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RESEARCH PAPER

# Late Cenozoic Faulting at Ziar Area in Central Alborz

**Amirhossein Sharifi, Ali Yassaghi ***

Department of Geology, Tarbiat Modares University, P. O. Box: 14115-175, Tehran, Iran

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**Abstract**
Field investigation and structural mapping of faults cut Mezozoic to Late Cenozoic (Pliocene-Quaternary) rocks in Ziar area of Central Alborz have led to identification of the NW- and NE- trending fault sets. Slickenlines, fault steps and riedel shear fractures are mainly applied as kinematic indicators for analysis of the faults mechanisms. The NW-trending reverse faults with left-lateral strike-slip kinematics and positive flower structure geometry (such as Golezard Fault) is the first set. This set cut through all rock formations up to Plio-Quaternary are proposed to develop during the northeastern oblique transpression deformation governs the Alborz during the final collision of the Arabian- Eurasian plates in Late Cenozoic (Pliocene). The NE-trending strike-slip faults with normal kinematics that cross-cut the Damavand Quaternary volcanic rocks as well as the first faults set are the youngest faults in the region. This fault set development have attributed to the northwestern movement of the South Caspian block in Quaternary, which led to an extension in Central Alborz. These young faults mapped for the first time in this work constrain the Late Cenozoic (Quaternary) faulting of Central Alborz zone, referred as a result of the range major faults reactivation, previously.

**Keywords:** Central Alborz, Quaternary Young Faults, Plio-Quaternary Angular Unconformity, Positive Flower Structure.

## Introduction

Alborz mountain range with an average width of 100 km located on the southern margin of the Caspian Sea. The range that is a part of the Alpine Himalayan orogenic system has shaped areas with active deformation in the Arabia-Eurasia collision zone (e.g., Allen et al., 2003). Alborz Evolution is the result of different terrestrial events from the Late Triassic (Cimmerian orogeny as a result of the Iranian block colliding with Eurasia) to Pliocene -Quaternary (intercontinental deformation affected by the simultaneous continuation of convergence between the Arabian and Eurasian plates and the movement of the South Caspian Block) (Alavi, 1992; Allen et al., 2003; Ritz et al., 2006).

It is generally believed that the major faults in Central Alborz, had predominant reverse mechanisms with the right lateral component before the Late Cenozoic (for e.g. Stocklin, 1974; Alavi, 1992; Allen et al., 2003; Yassaghi & Madanipour, 2008). In Pliocene and as the southern Caspian block moved toward southwest relative to Eurasia caused a change in the mechanism of faults, from Reverse faults with right lateral to left lateral components (e.g. Allen et al., 2003; Yassaghi & Naeimi, 2011;). Since Quaternary (1-1.5 My), the clockwise rotation of the southern Caspian block relative to Eurasia resulted in transtension deformation in Alborz and formation of the left lateral faults with normal components (Ritz et al., 2006). The precence of left lateral with normal component kinematic along the Taleghan, Mosha, Firoozkooh and Karaj-Chalous Road faults (e.g. Jackson et al., 2002; Yassaghi & Naeimi, 2011) provide

* Corresponding author e-mail: Yassaghi@modares.ac.ir

structural constrain for this rotation. The clockwise rotation of the southern Caspian block relative to Eurasia is also consistent with absolute gravitational and GPS data (Vernant et al., 2004; Djamour et al., 2010). Thus, it is generally belived that such rotation is mainly resulted in reactivation of the range major faults.

In this paper, structural evidences from the Late Cenozoic deformations on the Ziar region (along the Haraz Road route) south of Damavand Mount in Central Alborz (Figure 1) are presented and their formation is analyzed.

