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Structural overview of the Halab-Gheydar area, southwest of Zanjan, NW Iran

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Abstract

Understanding the folding style of a fold-thrust belt is crucial to understand the nature and structural history of structures that may trap natural resources within the belt. In this research, the geometry and mechanism of a number of fault-related folds has been investigated based on field data and satellite image interpretations. The main study areas are: the Sohrevard and Ushtaniyan anticlines, Bahman and Halab synclines, and Gharahdagh, Halab, and Gheydar thrust faults, which have a NW-SE direction. These thrust faults control the morphology and structural framework of the Halab-Gheydar area. Geomorphic features of the folds suggest that they are fault-related folds. The structural style of the faults and associated folds indicate that these faults were reactivated during the Alborz deformation event.

Keywords: *Structural analysis, geomorphic, fault-related fold, Zanjan, Iran.*

1. Introduction

Iran is divided into several structural zones; each characterized by a relatively unique record of stratigraphy, magmatic activities, metamorphism, orogenic events, tectonics, and overall geological style [1]. Central Iran, as one of these structural zones [2], is located between the Turkish syntax to the west, the Alborz and Kopeh-Dagh ranges to the north, the Zagros and Makran ranges to the west and south, and the east Iranian ranges to the east [3]. This triangle shaped zone consists of rocks of Precambrian to Quaternary that show several episodes of orogeny, metamorphism, and magmatism. The study area is located in the north-western corner of this triangle shaped zone and is placed in the southern part of Gheydar Mountains in northwest Iran. The previous structural studies in this area are limited to geological maps published by the Geological Survey of Iran [4, 5, 6, 7 and 8]. Some abundant features such as major strike-slip and reverse faults, as well as folds in this area make up the complicated structural history. This issue has motivated us to seek answers to these questions in regard to this area: What is the folding style? What is the structural relationship between folds and faults? What is the role of lithological contrast in the structural evolution of the study area? In this study, we present the results of fieldwork and satellite image interpretations to describe the complicated structural features that have not been considered in detail in the previous studies.

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2. Geological setting

Neotethys closure and its subsequent continent-continent collision between the Arabian and Eurasian plates led to the formation of large intra-continental deformations that extend from Turkey to Afghanistan and Pakistan [9]. Several controversies exist about the time of the collision and according to the previous researches, the collision occurred in a time span between the Late Cretaceous and Pliocene epochs [e.g. 10, 11]. However, most of the new studies suggest that the collision happened between the Eocene and Oligocene epochs [12, 13, 14, 15, 16, 17 and 18]. Although a wide range of variations had occurred all over central Iran during the collision, [19] post Cretaceous geological evolution of the study area has yet to be studied in detail [20, 21]. The simplified structural map of the north-western part of Iran is shown in Fig. 1.

The study area is located between the 48 - 48.5 and 36-36.33 degree of longitudes and latitudes, respectively. In this part of central Iran, thick sequences of Tertiary sedimentary deposits are exposed and they unconformably overlie the Cretaceous schist units [7]. The dominant lithostratigraphic units exposed in the study area belong to the Paleogene and Neogene periods. The oldest rocks exposed in the area are Cretaceous shale and dark green to gray sandstones with minor amounts of gray limestone and an andesitic

