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Evaluating the Fans in Active Palami and Jiroft Faults in South of Central Iran and Zagros-Makran Transition Zone

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Abstract: *Measurement of the area, slope and height of the land surface roughs and forms in the vicinity of the faults is a possible method for evaluating the active tectonics of a region. Fans are enumerated amongst the most distinct geomorphological forms and reliefs. The studied regions constitute the northern margin of Jazmouriyan Plain (Jiroft Fault) and Palami Fault in the form of a thin and continuous strip, respectively, featuring a northwest-southeastward trend and an approximate northern-southwestward trend. 23 and 6 fans of the structural type were correspondingly investigated in the northern margin of Jazmouriyan Plain and in the west of Palami Fault, respectively. The examined indices of the fans in the study region were symmetry, area and slope. The goal in calculating these indices in the studied fans was investigating the amount of the faults' activities according to the effects they would have on the shape and slope of the fans. Considering the symmetry index, the highest rate of asymmetry in the northern margin of Jazmouriyan Plain has been found in the Fan no.10, hence this part of the fault is deemed to be more active. Based on the area index, the fault segment overlooking the Fan numbers 2 to 5 and 15 is more active due to the non-correlation of the areas and, based on the index of slope, there is no inverse relationship between the slope of the fan and the area of the drainage basin in the fan numbers 4 and 8-10 and 15 which feature very steep slopes hence the fault segment overlooking them is more active. In the west of Palami Fault, the highest rate of asymmetry has been documented for the fan no.5 hence this part of the fault is more active. Based on the index of area, the fault segment overlooking the fan numbers 2 to 3 is more active due to the existence of no correlation between the areas and, based on the index of slope, there is no inverse relationship between the slope of the fan and area of the drainage basin in fan nos. 3 and 4 hence the fault segment overlooking them is more active. Blending the results obtained for the abovementioned indices, fan nos. 5, 6, 9 and 11 to 16, in the northern margin of Jazmouriyan Plain and fan nos.2, 3, 4 and 6, in the west of Palami Fault are amongst the fans overlooking the active fault segments due to the lack of positive correlation between slope and height.*

Keywords: *Northern Margin of Jazmouriyan Plain, Western Side of Palami Fault, Tectonic Activity, Fan, Active Fault Segments.*

INTRODUCTION

Makran zone is situated in the southeast of Iran and south of Pakistan with a length of about 1000km and it is considered as a part of the boundary between Eurasia and Arabia plates (figure 1) in which the oceanic

crust of the Arabia Plate (in Oman Sea) has been undergoing subduction underneath Eurasia plate since early Cretaceous Era with a northward slope and in a very low angle (e.g., Farhoudi and Karig, 1977; Sengr et al., 1988). The slide rate of the faults in Zagros-Makran transition zone has been investigated by Regard et al (2004) and, from their viewpoint, Zendan-Minab region is a transition zone between Zagros contact point in the west and Makran subduction zone in the east. As believed by Shafi'ei Bafti et al (2008), Sabzevaran-Jiroft Fault system along with Zendan-Minab-Palami Fault system play a considerable role in transferring the stress imposed from the southeast of Iran to the northern parts. The general rate of convergence between Eurasia and Arabia Plates ranges from 23mm to 35mm per year in north-northeast trend. As opined by Regard et al (2004), there are two generations of fans in the south of Iran within the studied region:

1) Fans within the area of Zendan region;
2) Fans in Jazmouriyan subduction zone

The studied regions are in the form of a thin and continuous strip stretched northwest-southeastward and constituting the northern margin of Jazmouriyan Plain (Jiroft Fault) and in the form of a thin and continuous strip stretched approximately north-southwestward and constituting Palami Fault. Thus, the geological properties of the region pertain to Makran Zone and Zagros-Makran transition zone (figure 1). In the studied region, 23 and 6 fans of the structural type were, respectively, investigated in the northern margin of Jazmouriyan Plain and in the west of Palami Fault. The goal was investigating the activity extents of the faults in the northern margin of Jazmouriyan Plain and in the west of Palami Fault according to the effects these can have on the form of these fans.

