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Present-day tectonic regime and stress patterns from the formal inversion of focal mechanism data, in the North of Central–East Iran Blocks

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ABSTRACT

The kinematic models and the associated orientation of compressional stress in northeastern Iran have long been the subject of debate. Previously proposed models have relied on the interpretation of overall fault geometry and geological fault slip data. These models generally suffer from low resolution of the temporal and spatial changes in the stress field and geodynamic regime. In the recent years there has been a significant increase in the number of focal mechanisms available for the study area, and it is now possible to estimate the present-day stress field in relative detail based on the formal stress inversion method. We compiled 59 earthquake focal mechanisms from the Global/Harvard CMT catalogue and various other sources. These we grouped into 7 separate regions (boxes). For each region reduced stress tensors have been obtained by formal stress inversion using the Win-Tensor program (Delvaux and Sperner, 2003). The present-day stress state obtained from earthquake focal mechanisms shows that the North of Central–East Iran Blocks (NCEIB) is presently subjected to a transpressional tectonic regime ($R' = 1.78 \pm 0.26$), with an N37 $\pm$ 7° E direction of horizontal principal compression. This stress state is consistent with the direction of convergence between the Arabian and Eurasian plates. In this part of northeastern Iran this convergence is accommodated by clockwise rotations. The Doruneh fault system (DFS) curves ESE–WSW, perpendicular to relative motion. This orientation results in oblique compression with a significant along-belt component of left-lateral shear in the western and central segments and belt-perpendicular compression in the eastern segment.

1. Introduction

The active deformation in Iran is controlled by the collision of the Arabian plate with Eurasia at Eocene–Oligocene boundary (e.g., McKenzie, 1972; Jackson and Mckenzie, 1984; Dewey et al., 1986; Hempton, 1987; Allen et al., 2004; Agard et al., 2011; Mouthereau et al., 2012). Both the northward decrease in GPS velocities, and the large number of earthquakes across Iran indicate that much of the deformation is concentrated in the Zagros, Alborz and Kopeh-dagh mountain ranges, and on N–S right-lateral and E–W left-lateral fault system in the Central–East Iranian Blocks (CEIB) (Jackson et al., 1995, 2006; Talebian and Jackson, 2002, 2004; Walker and Jackson, 2004, Allen et al., 2006; Hatzfeld and Molnar, 2010; Hollingsworth et al., 2010).

Recent GPS measurements indicate that Arabian plate moves NNE, with respect to Eurasia, at a rate of 22 $\pm$ 2 mm/yr at a longitude of 56° E (e.g., Sella et al., 2002; Nilforoushan et al., 2003; Vernant et al., 2004a, b; Bayer et al., 2006; Hessami et al., 2006; Walpersdorf et al., 2006, 2014; Masson et al., 2005, 2007; Tavakoli, 2007; Peyret et al., 2009; Djamour et al., 2010, 2011; Mousavi et al., 2013) and the CEIB moves northwards with respect to western Afghanistan at 15 mm/yr (Vernant et al., 2004a, b) or 6–13 mm/yr (Walpersdorf et al., 2014).

According to Walpersdorf et al. (2014) the northward convergence is accommodated in CEIB in two ways. First Eastern Iran is

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separated into five large ~N–S trending blocks, and those crustal blocks are rapidly moving northward (6–13 mm/yr) with respect to the stable Afghan Block at the eastern edge of the collision zone. It is likely that the collective behavior of these ~N–S faults contributes to allowing the Arabian promontory to impinge northward into the Eurasian crust. Second, the ~N–S CEIB faults achieve E–W shortening by rotating counterclockwise around a vertical axis of rotation. The rotation has been occurring over the last 12–20 Ma up to the present, at a rate averaging 1 ± 0.4°/Ma.

The CEIB consists of five major blocks (from west to east the Yazd, Posht-e-badam, Tabas, Lut and East Iran blocks) (Alavi, 1991; Aghanabati, 2004) (Fig. 1), which experience low GPS deformation rates (less than 2 mm/yr) and are commonly described as rigid blocks (e.g., Jackson and Mckenzie, 1984, 1988; Vernant et al., 2004a, b; Berberian and King, 1981; Takin, 1972; Ramezani and Tucker, 2003; Bagheri and Stampfli, 2008). These blocks are bounded by major right-lateral strike-slip fault zones and have a peculiar stratigraphy, style of deformation and pattern of recent seismicity (Berberian and King, 1981).

The seismic zones of the CEIB are mainly located along large N–S trending, right-lateral fault systems. In the north right-lateral shear is accommodated by the clockwise rotation of E–W left-lateral faults (such as the Doruneh and Dasht-e-Bayaz faults). Despite the major tectonic hazard in the CEIB relatively few studies have attempted to analyze the local seismotectonic stress regime.

Our study area is situated in the north of Central–East Iranian Blocks (NCEIB), between 34°–36° N and 55°–61° E, which is the transfer zone between the northern deformation domains (i.e., the Alborz, Kopeh-dagh, Binalud mountain ranges and Sabzevar domain) and the southern N–S fault systems. These domains are separated by the Doruneh fault system (DFS) (e.g., Tchalenko et al., 1973; Farbod et al., 2011) which precludes their direct structural connection.