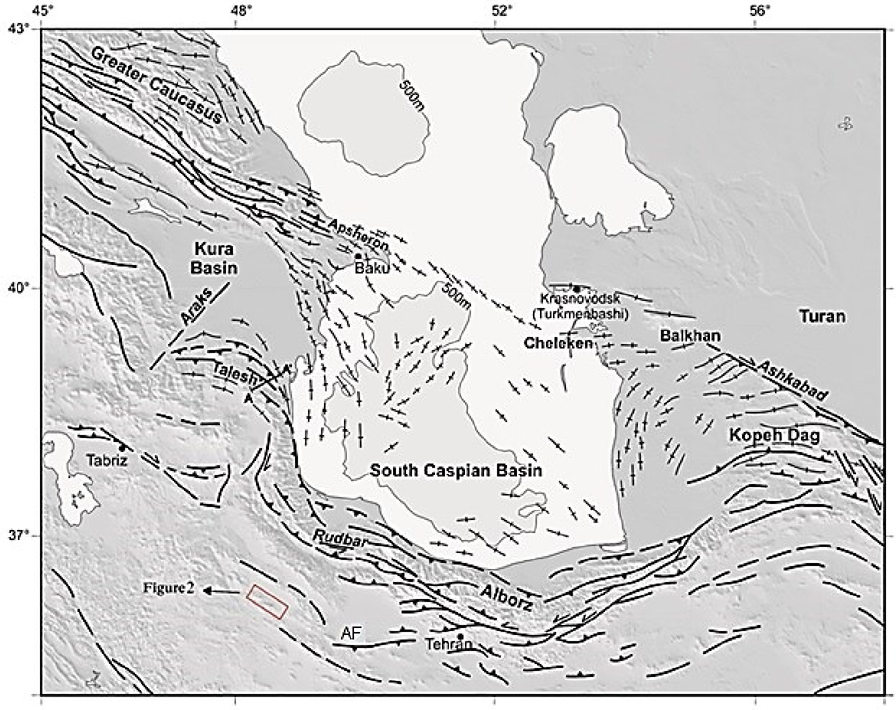

Fig 1. Simplified structural map of the South Caspian Basin. (AF, Avaj thrust fault) (Modified based on Keller and Tierney [31]). The red rectangle shows the location of the study area

volcanic unit. Accordingly, the Eocene deposits in the study area are classified into turbidities and volcanic units [5]. The turbidite units are composed of tuffaceous sandstones, tuff, and tuffaceous limestone. The volcanic unit consists of andesite, trachyandesite, basalt, and lithic tuff. The Eocene volcanic rocks are overlain by marine and non-marine sediments consisting of limestone, sandstone with intercalations of gypsum, marl and conglomerate in which the Upper Red Formation is very abundant. Based on dating studies [18] the Upper Red Formation is limited to the mid-late Miocene at the Eivanaki Basin in north central Iran. A number of studies show that the Upper Red Formation in central Iran is deposited in a compressional basin similar to the other Tertiary Formations [23, 19]. In contrast, it is believed that the sediments in Halab basin and other neighbouring basins are deposited in an extensional regime [7]. These units are overlain by the younger river sediments in the most parts of the study area.

3. Geometry of major structures

Although there are several studies that have focused on the Halab-Gheydar area [4, 5], a systematic study on the structures has yet to be carried ou. Therefore geometrical analysis and review of the structures in this area could have a significant importance. In the following sections, more details of structural geometry and kinematic analyses of the folds (Sohrevard, Ushtaniyan, Bahman and Halab) and faults (Gheydar, Gharahdagh, Halab and Loutchai) are presented.

3.1 Gheydar Fault

Gheydar Fault was first introduced by Toori and Seyitoğlu in 2014[8]. It is 35 km long and is located at the southeastern part of the study area in the Miocene deposits (Fig. 2). This fault continues towards the east up to the southern part of Gheydar and eventually links to the Ipeck Fault. The dip of this Fault varies from 45 to 83 towards the northwest. In the study area, rock units in the footwall and hanging wall of the Gheydar Fault are almost similar. The Gheydar Fault is a reverse fault (Fig. 3a) in the southeastern sector, in which its slope increases towards the west and shows left lateral strike slip movement with a reverse component (Fig. 3b, c).

3.2 Gharahdagh Fault

Gharahdagh Fault is located to the south of the Gharahdagh Mountain. This fault is 13 km long and trends NW-SE in its western sector and an eastwest trend in the eastern sector (Fig. 2). The Gharahdagh Fault translated the Cretaceous units over the Miocene units. A large mass of anhydrite with an approximate thickness of 50 meters forms the footwall of the Gharahdagh Fault. The fault plane has a N80W/55 NE orientation and includes several slip indicators representing reverse movement on the fault plane.

