Surface deformations attributed to the Dehkhwarghan-Tabriz earthquake fault zone

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ABSTRACT

This paper introduces evidences of surface deformations attributed to the causative fault zone of the 1641 Dehkhwarghan-Tabriz destructive earthquake, Ms 6.8 that seriously affected the Osku and Khosrowshahr regions. This earthquake, totally ruined Osku and Khosrowshahr and caused 1200 fatalities. Macroseismic epicenter of this earthquake is proposed to be near Osku. Plenty of normal faults and observed relay ramp imply fault damage zone, most possibly related to the Dehkhwarghan-Tabriz earthquake fault. Large number of springs (at least 172) surrounding the Osku, with noticeable increase in west of Osku, also confirms the existence of this damage zone. Such information is particularly important for studies of active tectonics and paleoseismology.

Keywords: 1641 Dehkhwarghan-Tabriz earthquake, Normal faults, Relay ramp, Osku

INTRODUCTION

Evidence for surface faulting in historical earthquakes is important to all modern studies of seismicity and tectonics (Ambraseys and Jackson, 1988). Northwest of Iran has witnessed many destructive historical earthquakes (see Ambraseys and Melville, 1982). For example; historical earthquakes of 1042 (Ms 7.6), 1721 (Ms 7.7) and 1780 (Ms 7.7) (Fig. 1); that attributed to the North Tabriz Fault, almost totally destroyed Tabriz and 280000 people are said to have perished (Ambraseys and Melville, 1982). In 1641, a devastating earthquake (Ms 6.8) occurred in an area between Tabriz city and Urmia lake (Fig. 1). This earthquake caused severe destruction, especially in the town of Osku, and ~1200 casualties (Ambraseys and Melville, 1982).

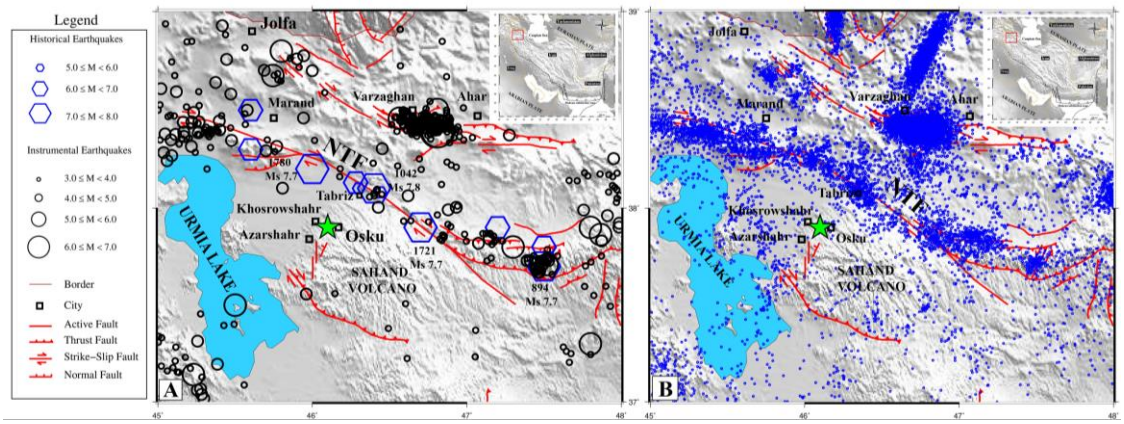

Figure 1. (A) Major faults and seismicity map of Tabriz and nearby regions. (B) Epicenter distribution map of microearthquakes recorded by Iranian Seismological Center (IRSC) from 2006 to 2019. Green star represents macroseismic epicenter of 1641 earthquake. NTF: North Tabriz Fault.

Intensity of 1641 earthquake has been defined as i=2 by Ambraseys and Melville (1982) based on their own intensity scale. This intensity scale has only five grades described as: i=1 Total destruction of all man-made structures, with a large number of people killed, including leading

citizens, and total loss of livestock; i=2 All dwellings destroyed and many public buildings ruined, with numerous casualties and some loss of livestock; i=3 Many houses ruined and a few people killed; i=4 Few dwellings ruined, public buildings cracked, without fatalities; i=5 Shock widely felt, causing concern and in places panic. In this intensity scale, damage to isolated public buildings, survival or collapse of minarets and free-standing walls, faulting, landslides and rockfalls, as well as liquefaction and slumping of the ground were not used as criteria for grading intensity.