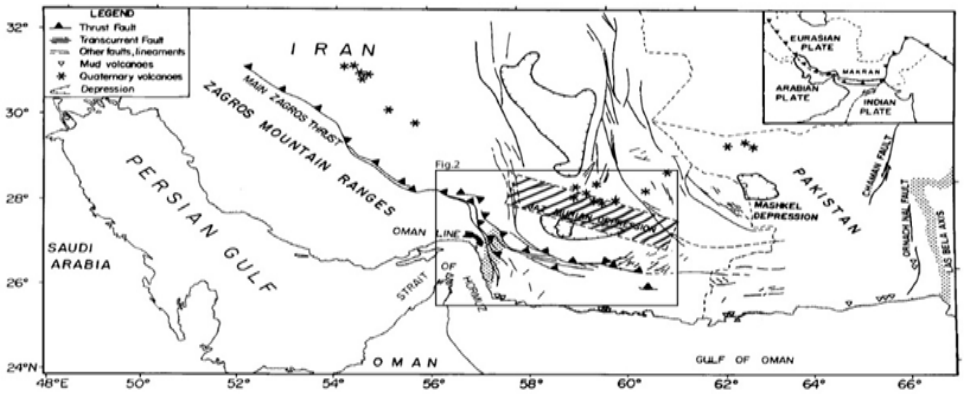


Figure 1: position of Makran zone and Zagros transition zone in respect to Iranian, Arabian and Indian Plates; the position of the studied region has been shown in a rectangular cadre (excerpted from Farhoudi and Karig, 1977).

Study Method

Fans are amongst the most distinctive features of the land forms and reliefs used in geomorphology. In terms of shape, fans normally resemble cones. However, they are morphologically similar to a sector of a circle. The triangular shape of a cone specifies the way it expands. The preliminary and primary shape of a fan is determined in a sedimentary reaction to the expansion of a stream that has been subjected to certain restriction before entering the plain in a valley. The stream loses its power of carrying the sediments hence resulting in the accumulation and settlement of the deposits when it leaves the stone valley and reaches the fan surface as a result of the reduction in slope and flowing of water in a vaster region. In the next stage, a chignon stream is formed on the surface of these sediments and causes the dislocation of the deposits along the longitudinal and transversal direction leading to a particular shape of the alluvial fans.

The indices studied for the foresaid fans are:

1) Symmetry of the fan

2) Area of the fan
3) Gradient of the fan

Symmetry of the Fan

The overall shape of a fan can reveal the pattern of tectonic activity in the vicinity of the mountain front. Since the fans are conical in shape, the contour lines in the transversal axis of the simple fans are nearly circular. Under proper conditions, asymmetry can be computed by matching an ideal oval onto the contour lines falling on the cone's width. So, measuring the longitudinal axis (a) and small axis (b) enables the calculation of the oval shape hence the asymmetry will be obtained (ß) (figure 2) (Keller and Pinter, 1996). Asymmetry is computed as shown in the formula below:

$$\beta = \arccos\{(b/a)^2 \sin^2 \alpha + \cos^2 \alpha\}^{0/5}$$

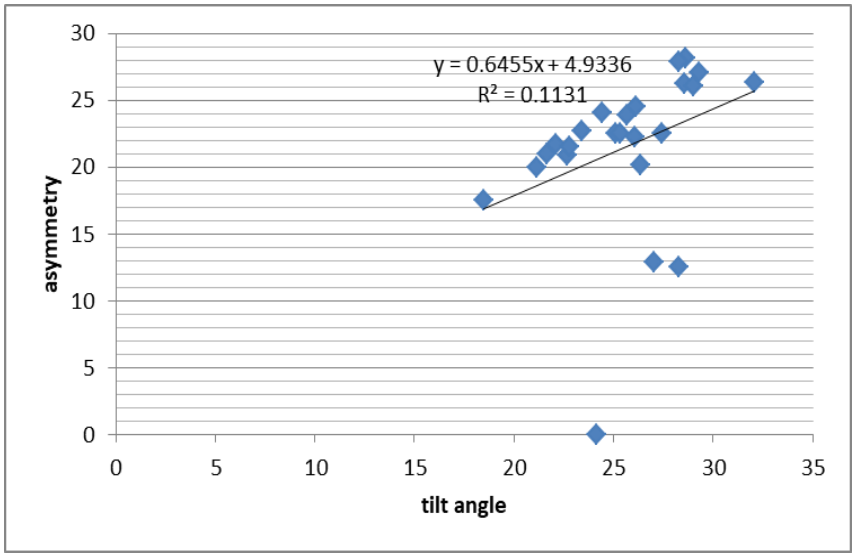
Where, a is half the size of the large diameter, b is half the size of the small diameter, α is the deviation or tilt angle in the adjacency of the small axis of the oval.

