EVALUATION OF ACTIVE TECTONICS OF THE SOHREIN FAULT ZONE USING MORPHOMETRY AND GEOMAGNETIC SURVEY

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ABSTRACT

In this study, mechanism and geometry of the Sohrein Fault zone, located in the North West of Zanjan, is investigated. Before this study, the ~75-km-long Sohrein Fault was supposed as a main seismogenic source of the region. Nearly eighty percent of the fault length was mapped based on subtle geomorphic features in late Quaternary deposits. Discovering true surficial extend, geometry and mechanism of this fault is thus a major interest for seismic hazard assessment in the Zanjan region and surrounding areas. These objectives were achieved by a combination of neotectonic and geophysical studies. The interplay of tectonic activity and erosion was investigated through field investigation and morphometric analyses. Two geomorphic indices of stream gradient index (SL) and valley width-to-height ratio (Vf) were evaluated using satellite imageries and digital elevation models (DEMs). The geomorphic response of streams in related to tectonic activity do not changes along the while length of the fault. Shallow geometry of the fault was investigated using magnetic survey, induced polarization and resistivity methods. The evidence of Quaternary faulting and even the shallow expression of the fault zone is not distinguished by these geophysical studies. The only effect of faulting is seen in induced polarization method along a small part (<4 km) of the active sector of the Sohrein Fault. These two lines of evidence suggest that the linear Quaternary risers previously interpreted as the surface trace of the Sohrein Fault are likely the landforms produced by retrogressive erosion in fluvial terraces around the Zanjan Rud River. This can be easily formed after a regional change in the base level of the river.

1-INTRODUCTION

Iran is part of the Alpine–Himalayan orogenic belt. The present tectonic of Iran results from the continental convergence of the Arabian and Eurasian plates. According to GPS measurement this convergence occurs at a present day rate of 23 to 25mm/yr (e.g., Reilinger et al., 2006; Vernant and Chery, 2006). Most of the deformation in Iran is accommodated in the major belts (Zagros, Alborz, Kopeh-Dagh) and along large strike-slip faults (e.g., Masson, 2003). NW Iran is a region of intense deformation and seismicity with a complex system of reverse and strike- slip faults situated between two thrust belts of the Caucasus to the north and the Zagros Mountains to the south. The Arabia–Eurasia direction of convergence is due north in this region with a present day rate of about 17 mm/yr (e.g., Reilinger et al., 2006).

The Zanjan region (NW Iran) lies at the junction between the southern termination of right-lateral North Tabriz Fault and the western end of the Alborz mountain range (See figure 2). In Zanjan, signatures of late Quaternary to active deformation had been reported by several authors (e.g., Solaymani et al., 2011) while, there is no evidence of instrumental and/or historical seismicity proportional to this conspicuous tectonic activity. In the absence of earthquake data, activity of geological structures becomes a key to evaluate seismic hazard of the region. Low rates of deformation, however, imply that neotectonic features associated with faults have subtle geomorphic expression. In such a context, the interplay between erosion and tectonics cannot be easily determined and the interpretation of geomorphic features becomes a difficult job. This study combines two different geophysical and geomorphic tools to evaluate the activity of the 75-km-long Sohrein Fault (NW of Zanjan), which is inferred to be one of the main seismogenic source for the city of Zanjan and adjacent areas (e.g., Solaymani et al., 2011). Along almost 85 percent of the length, the Sohrein Fault was traced based on subtle geomorphic features, with unclear erosional or tectonic nature (Solaymani, et al., 2011). Considering the entire length (~75 km) of the fault being reactivated in one seismic event, it is capable to produce a ~7.3 magnitude earthquake (Wells and Coppersmith (1994) empirical relationships). So, determining the active length of this fault is a major interest for seismic hazard assessment in the Zanjan region and surrounding areas.

