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Paleoseismological and morphological evidence of slip rate variations along the North Tabriz fault (NW Iran)

Shahryar Solaymani Azad [a,b,*], Hervé Philip [b], Stéphane Dominguez [b], Khaled Hessami [c], Majid Shahpasandzadeh [d], Mohammad Foroutan [a,e], Hadi Tabassi [f], Michel Lamothe [g]

[a] Geological Survey of Iran, Seismotectonics and Seismology Department, P.O. Box: 13185 1494, Tehran, Iran
[b] Université Montpellier 2, Laboratoire Géosciences Montpellier, UMR CNRS 5243, Montpellier 34095, France
[c] International Institute of Earthquake Engineering and Seismology (IIEES), Dibaji, 19531 Tehran, Iran
[d] Kerman Graduate University of Technology, Haftbagh Highway, Kerman, Iran
[e] Sorbonne Universités, UPMC Univ. Paris 06, UMR 7193, Institut des Sciences de la Terre de Paris (ISTeP), F-75005 Paris, France
[f] Islamic Azad University, Ashtian Branch, Ashtian, Iran
[g] Quebec University, P.O. Box: 8888, H3C 3P8, Canada

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ABSTRACT

Northwest Iran is characterized by a high level of historical and instrumental seismicity related to the ongoing convergence between the Arabian and Eurasian plates. In this region, the main right-lateral strike-slip fault known as the North Tabriz fault (NTF) forms the central portion of a large crustal fault system called the Tabriz fault system (TFS). The NTF is a major seismic source along which at least three strong and destructive earthquakes have occurred since 858 AD. The two most recent destructive seismic events occurred in 1721 AD and 1780 AD, rupturing the SE and NW fault segments, respectively. This paper reports paleoseismological and quantitative geomorphologic investigations on the SE segment of the NTF, between the cities of Bostanabad and Tabriz. These observations help to improve our understanding of the seismic hazard for Tabriz city and its surrounding areas. Our field investigations revealed evidence of successive faulting events since the Late Quaternary. Paleoseismic investigations indicate that since 33.5 kyr, the SE segment of the NTF has experienced at least three major ($M > 7.5$) seismic events, including the 1721 AD earthquake ($M = 7.6–7.7$). Along the NW segment of the fault, however, our results suggest that the amount of strong ($M \sim 7.5$) seismic events during the same period is significantly greater than along the SE segment. One possible explanation of such a difference in seismic activity is that the Late Quaternary–Holocene coseismic slip rate is decreasing along the NTF from the northwest to the southeast. This explanation contradicts the former hypothesis of a constant slip rate along the whole length of the NTF. In addition, more distributed deformation along several parallel fault branches, in a wider fault zone of the SE segment of the NTF may be considered as additional evidence for the estimation of lower rate of deformation along the fault segment. Such a slip distribution pattern can explain the existence of smaller (~300 m) Pliocene–Quaternary cumulative dextral offsets along the SE fault segment than the measured cumulative offsets along the NW segment (~800 m) of the NTF.

1. Introduction

The Iranian plateau forms the central portion of the Alpine–Himalayan orogenic belt (e.g. Jackson, 1992; Jackson and McKenzie, 1984; Sengör and Kidd, 1979; Şengör and Yilmaz, 1981). Its large-scale topography and regional surface morphology both resulted from the Eocene to Miocene collision and ongoing convergence between the Arabian plate to the south and the Eurasian plate to the north. Global positioning system (GPS) measurements (Nilforoushan et al., 2003; Vernant et al., 2004) reveal that present-day northward motion of the Arabian plate relative to the Eurasian plate is about 20 to 25 mm yr^{-1}.

In western Iran (between 45°E and 54°E), the Arabia–Eurasia convergence is mainly accommodated by crustal deformation localized on both the northern and southern sides of Central Iran, which is commonly described as a more rigid portion of the Iranian plateau (e.g. Jackson and McKenzie, 1984; Stöcklin, 1968, 1974). However, recent paleoseismic studies have documented the occurrence of several large-magnitude earthquakes along the prominent strike-slip faults slicing Central Iran indicating it does not behave totally as a rigid block (Foroutan et al., 2012, 2014). On the southern side of Central Iran, along the Zagros ranges, the rate of microseismicity is high (e.g. Berberian, 1995; Oveisi et al., 2008), but large seismic events are relatively rare and occur at depths ranging

* Corresponding author at: Geological Survey of Iran, Department of Seismotectonics and Seismology, P.O. Box: 13185 1494, Tehran, Iran.
E-mail address: shahryar.solaymani@gmail.com (S. Solaymani Azad).