Area of the Fan

Area of the fan experimentally depends on the area of drainage basin. The correlation between the two foresaid variables can be accessed through the following equation:

$$A_f = cA_d^n$$

Where, A_f is the area of the fan, A_d is the area of the drainage basin and C is a constant variable depending on the rock's type and solidarity and n is the line gradient. The constant C in this equation is directly correlated with the erodibility of the rocks in the drainage basin, tectonic dislocation, the amount and intensity of rainfall and the amount of accessible space. Figure (3) illustrates the quality of the relationship between the fan's area and the drainage basin's area of the fans in the studied region.



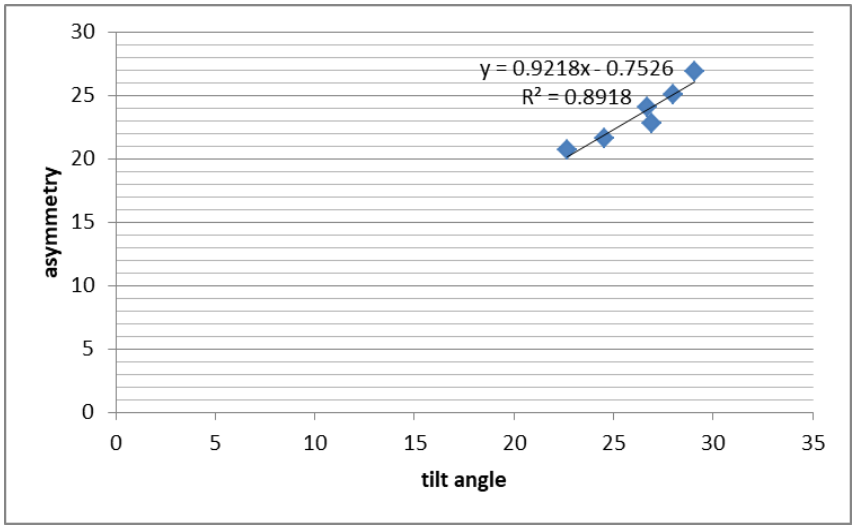


Figure 2: tilt angle and asymmetry of the fans in the northern margin of Jazmouriyan Plain and west of Palami Fault