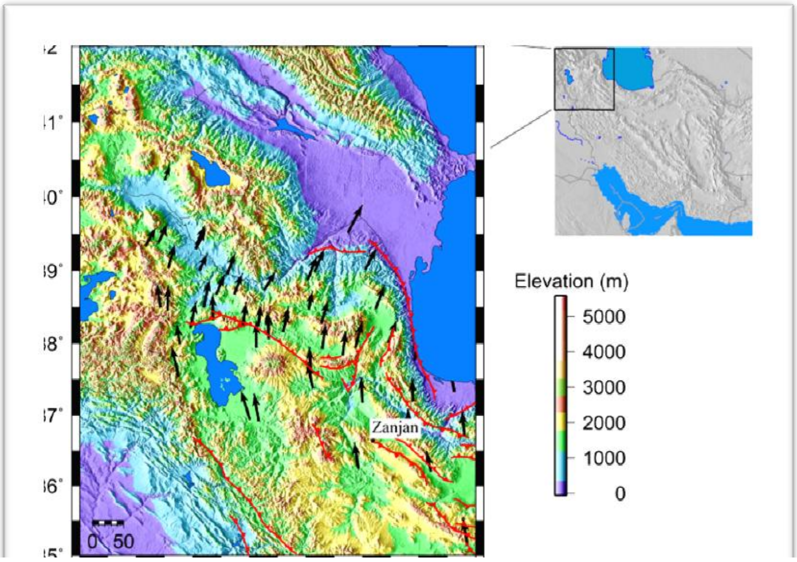


Figure 1. General geodynamic context of NW Iran. GPS vectors from Djamour et al. (2011)

2-GEOLOGY AND TECTONIC SETTING OF THE ZANJAN REGION

The area of interest is located at the junction of the NW Iran, western Alborz and central Iran tectonic provinces. The main geological structures in the Zanjan region are northwest-southeast, north-south and east-west faults which partly accommodates ongoing deformation due to the Arabia – Eurasia convergence. Among the recognized fault zones, the NNW-striking Sohrein Fault (northwest of the city of Zanjan and in the northwest of Zanjan Rud River) is an ambiguous structure traced through Pliocene and Pleistocene deposits as a main fault zone in NW of the city of Zanjan. The fault trace was mapped (Solaymani et al., 2011) in Quaternary deposits overlying the Eocene bedrock. The Quaternary deposits comprise alluvial fans generally composed of gravel, silt and sand, as well as unconsolidated deposits composed of silt, sand and clay. In some places, the trace of the fault makes a boundary between Quaternary and Pliocene deposits. Pliocene deposits mainly include red gypsiferous marl, siltstone and conglomerate. The Pliocene sequence is armored by a ~4-m-thick conglomerate which is principally constituted of andesitic pebbles sourced from volcanic rocks of the region. According to a geological cross-section northward from the right bank of Zanjan Rud River (figure 2) the minimum thickness of Pliocene deposits is suggested of 115 to 155 meter. We prepared a geological map (figure 2) for the study area to achieve a good accuracy in determining lithological boundaries which leads to choose the best site for geophysical surveying.

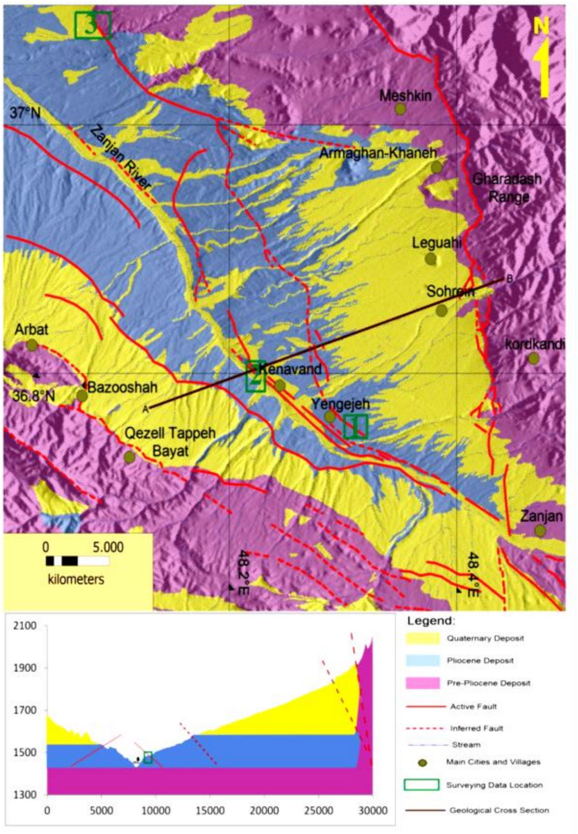


Figure 2. Simplified geological map of study area merged with shaded topography showing the main faults and geological formations (based on the geological map of Zanjan [Geological survey & mineral exploration of Iran] and SRTM Nasa DEM).