According to Berberian (2014), the historical earthquake of 1641 took place to the south of the North Tabriz Fault and was not associated with slip on that fault. It is probable that the region of Osku has experienced no historical earthquake of large magnitude, except the 1641 historical earthquake. There are only sparse micro-to small earthquakes that have been recorded by seismographic network of the Iranian Seismological Center (IRSC), for the region of Osku, since 2006 (Fig. 1).

Surface deformations and landforms

In the region, where 1641 Dehkhwarghan-Tabriz earthquake occurred, normal faults seem to be dominant structures (Fig. 2). Indications of sinistral strike slip faulting and rely ramps were observed in the field. Relay ramps are common in normal fault zones and commonly occur in areas of active extension (Hus et al., 2005) (Fig. 3A). It is an area of reoriented bedding between two normal faults that overstep in map view and have the same dip direction (Peacock et al., 2000).

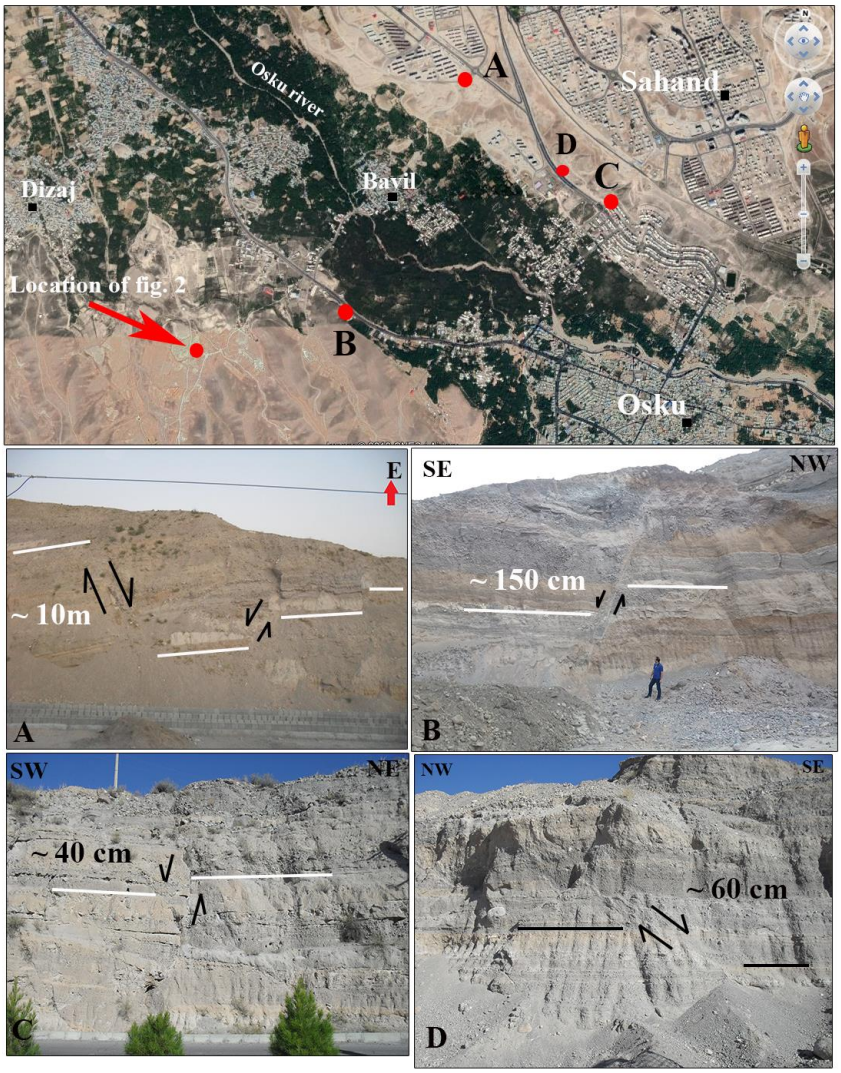

Figure 2. Normal faults, near Osku.

