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Research Article

Assessment the relationship between geometry and fault mechanism with geomorphic index of active tectonic in West Alborz region

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A R T I C L E I N F O

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A B S T R A C T

Background and objective: The movement of the earth's crust is one of the critical factors in the shaping of landscapes, so the effect of these movements on geomorphology and its related consequences can be identified by studying morphotectonics indicators. This study aimed to investigate the tectonic mobility, deformation pattern, and fault geometry of the Western Alborz zone in Iran.

Materials and methods: In this study, types of morphotectonics indicators such as sinuosity of the mountain front (Smf), river gradient (Sl), valley width to depth (Vf), asymmetry of waterways (Af), and hypsometric curves in thirty watersheds using topographic maps and satellite images were studied. The basins were classified into three categories: active, median, and inactive, and the status of the network of waterways and alluvial terraces, closely related to tectonics, were evaluated.

Results and conclusion: The results showed that the tectonic regime prevailing in this area is a compression type. Thirteen watersheds are active, fourteen are moderately active, and the rest are inactive. This conclusion was reached by combining all the data. Some faults are inclined towards the south and others towards the north. The main faults are mainly reverse type in all sections.

1. Introduction

In order to reach the kinematics of active faults in central Alborz, many researchers have suggested the direction of the prevailing tension in this area with the northeast direction. This tension has been obtained by solving the mechanisms of the earthquake center. Gillard and Wyss (1995) introduced the axis of maximum tension in Alborz along N40°E direction with the help of deep faults mechanism. Tatar (1999) introduces the general trend of the thrust axis in two directions, North-East-South-West and East-West, by studying the earthquakes. In every earthquake, a part of a fault zone is activated and its appearance appears as a rupture on the surface of the earth. In many cases, these ruptures appear with trends on the surface that are connected with the geometry and mechanism of the main fault in the depth of the earth.

Therefore, one can encounter a system of fractures on the surface of the earth, which is not necessarily the same trend as the main rupture in depth, but is directly related to the mechanism and geometry of the

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main fault. By studying the network of fractures on the surface and the direction of the tension that caused the main rupture, it is possible to better understand the behavior of the main fault that caused the earthquake in the depth. From the point of view of stratigraphy, the studied area is formed from the Precambrian units to the present era. What has been studied more in this paper is the young units of the 4th era (especially Holocene) and the study of the side effects and movement of the fault on these sediments. Quaternary units of the area can be seen as alluvial and flood terraces and red clay sediments. The young sediments of the western Alborz area are not limited to the limited coastal plains. In the mountains too, parts of young sediments can be found enclosed in intermountain depressions and sometimes in the form of debris and soil.

There are many fault zones in Western Alborz, some of which are mentioned in this paper and their mechanisms and trends have been evaluated. In the investigation of these faults, things like mechanism (slope slip, right slip and oblique slip), and their geometry and generally the parameters related to segmentation of the faults have been taken into consideration. In addition, any movement that occurs in the earth's crust, either slowly and gradually or suddenly, will affect the surface of the earth. The size and appearance of this movement and the shape it creates shows the type of movement and its amount. Summerfield (1991) considers any physical form created on the earth's surface to be directly or indirectly related to tectonic activities. Schroeder and Purser (1986) called any visible physical effect or shape on the surface of the earth, which was created by natural factors, a landform.

One of the natural factors that has a direct effect is tectonics, and the study of the relationship between these landforms and tectonics is called morphotectonics.

The methods that have been presented so far in structural geology for tension analysis in the fractured tectonic regime are divided into two groups:

A- Drawing methods, B- Calculation methods

Drawing methods include methods that can be used to obtain a general estimate of the direction of the main tension axes. These methods are suitable for obtaining the tension direction in field work. Determining the direction of tension in this method is done using stereographic networks, based on a mechanical model that is performed in a fracture environment (Jamali et al., 2021) by considering assumptions in the calculations.

These assumptions are:

1- Fractures move along the maximum shear tension (Bott, 1959; Wallace, 1951).

2- Measurements are performed in a homogeneous volume (mechanically)

3- A constant tension tensor has been dominant during the application of tectonic forces.

4- There has been no volume change in the tectonics regime.

5- Friction is not considered.

The result of the calculations will lead to determining the direction of the main and ellipse axes of tension. Although different methods have been presented in this way, all methods have the same pattern.

In tectonic studies, the identification and investigation of landforms that react to tectonic movements and their age cannot be determined. In morphotectonics, these shapes and landforms are used to evaluate the type and size of young and future movements of an area. In this field, various studies by scientists have been done (Strahler, 1952; Howard, 1967; Adams, 1980; Keller, 1986; Bishop, 1982; Schumm, 1985; Leeder et al., 1991). Research records in the country are very limited and only geomorphic indicators have been measured in the central Alborz basin (Tabasi & Bahauddini, 2022).

The aim of this study is to investigate the active tectonics and the deformation pattern and geometry of the faults in the Western Alborz zone in order to identify the trend and mechanism of the faults.

2. Materials and methods

West Alborz is located between 49 to 50'30 East between Khasar plain in north and Qazvin plain in south (Fig.1).

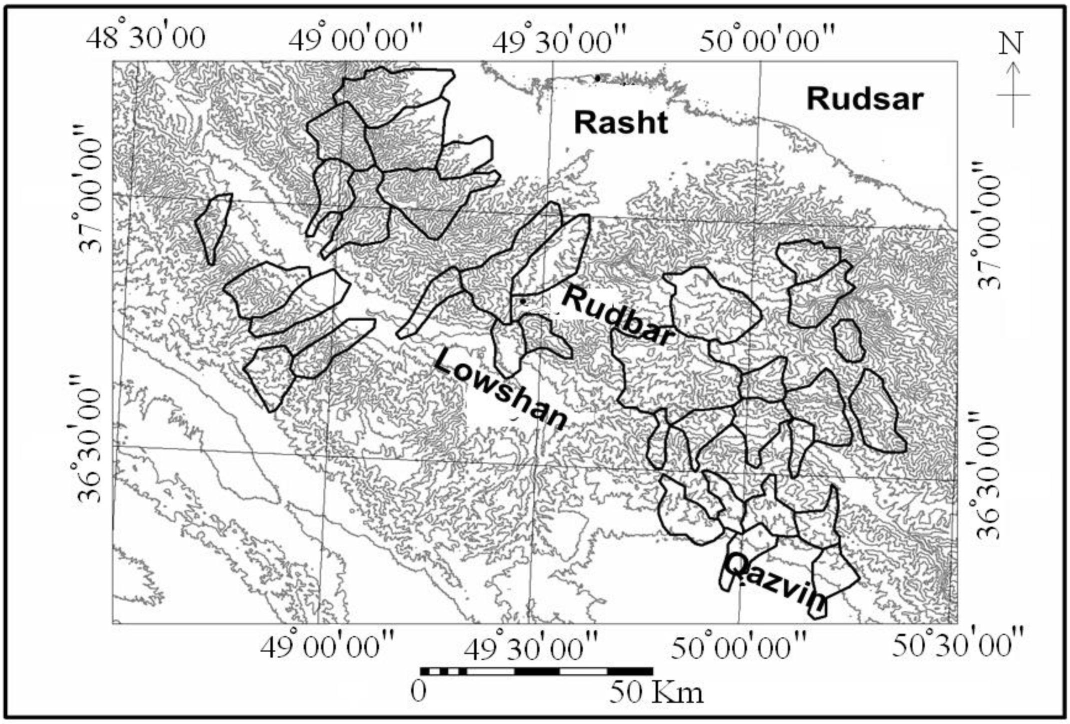


Fig. 1- Study area

At first, the watersheds were separated using satellite images (Jamali et al., 2022; Ghane Ezabadi et al., 2021) and topographic maps with a scale of 1:250:000. Inside each watershed, different geomorphic indicators were determined and evaluated and integrated using different software such as SDRMAP and Arcinfo. By adding spatial information of historical seismicity in the area of basins, which indicates the activity of each watershed, the conformity of quantitative and qualitative indicators of geomorphology and active tectonics with historical seismicity were shown. Finally, based on the above information, the basins were classified into three categories: active, median and inactive. In addition to the above information, the state of the waterways network and Alluvial Terrace, which are closely related to tectonics, were considered and the information set of the three mentioned categories was combined and then their close relationship with each other was evaluated.

2.1. Stratigraphy and sequence of soil sediments in the region

In the field studies, the presence of three parts including humus clay, brown clay and calcified part has been proven in some places (Fig. 2). Based on stratigraphic data and sequence of sediments, these soils are classified as the youngest unit (Holocene). The parameters of the studied structures have been measured in these units.