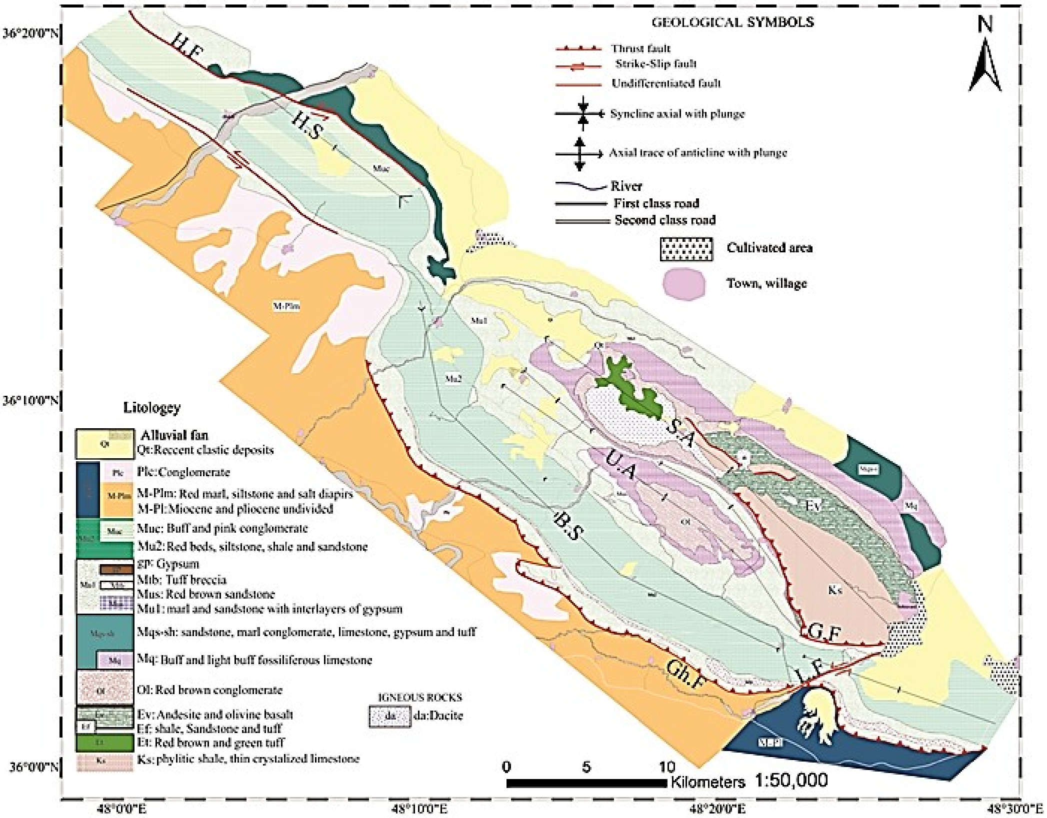

Fig 2. Geological map of the study area. Abberevations are: (Gh.F: Gheydar Fault), (L.F: Loutchai Fault), (G.F: Gharahdagh fault), (H.F: Halab Fault), (S.A: Sohrevard Anticline), (U.A: Ushtaniyan Anticline), (B.S: Bahman syncline) and (H.S: Halab Syncline).