Numerous studies have described examples of relay ramps observed at different locations and scales (Hus et al., 2005). Ramp's Bedding is reoriented because of flexuring between the two fault segments, producing steep displacement gradients along the segments at the ramp (Peacock and Sanderson, 1994). According to Bucci et al (2006), relay ramps commonly occur in areas of active extension and they have relevance in terms of fault segmentation, fault linkage, and related seismic potential. Bucci et al (2006), also, proposed consideration of field evidence of an active relay ramp in a seismic area as a clue to the definition of a seismogenic normal fault.

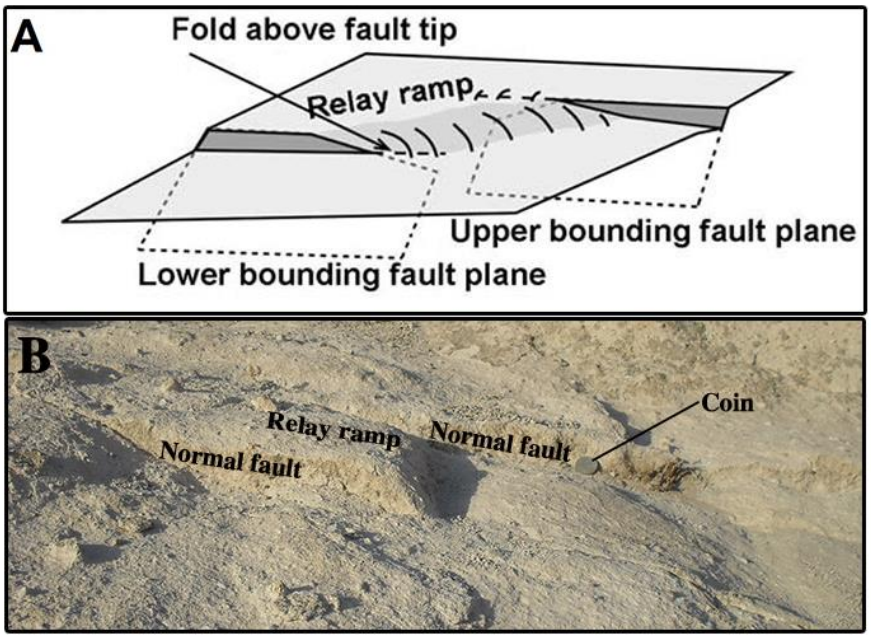

Figure 3. (A) Initial stage of relay ramp developed between two stepping normal faults (Matmon et al., 2010). (B) Northeastward view of a small-scale relay ramp between normal fault segments, in the limestones, near Osku.

According to Fossen and Rotevatn (2016), relay structures occur in many settings and scales in naturally deforming rocks where populations of structures evolve from small to large sizes. In near Osku, we observed a relay ramp associated with normal faulting within the volcanic ash of to Sahand Mountain (Fig. 3B). Sahand Mountain is located about 40 km southeast of Osku (Figs. 1).

Faridi et al (2017) indicated that the causative fault of the 1641 Dehkhwarghan-Tabriz earthquake is a left lateral strike-slip fault with length about 20km. Strike-slip faults usually leave recognizable topographic features. One of the specific geomorphic phenomena of the strike-slip faults are deflection of rivers. The Osku river, originated from north of Soltan Daqi mountains in the west of Sahand Mountain, has responded to tectonic deformation. Deflection of the river which passes through Osku reveals a left-lateral faulting (Fig. 4).