Fig. 2 - A view of young Holocene sediments in Bagh Dasht Alborz West station

2.2. Overall alignment of the examined faults

There are many fault zones in Western Alborz, some of which are mentioned in this paper and their mechanisms and trends have been evaluated. In the investigation of these faults, things like mechanism (slope slip, right slip and oblique slip), and their geometry and generally the parameters related to segmentation of the faults have been taken into consideration. The general direction of the investigated faults in Western Alborz is shown in Windrose diagrams (Fig. 3). For each fault, its alignment has been evaluated at several stations along the fault.

2.3. The orientation of the main tension axes in the Western Alborz region

In order to determine the direction of the main tension axes that caused young movements in the fault zones of the Western Alborz region, especially the fault that caused the 1369 Rudbar-Manjil earthquake, the related fracture plates and slickensides have been used.

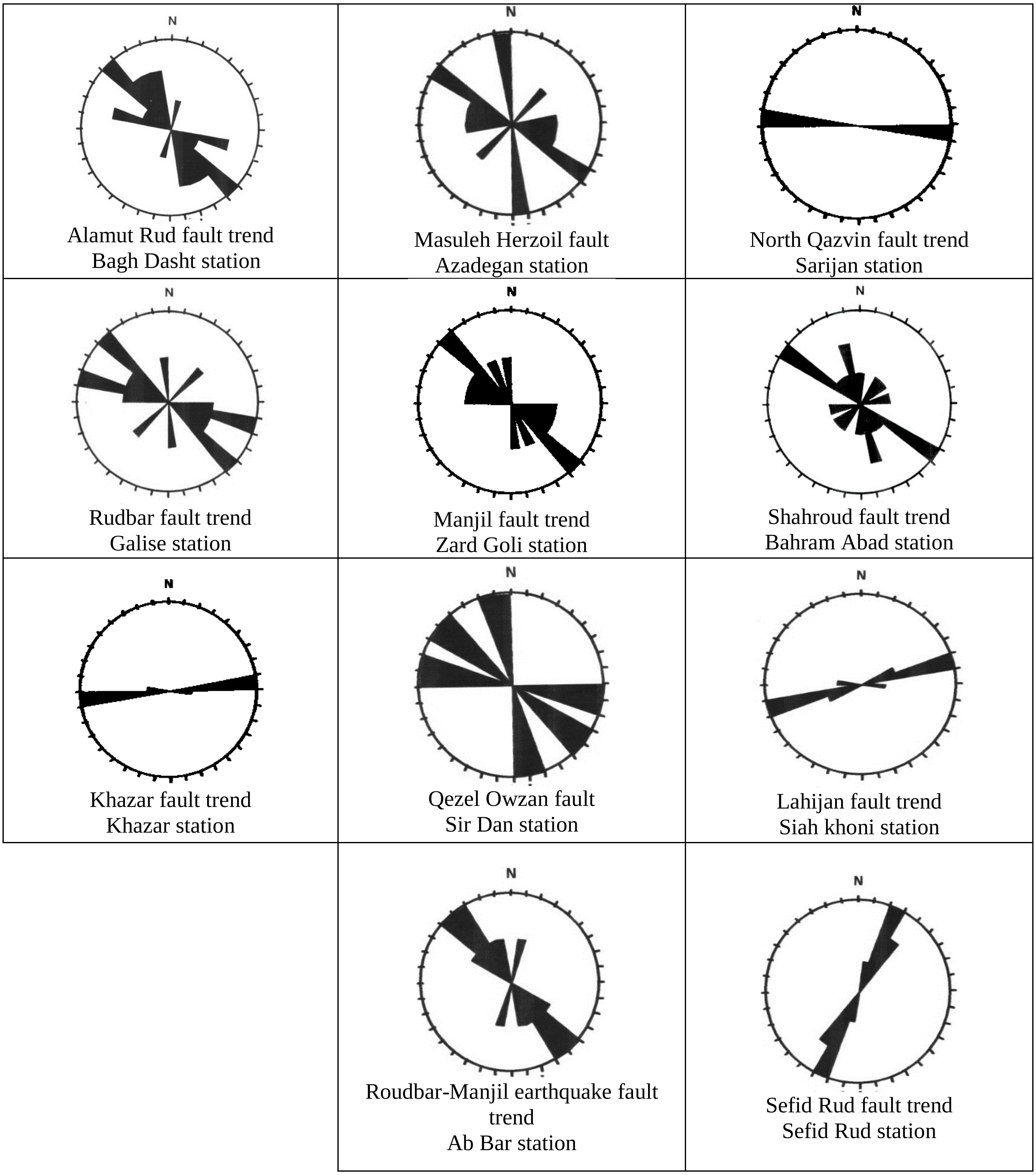


Fig. 3- Windrose diagrams of the trend of the western Alborz fractures by separating each fault zone

2.4. The network of waterways and tectonics in the study area

The study of river system is considered as alluvial geology. The forms of rivers and the processes created in their system are described by a number of characteristics such as channel width and depth, dissolved sediment load, floating load, channel slope and sinuosity, flow speed, channel roughness and a number of other factors (Summerfield, 1991). The partial balance between all these parameters in the river means that the rivers are very sensitive to partial changes, especially the changes that occurred in the climate during the fourth period and had a great impact on the landform systems of the rivers.

In this regard, based on Summerfield's statement (1991), in mountainous areas, the topography is the most important factor in the formation of waterways, and the topographical controllers affect the pattern of waterways in two ways: dynamic structural controller and smooth structural controller (consonant). In the study area, three patterns of parallel waterway, rectangular and dendritic (Fig. 4) have been investigated and identified.

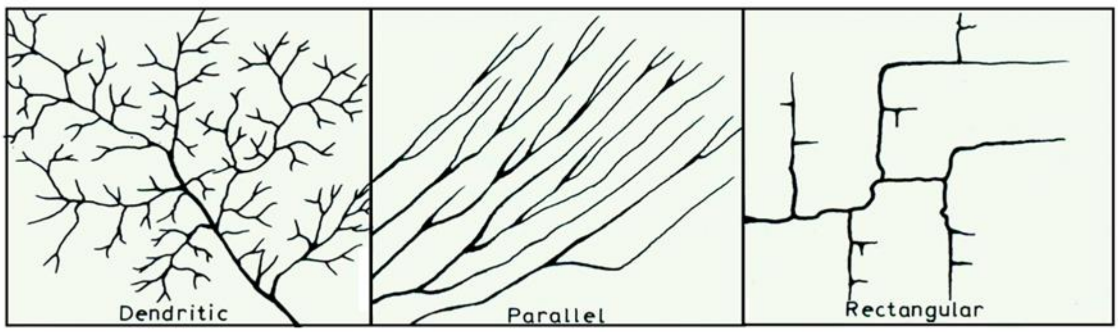


Fig. 4- parallel, rectangular and dendritic patterns (Verstappen, 1972)

2.5. Geomorphology indicators

In the Western Alborz range, the entire region has been studied in terms of geomorphology indicators. This collection includes 30 watersheds that cover the entire region. Figure 5 shows the studied basins. Bold dark lines show the boundaries of watersheds. For all these basins, all the indicators have been calculated and evaluated. In qualitative or quantitative studies, it should be considered that tectonics is one of the effective factors in shaping the appearance of the earth. Despite the importance of the tectonics factor, the features of lithology, topography, weather and climatic differences should not be ignored. Geomorphology indicators in Western Alborz are examined further.

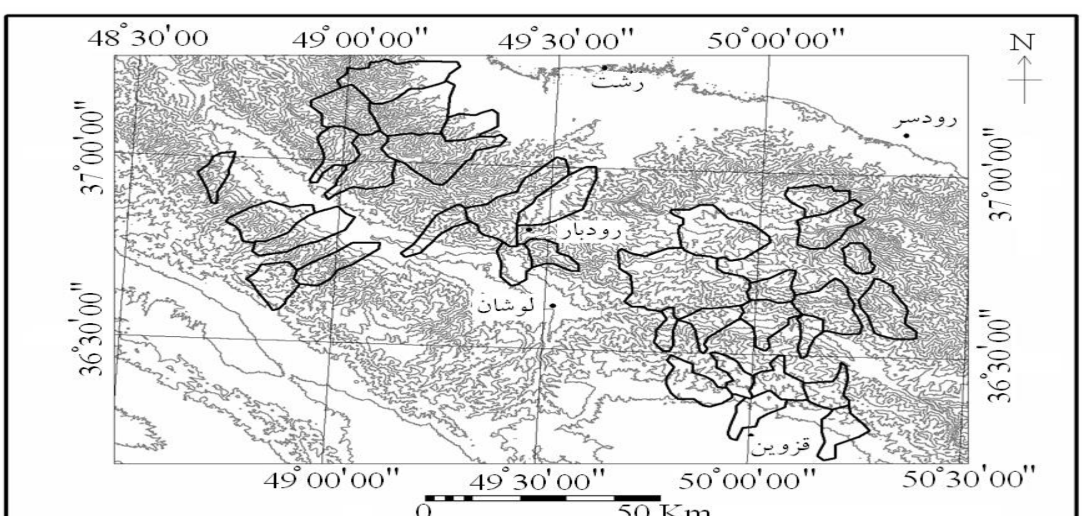


Fig. 5- Location of the studied basins

2.5.1. Sinusitis index of mountain front

This index shows the relationship between the strength of the river and the slope of the mountain front. In such a way that the mountain fronts, which have active faults in front of them and are constantly rising, have a straight shape that is clearly visible in satellite images and aerial photos. In the areas where the amount of rise and mobility is insignificant, erosion takes effect and the mountain front assumes a sinusoidal shape. Based on this point of view, the sinuosity index is defined as follows (Schumm, 1985):

$$Smf = \frac{Lmf}{Ls} \quad (1)$$

In this equation, Lmf is the length of the mountain front in the distance between the mountain and the foothills, and Ls is the direct length of the mountain front (Fig. 6).