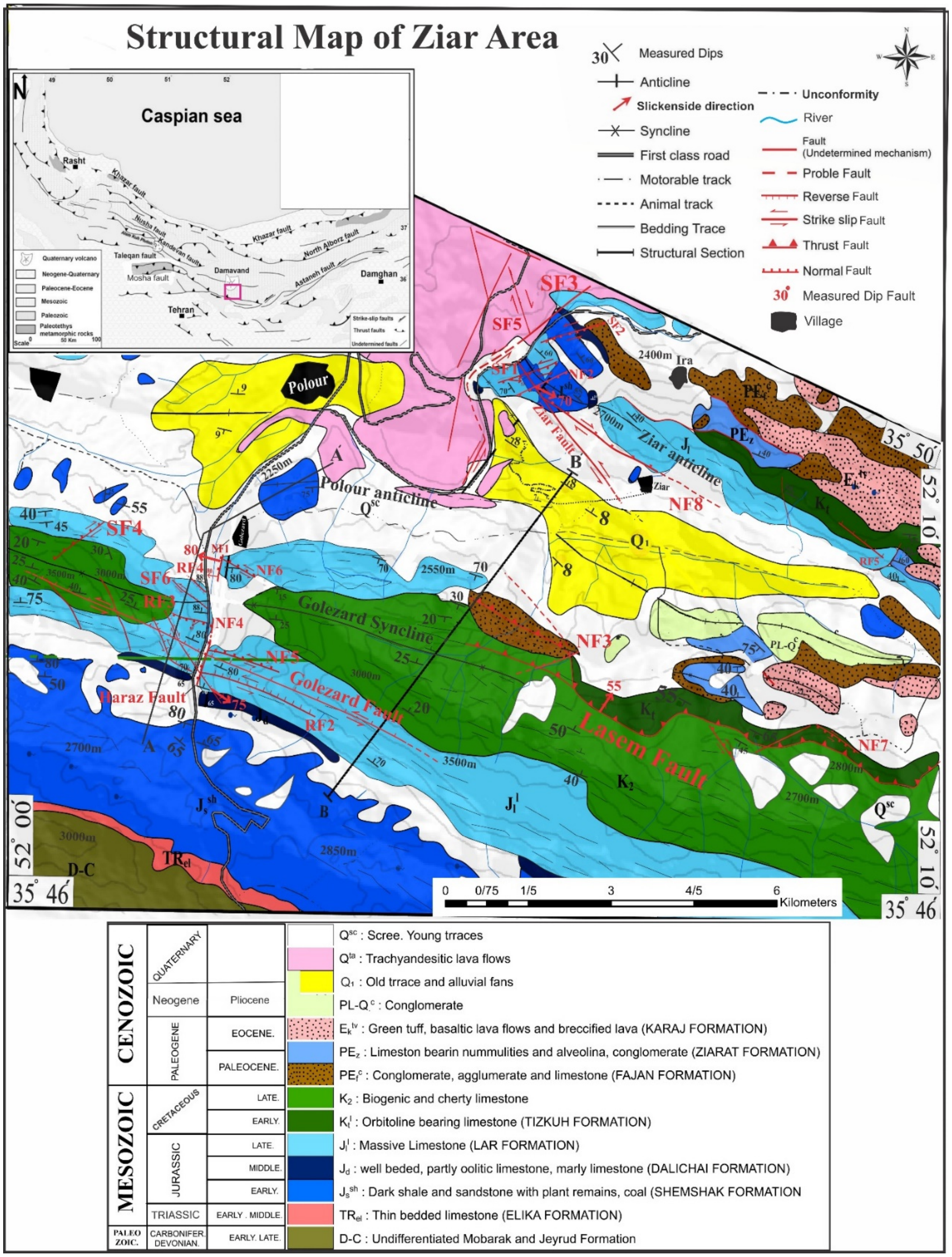


**Figure 1.** Structural geology map of the study area. Insect map shows the major Alborz faults (Berberian & Yeats, 1999) in which the study area is shown with a rectangle

This is carried out by geometric and kinematic studies of its major NW- and the younger NE-trending faults. Such analysis provides structural evidence for the effect of Pliocene-Quaternary events in Central Alborz not only on the reactivation and or reorganization of the range major faults but also on generation of younger faults.

## Materials and Methods

*Structural geometry of the Ziar area*

The Ziar area, located between longitude 52˚ 00΄ to 52˚ 20΄ and latitude 35˚ 48΄ to 35˚ 62΄, is one of the highest region in Central Alborz (Figure 1). Two faults sets, Golezard Syncline, and an angular unconformity of Pliocene-Quaternary deposits are the area main structures (Figures 1 and 2) in which their geometry and kinematic investigation and analysis are presented in this section. Faults identified, mapped and analyzed for the first time in this study have two dominant NE- and NW trends.

NW-trending Faults

These structures such as the Golezard, Ziar and Lasem faults ruptures Mezozoic to Plio-Quaternary rock formations (Figure 1). The Golezard Fault, dipping inversely to the northeast and southwest, have a positive flower structure geometry (Figure 2a) and lifted up the SW limb of the Golezard Syncline as Golezard Mount (Figure 2b). The fault mechanism according to kinematic indicators such as slickenlines (with 60˚ SE in its rake angle, Figure 3a and b) and Riedel shear fractures on the fault surface (Figure 3c) is analyzed as a left lateral reverse fault. To the north of the Golezard Fault, a subparallel structure, the WNW- trending NF4 Fault has mapped (Figure 1 and 4). Using slickenlines (with 45˚ NW in its rake angle, Figure 4c) and fault steps on the fault surface, left normal mechanism is analyzed for the fault kinematics (Figure 4c).