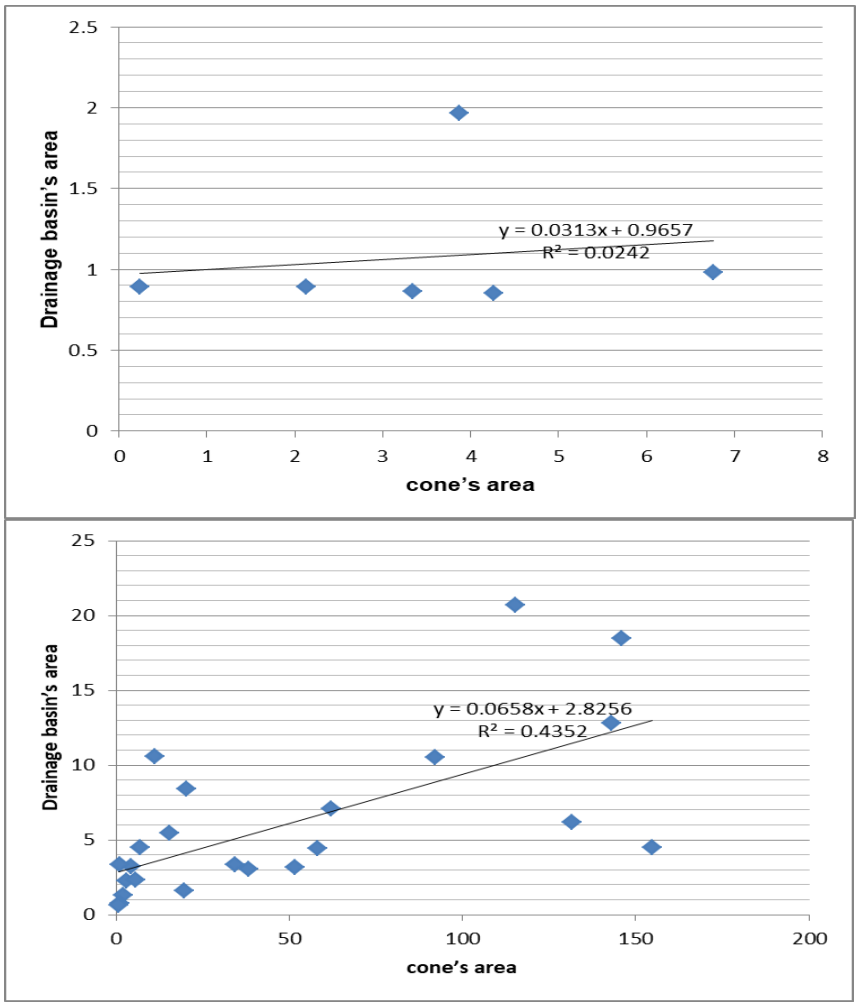


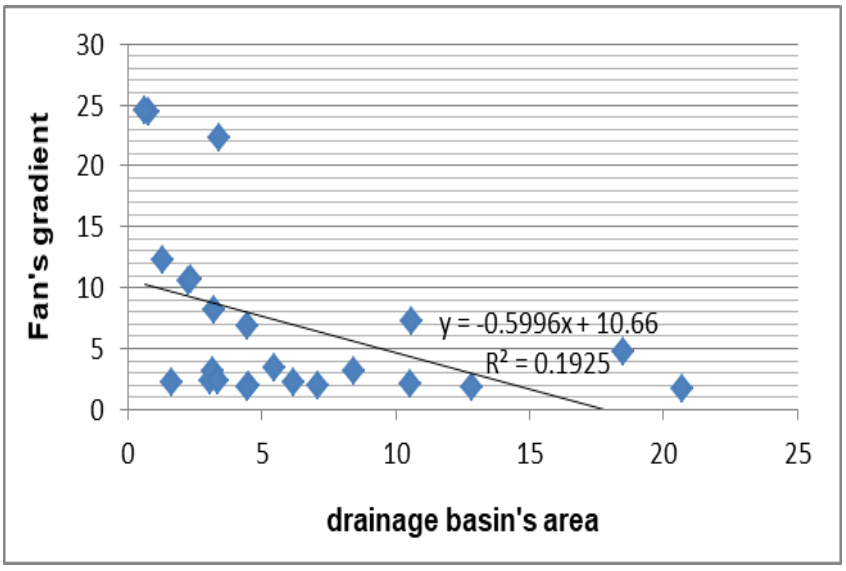
Figure 3: the correlation between the area of the fan and drainage basin's area in the northern margin of Jazmouriyan Plain and west of Palami Fault

Gradient of the Fan

Slope is an important factor in the study of the fans. The dimensions of the fans are very different and, resultantly, the surface slopes of the fans are also different (Maghsoudi, 2012). Based on the studies by Bull and McFadden (1977), the radial profiles of the fans are unevenly concave. Belsinbakh (1954) classifies fans based on gradient into three groups of highly sloped (over 5 degrees), mild (a slope between 2 to 5 degrees) and flat (below 2 degrees). He also knows the gradients above 5 degrees as being specific to the parts in the upstream side of the fans. There is an inverse relationship between the area of the fans and their gradients. On the other hand, the larger the area of the drainage basin, the larger the area of the fan will be. Therefore, there is an inverse relationship observed between the area of the drainage basin and the gradient of the fan (figure 4). Equation for slope is as shown below (Bull, 2011):

$$S_f = CA_d^{-b}$$

Where, S_f is the surface slope of the fan's apex, A_d is the area of the drainage basin, C is a constant coefficient that is commonly considered equal to unity; b is assumed like C equal to unity. On the other hand, the fan's radius is indicative of its expansion and largeness and the inverse relationship between the fan's area and its slope holds between the fan's gradient and radius, as well (Bull, 2011) in such a way that the longer the length of the fan's radius, the more the fan's radius will be decreased. This way, the larger the value of the cone's radius, the more it is indicative of the fan's expansion and its suitable space for cone development. This appropriate development causes the creation of a mild slope that is stretched from the mountain front to the ending fore deep (Maghsoudi, 2012). The investigation of the relationship between the fan's slope and radius assists the better specification of the fault activity and correlation between the slope and area of the cone. Normally, the fan's apical height is increased in regions featuring active tectonics due to the higher uplifting of the region and, consequently, the fan's slope is increased and its radius is decreased. The parameters computed for the fans in the study regions have been given in table (1).