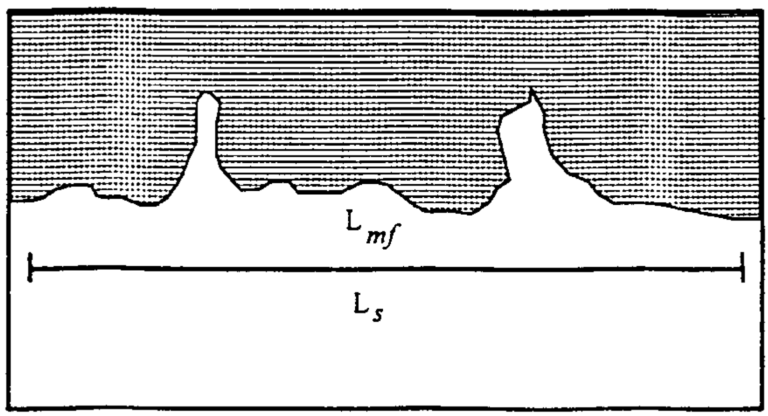


Fig. 6- Schematic view of the length of the mountain front (Lmf) and the direct length of the mountain front (Ls)

2.5.2. River gradient index

The river gradient index is calculated with the following equation (Keller, 1986):

$$Sl = \frac{\Delta H}{\Delta L} \times L \quad (2)$$

In this relation, L is the length of the channel from the exit point where the index is measured at the highest point of the channel and is equivalent to the local gradient of the river in the measured section (Fig. 7).

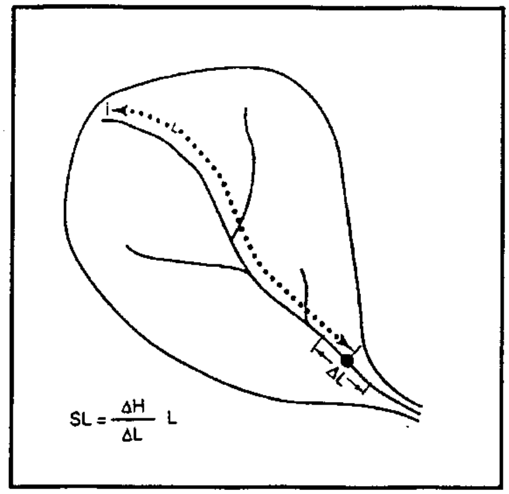


Fig. 7 - Objects that are used in determining the Gradian River index

The gradient index of the river is influenced by the strength of the river. The power of the river depends on the discharge of the river and the slope of the bed surface. When the tectonic mobility in the area is to the extent that it produces uplift, the gradient river index changes. When the bedrock of the river is resistant or the river flows in an area where tectonic mobility has caused a bulge in the area, the numerical value of the index is high.

Therefore, a large amount in rocks that have low resistance (in a relative state) indicates an active and young tectonic movement. This index is more effective in areas that are the same in terms of resistance. Sometimes they study the changes of the river gradient index along a river and in a basin. In this case, by examining the decrease and increase in the numerical value of the river's gradient index, it is possible to find out the changes in the area.

2.5.3. Valley width to depth index

This index was first presented by Bull (1978) with the following formula.

$$\mathrm{Vf} = \frac{2Vfw}{\left[(Eld - Esc) + (Erd - Esc)\right]} \qquad (3)$$

According to the above equation: (Vfw) is the width of the valley floor, (Eld) is leftvalley height, (ErD) is right-valley height and (Esc) is the height of the valley floor.

Figure 10 shows a section of the valley and the parameters that are measured to meet the index. Valleys with a wide bed (U-shaped) have a large numerical value of the Vf index, and deep valleys (V-shaped) have a smaller numerical value of the Vf index.

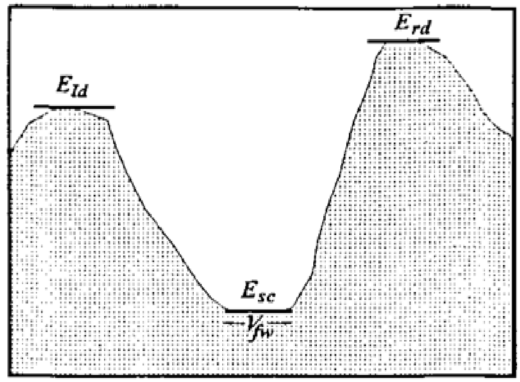


Fig. 8 - A section of the valley and the parameters that must be measured to estimate the Valley width to depth of the Vf index

In cases where the Vf index is measured for parts close to the mountain front, it is possible to estimate the mobility of the mountain front from the Vf index, because the decrease in Vf can be the result of the uplift of the downstream area of the basin. In a normal state and the same conditions, the growth process of the watershed is such that the end parts of the valley will be U-shaped. In other words, the amount of Vf index will increase due to the widening of the bed. In this way, the basins that have a smaller Vf in the final part of the V shape can be classified as mobility zones from the point of view of tectonics.

A number of basins have been selected in the western Alborz region and in the two western and eastern regions, and in each basin, three points (upstream, middle of the basin, and downstream) have been chosen to measure this index.

2.5.4. Asymmetry index of waterways

This index is used to identify basins that have received tilting (Fig. 9) due to the movement of mobility faults. This index is studied at the watershed scale. The asymmetry index is defined as follows (Keller, 1986):

$$Af=(100)\frac{Ar}{At}\ ) \qquad (4\ )$$

In the above equation, (Af) the asymmetry index of the waterway in the watershed, (Ar) the area of the basin including sub-drainages on the right bank of the main waterway (in square kilometers), And also (At) is the area of the basin including the sub-drainages on the left and right side of the main waterway (the entire drainage basin in square kilometers).

Since the topographical condition of the areas with uplift is related in the form of subsidence in one area and uplift in another area, the length of the sub-waterways and as a result the catchment area of these waterways are not the same on both sides of the basin (uplift and subsidence).

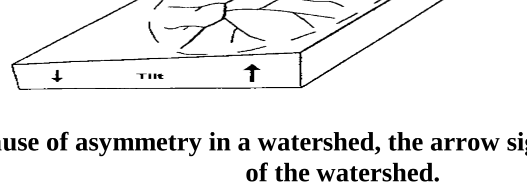


Fig. 9- The index and the cause of asymmetry in a watershed, the arrow sign indicates the rise and fall on both sides of the watershed.

When the numerical value of this index is around 50, the sign of the basin's symmetry is that the right and left sides of the main waterway are the same, and as a result, there is no tilting. Numerical values more than 50 and less than that show the role and importance of the rise on the right and left side of the main waterway, respectively.

2.5.5. Hypsometric curves

Histometric curves were first proposed by Strahler (1952). Hispometric curves show the distribution of height in an area. Hypsometric curves deal with the relative changes of height to area. These curves pay attention to the relationship between the basin area and elevations. Figure 10 shows how to measure the relative height of each point and the relative area.