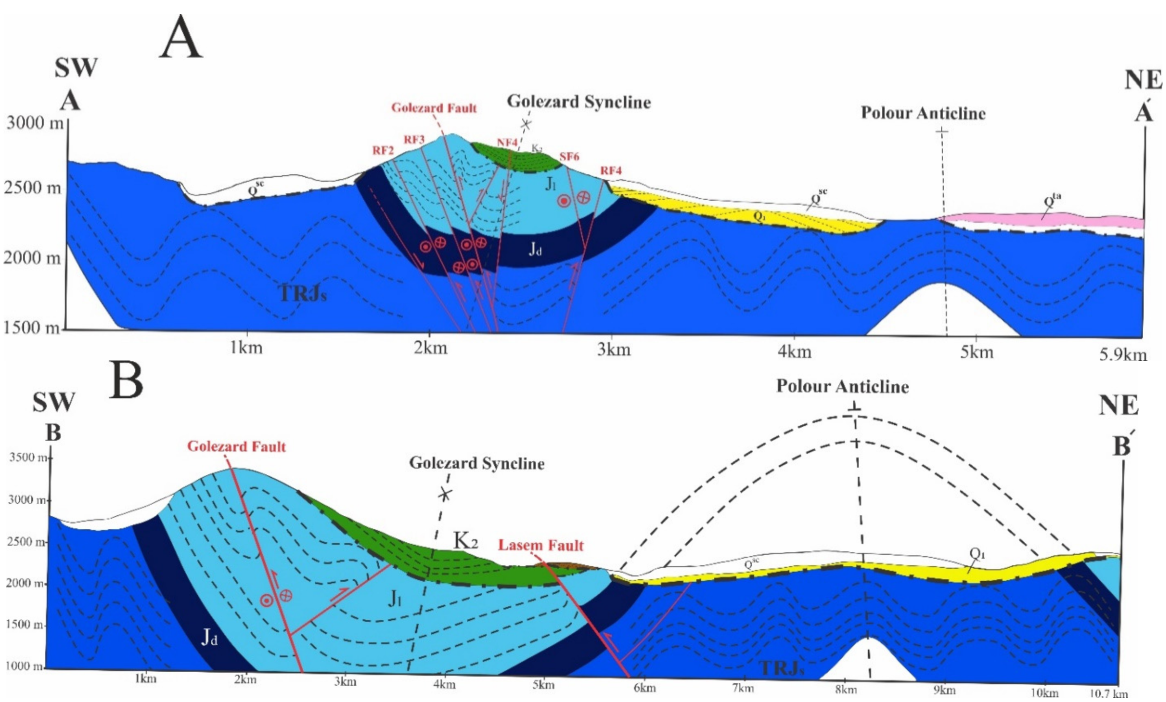


**Figure 2.** structural sections across the study area. For their location refer to Figure 1

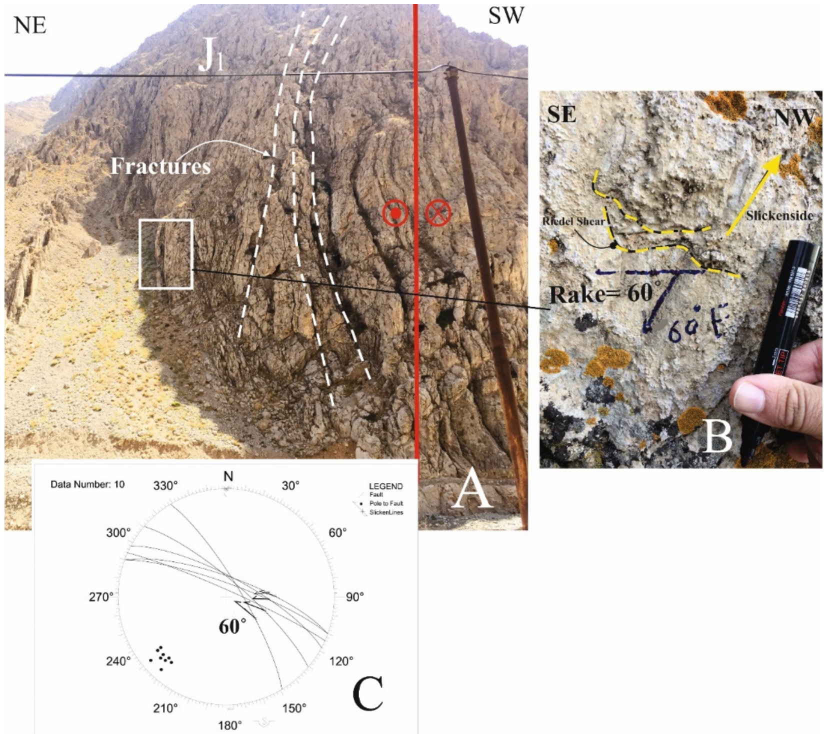


**Figure 3.** A: The Golezard fault zone in the Golezard Mountain (View to the southeast). The white box is location of B and the white dash lines are riedel shear fractures. B: Slickenlines and riedel shear fractures (yellow dash lines) on the fault surface. Yellow arrow indicates direction of the missing block movement C: The stereographic projection of the fault splays with their kinematic analysis