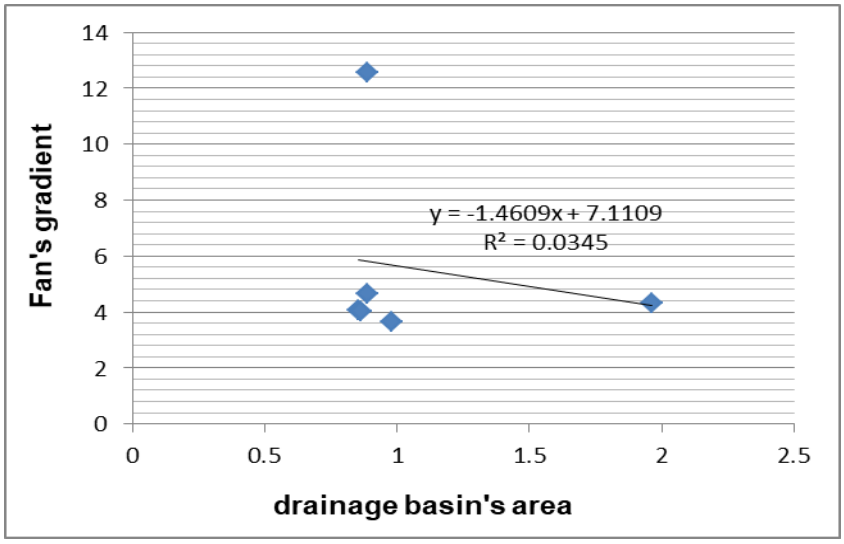


Figure 4: the relationship between the fan's gradient and area of the drainage basin in the northern margin of Jazmouriyan Plain and west of Palami Fault

Discussions

The asymmetry rate was calculated for the fans in the northern margin of Jazmouriyan Plain and western side of Palami Fault with the computation of symmetry index (table 1). The increase in α brings about an increase in ß. In other words, there is a direct correlation between the tilting rate of the oval's small axis and asymmetry of the fans for the reason that the more the tilting of the oval's small axis is increased, the more the fan's shape deviates from its symmetry. Based on the obtained beta-values, the lowest tilting rate belongs to the fan no.23 and the highest tilting rate goes to the fan no.10 in the northern margin of Jazmouriyan Plain and the lowest and the highest amounts of tilting were found belonging to the fan numbers 2 and 5 in the western part of Palami Fault. The increase in tilting is reflective of the asymmetry in the fans hence expressive of the idea that the fault segments overlooking these fans feature a higher uplift.

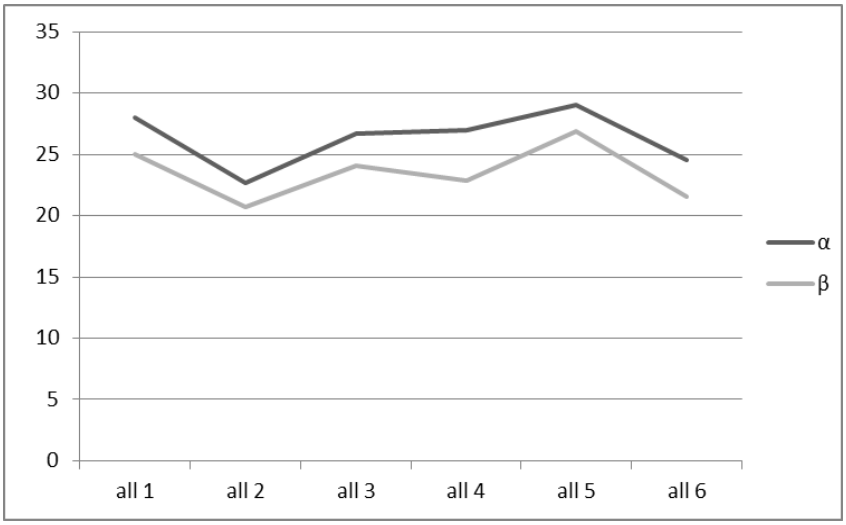


Figure 5: the relationship between the tilting angle and asymmetry of the fans in the northern margin of Jazmouriyan plain and western side of Palami fault