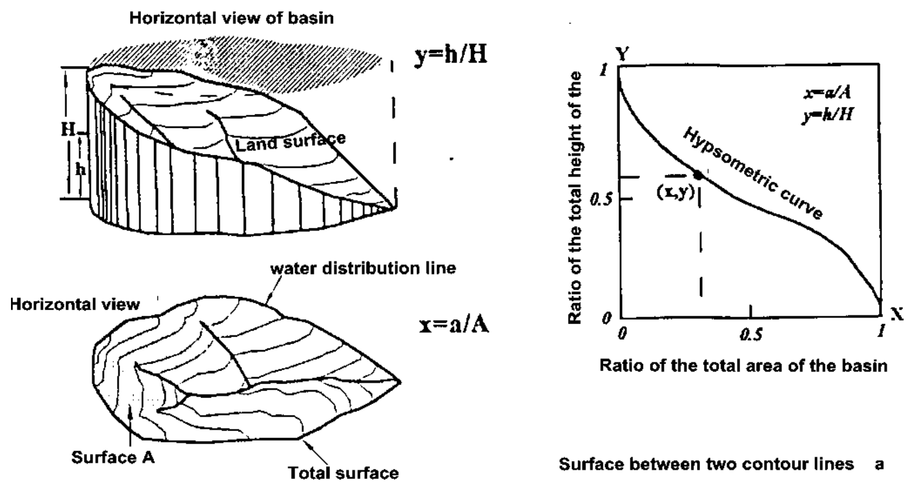


Fig. 10- Measurement of various parameters to draw hypsometric diagrams

In calculating the area, the cumulative area of a specific height level is considered. The values of a/A and h/H are measured from the topographic map with a suitable scale. In the relationships of hypsometric diagrams, a is the area of a part of the basin that is above the height level h, and A is the area of the whole area (drainage basin). The numerical value of a/A changes between 0 and 1. Strahler (1952) defined three standard limits including young, middle and old stages for hypsometric curves (Fig. 14). In the young stage, the basin is being excavated and there are many ups and downs, and in the middle stage, the morphotectonics processes are almost balanced. Finally, in the aging stage, ups and downs are gone and the basin is calm.

2.5.6. Zoning of the studied area based on morphotectonics indicators

The most important feature of Geomorphology indicators is helping to identify mobility zones and finding a general idea about mobility features of zones and comparing zones with each other. On the other hand, combining these data with field data reduces the possibility of error in the estimation of mobility zones. In the study area, different indices such as the sinuosity index of the mountain front, the river gradient index, the valley width to depth ratio index, the asymmetry index of the waterway in the drainage basins and hypsometric curves have been investigated. It is necessary to compare the results of different measured indicators with each other and finally compare them with field data. In this case, the investigated area can be zoned on the basis of geotechnical mobility.

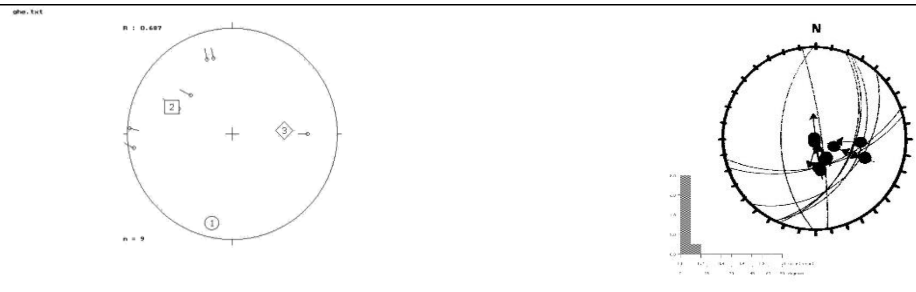
3. Results and discussion

3.1. The direction of the main axes of the dominant tension of the faults

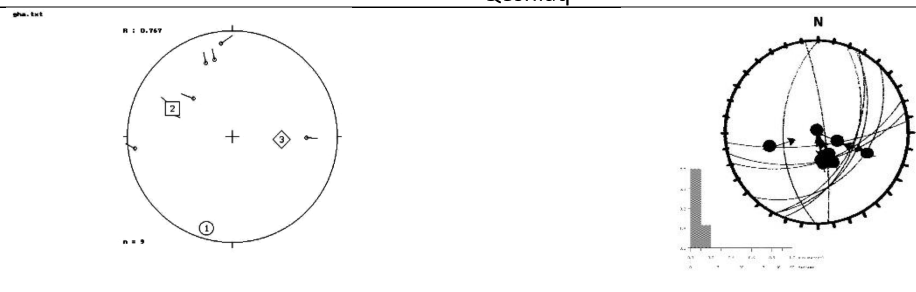
In the study area, the calculation method has been used to find the direction of the main tension axes. In the western Alborz zone, evaluation and measurement has been done in two parts, eastern and western. In the western part of this region, the Qezal owzan faults (Holocene Qeshlagh clays, Qajar mountain marl sediments), Rudbar (Holocene Rudbar marl), Masuleh-Herzoil faults (Neogene Sorankhani marls, ShahMoallem clays) have been carefully studied and the directions of the main tension axes have been obtained. (Fig. 11).

As shown in Figure 11 and Table 1, the maximum tension vectors governing the region follow a certain order. Statistical studies show that in the western and northwestern part of the study area, the direction of the tension vector is northeast-southwest, since most of the measurements were made in young units (roughly Holocene basin) and according to the time sequence of the main deformation stages in the area, It can be definitely said that these structures were formed in a deformed phase. The concordance of the results obtained from the analysis of data related to different stations also confirms this point of view.

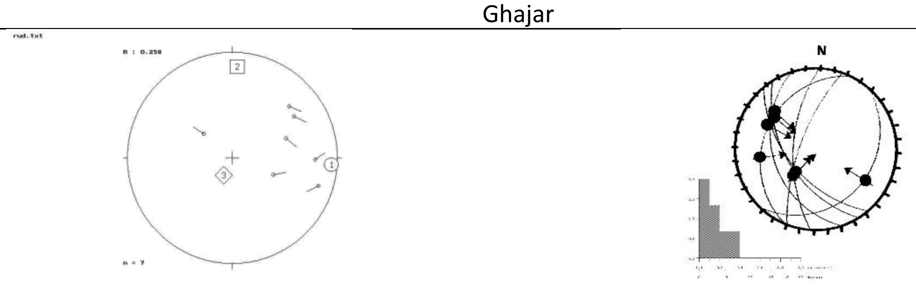
In all the measurements, there was no sign of multiple movements on the fault surfaces, which indicates that the deformation is single-stage in this part of the range. Therefore, it can be concluded that the obtained results will have good certainty. In Table 1, R, is the tension ellipse that varies between 0.094 and 0.864. In addition, based on the Ritz (1991) model, which expresses the relationship between R values and tectonic regimes according to the direction of maximum tension, it can be concluded that the dominant regime in the region is compressional regime, which is between the range of uniaxial compression and radial compression.



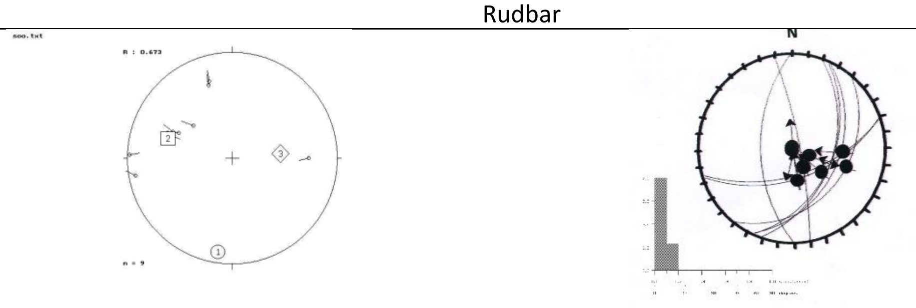
Qeshlaq



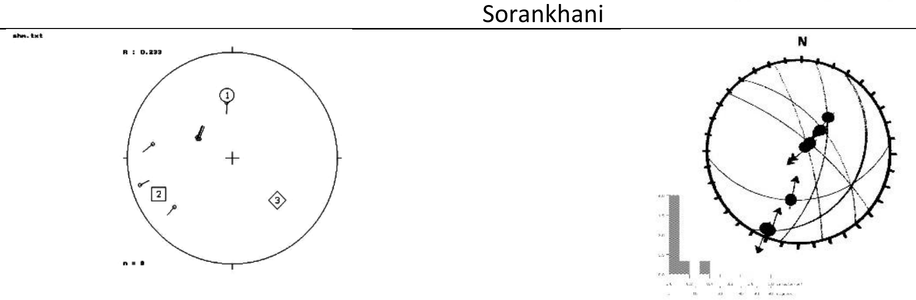
Ghajar



Rudbar



Sorankhani



Shahmoallem

Fig. 11- Tension diagrams of a number of measurement stations in the western part of the studied area. In each station, the distribution of the incongruity angle (difference between the measured Slickenside direction and the calculated Slickenside direction) is specified. The incongruity angle is considered smaller than 30 degrees.