Water Springs

Fault zone hydrogeology is very important in active tectonic studies; because, structural factors play a significant role in flow and motion of groundwater in aquifers (Bense et al., 2013). A fault zone, an area with many fractures and surface ruptures which are close together (Ben-zion and Sammis, 2003; Kim et al., 2004), can act as channels or barriers (Aydin, 2000; Bense and Person, 2006). The flow of groundwater can significantly be altering if faulting juxtaposed an impermeable rock, such as a plutonic or metamorphic rock against a good aquifer (Twiss and Moores, 1992). The core of fault zone, can act like a conduit or barrier in different situations, but damage zone acts as conduit for groundwater (Caine et al., 1996). Osku is located in the slopes of mount Sahand; where aqueducts carrying alluvial sediments from the mountain. The Quaternary sediments in this area, which are weakly cemented and poorly sorted (due to the short time for transported sediments), have suitable condition to form an aquifer. There are 10 villages and 172

springs surrounding the Osku. Location of the villages and the springs are presented in Figure 4 and Table 1.

Table 1- Distribution of springs in the villages of the Osku region.

No.	Village	Number of springs
1	Khasragh	10
2	Dizaj	27
3	Esfanjan	7
4	Eskandan	2
5	Osku	25
6	Milan	7
7	Bavil	45
8	Kalajah	25
9	Bayram	14
10	Fassaghandis	10
	Sum	172

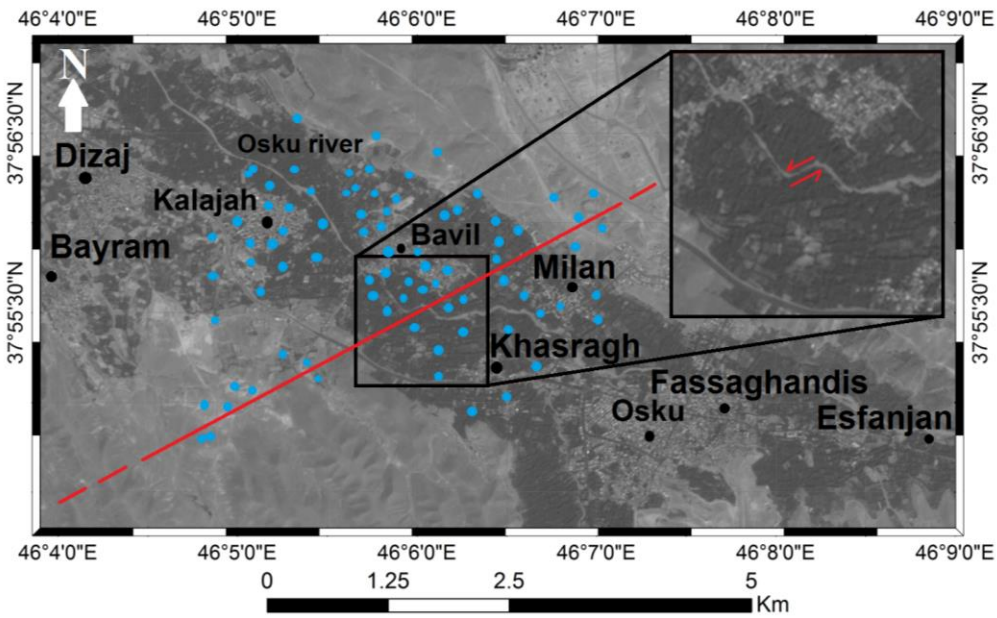

Figure 4. Satellite image of the left-lateral strike slip displacement along the Osku river. Proposed causative fault of the 1641 Dehkhwarghan-Tabriz earthquake (solid red). The blue circles represent locations of water springs in Bavil, Kalajah, Khasragh and Milan villages.

Esfanjan and Eskandan villages in east of Osku contain 7 and 10 springs respectively. To the northwest of Osku in the Bavil and Kalajah, number of springs increase noticeably, to 45and 25 respectively. From these villages to the west, the number of springs decreases again; in a way, in Khosrowshahr which is located in the west of Osku and 7 km away from it, there is only 7 springs. Noticeable increase of the springs in Bavil and Kalajah, most probably is related to the existing fault damage zone in this region (Fig. 4).

CONCLUSION

The evidences of fault damage zone in an area where historical earthquake of 1641 destroyed Osku region may indicate causative fault of this event. Noticeable increase of the springs in villages west of Osku, most probably is related to the existing fault damage zone in this region. Such evidences are important and key to studies of seismicity and tectonics in the Osku region.

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