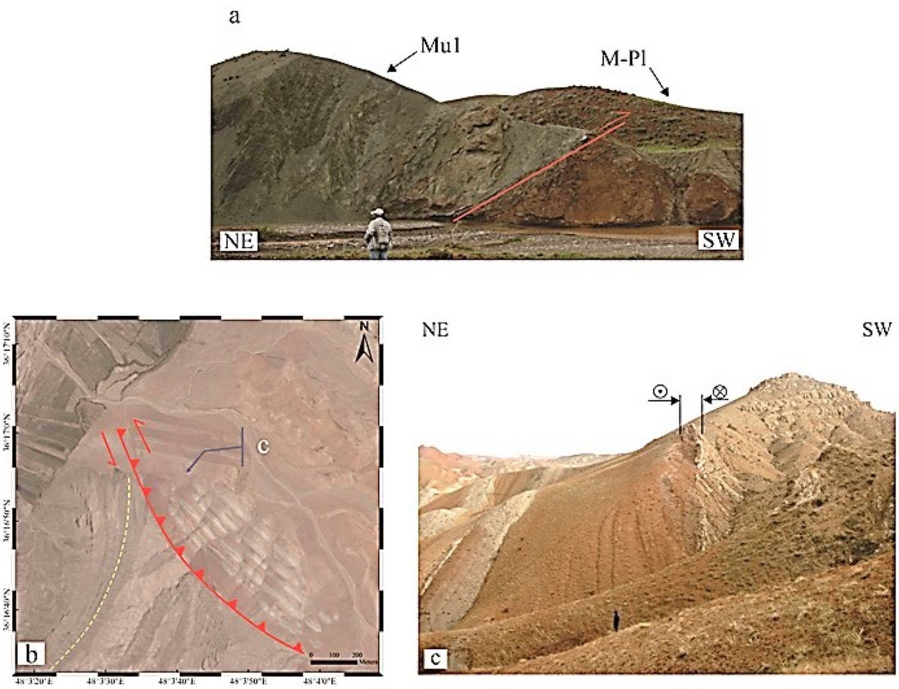

Fig 3. Northwest dipping Gheydar thrust fault in Chopoghlu villages (a) that has translated the Upper Red Formation over the Miocene-Paleocene unit. Google Earth image of the Gheydar fault trace marked with red line (b). A field photo of the Gheydar Fault (c) at the northwest of Halab city.

3.3 Loutchai Fault

Loutchai Fault trends northeast-southwest, parallel to the Loutchai River, is 7 km long and extends towards the east up to the city of Sohrevard (Fig. 4). Left lateral strike slip with thrust component mechanism is inferred for the fault due to the left lateral displacement in the Miocene units on both sides of the river.

3.4 Halab Fault

In 1917 Pourkermani and Arian [24] introduced the Halab Fault as a reverse fault with a right lateral strike slip component, whereas Toori [25] believed that this fault is a left lateral strike slip fault with a 2.5 km displacement. Based on our data, the Halab Fault trends WNW-ESE, is 20 km long, and is located northeast of Halab city (Fig. 5). This fault has emplaced the upper part of the Upper Red Formation against its lower part as well as the Plio-Quaternary deposits. The Halab Fault has cut and disappeared the western flank of the Halab syncline. It dips towards the northeast and is a left lateral strike slip fault with a reverse component and 10 m wide fault zone.

