EVALUATION OF RELATIVE TECTONIC ACTIVITY IN THE EASTERN PART OF KHAZAR FAULT ZONE, NORTH IRAN

M. Tourani[1*], R. Saber[2], V. Isik[3], A. Caglayan[4] and F. Chitea[5]

[1] *Mrs., Department of Geological Engineering, Ankara University, Ankara, Turkiye*
[2] *Dr., Department of Geological Engineering, Ankara University, Ankara, Turkiye*
[3] *Prof. Dr., Department of Geological Engineering, Ankara University, Ankara, Turkiye*
[4] *Dr., Department of Geological Survey, Ministry of Environment, Urbanisation and Climate Change, General Directorate of Spatial Planning, Ankara, Turkiye*
[5] *Lect. Dr., Department of Engineering Geology and Geophysics, Bucharest University, Bucharest, Romania*
Email: tourani@ankara.edu.tr

ABSTRACT

The Alborz Mountain range, a typical orogenic region located in North Iran, was formed due to the collision of the Iran and Eurasian Plates. This mountain range is characterized by active range-parallel fold and thrust structures that reflect the ongoing tectonic processes in the region. The Khazar Fault Zone is the main active north-bounding fault of the range, characterized by a south-dipping reverse/thrust fault with a left-lateral component. The Khazar Fault Zone represents a significant source of seismic hazard for the entire Alborz Mountain range, especially for densely populated cities on the region's northern side. We employ quantitative geomorphometric analysis techniques to assess the relative tectonic activity within the eastern segment of the Khazar Fault Zone and to explore the variations in deformation along its length. We computed seven geomorphic indices, including Stream length-gradient index (Sl), Drainage basin asymmetry (Af), Valley floor width-valley height ratio (Vf), Index of drainage basin shape (Bs), Mountain-front sinuosity ratio (Smf), Normalized steepness index (Ksn), and Hypsometric curve/Hypsometric integral (Hi), for 39 drainage basins along the study area. Along the eastern part of the zone, the low Smf values (ranging from 1.04 to 1.66) and Vf values predominantly less than 1 across the entire study area indicate relatively straight mountain fronts and young V-shaped valleys, respectively. Moreover, measured uplift rates due to these indices show that the uplift rate is higher than 0.5 mm/yr in the entire area. The values of Af and Bs suggest that most basins indicate notable tilting and elongation. The Sl and Ksn values show a rising trend from west to east in the study area. The Hi results also show that most valleys are young in terms of geological age and deeply excavated. Our results emphasize that relative tectonic activity increases toward the east of the Khazar Fault Zone within the study area. The overall result of the geomorphometric analysis shows that the deformation forces associated with the intense tectonic process along the eastern part of the Khazar Fault Zone are the dominant factors in shaping the surface topography. The geomorphometric results also correlate well with seismological observations, the landscape evolution in the east of the Khazar Fault Zone reflecting the increasing tectonic activity towards this part of the fault.

Keywords: Geomorphic indices, Alborz Mountains, Khazar Fault Zone, Active tectonics, North Iran, Turkish-Iranian Plateau

1-INTRODUCTION

Geomorphological, geodetic, and geological data are commonly employed to analyze and define deformation occurring within tectonically active regions (e.g., Molin et al., 2004; Saber et al., 2022).

Since the early 2000s, the utilization of geomorphic indices has been crucial in establishing the correlation between erosion mechanisms and the tectonic activity of the region (e.g., Silva et al. 2003; Bull 2007; El Hamdouni et al., 2008; Saber et al. 2020; Caglayan et al. 2021). Also, Geomorphic indices serve as valuable tools in evaluating tectonic activity and deformation along active faults, enabling the segmentation of fault sections into intervals of relative tectonic activity (e.g., Rockwell 1984; Saber et al. 2018). Our study focuses on quantitative geomorphometric analysis techniques to assess the relative tectonic activity within the eastern segment of the Khazar Fault Zone located at Alborz Mountain Range in northern Iran. The Alborz Mountains stand out as one of the remarkable morphological features within the Turkish-Iranian Plateau (Fig 1a). This mountain range is characterized by its curved shape with ~ 600 km in length and ~ 100 km in width, located in northern Iran (Fig 1b). The Alborz Mountain range is one of the regions where earthquakes most frequently occur, and active fault zones have historically and instrumentally caused numerous destructive earthquakes (Fig 1b). Both structural and seismological information indicates that parallel and sub-parallel reverse/thrust and strike-slip faults are widespread tectonic structures developed along the range (e.g., Jackson et al., 2002; Allen et al., 2003; Rashidi, 2021; Nazari et al., 2021).