Based on the values obtained for the areas of the fans and drainage basins existent in the studied regions, it can be figured out that the increase in the drainage basin's area causes an increase in the majority of the cases in the area of the formed fan. These two parameters have a positive correlation with a regression rate of about 0.43 in the northern margin of Jazmouriyan Plain and about 0.02 in the western side of Palami Fault (figure 3). The reason for this correlation can be expressed by the idea that the larger the drainage basin supplying the fan formation with sediments, then, the more the volume of the deposits it carries from the elevations hence the larger the formed fan.

Considering the areas of the fans (A_f) and the area of their drainage basins (A_d), it can be stated that the increase in the areas of the drainage basins causes reductions in the areas of the cones in the northern margin of Jazmouriyan Plain and western side of Palami Fault from the fan no.2. Based on table (1), fan no.3 is the biggest in the northern margin of Jazmouriyan Plain and the fan no.4 is the biggest in the western side of Palami fault. Fan no.2 possesses the largest drainage basin in the northern margin of Jazmouriyan Plain and the low rate of the correlation between these two parameters stems from the activeness of the northern margin of Jazmouriyan Plain and the fan no.5 possesses the largest drainage basin in the western side of Palami Fault and the low correlation rate between these two parameters is due to the activeness of Palami Fault.

Based on the values obtained for the gradient of the fans in the studied region, it can be stated that the fans of the studied region feature slopes below 2 degrees, between 2 and 5 degrees and above 5 degrees. Thus, the streams supplying them, as well, are among the small and permanent type. The highest gradients have been documented for fan nos.22 and 24 in the northern margin of Jazmouriyan Plain and fan no.2 in the western side of Palami Fault. The lowest mild slope has been evidenced for fan no.2 in the northern margin of Jazmouriyan Plain and fan no.4 in the western side of Palami fault (table 1).

The increase in the areas of the fans and areas of the drainage basins brings about a decrease in the fans' slope (figure 6). The correlation coefficient between the fans' slopes and drainage basins' areas is equal to 0.19 for the northern margin of Jazmouriyan Plain and 0.03 for the western side of Palami Fault (figure 4). These coefficients are suggestive of significant, weak and inverse correlation between the two aforesaid parameters. The reduction in the cone's slope is reflective of the idea that the region is morphologically flat but the increases in the drainage basins' areas cause increases in the gradients in the fans numbered 11 and 12, in the northern margin of Jazmouriyan Plain and fans numbered 3 to 5 in the western side of Palami Fault and this is expressive of the youngness of the fans and the mountain's higher uplift (figure 7).