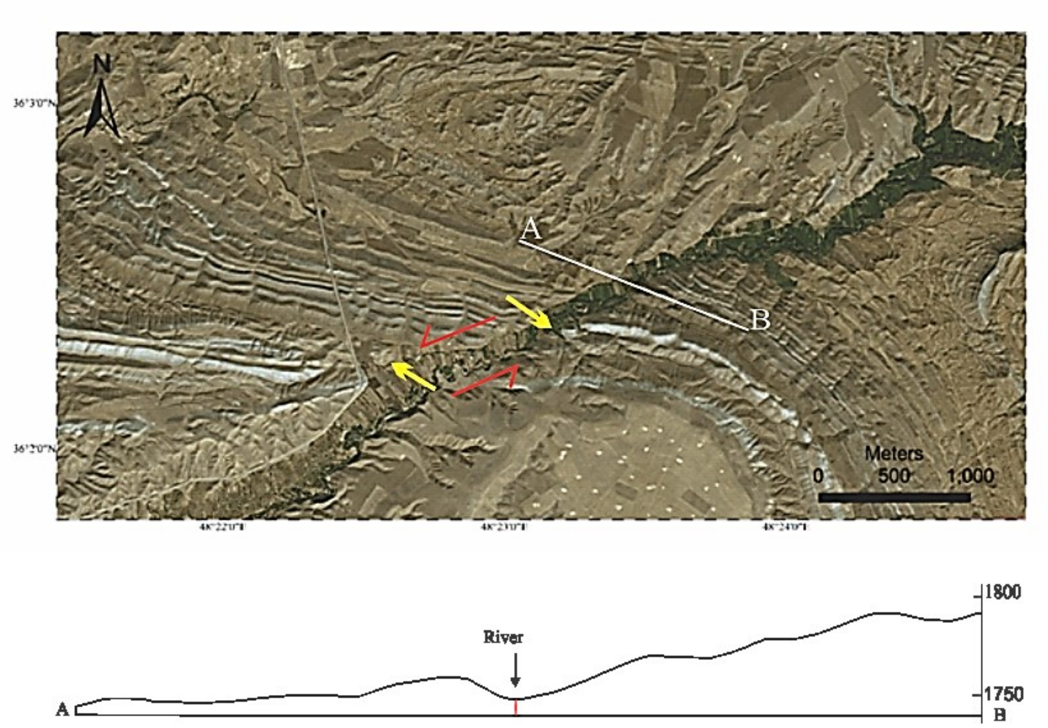

Fig 4. Google Earth image of the NE-SW trending left lateral Loutchai fault that has cut the Miocene deposits. The white line shows the topography profile path and yellow arrows show displacement of the light colored layer.

3.5 Ushtaniyan Anticline

Ushtaniyan Anticline is located at the middle part of the study area and seems to be a fault-related fold. It is a narrow and long anticline located between the Sohrevard Anticline and Bahman Syncline (Fig. 2). It has about 18 km long and nearly 3.5 km wide. Rock units exposed in this anticline are Cenozoic deposits including the Lower Red Formation, Qom Formation, and Upper Red Formation, in which the Lower Red Formation is exposed in the core of the anticline (Fig. 2). In order to determine the position of the anticline axis and axial plane orientation, bedding data were collected from both the northern and southern flanks of the anticline in c and d sections (Fig. 6). The obtained data were plotted on the stereonet diagram (Fig. 7). Based on the π diagram, the orientation of the axial plane is N50W/60 NE.

3.6 Sohrevard Anticline

The Sohrevard anticline, having the same trend as the Ushtaniyan Anticline, is located at the northern part of the study area. Based on the structural position, this anticline is also most probably a fault-related fold. Sohrevard Anticline is a long anticline trending northwest-southeast (Fig. 2). It is 24 km long and its width varies from 3 to 7 km. Exposed rock units of this anticline belong to the Cretaceous and Cenozoic time including the Cretaceous Ks unit, Lower Red Formation, Karaj Formation, Qom Formation, and Upper Red Formation.