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between 8 and ~30 km, and mostly reported without surface faulting (e.g. Maggi et al., 2000; Nissen et al., 2011; Oveisi et al., 2008; Talebian and Jackson, 2004; Tatar et al., 2004). On the northern side of Central Iran, despite a lower rate of instrumental seismicity, the region including southern Armenia–eastern Turkey and northwestern Iran–Transcaucasian territories has experienced large and destructive historical earthquakes (e.g. Berberian, 1997; Cisternas and Philip, 1997) (Fig. 1). In this framework, most of the earthquake hypocenters are shallow (e.g. Siahkali Moradi et al., 2011) and commonly associated with surface faulting (e.g. Berberian and Yeats, 1999; Hessami et al., 2003a; Karakhanian et al., 2004). Considering their large magnitudes and long return periods, these earthquakes can be interpreted as typical intra-plate seismic events (e.g. Berberian and Yeats, 1999). According to the amount of seismic moment released by earthquakes within E Turkey and NW Iran, tectonic deformation in the region is almost totally accommodated by coseismic slip (e.g. Jackson and Ambraseys, 1997). Because of these characteristics, the region of NW Iran, characterized by a dense population, is clearly subjected to a high level of seismic hazard and risk as well. However, in some cases (e.g. 1988 Spitak earthquake in Armenia, M ~6.7) the level of seismic hazard was underestimated by previous seismic hazard analysis (Berberian, 1997). During the last three decades, many researchers (e.g. Avagyan, 2001; Berberian, 1997; Berberian and Arshadi, 1976; Cisternas and Philip, 1997; Davtyan, 2007; Hempton and Dewey, 1983; Hessami et al., 2003a; Jackson et al., 2002; Karakhanian et al., 2002, 2004; Solaymani Azad, 2009) have performed active tectonic and paleoseismological studies to improve the seismic hazard assessment within this intra-plate region. The occurrence of strong earthquakes, long quiescent times, and intensely active periods (temporal seismic clustering) are the main characteristics of this active region. In the Iranian part of the region, most active tectonic studies have focused on the North Tabriz fault (NTF) as a well-known seismic source in the area (e.g. Berberian and Arshadi, 1976; Hessami et al., 2003a).

Hessami et al. (2003a) performed the first paleoseismological study on the NW segment of the NTF to characterize both its kinematics and seismic behavior. Their study revealed that the NW segment of the NTF has ruptured at least during four large earthquakes, since 3600 BP, with a mean recurrence interval of 820 ± 170 years, including the most recent one in 1780 AD. The return period of strong earthquakes along the entire length of the fault is still to be assessed; nevertheless, these results clearly indicate that the seismic risk for the city of Tabriz and its surrounding regions is increasing to a very high level (e.g. Copley and Jackson, 2006). Unfortunately, the rapid development of the Tabriz region, in terms of industry, population, and urban extension,