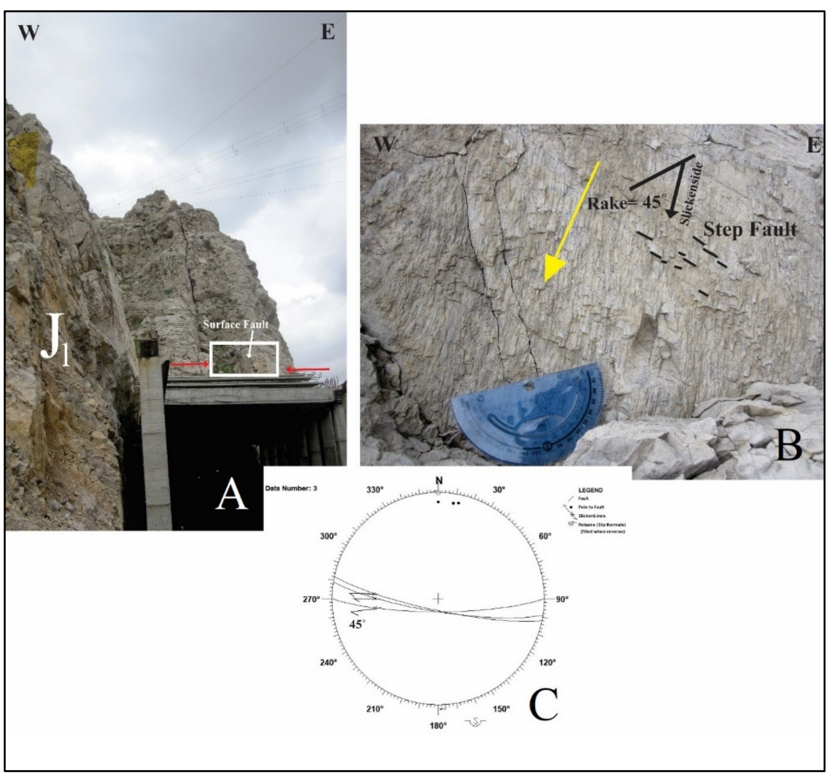


**Figure 4.** A: The NF4 Fault surface crossing the Haraz Road in the Central part of the Golezard Syncline (view north) B: Slickenlines and fault steps on the fault surface. Yellow Arrow indicates the movement direction of the missing hanging wall block. C: The stereographic image of the fault kinematic analysis

The Lasem Fault dipping about 55˚ to northeast is another NW-trending fault in the study area that has ruptured the southern limb of the Golezard Syncline (Figures 1 and 2b). This fault thrust the calcareous units of the Early Cretaceous Tizkuh Formation (Kt) over the the Late Cretaceous carbonate rocks (K2) (Figure 5a). Using slickenlines (with 85˚ NW in its rake angle, Figure 5c) and Riedel shear fractures on the fault surface (Figure 4b), reverse mechanism is analyzed for the fault kinematics (Figure 5c).
The Ziar Fault is the other NW- trending fault mapped in this study (Figures 1 and 6a). Kinematic indicator such as riedel shear fractures and slickenlines orientation (with 25ºSE in its rake) on the fault surface shows the left lateral with reverse component for the fault kinematics (Figure 6c and d).

The NE-trending Faults

The NE-trending faults crosses the study area main structures such as the Golezard Syncline, the NW-trending faults such as the Golezard, Lasem and Ziar faults as well as Damavand Quaternary volcanic rocks are most prominent young stuctures in the area. The Haraz, NFn and SFn faults, mapped for the first time in this study, are among these faults (Figure 1). The Haraz Fault goes through the Haraz valley has displaced Mezozoic rock formations as well as the Damavand Quaternary volcanic rocks (Figure 7a).

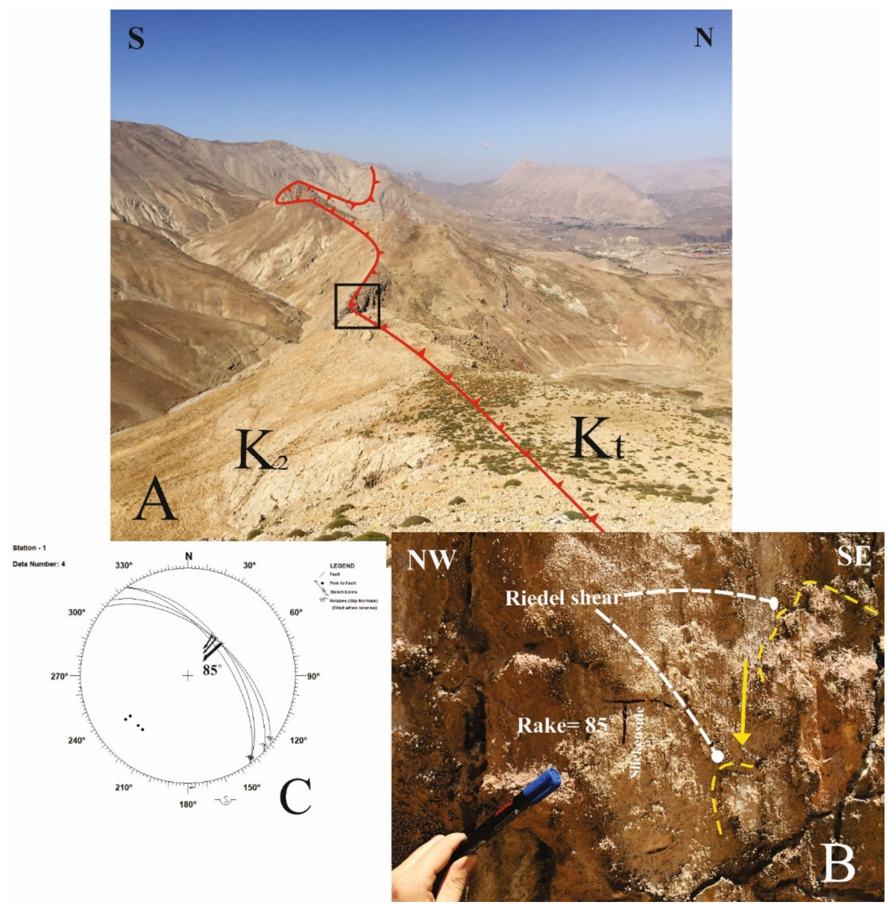


**Figure 5.** A: The Lasem Fault, showing emplacement of the Cretaceous Tizkuh Formation ($K_t$) over the calcareous units of the Late Cretaceous rocks ($K_2$) (view to West) B: The Lasem Fault surface having slickenlines and riedel shear fractures (yellow dash lines). The yellow arrow indicates the movement direction of the footwall-missing block (photo view from the fault bottom surface). C: Stereographic projection of the fault kinematic