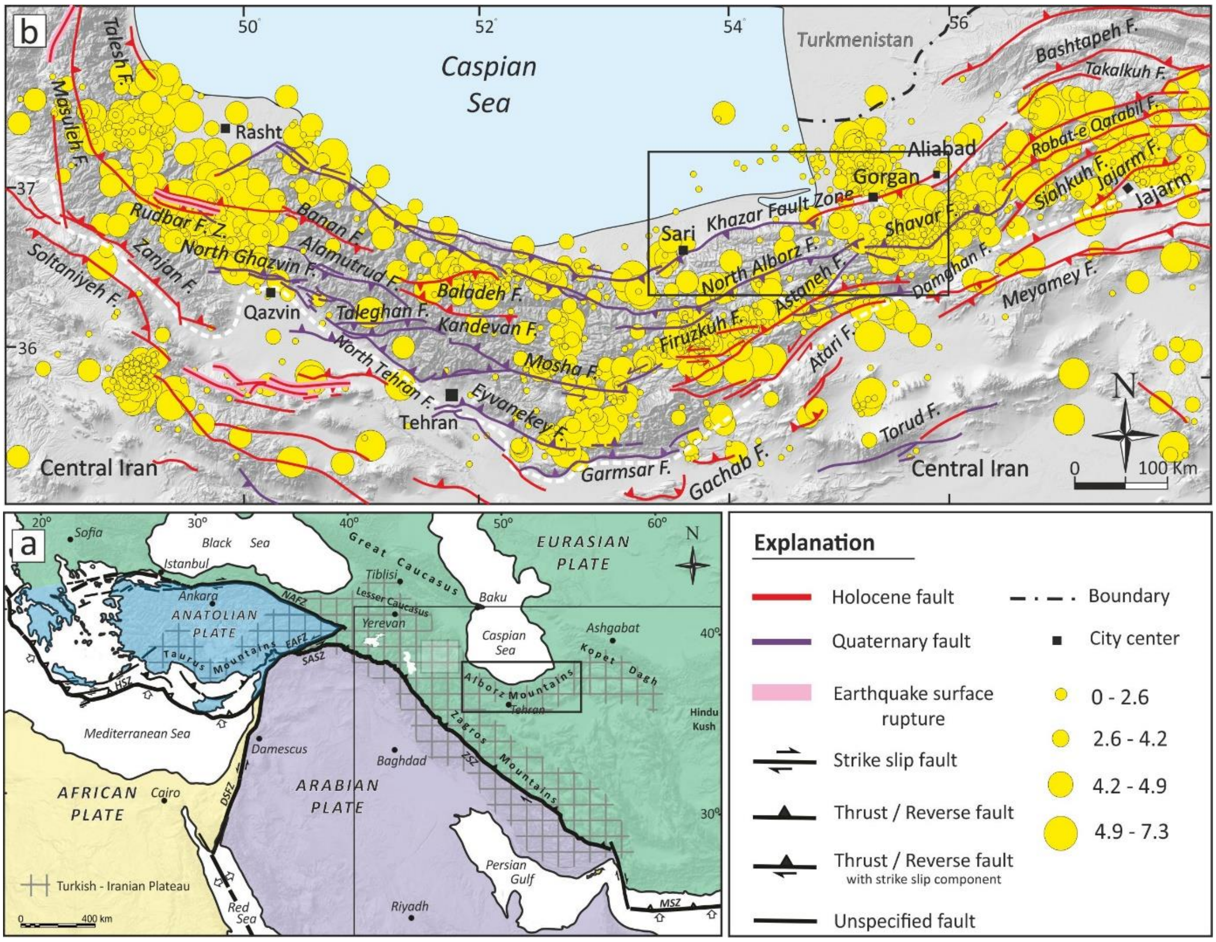

Fig. 1. (a) A simplified tectonic map showing the relationship of the Eurasian, Arabian, African and Anatolian Plates (re-drown from Isik et al., 2021), (b) A map showing active fault zones and the distribution of earthquake epicenters (ISC earthquake catalog) since 1964 along the Alborz Range. Active faults and earthquake focal mechanisms are adopted from the International Institute of Earthquake Engineering and Seismology (2013) and Oveisi et al. (2019).