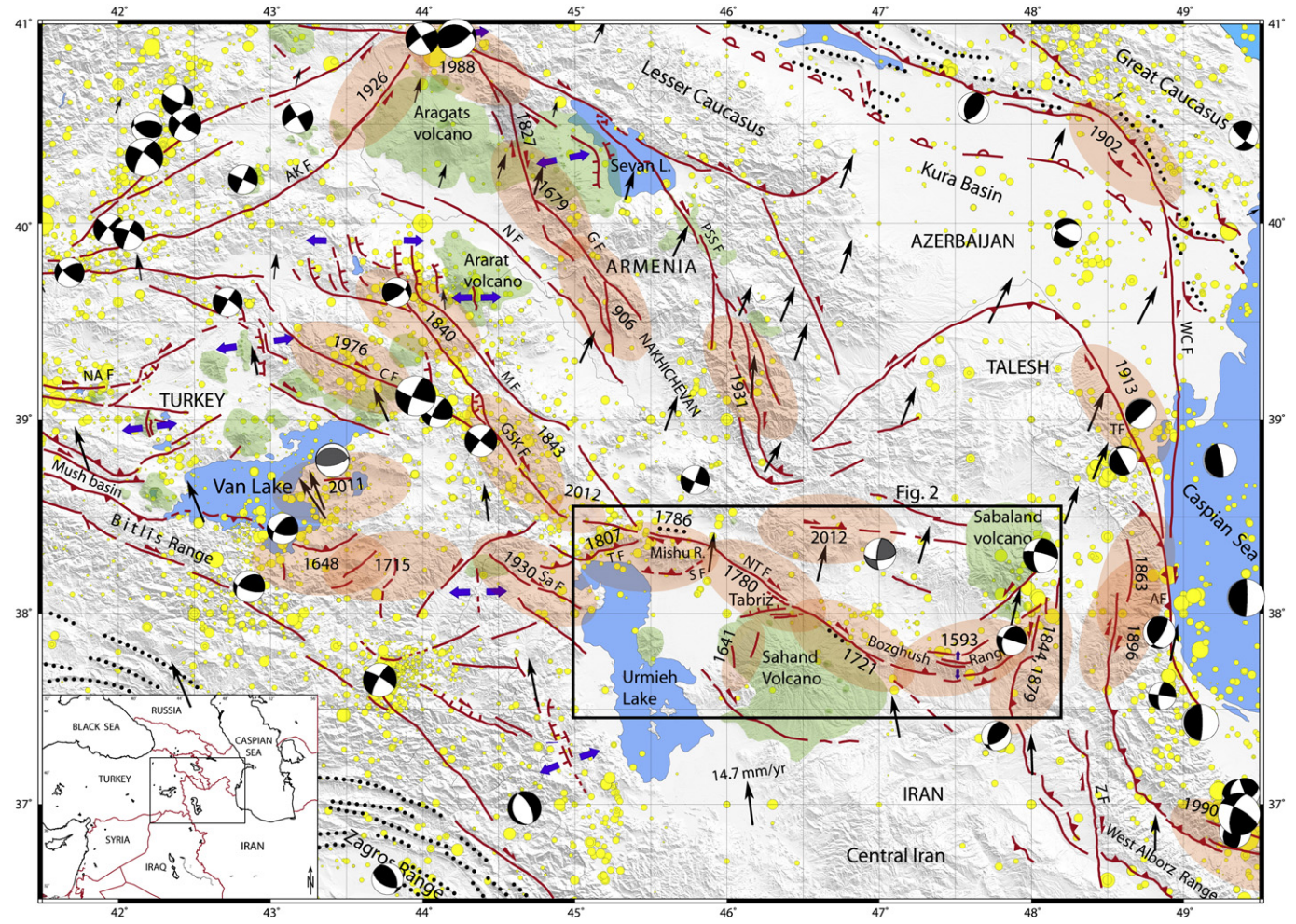

Fig. 1. Active tectonic map showing the general pattern of recent deformation in the north-central portion of the Arabia–Eurasia collision zone and the situation of the North Tabriz fault (NTF) within the NW Iran–Transcaucasian region. Right- and left-lateral strike-slip faulting occurs along the NW and NE fault trends, respectively. Fold and thrust belts and normal faulting, associated with active volcanoes, revealed active N–S compression and E–W extension (see text for details). The instrumental seismicity (yellow circles) is from the Incorporated Research Institutions for Seismology (IRIS). The black and gray focal-mechanisms are respectively from Jackson et al. (2002) and USGS. GPS arrows are from Reilinger et al. (2006). The historical seismicity is from Berberian (1997), and Ambraseys and Melville (1982). The pointed lines show the active fold axis. GSKF: Guilato–Siahcheshmeh–Khoy fault system; NAF: North Anatolian fault; CF: Chalderan fault; AKF: Akurian fault; MF: Maku fault; TF: Tassuj fault; SaF: Salmas fault; GF: Garni fault; PSSF: Pambak–Sevan–Sunik fault; WCF: West Caspian fault; AF: Astara fault; TF: Talesh fault; ZF: Zandjan fault (Solaymani Azad et al., 2011).