3-ACTIVE TECTONICS, ACTIVE FAULTS AND SEISMICITY IN THE ZANJAN REGION

The Zanjan region is the transition between two opposing crustal-scale tectonic movements whose interaction can produce a particular form of active tectonic deformation. In the east side, there is the oceanic-like South Caspian Basin that moves southwest relative to central Iran. This motion is principally accommodated by NW-striking sinistral faults. In the west side, the SW-ward motion of NW Iran relative to central Iran is mainly taken up by NW-striking dextral faults.

Zanjan province and surround area contains lots of important fault like North Tabriz Fault, Bozghush, Astara, Manjil-Rudbar and Sangavar. Some fault zones like Soltanieh, North Zanjan and Mahneshan faults directly affect the city of Zanjan.

Despite this location there is no evidence of instrumental and/or historical seismicity proportional to this conspicuous tectonic activity and our knowledge of active faulting in the region is limited to fault traces mapped mainly based on remote sensing observations.

4-MORPHOLOGİCAL ANALYSİS OF THE SOHREİN FAULT

The Sohrein Fault which is 75-km-long was inferred being one of the main seismgenic sources for Zanjan city and adjucent areas (Solaymani, 2011). What is attributed to activity of the fault is some scarps and topographic edges are seen on STRM DEMs, but the nature of these scarps was undetermined. They could be alluvial trace as a result of erossion along the Zanjan Rud River. Based on detailed field investigations no symmetric trace of active faulting was seen not only along the inferred section, but also along the defenite section. To evalute tectonic activity of the fault two geomorphic parameters (stream-length gradient index *SL* and valley floor width to height ratio *Vf*) were calculated using digital elevation models (DEMs) and satellite imageries.

4.1.STREAM-LENGTH GRADİENT İNDEX

The stream-gradient index is particularly sensitive to changes in slope and thus is a valuable tool in evaluating active tectonics with a strong vertical component of deformation. However, the index is also sensitive to rock resistance (Keller and Pinter, 1996). In a simple way, values of the index are high in areas where the rocks are particularly resistant or where active tectonics has resulted in vertical deformation at the Earth's surface. The *SL* index is defined as:

$$SL= (\Delta H / \Delta L) \times L \tag{1}$$

where SL is the stream-gradient index, $(\Delta H / \Delta L)$ is the local gradient of the stream reach where the index is computed, (ΔH is the drop in elevation of the reach and ΔL is the length of the reach), and L is the horizontal length from the watershed divide to midpoint of the reach (Keller and Pinter, 2002). The value of the *SL* index will increase as rivers flow over active uplifted areas (Keller and Pinter 2002).

The SL index was calculated for seven sub-basins covering whole length of the fault (Table 1); the pattern of SL changes is shown in figure 3.

These result show that SL index increase in a section between the Sohrein Fault and Zanjan Rud River; in contradiction with tectonic activity of the fault. The higher SL value in the section is due to active incision in the Zanjan Rud bed that leads to a local base level change for the surrounding sub-basins. The other reason for higher SL values in the section can be the presence of the Kenavand reverse fault which its activity has been proved through field investigation.

