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Spatial variation in the frequency-magnitude distribution of earthquakes under the tectonic framework in the Middle East

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ABSTRACT

Spatial variations of seismic energy released and b-value over the Middle East region are investigated based on a seismicity catalog from 1995 to 2007. The goal is to use these seismic parameters and based on other geodetic and geophysical observations, such as GPS measurements, strain rate model, fault distribution, focal mechanism, crustal model, Q model, and gravity measurements, etc., to uncover spatial patterns that seem anomalous. Areas of high energy released (cumulative) seem to correspond to the areas of relatively high b-values. Areas of high energy released and high b-values seem to correspond very well with the location of continental collision where earthquake activities are high. The divergent boundary between Arabia and African plates and subduction zone at Makran seem to correspond to low to moderate energy release.

Northern Pamir, Azerbaijan-Caucasus, the lower part of Zagros Mountains, eastern Turkey, Owen Fracture Zone, Strait of Bob-el-Mandeb, and south of the Sulaiman Shear Zone seem to correspond to high cumulative energy-released, high strain rate, high b-values, and high fault density. While, the central and eastern Iran, southern Zagros, northern Pakistan, Gulf of Aden, Alborz, southwest of the Caspian Sea, western Caucasus and Kopeh-Dagh seem to correspond with lower b-values.

The cross-section map for Hindu-Kush shows general decreasing of the b-values with depth, however, a region of high b-value is observed underneath Pamir at depths from 170 to 230 km. This anomaly region can be due to dehydration of Pamir crustal slab at depth.

1. Introduction

The elastic rebound theory (Reid, 1910) explains well the process of stress accumulation and energy release during an earthquake. Plate motions are the primary source of stress that accumulates at plate boundaries in tectonically active regions (Turcotte and Schubert, 1982). Some of these tectonic stresses and, therefore, strains are released by earthquakes in the form of faulting (Richter, 1958). Hence, valuable information about tectonic processes occurring in seismically active regions on the earth is reflected in earthquake catalogs. Earthquake catalogs can be used to explore spatial and temporal patterns and their variations corresponding to changes in regional tectonic processes (Habermann, 1987).

The Middle East region is a tectonically and seismically very active part of the Alpine-Himalayan orogenic belt. This region extends from the Himalayas to the Eastern Mediterranean along east–west direction and from the Greater Caucasus to the Gulf of Aden in north–south direction where remarkably long historical records of major earthquakes were documented (e.g. Ambraseys, 1975; Ambraseys and Jackson, 1998). Complex tectonics associated with the interaction of four major plates (Arabia, Eurasia, Indian, and African) and one smaller tectonic block (Anatolia) is responsible for most seismicity in the Middle East (McKenzie, 1970, 1972). Because of the wide variety of tectonic processes, this region has been identified as an ideal natural laboratory for studying the kinematics and dynamics of plate interactions (Reilinger et al., 2006).

In a recent study by Zare et al. (2014), a unified earthquake catalog (Fig. 1) for the Middle East has been developed as a part of the Global Earth Model (GEM). The earthquake model of the Middle East (EMME) project incorporates historical, early and modern instrumental events recorded by local and international agencies between 1250 BCE and 2007. Mousavi (2016a) has analyzed and discussed the homogeneity of the catalog. This dataset offers an opportunity to study spatial variation of seismicity under the tectonic framework of the region.

One important parameter embedded in an earthquake catalog is seismic b-value estimated from frequency-magnitude distribution of earthquakes, also known as the Gutenberg-Richter relation (Gutenberg and Richter, 1944). The seismic b-value expresses the rate of decrease in the frequency of events with increasing magnitude, i.e. a low b-value indicates a greater proportion of larger events. Many studies suggest