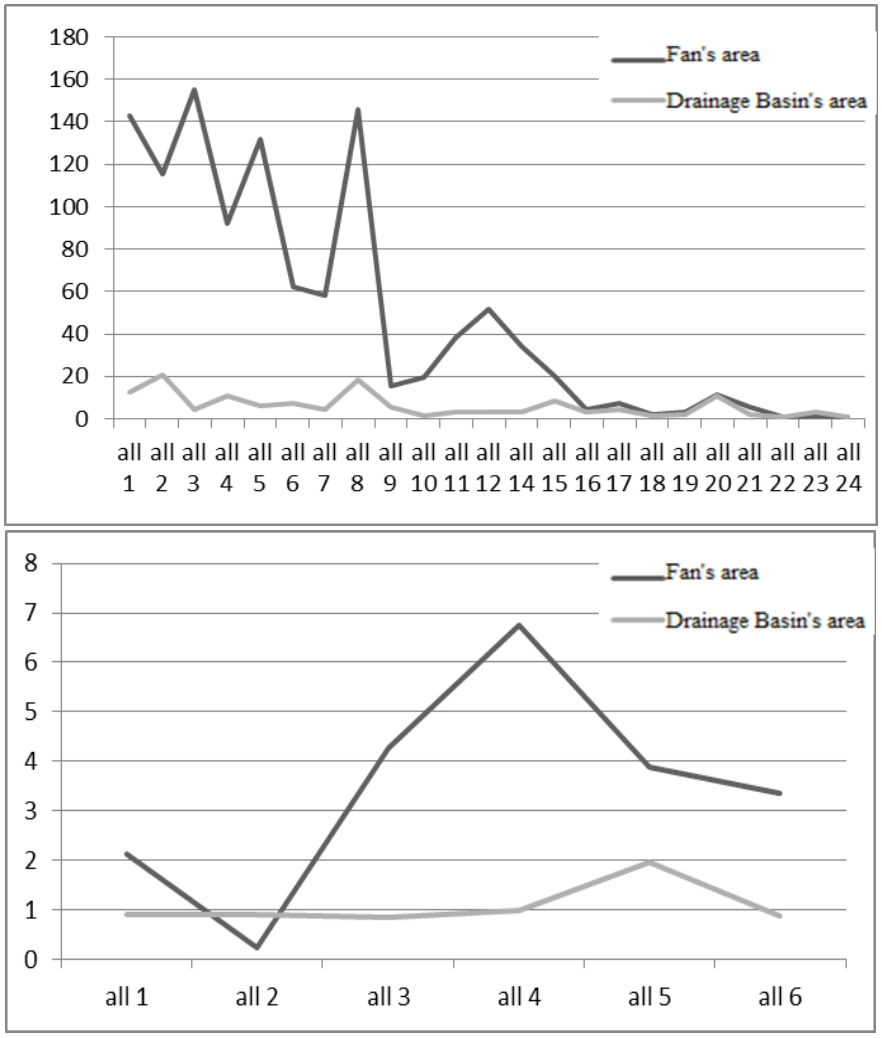
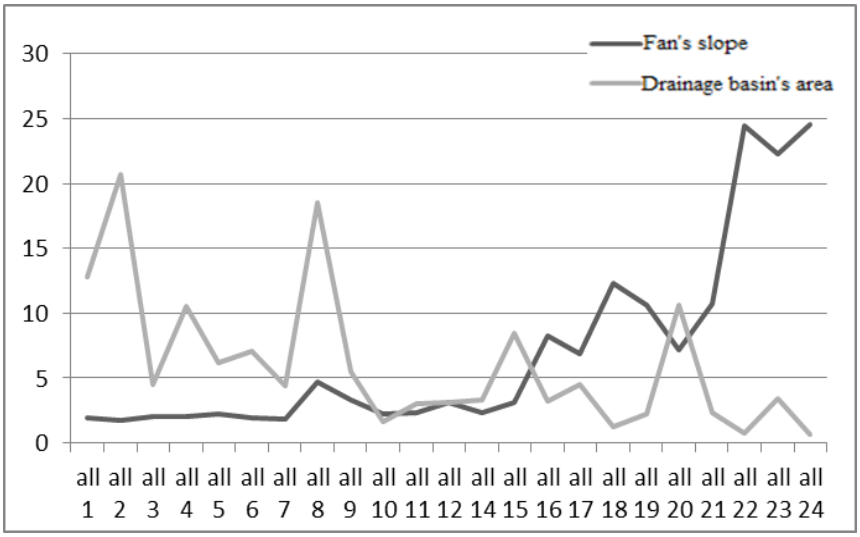


Figure 6: the relationship between the areas of the fans and the areas of the drainage basins in the northern margin of Jazmouriyan Plain and western side of Palami Fault