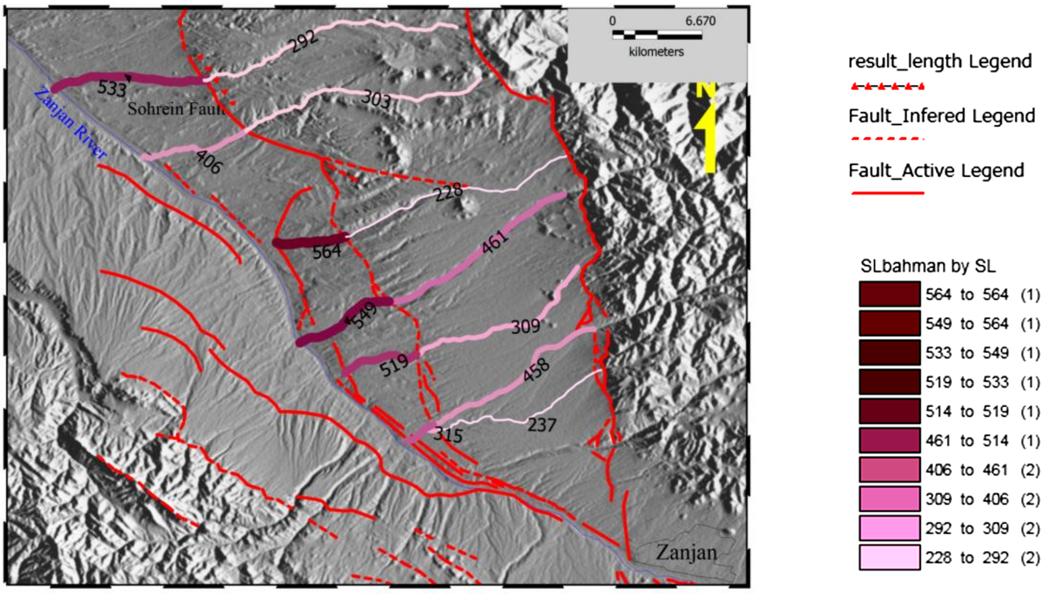


Figure 3. Topographic sun-shaded map derived from the 90m resolution SRTM DEM (NASA). Red continuous line are active faults and red dotted line are inferred faults based on Solaymani, et al., 2011. Calculated SL values written on the streams. Dark violet streams show the maximum SL value and pale violet streams show the minimum one.

4.2. THE VALLEY WIDTH-TO-HEIGHT RATIO

The valley width to height ratio index was originally used to distinguish V-shaped valleys from U-shaped valleys (Bull and McFadden, 1977). V-shaped valleys are common in areas of active uplift and deep, linear stream incision (low *Vf* values, often close to 0). U-shaped valleys are representative of formerly glaciated or tectonically stable areas where stream valley bottoms tend to be wider (higher *Vf* values). The *Vf* index is defined as:

$$Vf = 2.\ Vfw/[(Eid\text{-}Esc+(Erd\text{-}Esc)] \qquad (2)$$

The *Vf* index is defined as the ratio of the valley width to height, *Vf*w is the width of valley floor, E*id* and E*rd* are the respective elevation of the left and right valley divides, and E*sc* is the elevation of the valley floor (Bull and McFadden, 1977).

The *Vf* index was calculated for seven sub-basins covering whole length of the fault (Table 1); Topographic profile along the south part of the Sohrein Fault is shown in figure 4.

Table 1. Classification of the relative tectonic activity index in the Zanjan Rud basin.

No-Part	*SL* (hangingwall)	*SL* (footwall)
1-definite part	303	406
2-definite part	292	533
1-south part	237	315
2-south part	458	514
3-south part	309	519
4-south part	461	549
5-south part	228	564

No-Part	*Vf* (hangingwall)	*Vf* (footwall)
1-definite part	0.85	9.43
2-definite part	0.40	1.58
3-definite part	3.49	1.05
1-south part	1.84	1.32
2-south part	0.41	1.34
3-south part	2.60	3.19
4-south part	2.25	0.79

It is expected that lower and higher *Vf* values being observed on the hanging wall and footwall of the fault, respectively. But the *Vf* values do not show any regular and systematic changes along the fault. This rule is only valid for two valleys traversing the north part of the definite fault portion (see figure 3), where Low *Vf* values are observed on the hanging wall and higher ones on the footwall. Field work in this area provided subtle evidence of fault activity along a small fault (about 4 kilometer) that may be active, but it is not representative of the Sohrein Fault.