The Khazar Fault Zone is defined as an active south-dipping, reverse/thrust fault 600 km long located in northern foothills of the Alborz mountains (Rashidi, 2021; Nazari et al., 2021) (Fig. 1b). The Khazar Fault Zone has formed a distinctive morphological landscape between the Caspian Sea and the Alborz

Mountains (Allen et al., 2003; Rashidi, 2021). Ghassemi (2005) states that in the eastern Alborz, the Khazar Fault Zone is usually hidden, segmented and indicated as fault-propagation folds. On the hanging wall of this part of the Khazar Fault Zone, there are low-grade metamorphosed rocks (Fig 2). The eastern part of the Khazar Fault Zone has juxtaposed Percamberin, Paleozoic, Mesozoic and Neogene units over Quaternary deposits (Fig 2). Several destructive historical (Ambraseys and Melville, 1982) and instrumental earthquakes (e.g., the 1985 October 29 Gorgan earthquake - Mw 6.2: Priestly et al., 1994 and the 2004 May 28 Baladeh earthquake - Mw 6.2: Tatar et al., 2007) attributed to the Khazar Fault Zone. Therefore, the Khazar Fault Zone is the most active structure, representing a notable seismic hazard for the entire Alborz Mountain range, especially for densely populated cities on the region's northern side (Nazari et al. 2021).

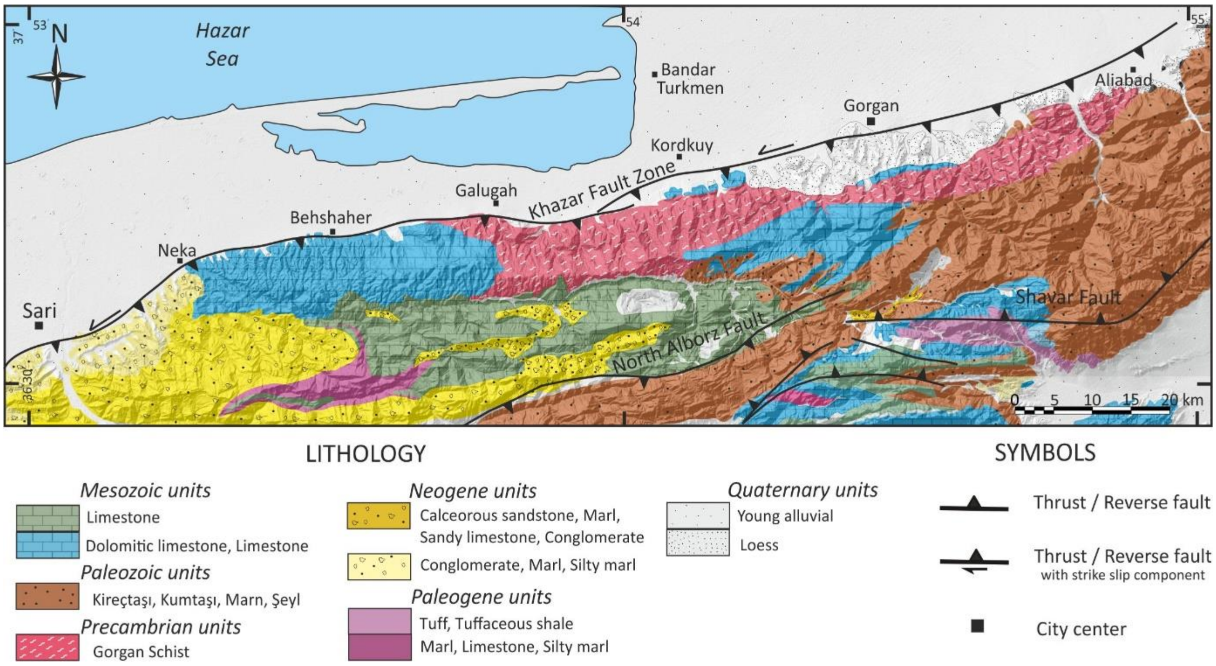

Fig. 2. Simplified geological map of the study area (modified from 1:250,000 geological maps of the Geological Survey of Iran).

