Proceedings of the 18th Iranian Geophysical Conference, May 2018, pages 249-252

Landslides as paleoseismic indicators along the North Tehran Fault (North of Iran)

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ABSTRACT
Study of large earthquakes in mountainous ranges suggests that earthquakes have always caused multiple landslides. We used Earthquake-induced Landslides for our paleoseismology investigations along North Tehran Fault (NTF). After identifying 4 landslides (Kan (2 landslides), Suleghan and Keshar) we studied them for seismic triggering. Based on our field studies and some other evidences like 958AD Ray-Taleghan earthquake's report, seismic triggering can be inferred. We collected our OSL samples for dating Suleghan landslide from its Lake sediments which caused by the landslide. We also have a plan to take samples from other landslide so we can compare the ages of landslides. If all four landslides show a similar age, all four of them are triggered in an earthquake and otherwise there will be other scenarios. We also observed Olistolith deposits which they are most likely to be deposited during the paleo-earthquakes (Eocene) in the Karaj sedimentary basin and show inversion tectonics in central Alborz (normal to reverse).
Keywords: (Earthquake-induced landslide, Olistolith, Alborz)

INTRODUCTION
Study of large earthquakes in mountainous ranges suggests that moderate to large earthquakes have usually caused multiple landslides (McCalpin, 2009). An obvious example is the Roudbar-Manjil earthquake (A magnitude 7.4 earthquake on June 20, 1990 in the Alborz mountain range). More than 100 landslides were triggered by the earthquake of which some were catastrophic. Therefore, landslides can be analyzed to determine the likelihood of seismic triggering. Due to its importance McCalpon (2009) has dedicated one chapter of his book entirely to explain how to use landslides for Paleoseismic Analysis. If evidence suggest that a seismic source have triggered a group of landslides, and if the landslides can be dated, then a paleoearthquake can be deduced, such paleoseismic landslide studies thus can help reconstruct the seismic shaking history of a site or region. This paper attempts to examine the potential of Landslides (EIL) for paleoseismic analysis along North Tehran Fault (NTF) in the near future.

NORTH TEHRAN FALT AND STUDY AREA
According to the description of the previous section, we have been able to carry out our paleoseismology investigation along the Northern Tehran Fault (NTF) which is a north-dipping thrust fault marking the boundary between Eocene rock formation and alluvium (Fig.1) and as mentioned by Abbassi and Farbod (2009) the NTF is consisted of two major faults arranged in an enechelon manner namely, Niavaran and Hessarak affecting mainly younger alluvial units (Holocene and late Pleistocene) and these two faults lye 1.5 km southward the NTF (Note that the entire boundary between rock formation and alluvium mapped as a fault (North Tehran Thrust) by previous workers is not active nowadays). To find a suitable segment of the NTF for our study, we conducted extensive literature review. It's clear that the NTF extends over a length of about 110 km (Ritz et al., 2012) and is located at the southernmost piedmont of Central Alborz and in the north part of the Tehran metropolis. Aerial photos, Google Earth images, geological maps and lithology of the region have been investigated to help us to make the best possible choice. A few points have been considered in these reviews. i) We have tried to choose a region that is close to the NTF and is not far from it. ii) An attempt has been made to select a region that has reports of historical earthquakes. iii) A cluster of landslides has taken place in a nearby area. iv) Seismic origin for landslides can be interpreted. Regarding these points, we select the Kan-Suleghan area in the northwest of Tehran (Fig.1). Our study area is a segment of the NTF with the approximate east-west trend and located in the meisoseismal area of 958 AD Ray-Taleghan earthquake, and in the vicinity of it, in the Kan-Suleghan area, we identified four landslides.