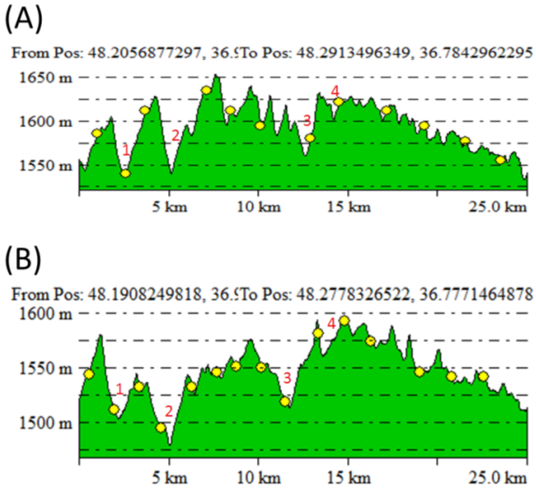


Figure 4. Topographic profile along south part of Sohrein Fault. Profile (A) is on hangingwall and profile (B) is on footwall. There is no significant difference in valley width and height between two profiles. İn this section the calculated *vf* value for four vallies are shown. They are also reported in table 1.

5.MAGNETIC SURVEY OF SOHREIN FAULT

Magnetic surveys were carried out in three sites; two sites along the Sohrein Fault and one site was across the Kenavand fault (shown in Fig 2). Surveying on the Kenavand fault was aimed to evaluate the kind of anomaly which can be produced by an active fault cutting Pliocene and Quaternary deposits of the region.

Alonge Sohrein Fault one site is on the inferred sector and the other is on the definite part of the fault. Ground survey lines were designed to be almost perpendicular to the fault.

In first site, on the south part of the Sohrein Fault, forty-four survey lines were conducted in north-south direction, with 20-m line spacing. A total of 1718 sample points from individual survey lines were collected. The magnetic anomaly map and the 3-D magnetic map are shown in figures 5 and 6. No trace of faulting is seen in these maps and the weak magnetic anomalies are match with topography, so they are related to elevation differences. The result in third site on the definite part of the Sohrein Fault shows also no signature of fault (figure 7). Here forty-six survey lines were conducted in east-west direction, with 20-m line spacing. A total of 2425 sample points from individual survey lines were collected in this site. In the map, a northeast southwest anomaly in the order of 1000nT is observed. This is not related to the fault because it is in a different direction. It can be assigned to a local old structure like a fracture zone, a dike etc.

In second site on the Kenavand fault forty-six survey lines were conducted in north-south direction, with 20-m line spacing. A total of 543 sample points from individual survey lines were collected in this site. The magnetic total map and the 3-D magnetic map are shown in figures 8 and 9. At the bottom of the map, the enormous anomaly is related to the railway line In this map the trace of fault can be seen through the truncation of magnetic anomalies formed by the Quaternary conglomerate units (shown in Fig 8 and 9).). It is a very low anomaly but it is visible. The fault vertically offset the topographic ridges armored by the andesitic conglomerate and disturb the magnetic anomalies the produce in the map. This spatial configuration is confirmed in the field.