2-METHOD and APPLICATION

We employ quantitative geomorphometric analysis using geomorphic indices to assess the relative tectonic activity within the eastern segment of the Khazar Fault Zone and to explore the variations in deformation along its length. The geomorphic indices are extracted with the help of 1 arc second Shuttle Radar Topography Digital Elevation Model (SRTM DEM) data of 30m resolution. Geomorphic indices were calculated and analyzed using the Matlab-based TecDEM toolbox (Shahzad and Gloaguen, 2011), Topo-Toolbox (Schwanghart and Scherler, 2014) and ArcGIS (10.3) modules and some other graphical programs. We computed seven geomorphic indices in Table 1 for 39 drainage basins along the study area (Fig 3a).

Table 1. Morphometric indices were used in the study.

S. No.	Geomorphic Indices	Formula	Reference
1	Mountain front sinuosity (Smf)	Smf = Lmf/Ls	Bull (1977); Keller and Pinter (2002),
2	Drainage basin asymmetry (AF)	AF = 100*Ar/At	Keller and Pinter (2002); Saber et al., (2018)
3	Valley floor width to valley height ratio (Vf)	Vf = 2Vw/[(Eld-Esc) + (Erd-Esc)	Keller and Pinter (2002); Silva et al., (2003).
4	Hypsometric Integral and Curve (Hi)	HI = Hmean – Hmin/ Hmax-Hmin	Keller and Pinter (2002); Saber et al (2022)
5	Stream length gradient index (SL)	Sl=(ΔH/ΔL) L	Hack (1973); Keller and Pinter (2002)
6	Index of drainage basin shape (Bs)	Bs=Bl/Bw	El Hamdouni et al., (2008)
7	Normalized steepness index (Ksn)	S = Ksn∗A−u, and therefore Ksn = S/A−u,	Hack (1973); Flint (1974)

3-RESULTS and CONCLUSIONS

The calculated Vf values along the study area mainly vary between 0.12-0.97 (Fig 4b). The low Vf values, predominantly less than 1 across the study area, indicate relatively young V-shaped valleys. The Smf values range from 1.04 to 1.66 (Fig 4c), and these low values of smf also indicate straight mountain fronts due to relatively high tectonic activity. Moreover, measured uplift rates due to these indices show that the uplift rate is higher than 0.5 mm/yr in the area (Fig 3). According to Af values, 15 basins (38.46%) belong to class 1, 11 basins (28.21%) belong to class 2 and 13 basins (33.33%) belong to class 3 (Fig 4d). So, the majority of drainage basins show high tilting amounts around the fault zone. The Bs values show that 53.85% of drainage basins represent elongated shapes in the study area, and the majority of these elongated basins are located in the eastern section of the study area, suggesting higher tectonic activity (Fig 4e).