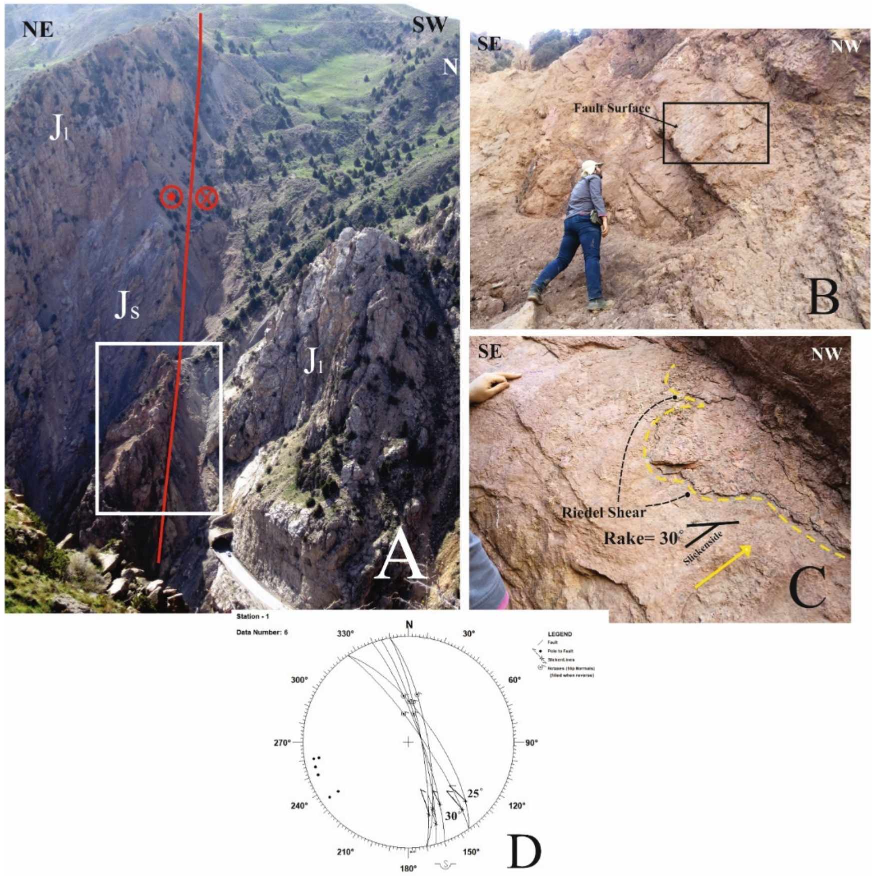


**Figure 6.** A: View of Ziar Fault along the Haraz Road (view south-east) The white frame in the image shows location of image B. B: The Ziar fault surface (view southwest) C: Slickenlines and riedel shear fractures (yellow dash line) on the Ziar fault surface. The yellow arrow indicates the movement direction of the fault missing block. D: Stereographic image of the Ziar Fault kinematic analysis

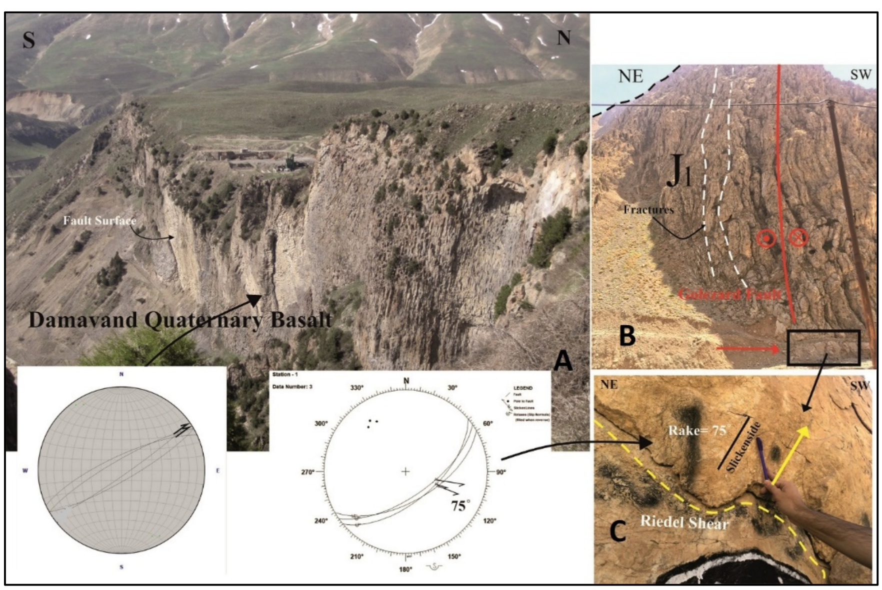


**Figure 7.** A: Haraz fault surface ruptures the Damavand volcano Quaternary rocks. B: Black box drawn on the Haraz Fault surface that crosses the Golezard Fault (view to East). C: Haraz Fault surface showing slickenlines and Riedel shear fracture (yellow dash line) kinematic indicators on the fault bottom surface. Yellow arrow indicates the movement direction of the footwall missing block

The Haraz Fault dipping 70 to 85 degrees towards SE or NW displaced the region main structures, such as the Golezard Syncline and the Golezard Fault where the fault surface form a road cut wall along the Haraz Road route (Figures 1 and 7b). Kinematic indicators such as slickenlines as well as Riedel shear fractures on the fault surface document left lateral (Figure 7a) to left lateral with normal component (Figure 7c) for the fault zone kinematics.The NF3 Fault as another NE-trending structure is dipping about 65˚ to the northwest (Figure 1). Slickenlines with 70ºSW in rake angle as well as Riedel shear fractures on the fault surface indicate a normal with left-lateral component for the fault mechanism (Figure 8). The SF3 Fault cut through the Damavand Quaternary volcanic rocks along the Haraz Road route in the Polour area, is the other main NE-trending faults that dipping 80º to NW (Figures 1 and 9a). Riedel shear fractures on the fault surface indicates left lateral kinematics for the fault (Figure 9).