Table 1- Summary of the results of the tension investigations in different stations of the study area

<table>
<tr><th rowspan="2">Row</th><th rowspan="2">Station name</th><th colspan="2">Maximum tension σ1</th><th colspan="2">Median tension σ2</th><th colspan="2">Minimum tension σ3</th><th rowspan="2">Elliptical shape of tension R</th></tr>
<tr><th>Plunge</th><th>Azimuth</th><th>Plunge</th><th>Azimuth</th><th>Plunge</th><th>Azimuth</th></tr>
<tr><td>1</td><td>Manjil</td><td colspan="2">105.40</td><td colspan="2">234.38</td><td colspan="2">349.28</td><td>0.198</td></tr>
<tr><td>2</td><td>Saravan</td><td colspan="2">261.4</td><td colspan="2">352.16</td><td colspan="2">160.73</td><td>0.864</td></tr>
<tr><td>3</td><td>Azadegan</td><td colspan="2">340.47</td><td colspan="2">196.37</td><td colspan="2">91.19</td><td>0.859</td></tr>
<tr><td>4</td><td>Raz nian</td><td colspan="2">350.40</td><td colspan="2">244.23</td><td colspan="2">135.41</td><td>0.618</td></tr>
<tr><td>5</td><td>Kobte</td><td colspan="2">11.02</td><td colspan="2">276.68</td><td colspan="2">102.22</td><td>0.309</td></tr>
<tr><td>6</td><td>Changal dasht</td><td colspan="2">106.29</td><td colspan="2">196.01</td><td colspan="2">287.61</td><td>0.758</td></tr>
<tr><td>7</td><td>Eshkelak</td><td colspan="2">115.28</td><td colspan="2">206.02</td><td colspan="2">70.83</td><td>0.637</td></tr>
<tr><td>8</td><td>Zard Goli</td><td colspan="2">223.06</td><td colspan="2">313.03</td><td colspan="2">166.79</td><td>0.829</td></tr>
<tr><td>9</td><td>Rudbar</td><td colspan="2">94.06</td><td colspan="2">003.14</td><td colspan="2">206.75</td><td>0.258</td></tr>
<tr><td>10</td><td>Qeshlaq</td><td colspan="2">193.14</td><td colspan="2">294.37</td><td colspan="2">86.49</td><td>0.687</td></tr>
<tr><td>11</td><td>Ghajar</td><td colspan="2">196.11</td><td colspan="2">295.37</td><td colspan="2">93.51</td><td>0.767</td></tr>
<tr><td>12</td><td>Sorankhani</td><td colspan="2">189.11</td><td colspan="2">287.36</td><td colspan="2">85.52</td><td>0.637</td></tr>
<tr><td>13</td><td>Ab bar</td><td colspan="2">204.01</td><td colspan="2">294.13</td><td colspan="2">111.77</td><td>0.842</td></tr>
<tr><td>14</td><td>Shahmoallem</td><td colspan="2">355.40</td><td colspan="2">244.23</td><td colspan="2">133.41</td><td>0.233</td></tr>
<tr><td>15</td><td>Amlash</td><td colspan="2">327.08</td><td colspan="2">57.00</td><td colspan="2">149.82</td><td>0.85</td></tr>
<tr><td>16</td><td>Moallem khan</td><td colspan="2">171.04</td><td colspan="2">271.33</td><td colspan="2">62.53</td><td>0.232</td></tr>
<tr><td>17</td><td>Jirandeh</td><td colspan="2">331.11</td><td colspan="2">62.03</td><td colspan="2">166.79</td><td>0.361</td></tr>
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<tr><td>23</td><td>Bahram abad</td><td colspan="2">173.85</td><td colspan="2">286.02</td><td colspan="2">16.04</td><td>0.212</td></tr>
<tr><td>24</td><td>Bagh dasht</td><td colspan="2">286.09</td><td colspan="2">21.31</td><td colspan="2">182.57</td><td>0.274</td></tr>
<tr><td>25</td><td>Jaliseh</td><td colspan="2">281.07</td><td colspan="2">188.22</td><td colspan="2">29.67</td><td>0.735</td></tr>
<tr><td>26</td><td>Nava</td><td colspan="2">85.65</td><td colspan="2">259.25</td><td colspan="2">350.02</td><td>0.247</td></tr>
<tr><td>27</td><td>Malekut</td><td colspan="2">177.13</td><td colspan="2">272.18</td><td colspan="2">54.67</td><td>0.515</td></tr>
<tr><td>28</td><td>Masuleh</td><td colspan="2">105.06</td><td colspan="2">354.73</td><td colspan="2">195.16</td><td>0.067</td></tr>
</table>

3.2. geomorphic tectonic indicators

The summary of the results of measurements related to various indicators for different areas in study area is presented in Table 2. Based on this table, the different basins of the study area are classified as below based on mobility:

A: The basins of Koh Velan, Pakdeh, Darmkhani, Cheshme Roud, Siahkoh Balai, Takas, Khas Rud, Chelgan, Zereshk, Zarijan, Pirkouh, Zardgoli are among the Active and active basins.

B: The basins of Haft Cheshme, Rudbar paeini, Siahkoh paeini, Pa Rudbar, Changal Dasht, Ali Nezam, Khorramabad, Shahmollem, Sorankhani, Faraj Abad, Kohkan, Qeshlaq Jozla, Saravan, Glenkash are classified as median basins.

C: The basins of Eastern Foman, Rize Gar ab, and Marzun Sar are among the very weak basins in terms of activity.

D: The eastern region in Western Alborz has more mobility than the western region in Western Alborz.

Based on Table 2 below the sub-morphotectonics indicators, the studied watersheds are divided into three categories: Active, median and weak.

For the zoning of the watersheds in the entire study area, considering the average activity obtained from the results of different indices, three ranges with different colors were considered (Fig. 12).