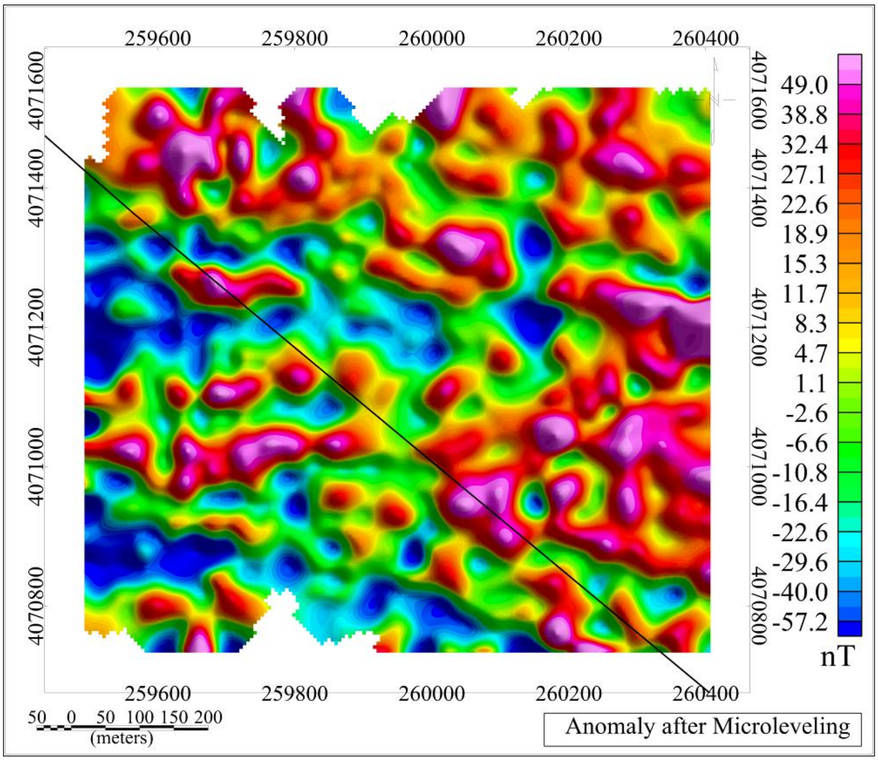


Figure 5. Magnetic anomaly of a section of southern part of Sohrein Fault after microleveling. The black line shows fault trace based on Solaymani, et al., 2011.

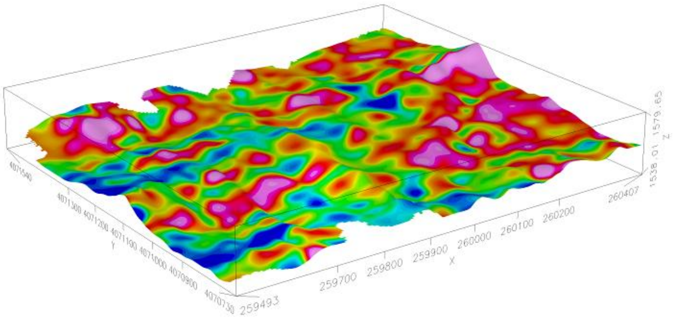


Figure 6. 3-D magnetic map of a section of southern part of Sohrein Fault. The map shows that weak magnetic anomalies are match with topography.

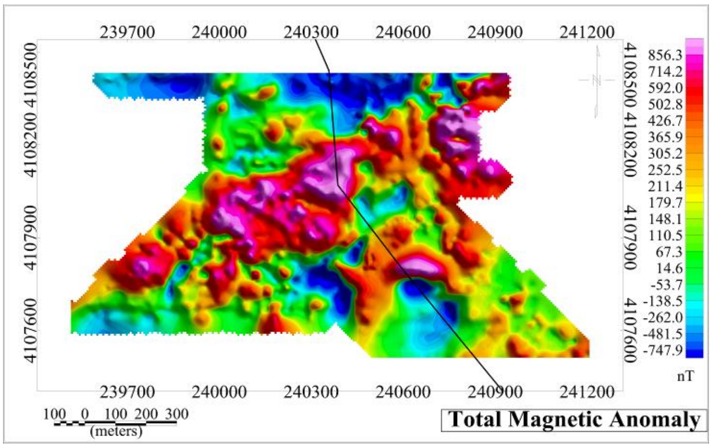
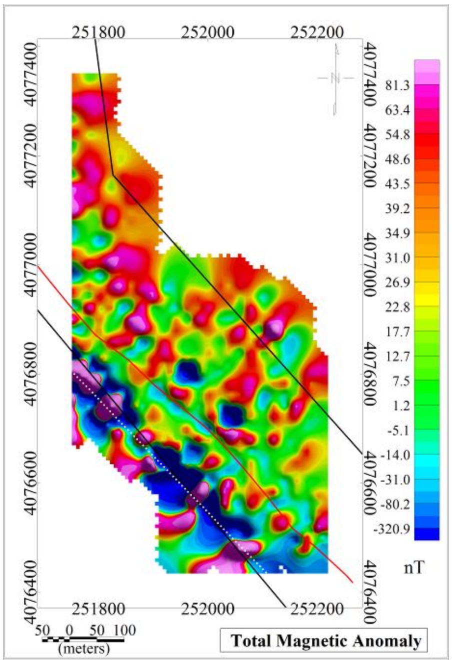


Figure 7. Magnetic anomaly of a section of the definite part of Sohrein Fault. The black line shows fault trace based on Solaymani, et al., 2011. A NE-SW anomaly, non-related to the fault, in the order of 1000nT is seen in the map.