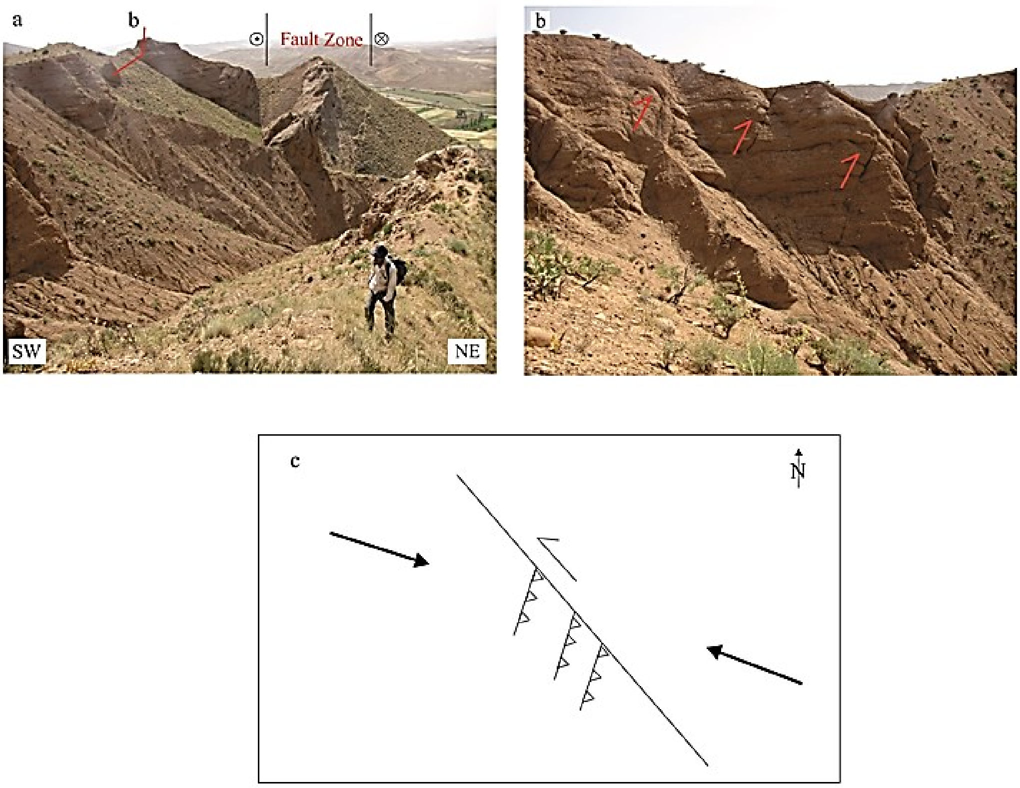

Fig 5. Field images of the Halab Fault. (a) The fault zone at southeast of Halab city. (b) The reverse movement related to the Halab Fault. (c) Sketch map of the Halab Fault.

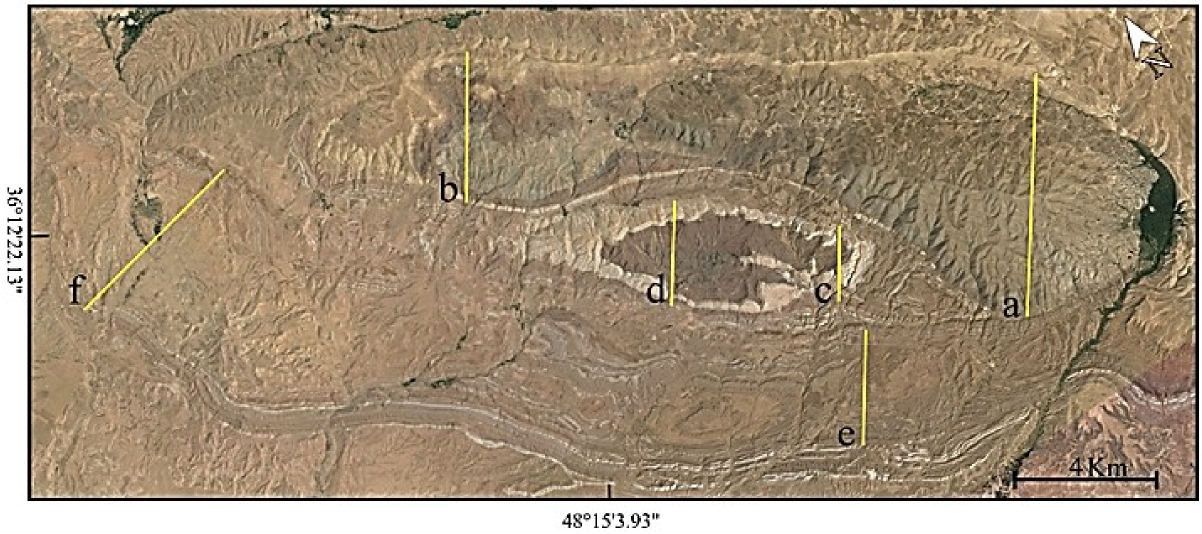

Fig 6. Google Earth image of the major structures in the Halab-Gheydar area. Filed traverses are marked with the yellow lines.

The Cretaceous Ks unit and Karaj Formation are exposed in its core. The orientation of its axial plane based on the data obtained in a and b sections (Fig. 6) is N39W/86NE (Fig. 7). The Sohrevard Anticline is limited to the Gharahdagh Fault in the southern flank.