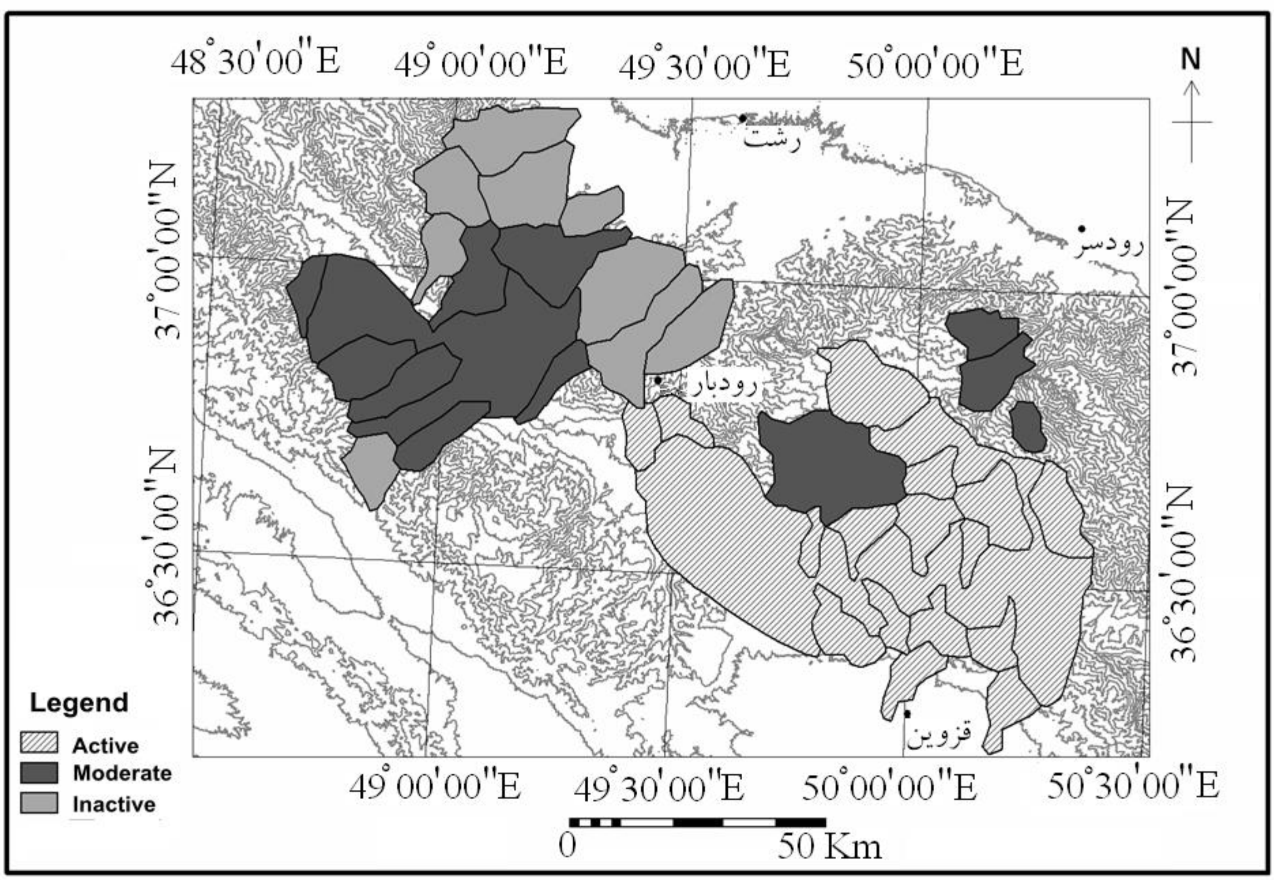


Fig. 12- Zoning of Western Alborz region based on morphotectonics indicators

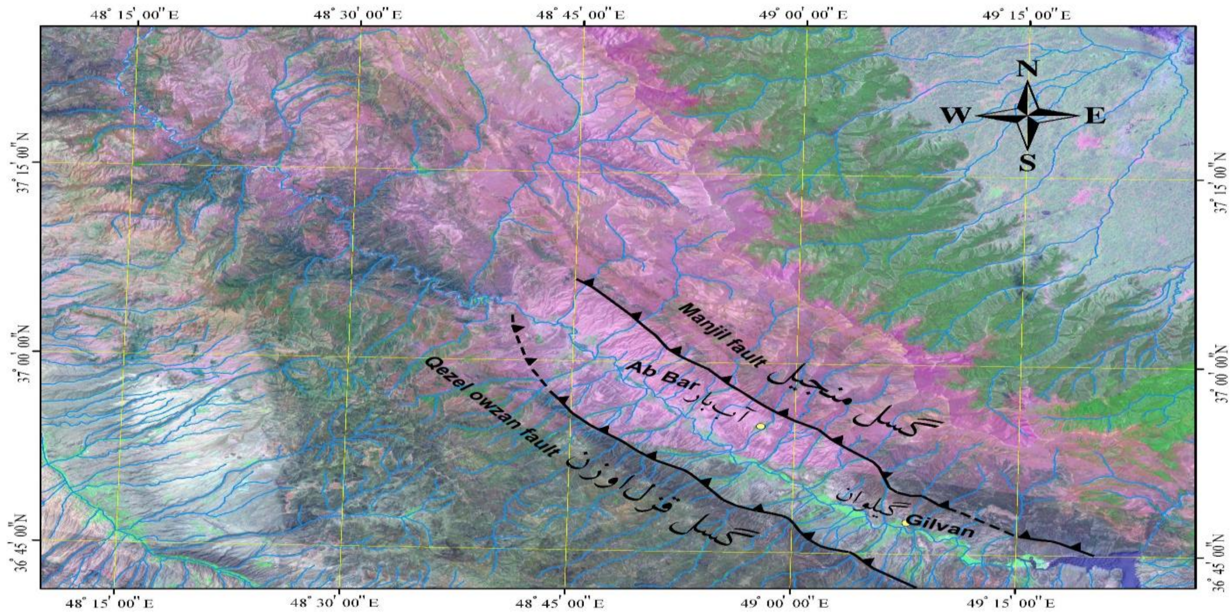
Table 2- The results of the summary of active geomorphic tectonic indicators in Western Alborz

Basin	Smf	Sl	Vf	Af	Hypsometry	Average
Gilavan		Weak	Active	Weak	median	Median – weak
RoudKhan		Active	median	Weak	Weak	Median – weak
Shaft		median	median	Weak	Weak	Median – weak
khoramabad		median	median	median	Active	median
Shahmoallem		median	median	Weak.	median	median
Eastern Foman	Weak	Weak	Weak	Weak	Weak	Weak
Riz Gar ab		median	median	Weak	Weak	Weak
Marzun Sar		Weak	Weak	Weak	median	Weak
Sorankhani		median	median	median	Active	median
Faraj abad		Active	Active	Weak	median	Median – Active
Koh Velan		Active	median	Active	Active	Active
Chalgan		Active	Active	Active	Active	Active
Kohkan		median	median	Weak	median	median
Qeshlaq jozla		median	median	median	Active	median
Zereshk		median	Active	Active	Active	Active
Zarijan		Active	Active	Active	Active	Active
Pir koh		Active	Active	Active	Active	Active
Zard goli		median	Active	Active	median	Active
Saravan	Weak	median	median	median	Weak	median
Galangash		median	Active	median	median	median
Pakdeh		Active	Active	Active	Active	Active
Haft cheshme		median	median	Active	median	median
Rudbar paein		median	Active	Active	median	Median – Active
Siah koh		median	median	Active	Weak	median
Dram khani		Active	Active	median	Active	Active
Pa Rudbar		median	Active	median	Active	Median – Active
Cheshmeh rud		Active	Active	median	Active	Active
Siah koh balaei		Active	Active	Active	Active	Active
Changal dasht		median	Active	Active	median	Median – Active
Ali nezam		median	median	median	median	median
Takas	Active	Active	Active	Active	Active	Active
Khas Rud	Active	Active	Active	Active	Active	Active

3.3. Waterway network

In the southern slope of Western Alborz, especially in Qazvin and Southern Qezel Owzan regions, a network of waterways can be seen, the pattern of which seems to be parallel. These waterways, which are the sub-branches of Qezel Owzan and Shahroud rivers, are connected to the main branches at a sharp angle, and the type of formations and bedrock in these areas are mostly the same. In the south-western and south-eastern regions, in the territory of the Shahroud, Alamut Rud and Qezel Owzan rivers, regular fractures have caused the formation of a rectangular waterway.

As shown in Figure 13, the collision of the sub-branches with the main one has taken place at an angle of 90 degrees. The most important factor controlling the shape of the waterway system in these places is parallel and active fractures that have acted as a regular fracture network. In the north-west and north-



east of the study area, a dendritic waterway pattern is observed (Fig. 13).

Fig. 13- Satellite image of a part of the study area with parallel, rectangular and dendritic pattern

3.4. Hypsometric curves

In the study area, hypsometric curves have been prepared for different basins, the results of which are shown in Fig.14. It is obtained by comparing the diagrams of Alborz areas (Fig. 12) with standard diagrams (Fig. 14), the basins of Zereshk, Changal Dasht, Cheshme Rood, Takas, Pa Rudbar, Deramkhani, Pakdeh, Khas Rud, Koh Velan, Algaf, Pirkoh, Zarijan, Chalgan, Khorramabad, Sorankhani, Qeshlaq Jozla, Siyahkohe Balaei are active and young, on the other hand, Ali Nezam, Haft Cheshme, Glenkash, Zardgoli, Rudbar Paein, Faraj Abad, Kohkan, Gilvan, Shahmollem, Marzun Sar, Qezl owzan basins are in the middle stage and Siah kohe paeini, Saravan, Rudkhan, Shaft, Eastern Foman and Rize Gar ab, where erosion has dominated the uplift are classified as old and inactive.

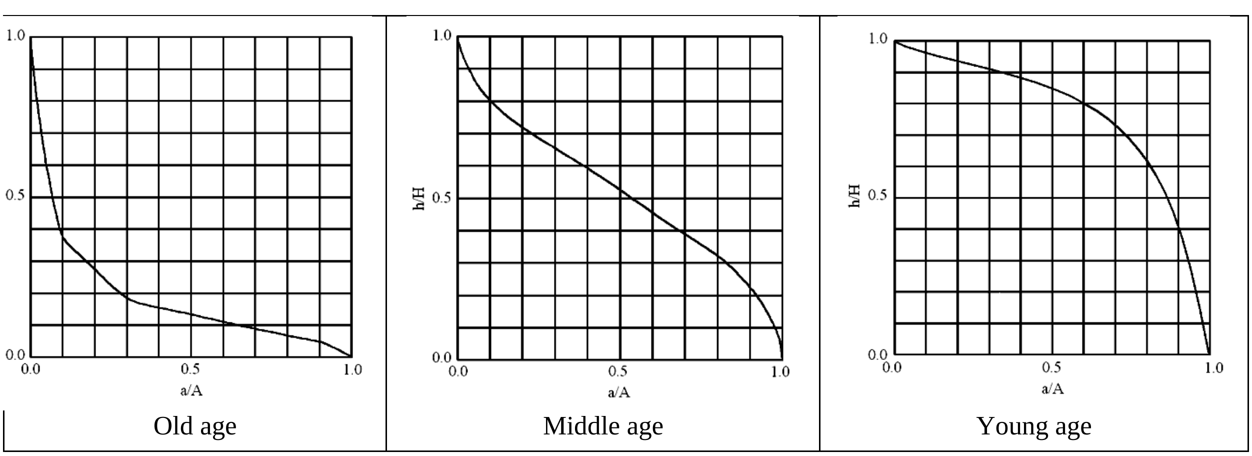


Fig. 14- The standard curves of the three stages of young age, middle age and old age

3.5. New tectonics movements

The depth of most earthquakes in Alborz, especially in Western Alborz, is less than 15 kilometers, and the number of earthquakes with a focal depth of more than 60 kilometers is very limited. Solving the deep faulting mechanism of most of the earthquakes shows their mechanism to be inverted or along left-tilt slip with inverted vector. In this regard, many reverse faults and young folds have been identified in Western Alborz, which are caused by the action and activity of earthquakes (Berberian,1983).