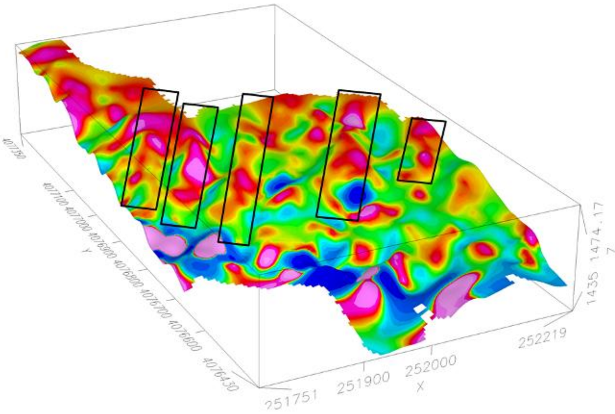


Figure 9. 3-D magnetic map of a section of Kenavand Fault. The distribution of andesitic conglomerates is indicated by rectangles.

Figure 8. Total magnetic anomaly of a section of Kenavand Fault. The black lines show fault trace based on Solaymani, et al., 2011. The red line shows the exact fault trace based on SRTM DEM. The white dotted line is railway

6.CONCLUSIONS

The interpretation of the magnetic surveys of two sites along the Sohrein Fault shows no conspicuous evidence of active faulting. The results of geomorphic investigations also do not show systematical changes in stream responses to tectonic activity. These two lines of evidence suggest that the linear Quaternary risers previously interpreted as the surface trace of the Sohrein Fault are likely the landforms produced by retrogressive erosion in fluvial terraces around the Zanjan Rud River. This can be easily formed after a regional change in the base level of the river. However, other ongoing geophysical techniques (e.g., geo-electric) will improve this preliminary result achieving a firm conclusion on the nature of these geomorphic features.

REFERENCES

Bull WB and McFadden LD (1977) Tectonic geomorphology north and south of the Garlock fault California, In Doehring D.O. (Ed.), Geomorphology in Arid Regions, Proceedings of the Eight Annual Geomorphology Symposium, State University of New York, Binghamton: 115-138

Keller EA and Pinter N (1996) Active tectonics: Earthquakes Uplift and Landscapes, Prentice Hall, New Jersey

Keller E (2000) Investigation of Active Tectonics: Use of Surficial Earth Processes, the National Academy of Sciences

Keller EA and Pinter N (2002) Active Tectonics: Earthquakes,Uplift, and Landscape 2nd Ed., Prentice Hall, New Jersey

Masson F, Djamour Y, Van Gorp S, Chery J, Tatar M, Tavakoli F, Nankali H and Vernant P (2006) Extension in NW Iran driven by the motion of the south Caspian basin. Earth Planetary Science Letters 252, 180–188

Reilinger R, McClusky S, Vernant P, Lawrence S, Ergintav S, Cakmak R, Ozener H, Kadirov F, Guliev I, Stepanyan R, Nadariya M, Hahubia G, Mahmoud S, Sakr K, ArRajehi A, Paradissis D, Al-Aydrus A, Prilepin M, Guseva T, Evren E, Dmitrotsa A, Filikov SV, Gomez F, Al-Ghazzi R and Karam G (2006) GPS constraints on continental deformation in the Africa–Arabia–Eurasia continental collision zone and implications for the dynamics of plate interactions, *J. Geophysical Research Solid Earth* 111, B05411, doi:10.1029/2005JB004051

Solaymani Azad S, Dominguez S, Philip H, Hessami K, Forutan MR, Shahpasan Zadeh M and Ritz JF (2011) The Zandjan fault system: Morphological and tectonic evidences of a new active fault network in the NW of Iran *Tectonophysics*, 506: 73-85

Vernant P and Chery J (2006) Low fault friction in Iran implies localized deformation for the Arabia–Eurasia collision zone, *Earth Planetary Science Letters*, 246: 197–206

Wells L and Coppersmith J (1994) New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement, BSSA, 84(4): 974-1002