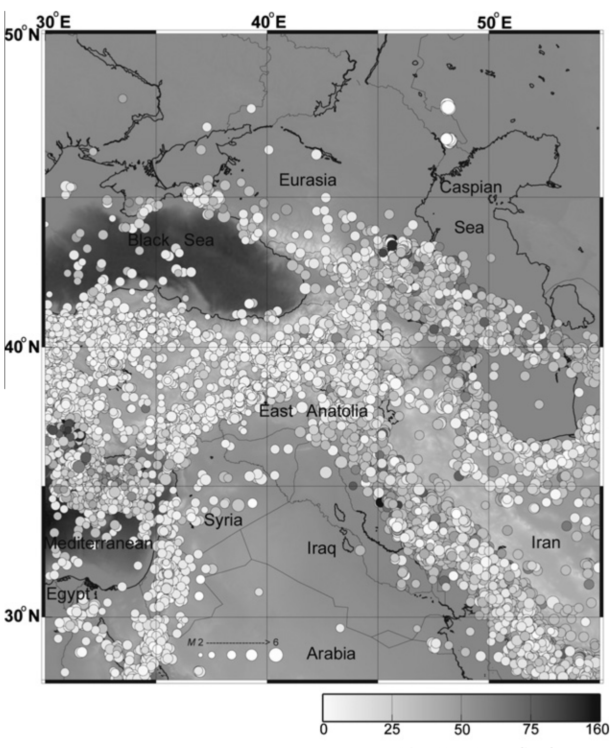

Fig. 2. Epicentral distribution of NEIC (US Geological Survey) seismicity in eastern Anatolia and the surrounding regions. Circles vary in size according to magnitude and in grey color according to the depth of the hypocenter.

accompanied by anticlockwise rotation (McKenzie, 1970; Westaway, 1994; Seber et al., 1997; Reilinger et al., 2006), and is interpreted as a lateral escape of the continental lithosphere away from zones of compression (tectonic escape) to minimize topographic relief and to avoid subduction of buoyant continental material. Whether the westward motion is driven by push forces caused by topography in eastern Turkey or by pull forces caused by subduction south of the Aegean since the late Oligocene (Jolivet et al., 1994; Jolivet and Patriat, 1999) is still a matter of controversy (Bozkurt, 2001). Earlier results of Reilinger et al. (1997), however, suggest that the westward displacement and counterclockwise rotation of Anatolia is driven both by pushing from the Arabian plate and by pulling or basal drag associated with the foundering African plate along *the Aegean and Cyprean arcs* (Fig. 1). In general, there is an agreement that these are the boundary conditions allowing the westward mass transfer of Anatolia, frequently considered as a rigid plate bounded by the NAFZ and the EAFZ meeting at Karliova.

The eastern Mediterranean region has a remarkably long historic record of major earthquakes (e.g., Ambraseys, 1975; Ambraseys and Jackson, 1998) and has been the focus of intense geologic and geophysical investigations (e.g., Sengör et al., 1985; Spakman, 1991; Mueller and Kahle, 1993; De Jonge et al., 1994). Because of sparse seismic stations in the region, the seismic activity could not be monitored well and earthquakes with magnitudes <4.0 were not accurately located. Recent observations show that the seismic activity in eastern Turkey is higher than previously observed. The upper crust of eastern Anatolia is seismotectonically very active, where the majority of earthquakes are shallower than 20 km depths. This implies that there is no continental underthrusting/subduction of Arabia beneath Eurasia (Türkelli et al., 2003) and that only the upper crust in Anatolia is seismogenic, which is consistent with similar results in other continental plateaus (e.g., Maggi et al., 2000). Moreover, Türkelli et al. (2003) found that most of the seismic activity seems to occur in the upper crust (in the first 10 km). However, the EAFZ, the Bitlis suture zone, the Karliova junction area and the area east of Karliova have some hypocenters which may originate in the lower crust ($h > 20$ km) as well (Fig. 2). This may suggest that the EAFZ and Bitlis suture are seismogenically thicker than the NAFZ. A continuous band of seismicity stretches eastward from the commonly defined easternmost extent of the NAFZ (Karliova) to *Lake Van*. This observation may suggest that the NAFZ continues all the way to the main recent fault in northwestern Iran (Zagros Mountain). This is consistent with the observation of Talebian and Jackson (2002) that the main recent fault in northwestern Iran and the NAFZ combine to