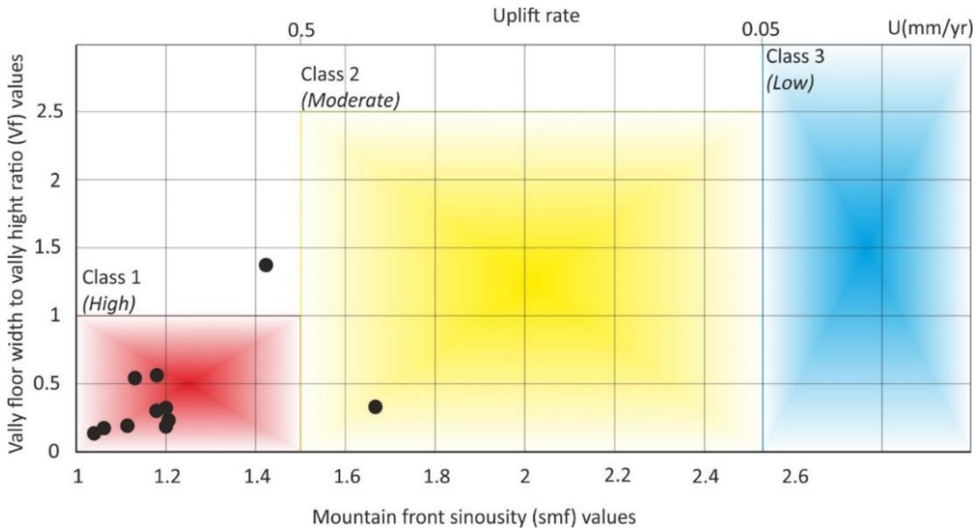

Fig. 3. Chart showing Smf (mountain-front sinuosity ratio) values versus Vf (valley floor width–valley height ratio) values for the mountain fronts of each segment, along with inferred activity classes. The numbers at the top represent inferred uplift rates U (mm/yr) based on Rockwell et al. (1984).

The Sl values range from <200 to >800, indicating a rising trend from west to east in the study area. This suggests that in the eastern part, the Sl anomalies dominantly result from tectonic activities, specifically faulting (Fig 3f). The Ksn values range from 0.005 to 43.38. the Ksn values, also the same as Sl values, show a rising trend from west to east in the study area (Fig 4g). The high values of Ksn in the study area highlight mainly the effect of tectonic processes indicating rapid uplift. The calculated Hi values along the study area vary between 0.15-0.55 and show a rising trend from west to east in the study area (Fig. 4h). The majority of the basins (76.92%) exhibit low Hi values in the study area and these low values show that most valleys are young in terms of geological age and deeply excavated. Our results emphasize that relative tectonic activity increases toward the east of the Khazar Fault Zone within the study area. The overall result of the geomorphometric analysis shows that the deformation forces associated with the intense tectonic process along the eastern part of the Khazar Fault Zone are the dominant factors in shaping the surface topography. The geomorphometric results also correlate well with seismological observations, the landscape evolution in the east of the Khazar Fault Zone reflecting the increasing tectonic activity towards this part of the fault zone.