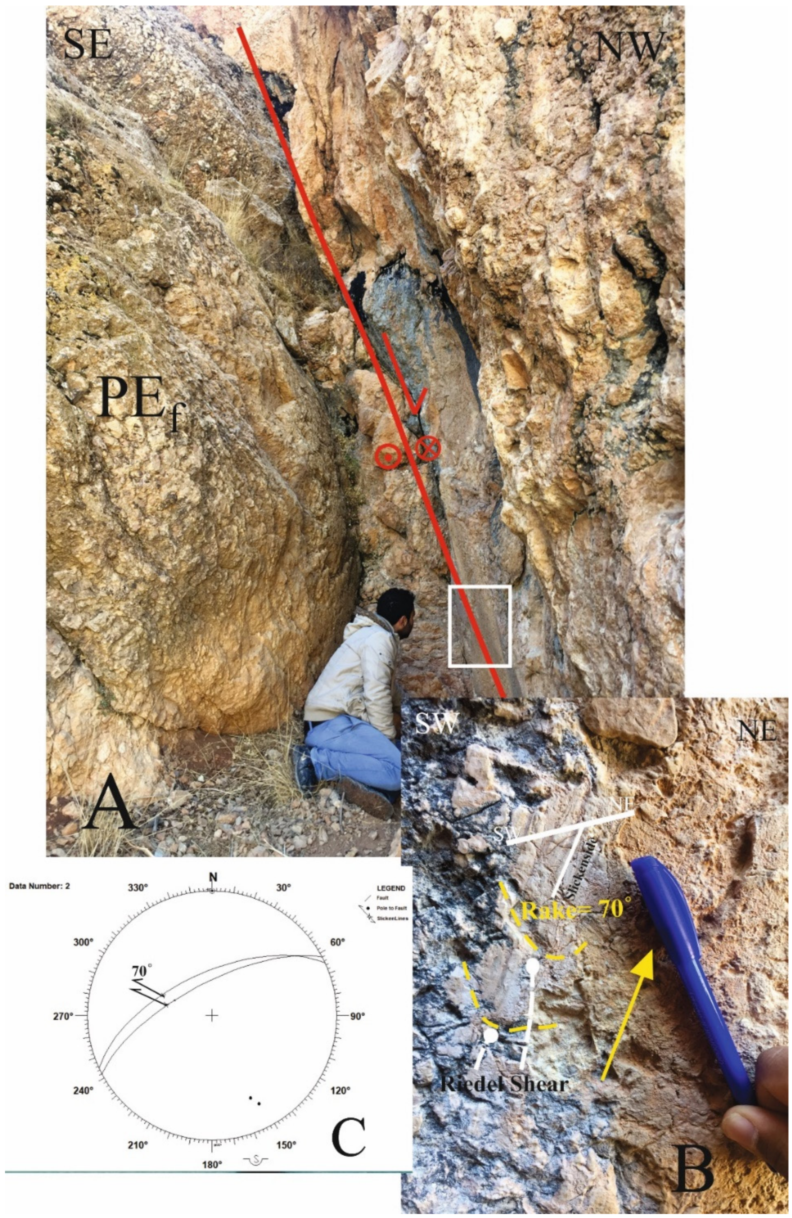


**Figure 8.** A: NF3 Fault surface on the eastern side of the Golezard Syncline crossing the Paleocene Fajan Conglomerate (view southwest) B: Slickenlines and Riedel shear fracture (yellow fold line) on the fault bottom surface. Yellow Arrow indicates the movement direction of the missing footwall block. C: The stereographic image of the fault kinematic analysis