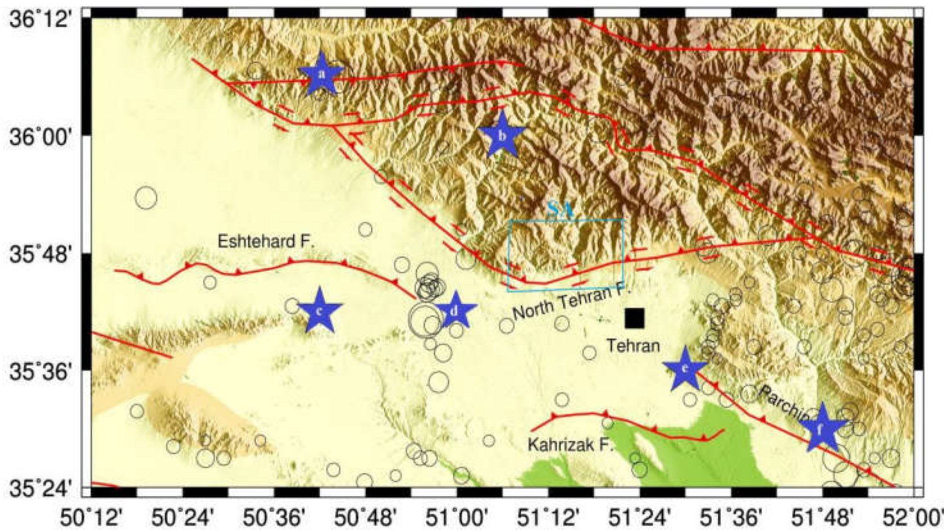


Figure 1. Sothern part of Central Alborz region (North of Tehran), and its major faults. Hollow circles are Instrumental earthquakes and blue stars are Historical earthquakes (Ambraseys and Melville, 1982; Berberian and Yeats, 1999). Blue stars: a 958AD, b 1830 Damavand-Shamiranat, c1177 East Buyin Zahra, d 312-280BC, e 855AD and f 743AD. The blue rectangle represents the study area.

958 AD RAY-TALEGHAN EARTHQUAKE

Since our study area is within the meisoseismal area of 958 AD Ray-Taleghan earthquake (Ambraseys and Melville, 1982), the report of this historical earthquake will be our first evidence for seismic triggering. On February 23, 958 AD, a catastrophic earthquake destroyed all villages in the districts of Ray-Taleghan. One village in the Taleghan area overwhelmed by landslides and in the mountains of Ruyan to the north of Ray, large-scale landslides blocked the course of a river whose waters receded to form a lake (Ambraseys and Melville, 1982) which we believe that the lake has been created as a result of the Suleghan landslide because field studies in the Suleghan area and on its landslide proved the existence of lake sediments and lake dam (Table 1, b and d).