3.7 Bahman Syncline

The Bahman Syncline is a narrow and long syncline trending northwest-southeast (Fig. 2). This syncline is 30 km long and its width varies from 4.5 to 6 km. The Upper Red Formation is the only exposed rock unit in this syncline. This syncline is limited to the Gheydar

Fault in its southern flank. Based on the obtained bedding data along e and f sections (Fig. 6) plotted on the diagram, its axial plane has an approximate orientation of N60W/87NE (Fig. 7).

3.8 Halab Syncline

The Halab Syncline trending northwest-southeast is about 22 km long (Fig. 2). Both flanks of this syncline are cut by the Halab and Gheydar Faults, respectively. The Halab Fault has cut and caused the northeastern flank of this syncline to disappear. The Halab Syncline is distinguished on the basis of the bedding data obtained from its southern nose. In the southwestern flank of the Halab Syncline dip the layers varies from 40 to 80 towards the northeast.

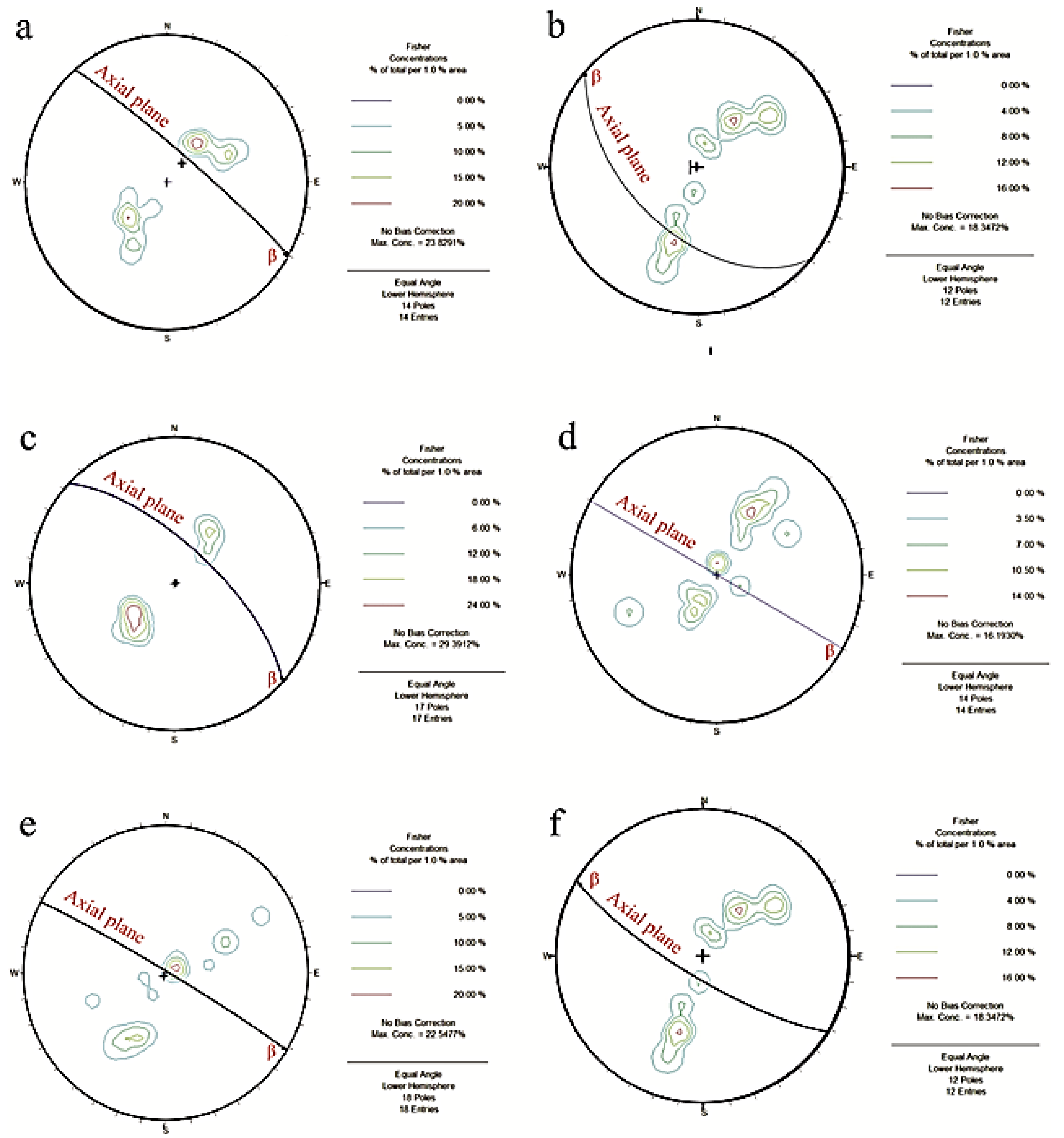

Fig 7. Theπ diagram of bedding measurement on the structures in the study area. The figures a, b, c, d, e and f are the π diagrams for the traverses marked with the same letters on Figure 6.

4. Discussion

With a glance over the geologic maps and satellite images of the study area, several folds are distinguishable and it is inferred that the folds are the dominant structures in the area. Most of them are double plunge and trend northwest-southeast. The major folds in the study area are the Ushtaniyan and Sohrevard anticlines and the Halab and Bahman synclines, which are all parallel to each other. They are located between the Gheydar Fault in the southeast and Halab Fault in the northwest. Based on the field observations, thinning has occurred in the southwestern flanks of the Ushtaniyan and Sohrevard anticlines. The morphology of the area is quite similar to that of the Zagros thrust-related folded belt located nearly 200 km away towards the southwest. Based on the field evidence related to the influence of faulting on the layering attitude, it seems that the folds of study area have evolved through subsurface fault growth [26]. Therefore, the morphology of the study area was probably affected by the Halab and the Gheydar faults. Since an erosional zone exists on the compressional step of the Gheydar and Halab faults, it is inferred that the Ushtaniyan and Sohrevard anticlines and Halab and Bahman synclines have been influenced by these faults. According to GPS vector analysis the morphological evidence of fault and related fold growth and its subsequent intensive erosion [27, 28] indicate that a shortening event is going on in the