An example of young surface faults is a fault with a length of more than 80 kilometers that occurred due to the Rudbar-Tarom (Manjil) earthquake in 1990 (Berberian, 1983). The field work done in this area indicates its mobility, especially the fault zones in this area. For example, we can point out the presence of high alluvial terrace in the Alamut and Qezel Owzan rivers (Fig. 15), which can be seen in the eastern and western parts of the area. In addition to the geological evidence, seismic data and geodetic indicators calculated in the range confirm its mobility. In addition to the geological evidence, seismic data and geodetic indicators calculated in the range confirm its mobility. Many earthquakes have also occurred continuously in this area (Masoumi et al., 2014; Ambraseys & Douglas, 2004).

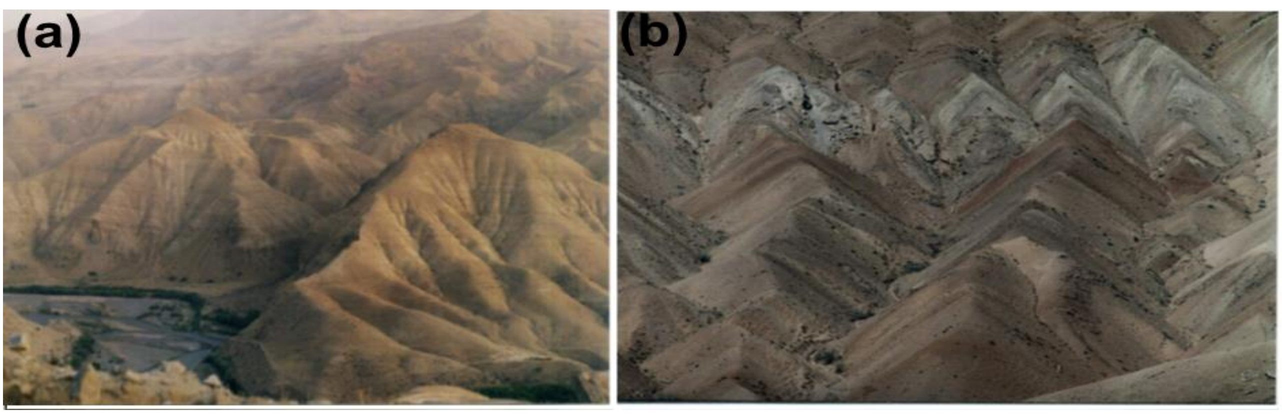


Fig. 15- Raised terraces a: Alamut Rud in the eastern part b: Qezel Owzan in the western part of the studied area

The solution of the deep fault mechanism of the 1983 Rudbar earthquake, which shows that the Rudbar fault has a left-lateral slip mechanism with a small reverse component. Also, the solution of the deep fault mechanism of the 1369 Rudbar-Manjil earthquake, which shows the mechanism of this fault to be strike-slip with a small dextral strike-slip component (Fig. 16).

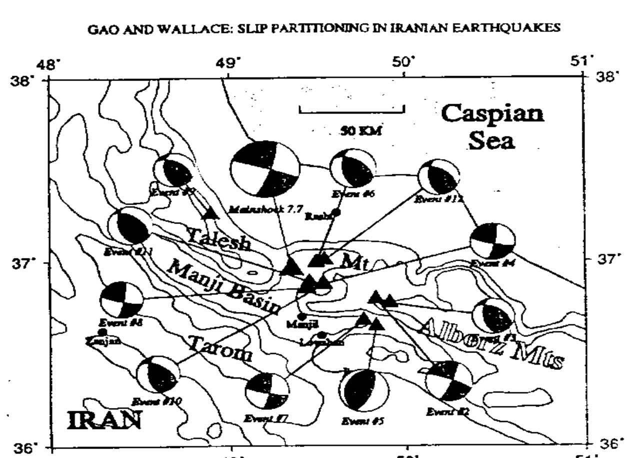


Fig. 16- The deep mechanism of the Rudbar earthquake and its large aftershocks (Gao & Wallace, 1995)

In 1999, Tatar studied the device data of 71 earthquakes in the study area and mapped the focal mechanism of all earthquakes. According to the above data, the length and angle of inclination of the compressive axis and the tensile axis of measurement and its Windrose polar and contour diagrams were compared with the maximum tension diagrams (σ1) in the stations of the region (Fig.17). As a result, a relatively perfect match between P trend and σ1 was observed. From the information available in the field of historical and systematic earthquakes (Tatar, 1999; Gao & Wallace, 1995) and solving their deep faulting mechanism and measuring the levels of faulting and slips in young sediments and determining the trend of the maximum tension with the return method in different stations, we came to this conclusion that historical earthquakes start from the central areas of the studied area and continue and develop to the southeastern area of the area towards the valley of Alamut Rud.

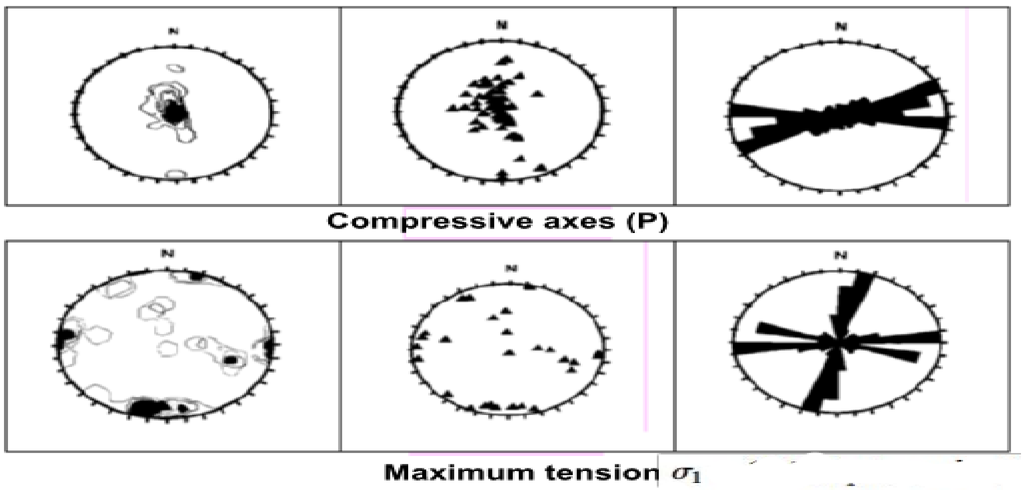


Fig. 17- Windrose, polar and contour diagrams of compressive axes (P) of earthquakes (Tatar, 1999) and its comparison with the maximum compressive tension obtained by the return method in different stations of the Western Alborz region.

It is the case that in the north-western region of the study area, the number of historical earthquakes has been the least and sometimes no seismic activity has been observed. In addition, the levels of faulting and seismic slips measured in young sediments in the northeastern region and the determination of the maximum tension trends indicate the occurrence of new earthquakes in these regions and in fact structural activity in the Holocene period in this region. In short, it can be said that the rhythm of tectonic and structural earthquake activity does not increase from the west to the east and especially to the southeast.

3.6. Trend of faults

The mechanism of the dominant main faults is mainly reverse in all section (Fig.18).