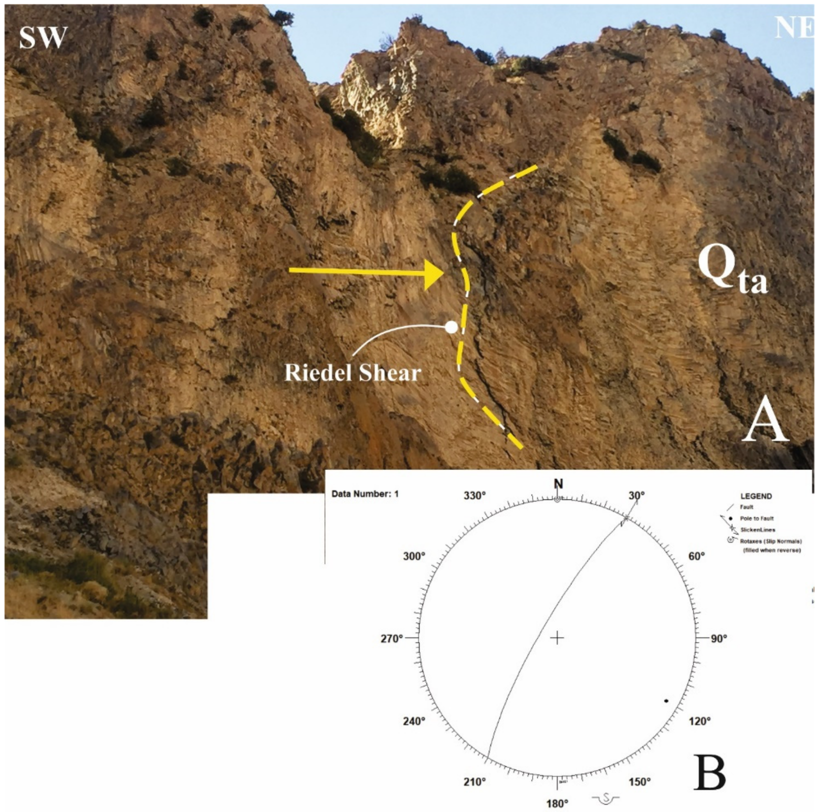


**Figure 9.** A: SF3 Fault surface disrupt the Damavand Quaternary volcanic rocks. The yellow fold line on the fault surface marks Riedel shear fractures and the yellow arrow indicates the fault missing block movement direction (view to the northwest). B: The stereographic image of the fault kinematic analysis.

Folding and Angular unconformity

The Golezard Syncline, Ziar and Polour anticlines, as well as folding of the Plio-Quaternary deposits are the other major structures in the study area (Figures 1, 2, 10). The Golezard Syncline with 75 km in length is one of the major folds in the study area and Central Alborz. The fold axial surface is dipping about 80° to NW. The Jurassic Shemshak, Dalichai and Lar formations comprises of the syncline limbs whereas the Late Cretaceous rocks (K2 in Figures 1 and 2) form its core.

Folding of Pliocene-Quaternary deposits (PL-Q in Figure 10) with an almost asymmetric geometry in which its axial surface is dipping about 85° to NE is the other study area fold structure. This folding is unconformly overlaid by the Damavand volcanic rocks (Figure 10). The activity of the Damavand volcano is dated from 0.8-1.8 Ma for the old volcanic activity to about 7300 years for the youngest eruption by (U-Th)/He thermochronology method (Davison et al., 2004). Since in the study area the Damavand volcanic rocks overlay unconformably the Plio-Quaternary rocks (Figure 10) but cross-cut by the mapped Haraz and SF3 faults (Figures 7 and 9), we inferred that these faults cross-cut the older volcanic rocks of the Damavand activity.

## Results and Discussion

Both the NW- and NE-trending faults in the study area have cut and displaced the Plio-Quaternary deposits (e.g., the Ne-trending SF1-3 and the NW-trending Ziar and NF8 faults in the northern part of study area in Figure 1).

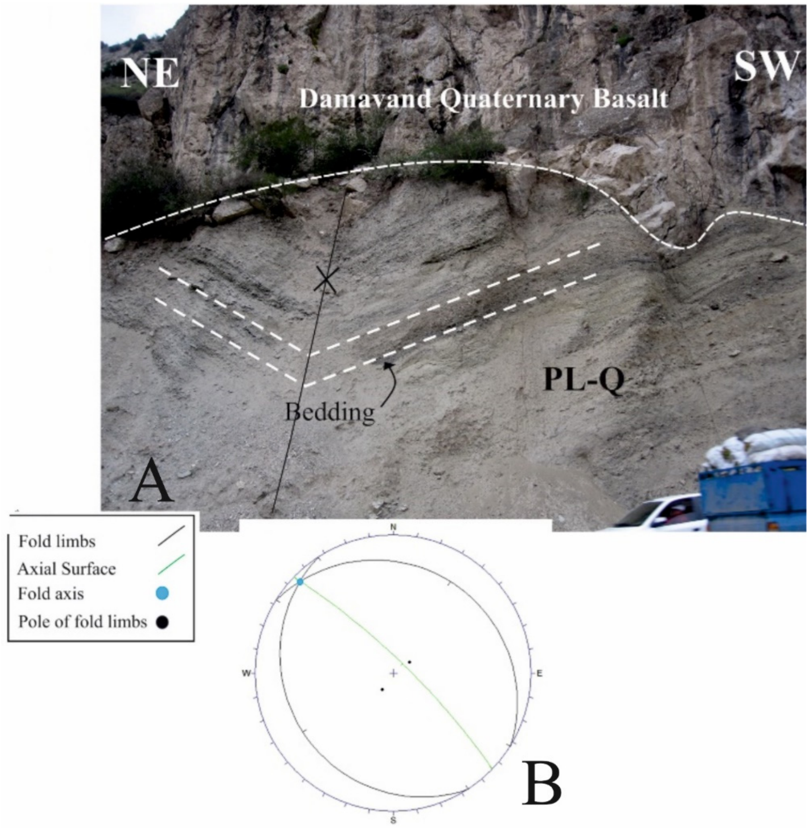


**Figure 10.** A: Folding of young Plioquaternary units covered by Damavand Quaternary volcanic rocks (View to the southeast) B: Stereographic image of folding analysis (Axial surface green lines and Blue is the axis of folding)

Thus, it can be inferred that the Late Cenozoic deformation have played a major role in faulting of the both sets in this region of Central Alborz. The faulting of the NE-trending set, however, is younger since in almost all detected cases they cross cutting the NW-trending faults. An example of this relation can be seen along the Haraz Road in the southern parts of the study area where the NE-trending Haraz Fault cut through the NW-trending Golezard Fault (Figure 7b). In addition, the cross-cutting relations between the fault sets are detectable in northern parts of the map area where the NE-trending SF3 Fault cross-cut and displace the NW-trending faults (northern part of Figure 1). Similarly, in the Golezard Syncline area to the south of the study area, the NE-trending NF3 and NF5 faults crosses the NW-trending Lasem and Golezard faults (southern part of Figure 1).