The purpose of this paper is to deduce the present-day stress pattern of the northeastern part of the Arabian–Eurasian collision zone in this transfer zone between NE and E Iran. In this paper we first compile all presently available well-constrained focal mechanism data up April 2014 (59 events). We then group this data into 7 distinct areas (Fig. 2) as a function of the geographic proximity, the general tectonic structure and the greatest density of similar focal mechanisms. We perform a formal inversion in order to determine the present-day stress field. We used two different stress inversion methods; Right Dihedron and the Rotational Optimization methods of Delvaux and Sperner (2003).

2. Tectonic and geological setting

Cenozoic deformation in Iran is the result of the Arabian–Eurasia convergence that culminated in the Arabian Eurasia collision (Allen et al., 2004; Agard et al., 2011; Mouthereau et al., 2012). The NCEIB is an important independent continental block in the Arabia–Eurasia collision zone and controls the distribution of strain in the northeastern portion of the Iranian plateau. This block is bounded by Doruneh fault system (DFS) to the north and Dasht-e-Bayaz fault zone to the south (Fig. 1).

The DFS is a left-lateral intracontinental transform fault between the northern and southern sections of the CEIB defined above. The Doruneh fault is one of the longest and most clearly

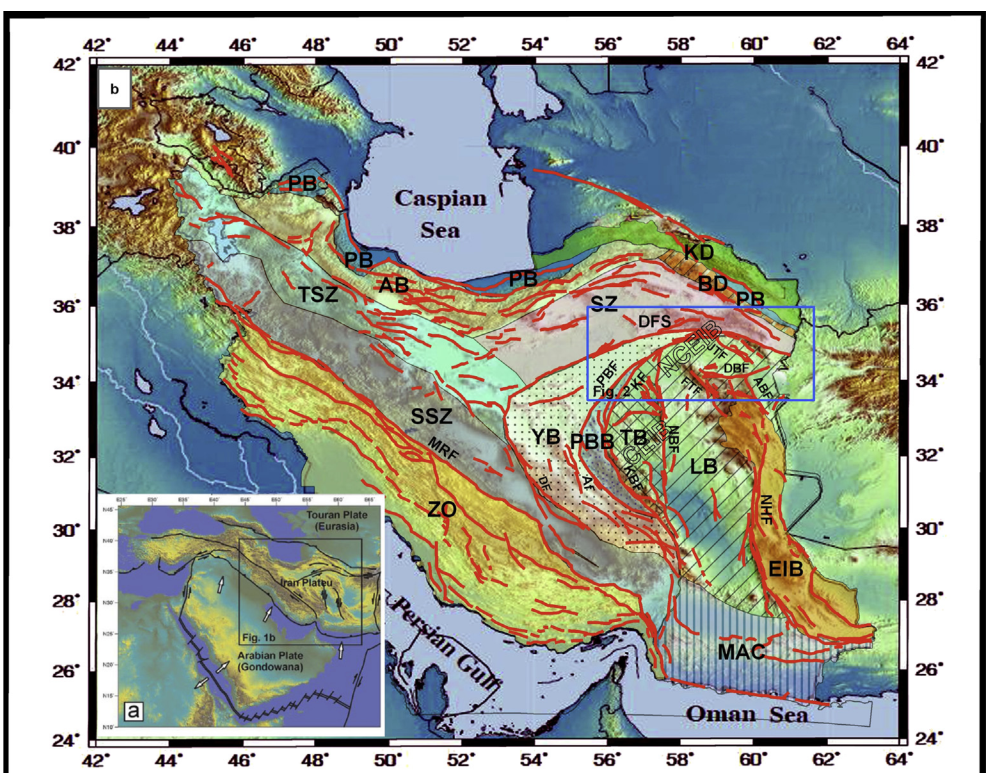

Fig. 1. (a) Tectonic setting of Iran in the Middle East and presentation of major convergence vectors of the region. (b) Generalized tectonic map of Iran (modified from Aghanabati, 2004; Hessami et al., 2003 and Alavi, 1991). Abbreviations: AB, Alborz belt; ABF, Abiz fault; AF, Anar fault; BD, Binalud mountain range; CEIB, Central–East Iranian Blocks; DBF, Dasht-e-bayaz fault; DF, Dehshir fault; DFS, Doruneh Fault System; EIB, East Iran belt; FTF, Ferdows Thrust fault; JTF, Jangal Thrust fault; KD, Kopeh Dagh; KF, Kalmard fault; KBF, Kohbanan fault; LB, Lut Block; MAC, Makran accretionary complex; MHF, Main Zagros Reverse Fault; NHF, Nehbandan fault; NBF, Nayband fault; PB, Paleo-Tethyan basin; PBB, Posht-Badam Block; PBF, Posht-Badam fault; SZ, Sabzevar zone; SSZ, Sanandaj-sirjan zone; TB, Tabas Block; TSZ,Tabriz-Saveh zone; YB, Yazd Block; ZO, Zagros orogen. Box shows the North of Central–East Iranian Blocks (NCEIB) by Fig. 2.