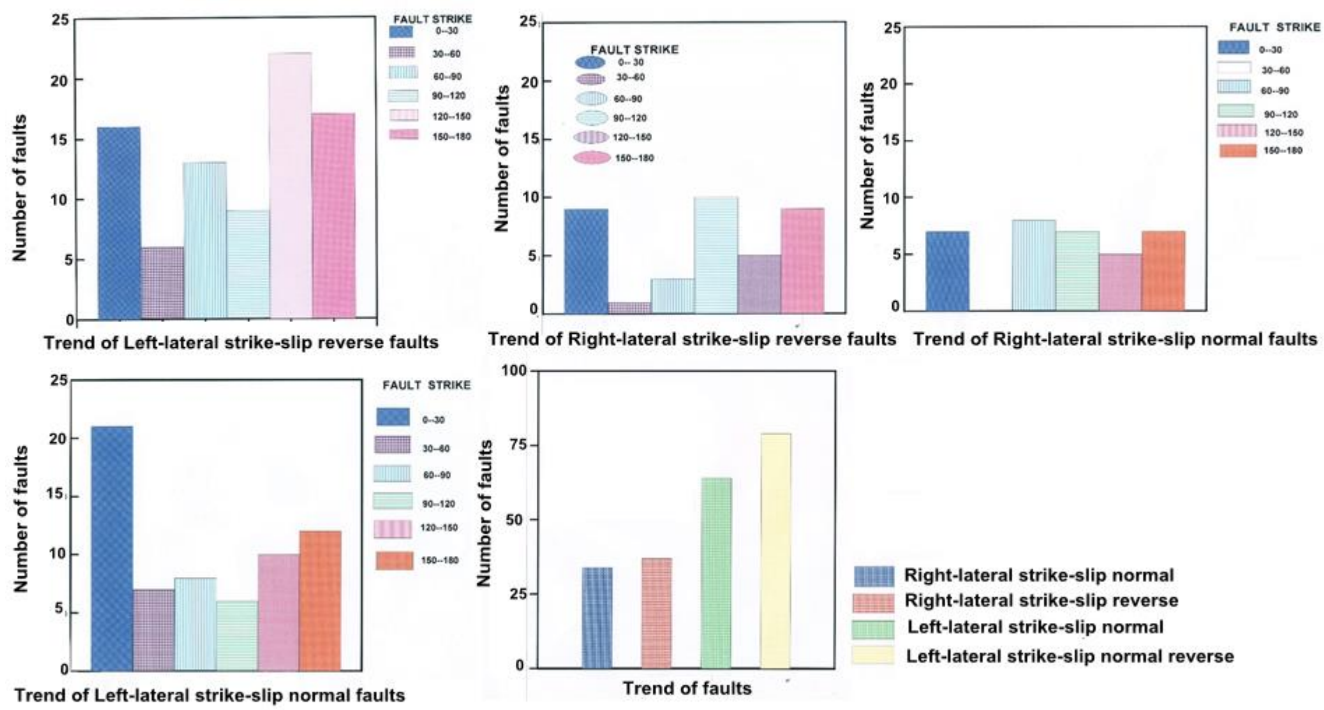


Fig. 18 - Cumulative diagrams of the types of faults in the study area

4. Conclusion

Mobility can be seen in different parts of the range in different ways. Mobilities are in the form of either zone uplifts (alluvial fans, barracks or uplifts of young folds) or linear uplifts (resulting from the uplift of young faults). The alluvial terraces that can be seen in the big rivers of the region, especially Qezel Owzan, indicate the mobility of their areas.

Based on what was discussed in the previous sections, the following are important regarding the western region, especially the surface fault that caused the Rudbar-Manjil earthquake:

1- The main fractures of the range have been seen according to Windrose diagrams in four main directions, which include:

A: North-East-South-West direction, like the Sefid Rud fault and... (It is dominant in the central and south-western parts of the area).

B: North-West-South-East direction, such as Alamut Rud, Shahrud, Qezel Owzan and the surface fault that caused the Rudbar-Manjil earthquake (69) and... (it is dominant in the western part of the area).

C: North-South direction (which is small in number but dominant in the central part of the area).

D: The east-west direction, such as the faults in the north of Qazvin, Lahijan and... (It is dominant in the eastern part of the area).

2- The maximum tension vectors dominating the range follow a certain order. Statistical studies show that in the eastern part of the range, the majority of the direction of the maximum tension is east-west and a small number of the direction of the tension is northeast-southwest, but in the western part, the majority of the direction of the maximum tension is northeast-southwest and a few of them have an east-west trend. The northwest-southeast trends are mainly the trend of old tensions.

3- Considering the trends of the maximum tension and the trends of P axes of seismometer (Tatar, 1999) and the trend of surface faulting causing the Rudbar-Manjil earthquake (N140) and based on the Slip Partitioning model (Berberian, 1983) and the mechanism of the above fault which is reversed and sinistrogyrate, it can be suggested that the block of the north-eastern wall of the fault is moving towards the north and north-west.

4- From the information available in the field of historical earthquakes and seismometer and solving their deep faulting mechanism and measuring fault levels and seismic slickensides in young sediments and determining the maximum tension trend, it can be concluded that the density of historical earthquakes has continued and developed from the center towards the east, and from the northeast towards the Alamut valley, which is confirmed by the measurement of the maximum tension trend in young sediments, as a result of which the fault activity increases from the west to the east.

5- Mobility can be seen in different ways in different parts of the range; they are either in the form of wide uplifts (alluvial fans, terraces or uplifts of young folds) or in the form of linear uplifts (caused by the uplift of young faults).

6- The alluvial terraces that can be seen in the big rivers of the region, especially Qezal Owzan, indicate the mobility of their zones.

7- The pattern of waterways in the areas are rectangular, parallel and dendritic, all of which are somehow affected by the structures of the area. Sometimes, the landforms created by the action of the young faults of the area have shaped the design of the waterway (Jamali et al., 2020). Since the pattern of waterways is affected by the design of fractures and other structures of the area, it is placed in the category of active controls in the classification of Han (1985), which is the result of the action of some faults such as Qazvin and Qezl Owzan.

8- The depth of the river channels of the alluvial zone of Qezel Owzan and Shahroud indicates the high level of vertical excavation, which is the result of relatively fast vertical movements. Their rapid rise and this phenomenon is due to their location next to the active faults of Qezel Owzan, Alamut Rud and Shahroud. In fact, the action of the Alamut-Rud, Shahroud and Qezl Owzan faults, all three of which are active and seismic faults, have caused the formation of this area and as a result, the formation of a rectangular pattern in these areas.

9- In addition to the elevation index of the zones and the alluvial terrace, which is a proof of the mobility of the desired zones of Western Alborz, the cutting of these sediments and the formation of V-shaped valleys leave no doubt in the activeness of this zone.

10- The sinuosity index of the front of the mountain in the north of Qazvin shows the mobility of this region compared to other regions.

11- River gradient index of Takas, Khas Rud, Pakdeh, Zardgoli, Pirkoh, Zarijan, Ali Nezam, Chelgan, Koh Velan, Faraj Abad, Rudkhan and Qeshlaq basins in the next category shows a high elevation.

12-Measurements related to the ratio of valley width to depth, for the basins of Takas, Khas Rud, Pakdeh, Zardgoli, Pirkoh, Zarijan, Ali Nezam, Chelgan, Kuh Valan, Faraj Abad, Zershak, Zardgoli, Siahkoh, Dermkhani, Cheshme Rood, Gilvan, Faraj Abad and Qezel Owzan Pertkapo suggest for them.

13- The asymmetry index of waterways, Khas Rud, Takas, Haft Cheshme, Pakdeh, Zarijan, Upper Siahkouh, Lower Siahkouh, Zardgoli and Zarshek basins in the eastern region points to the high asymmetry in them, this asymmetry can be attributed to the activities of faults North of Qazvin, Shahroud and Alamut rivers and their mechanisms, and also the basins of Qezel Owzan, Chalegan and Koh Velan in the western region, which are related to the activity and mechanism of the faults of Qezel Owzan and Masoleh Herzoil, have been tilted more than other basins.

14- Based on hypsometric measurements, Zershek , Changal Dasht basins, Cheshme Roud, Takas, Pa Rudbar, Deramkhani, Khas Rud, Koh Velan, Algaf, Pirkoh, Zarijan, Chalgan, Khorramabad, Sorankhani, Qeshlaq Jozla and Siahkoh Balei are the most active basins of Western Alborz and in other basins of this region, erosion and sedimentation are in balance.

15- In the comprehensive study of active morphotectonics indicators, the basins of Kohe Velan, Pak deh, Darmkhani, Cheshme Roud, Siahkoh Balai, Takas, Khas Rud, Chalgan, Zershek, Zarijan, Pirkun and Zardgoli are included in the category of active basins. While the basins of Haft Cheshme, Rudbar paein, Siahkoh paeini, Pa Rudbar, Changal Dasht, Ali Nezam, Khorramabad, Shahmollem, Surankhani, Faraj Abad, Kohkn, Qeshlaq Jozla, Saravan and Glenkash are in the middle zones and the basins of Eastern Foman, Riz Gar ab and Marzun Sar are classified as weak areas from the point of view of mobility.

16- The occurrences of small and large earthquakes along most of the faults in the region, especially Rudbar, Alamut, Shahroud, Menjil and North Qazvin, indicate the continuous mobility of these structures.

17- Comparatively, the basins of the eastern region of the region have more mobility than the western region.

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Availability of Data and Material (Data are available when requested)

Consent to Publish (Author consent to publishing)

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