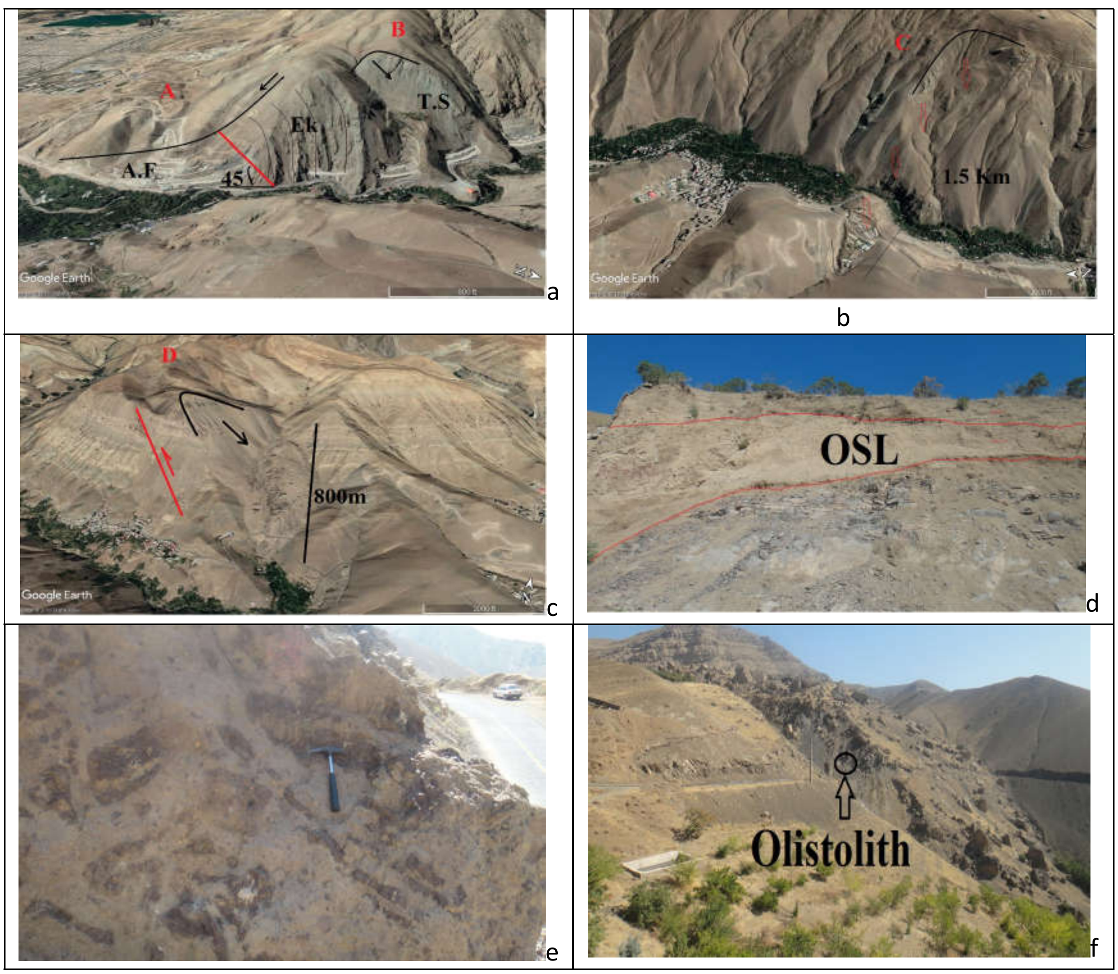
IDENTIFYING LANDSLIDES AND INTERPRETING THEIR SEISMIC ORIGIN ALONG NTF

Landslides preserved in the geologic record can be analyzed to determine the likelihood of seismic triggering (McCalpin, 2009). Firstly, evidence must indicate that a seismic origin is likely for a landslide or group of landslides. Then if the landslides can be dated, a paleoearthquake can be inferred, and some of its characteristics can be estimated. These studies can help reconstruct the seismic shaking history of a site or region. Many paleoseismic landslide studies involve analysis of large groups of landslides rather than individual features and the premise of these regional analyses is that a group of landslides of the same age, scattered across a discrete area, were triggered by a single event of regional extent, and in an active seismic zone (e.g., NTF), that event commonly is inferred to be an earthquake (McCalpin, 2009). We identified four landslides in our study area (Table1, a,b and c).

After identifying landslides (Kan, Suleghan and Keshar), interpreting an earthquake origin for a landslide or group of landslides is by far the most difficult step in the process, and methods and levels of confidence in the resulting interpretation vary widely. The 958AD Ray- Taleghan earthquake's report will be our first evidence for seismic triggering which we talked about it in the previous section. Also we reviewed and studied other criteria to support a seismic origin for this landslides. There are different criteria. For example, Crozier (1992) cited six criteria to support a seismic origin for some landslides in New Zealand; these criteria can be applied generally: (1) ongoing seismicity in the region, which has triggered landslides; (2) coincidence of landslide distribution with an active fault or seismic zone; (3) geotechnical slope-stability analyses showing that earthquake shaking would have been required to induce slope failure; (4) large size of landslides; (5) presence of liquefaction features associated with the landslides; and (6) landslide distribution that cannot be explained solely on the basis of geological or geomorphic conditions. It should be noted that perhaps a landslide does not have all the criteria (there are more criteria like, mobility, displacement and size). But a cluster of landslides will have all of them. If we consider the criterion of proximity to the fault, each of the four landslides have this criterion. But the landslides in the Kan region are exactly on the fault and the other landslides, Suleghan and Keshar, are 5 and 6 kilometers far from the fault, respectively. The Sulaghan landslide also damped the river of Kan and the dam and lake sediments are visible. About one and a half kilometers displacement is observed in Suleghan landslides

(Table1, b) which is the highest amount of mobility among landslides in the region (which shows high energy). All four landslides are located in a small area (In a rectangle with a length of four and a width of two kilometers). The slip surface in Keshar landslide is exactly parallel to a reverse fault (Table1, c), and this landslide is located exactly on the hanging wall of the fault (It seems to be one of the branches of the NTF with a dip of about 70 degrees to the northeast). According to this description, we consider the seismic origin for each of the four landslides. And we have taken samples of lake sediments of Suleghan landslide in order to date this landslide with OSL method. We also plan to take samples from other landslide so we can compare the ages of landslides. If all four landslides show a similar age, all four of them are triggered in an earthquake and otherwise there will be other scenarios. Finally, in our field studies, we encountered an interesting phenomenon in the Keshar landslide. We observed Olistolith deposits (Table1, e and f) which they are most likely to be deposited during the paleo-earthquakes (Eocene) in the Karaj sedimentary basin. An olistostrome is a sedimentary deposit composed of a chaotic mass of heterogeneous material, such as blocks and mud, known as olistolith, that accumulates as a semifluid body by submarine gravity sliding or slumping of the unconsolidated sediments (in the Keshar area we can see Landslide and Slumping in exactly one location and are on each other). We think Keshar is a reactivated graben in which Landslide shows reverse faulting and slumping (Olistolith deposits) shows normal faulting and one can see inversion tectonics of central Alborz in this unique site (Table1, f).

Table1. Pictures of field study and Google Earth images. a (A and B are Kan Landslides, A.F is A formation, Ek is Karaj Eocene Formation and T.S is Travertine spring), b (C is Suleghan Landslide) and c (D is Keshar Landslide) are Google Earth images. d is Lake sediments of Suleghan Landslide which we collected our OSL samples from it. e is Olistolith deposits in the Keshar landslide. f shows Keshar landslide and the location of Olistolith deposits.



CONCLUSIONS

There is a very high potential for paleoseismic analysis of landslides along the NTF. Identifying surface features as landslides can be relatively easy for fairly recent, well-developed, simple landslides. According to our studies, the seismic origin of all four landslides (Keshar, Suleghan and Kan (2 landslides)) is likely. At present, sediment samples are taken from the Suleghan landslide for dating with OSL method. The next step in our study is dating these landslides. We also observed evidences of inversion tectonics in the Keshar area which shows normal faulting in the past (Slumping or Olistolith deposits) and reverse faulting at present (Landslide).

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