area, which was previously mentioned [29]. Although seismic activity in the study area is not now noticeable, an earthquake did happen in 2002 in the Avaj area, which is located east of the study area. Most of the earthquakes occurred at the eastern Gheydar area and the 2002 earthquake [30] showed a thrust focal mechanism. However, it is believed that all these earthquakes show slip vector towards the northeast [25]. The present-day convergence between the Arabia and Eurasia is primarily accommodated by distributed shortening and strike-slip faulting in the Alborz, as well as Zagros and Kopeh Dagh ranges of Iran [18]. In fold-thrust belts, there is a close connection between the development of folds and associated blind thrusts [31]. Based on the geomorphological characteristics of the folds, these structures can be divided into a number of segments. These segments probably started as separate folds formed from separate thrusts. Then they were propagated laterally and linked to form a single linear fold or en-echelon folding style. The fold growth and fold segments were affected by the distribution of the thrust faults in the study area. Since the studied folds and associated faults are located in the Azarbaijan-West Alborz structural zone and similarity in the orientation of Gheydar and Avaj thrust faults and continuation in the left lateral step over of Ipeck fault towards the west [8], these structures are formed by the stresses influencing the Alborz deformation event.

5. Conclusions

The Gheydar, Gharahdagh, and Halab faults are the main structures that control the morphology and structural framework of the study area. With respect to satellite images and field observations, it is clear that the general orientation of these faults, except for the Loutchai fault, is northwest-southeast. The trend of the Loutchai transverse fault is northeast-southwest and shows a left lateral displacement with a reverse component. The Gheydar Fault is the largeset fault in the study area and can be interpreted as the continuation of the Ipeck Fault that extends up to the Halab area. In the space among these faults, fold formation has occurred such as the Sohrevard and Ushtaniyan anticlines and the Bahman and Halab synclines, which all trend northwest-southeast. According to the general trends of the geological structures and lateral growth of folds in the study area, the direction of the compressional vector is northeast-southwest. The structural style of fault-related folds in the study area indicates that these stuctures are formed by the stresses influencing the Alborz Mountain ranges.

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