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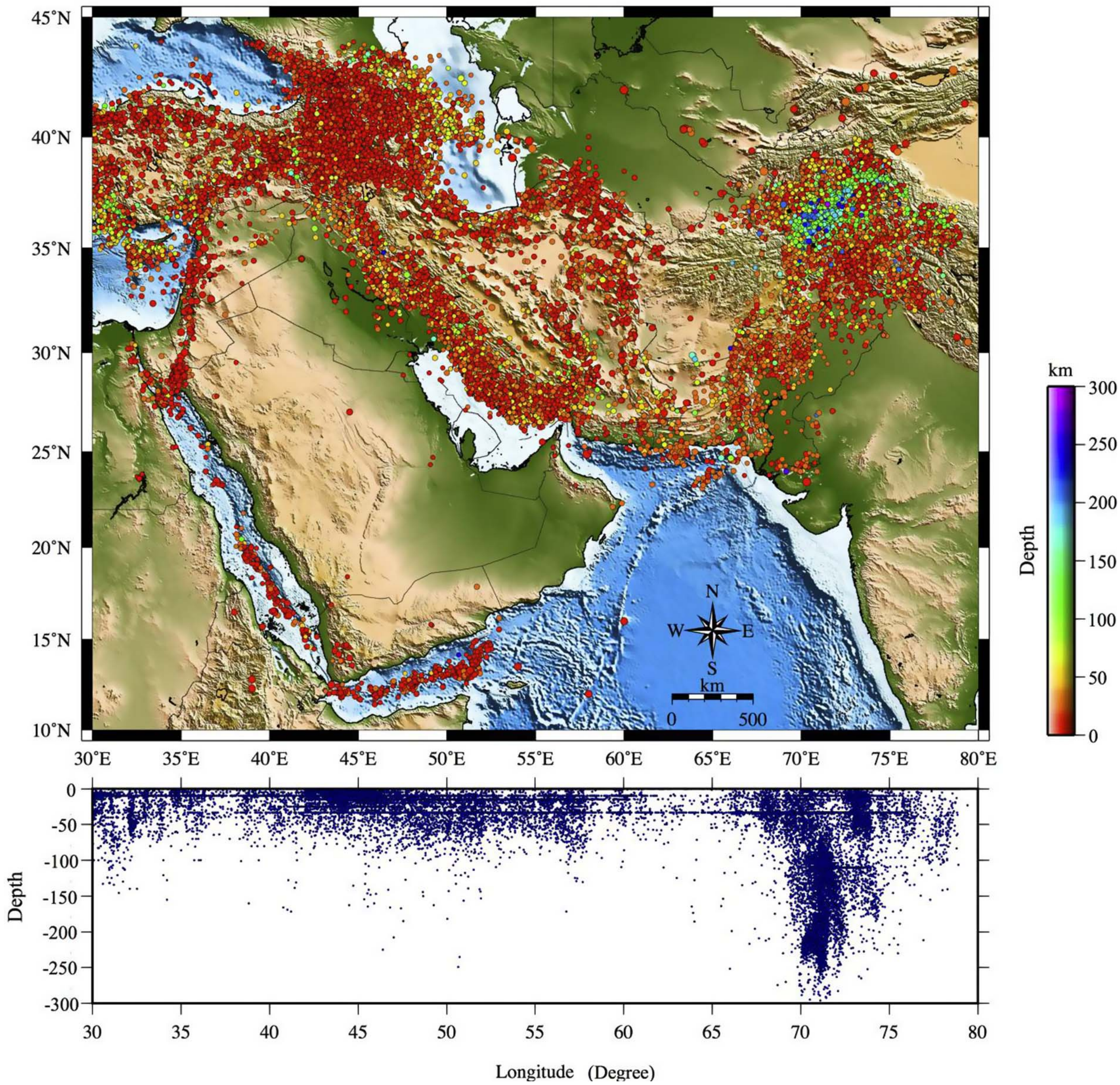

Fig. 1. Epicentral (top) and 1D depth distributions (bottom) of the seismicity between 1995 and 2007 in the region, color-coded based on focal depths.

that the b-value reflects the state of stress and level of heterogeneity in the Earth's crust (e.g. Mogi, 1962; Scholz, 1968; Wyss, 1973; Urbancic et al., 1992; Zang et al., 1998; Wiemer and Katsumata, 1999; Lei, 2003; Schorlemmer et al., 2004a,b; Schorlemmer and Wiemer, 2005; Khan and Chakraborty, 2007; Mousavi, 2017) and therefore can provide important information on seismotectonic and hazard potential of a region. Moreover, various laboratory and observational studies revealed relations between the b-value and faulting styles (Schorlemmer et al., 2005), pore pressure (Lockner and Byrlee, 1991; Power et al., 1995; Wiemer and McNutt, 1997; Wyss et al., 1997; Wiemer et al., 1998; Jolly and McNutt, 1999; Murru et al., 1999; Sanchez et al., 2004; Bridges and Gao, 2006; Farrell et al., 2009; Van Stiphout et al., 2009; Bachmann et al., 2012; Mousavi et al, 2017), earthquake size (Hamilton and McCloskey, 1997; Ikeya and Huang, 1997; Pacheco et al., 1992), earthquake depth (Wiemer and Wyss, 1997), thermal gradient (Warren and Latham, 1970), and geotectonic features of seismic zones (Niazi, 1985). b-values less than 1 implies areas of crustal homogeneity and high stress and values greater than 1 implies crustal heterogeneity and low stress (Bridges and Gao, 2006). Observations in tectonic areas reveal that when large volumes are sampled the b-value is generally around the constant of 1.0 (Frohlich and Davis, 1993; Kagan, 1999). This means that for given a frequency of magnitude 4.0 events there will be ten times as many magnitude 3.0 earthquakes and 100 times as many magnitude 2.0 earthquakes. In contrast, b-values of the volcanic region with earthquake swarms are rather high, e.g. $b > 1$, and can have values as high as 3.0 (McNutt, 2005). *b*-values in the range of 0.8–1.2 have been reported for tectonic events (e.g., Schorlemmer et al., 2005; Kamer and Hiemer, 2015).

Another geophysical parameter that can be estimated from earthquake magnitudes is seismic energy release. Earthquake wave radiation reflects parts of elastic energy released during fracturing (Kanamori, 1977; Kanamori et al., 1998; McGarr, 1999). This radiated earthquake energy is related to the brittle strength of the crust (Turcotte and Schubert, 1982) and at some level, reflects the state of strain and stress drops within the elastic lithosphere (Hanks, 1977; Kirby, 1980).

In this study, I investigate the spatial distribution of seismic energy released and b-value and their relationship with tectonic elements in the Middle East region (enclosed by 10 °–45 °N latitude and 30 °–80°E longitude). The goal is to use these seismic parameters as a proxy for stress and based on other geodetic and geophysical observations, such as GPS measurements, strain rate model, fault distribution, focal mechanism, crustal model, Q model, and gravity measurements, uncover