Variations of the fault sets kinematics and their cross-cutting relations imply that Late Cenozoic faulting in Central Alborz can be attributed to at least two events. Since the NE-trending faults cut through both the NW-trending faults and the Pliocene-Quaternary deposits, they are considered as the youngest faulting in the region. The Late Cenozoic faulting in Central alborz is constrain by the earlier oblique transpression (e.g, Guest et al., 2006; Allen et al., 2003) and the later transtession (Ritz et al., 2006). We propose that the NW-trending faults in the study area which associated with the development of a positive flower structure (Golezard Fault in Figures 1, 2 and 3) are developed during the earlier Late Cenozoic deformation (Figure 11a). This is coincide with the continental collision of the Arabian Plate with the Eurasia Plate in Iranian Plateau (e.g., Allen et al., 2003). Accordingly, The NE-trending faults that cut and displaced (Figure 9) the Damavand Quaternary volcanic rocks, dated 0.8-1.8 Ma (Davidson et al., 2004) are among the youngest faults in the region.

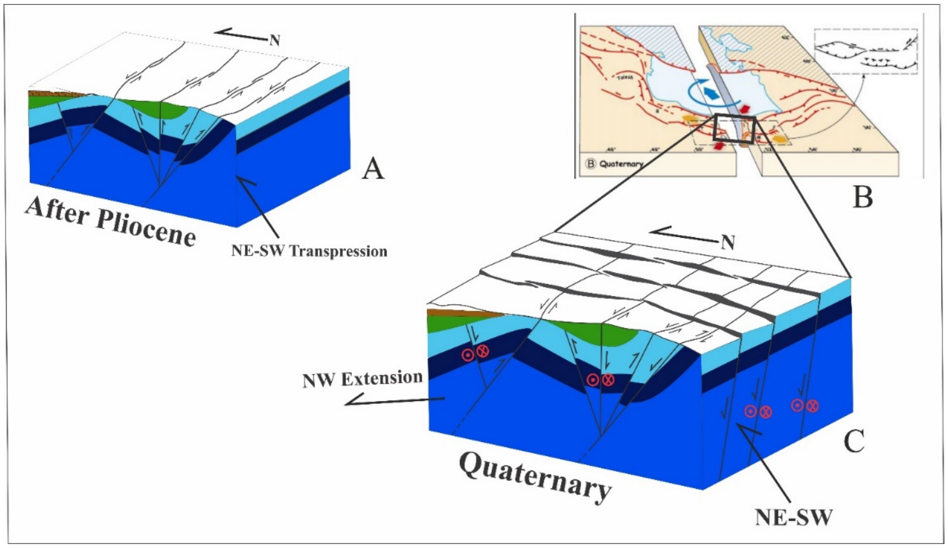


**Figure 11.** Schematic 3D diagrams showing the structural evolution of the study area. A: Formation of the NW-trending left-lateral reverse faulting since Late Pliocene period. B: 3D model shows Alborz's recent kinematics during Quaternary in which to the range northwest movement occurred by clockwise rotation of the southern Caspian crust (Ritz et al., 2006). The study area is shown by a black box. C: Development of of the NE-trending left-lateral normal faulting during Quaternary. For more detail refer to text. Legend for the rock units is presented in Figure 1.

Therefore, it is postulated that these faults have formed by the northwestern movement of the South Caspian Block in Quaternary (1 to 1.5 million years) (Ritz et al., 2006), which led to transtesion deformation and formation of the NW-trending left-lateral normal faults (e.g., the Haraz, SF3 and NF3 faults in figures 7, 8 and 9) in the study area and in Central Alborz (Figure 11b and c).

Precise leveling data collected along the Haraz Road route (Saberi et al., 2017) indicate the precences of left normal fault kinematics as well as the focal mechanism of earthquakes occurred in Central Alborz (Jackson et al., 2002) constrain this proposition. Beside the NE-trending younge fault set, few pure normal faults (e.g., the NF1 Fault in Figure 1) is also mapped in the study area. These faults can be assumed as the result of the Damavand volcanos doming and subsidence (e.g., Leng and Zhong, 2010).

The proposed assumption for development of the NE-trending faults as the youngest Late Cenozoic in Central Alborz also provides structural data for the clockwise rotation of the southern Caspian block relative to Eurasia (Ritz et al., 2006) that is generaly constrain by the young geomorphic features as well as by absolute gravitational and GPS data (Vernant et al., 2004; Djamour et al., 2010). It is generally belived that such rotation is resulted in reactivation of the Alborz range major faults such as the Mosha and Karaj-Chalous Road faults (e.g. Jackson et al., 2002; Yassaghi & Naeimi, 2011). The fault data presented here from the analysis of the Ziar region structures show that this rotation in Late Cenozoic also causes generation of new and active faulting such as the Haraz and SF3 faults in the study area (Figures 8 and 9).

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