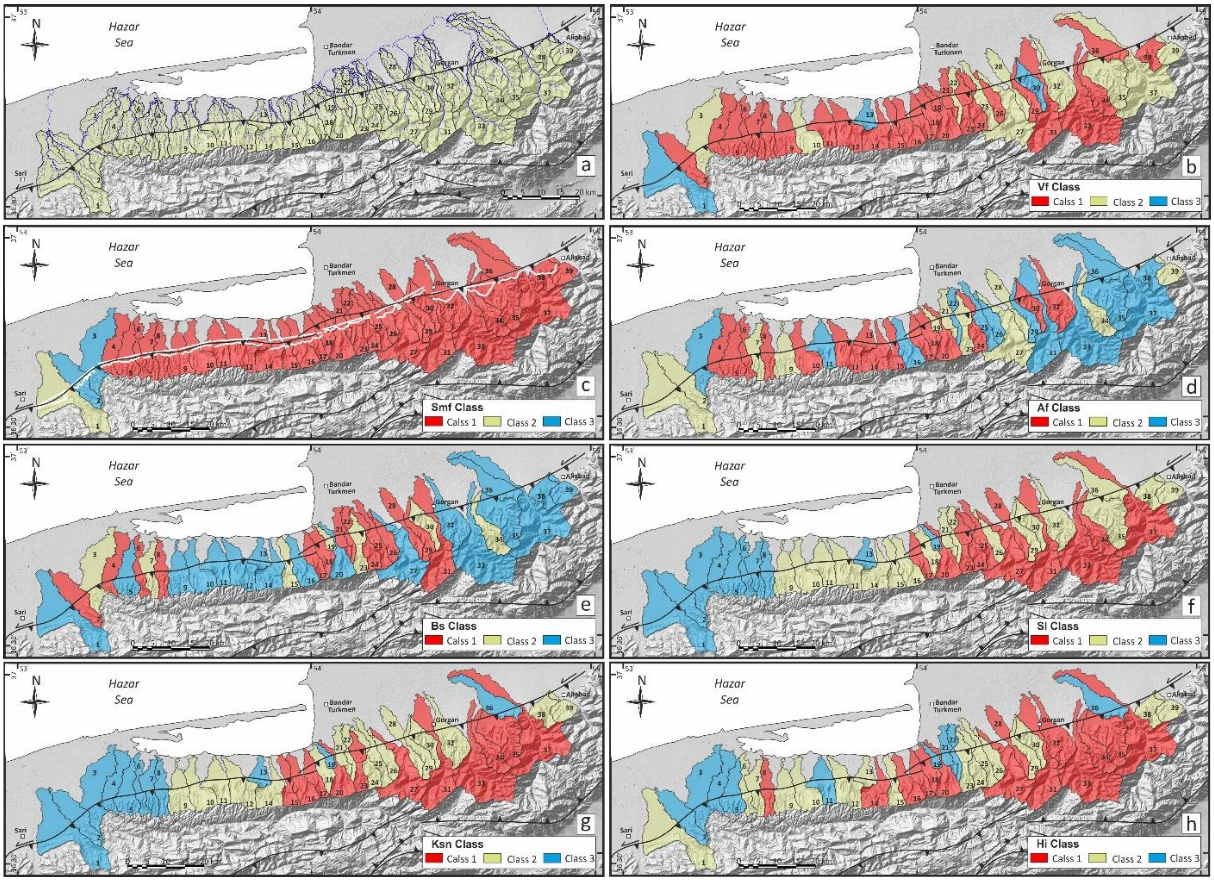

Fig 4. Maps displaying morphometric analysis results along the eastern segment of the Khazar Fault Zone. (a) Extracted drainage basins, (b) Ratio of valley floor width to valley height (Vf), (c) Mountain-front sinuosity ratio (Smf), (d) Drainage basin asymmetry (Af), (e) Drainage basin asymmetry (Bs), (f) Stream length gradient (SL), (g) Normalized steepness index (Ksn) and (h) Hypsometric integral (Hi).

4-REFERENCES

Allen, M.B., Vincent, S.J., Alsop, G.I., Ismailzadeh, A., Flecker, R. 2003. Late Cenozoic deformation in the South Caspian region: effects of a rigid basement block within a collision zone. Tectonophysics, 366, 223-239.

Ambraseys, N.N., Melville, C.P. 1982. A history of Persian earthquakes. Cambridge Univ, Cambridge.

Bull, W.B., 2007. Tectonic Geomorphology of Mountains: A New Approach to Paleoseismology. Wiley-Blackwell, Oxford, pp. 328.

Bull, W.B 1977. Tectonic geomorphology of the Mojave Desert, California. In the US Geological Survey contract report. 14–0-001-G-394 (p. 188). Menlo Park, CA: Office of Earthquakes, Volcanoes, and Engineering.

Caglayan, A., Saber, R., Isik, V., 2021. Geomorphic evidence of active faulting in the Simav Half-graben, Western Turkey. 11th Congress of the Balkan Geophysical Society 10-14 October 2021, Bucharest.

El Hamdouni, R., Irigaray, C., Fernández, T., Chacón, J., Keller, E.A. 2008. Assessment of relative active tectonics, southwest border of the Sierra Nevada (southern Spain). Geomorphology 96, 150-173.

Flint, J.J. 1974. Stream gradient as a function of order, magnitude, and discharge. Water Resour. Res. 10, 969-973. http://dx.doi.org/10.1029/WR010i005p00969.

Ghassemi, M.R. 2005. Drainage evolution in response to fold growth in the hanging wall of the Khazar fault, north-eastern Alborz, Iran. Basin Res. 17, 425-436.

Hack, J.T. 1973. Stream-profile analysis and stream-gradient index. Journal of Research of the U.S. Geological Survey, 1(4), 421-429.

Isik, V., Saber, R., Caglayan, A. 2021. November 08, 2019 Turkmanchay earthquake (Mw 5.9) in NW Iran: an assessment of the earthquake using DInSAR time-series and field evidence. Natural Hazards. https://doi.org/10.1007/s11069-020-04439-1

Jackson, J.A., Priestley, K., Allen, M., Berberian, M. 2002. Active tectonics of the South Caspian Basin. Geophys. J. Int. 148, 214-245.

Keller, E.A., Pinter, N. 2002. Active tectonics: Earthquakes, uplift, and landscape (2nd ed., p. 362). Upper Saddle River, NJ: Prentice Hall.

Molin, P., Pazzaglia, F.J., Dramis, F. 2004. Geomorphic expression of active tectonics in a rapidly deforming forearc, Sila massif, Calabria, southern Italy. Am. J. Sci. 304, 559-589.

Nazar,i H., Ritz, J.F., Burg, J.P., Shokri, M., Haghipour, N., Vizheh, M.M., Avagyan, A., Nashli, H.F., Ensani, M. 2021. Active tectonics along the Khazar fault (Alborz, Iran). J Asian Earth Sci. https://doi.org/10.1016/j.jseaes.2021.104893

Oveisi, B., Sabour, M., Sadeghi, M., Heibati, Z. 2019. Seismotectonic map of Iran, Version I- mint/6294-5890. Ministry of Industry, Mine and Trade. Geol Surv Iran Seismotectonic Department, Tehran, Iran.

Priestley, K. Baker, C. Jackson, J. 1994. Implications of earthquake focal mechanism data for the active tectonics of the South Caspian Basin and surrounding regions. Geophys J Int. https://doi.org/10.1111/j.1365-246X.1994.tb04679.x

Rashidi, A. 2021. Geometric and kinematic characteristics of the Khazar and North Alborz Faults: Links to the structural evolution of the North Alborz-South Caspian boundary, Northern Iran. J Asian Earth Sci. https://doi.org/ 10.1016/j.jseaes.2021.104755.

Rockwell, T.K., Keller, E.A., Johnson, D.L., 1984. Tectonic geomorphology of alluvial fans and mountain fronts near Ventura, California. In: Morisawa, M. (Ed.), Tectonic Geomorphology. Proceedings of the 15th Annual Geomorphology Symposium. Allen and Unwin Publishers, Boston, MA, pp. 183-207.

Saber, R., Caglayan, A. Isık, V. 2018. Relative tectonic activity assessment and kinematic analysis of the North Bozgush fault Zone, NW Iran. Journal of Asian Earth Sciences 164, 219-36. https://doi.org/10.1016/J.JSEAES.2018.06.023.

Saber, R., Isik, V. Caglayan, A. 2020. Tectonic geomorphology of the Aras drainage basin (NW Iran): implications for the recent activity of the Aras Fault Zone. Geological Journal. 55, 5022-48. https://doi.org/10.1002/gj.3724.

Saber, R., Caglayan, A. Isık, V. 2022. Landscape response to deformation in Sabalan area, NW Iran: Inferred from quantitative morphological and structural analysis. Earth Environ. Sci. Trans. R. Soc. Edinb. 113, 227-252. https://doi.org/10.1017/S1755691022000135

Schwanghart, W., Scherler, D. 2014. Short communication: TopoToolbox 2-MATLAB-based software for topographic analysis and modeling in earth surface sciences. Earth Surf. Dynam. 2 (1), 1-7.

Shahzad, F., Gloaguen, R. 2011. TecDEM: a MATLAB-based toolbox for tectonic geomorphology, Part 1: drainage network preprocessing and stream profile analysis. Comput. Geosci. 37, 250-260.

Silva, P.G., Goy, J.L., Zazo, C., Bardají, T. 2003. Fault generated mountain fronts in southeast Spain: geomorphologic assessment of tectonic and seismic activity. Geomorphology. 50, 203-225.

Tatar, M., Jackson, J., Hatzfeld, D., Bergman, E. 2007. The 2004 May 28 Baladeh earthquake (Mw 6.2) in the Alborz, Iran: over thrusting the South Caspian Basin margin, partitioning of oblique convergence and the seismic hazard of Tehran. Geophys J Int. https://doi.org/10.1111/j.1365-246X.2007.03386.x