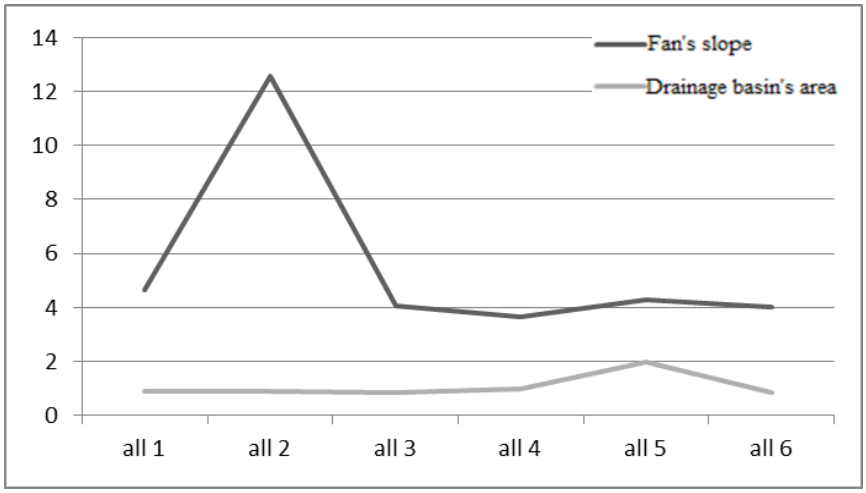


Figure 7: the relationship between the fans' slopes and area of the drainage basin in in the northern margin of Jazmouriyan Plain and western side of Palami Fault

Conclusion

Since the highest rate of asymmetry has been scored for fan no.10 in the northern margin of Jazmouriyan Plain, it can be stated according to the asymmetry of the fan in this locality that this part of the fault is more active. In the western side of Palami Fault, the highest rate of asymmetry has been found belonging to the fan no.5 hence this part of Palami Fault is more active.

Based on the results obtained from the measurements of fans' areas and drainage basins' areas in the northern margin of Jazmouriyan Plain and according to the relationships between these two parameters, it can be stated that the fault segments overlooking the fans numbered 2 to 5 and 15 are more active due to the non-correlation of the areas. In the western side of Palami Fault, faults numbered 2 to 3 are more active due to the non-correlation of the areas.

Based on the obtained gradients and considering the relationships between the slope and area of the fans with the area of the drainage basin, it can be stated that there is no inverse relationship documented between the fans' slopes and drainage basins' areas for the fans numbered 4 and 8 to 10 and 15 in the northern margin of Jazmouriyan Plain and the fans numbered 3 and 4 in the western side of Palami Fault hence the fault segments overlooking these fans are more active.

Blending the aforementioned indices, the active segments of the northern margin of Jazmouriyan Plain and western side of Palami Fault were identified and introduced (figures 8 and 9).

Table 1: parameters calculated for the fans of the northern margin of Jazmouriyan Plain and western side of Palami Fault

Alluvial fan	A_f (km^2)	A_d (km^2)	S_f	Dip (degree)	α	ß	Altitude
Al1	142.9	12.8	1.8	1.8	27.42	22.54	520
Al2	115.3	20.6	1.7	1.7	26.06	22.21	620
Al3	154.8	4.5	2.0	2.0	25.10	22.55	655
Al4	92.2	10.5	2.0	2.0	26.12	24.53	700
Al5	131.5	6.1	2.2	2.2	28.54	26.28	755
Al6	61.9	7.0	1.9	1.9	21.63	20.98	665
Al7	58.0	4.4	1.8	1.8	23.41	22.71	600
Al8	145.8	18.4	4.7	4.7	22.67	20.86	620
Al9	15.5	5.4	3.3	3.3	21.12	19.94	610
Al10	19.6	1.6	2.2	2.2	28.60	28.10	605
Al11	38.2	3.0	2.3	2.3	22.12	21.69	555

Al12	51.8	3.1	3.1	3.1	18.47	17.54	620
Al13*	11.3	-			24.45	24.06	-
Al14	34.2	3.3	2.3	2.3	25.34	22.50	475
Al15	20.2	8.4	3.1	3.1	28.26	27.88	485
Al16	4.5	3.2	8.2	8.2	22.79	21.55	525
Al17	7.0	4.4	6.8	6.8	25.67	23.86	630
Al18	2.0	1.2	12.2	12.2	29.28	27.02	570
Al19	3.1	2.2	10.6	10.6	29.02	26.01	575
Al20	11.2	10.5	7.2	7.2	32.10	26.28	580
Al21	11.2	10.5	10.6	10.6	28.27	12.51	670
Al22	5.6	2.3	24.4	24.4	27.01	12.87	640
Al23	1.1	0.7	22.2	22.2	24.12	0.13	575
Al24	1.1	3.3	24.4	24.4	26.35	20.13	640
Al1	2.12	0.88	4.66	4.66	28.00	25.03	255
Al2	0.24	0.88	12.56	12.56	22.69	20.73	210
Al3	4.26	0.85	4.07	4.07	26.68	24.03	255
Al4	6.75	0.98	3.64	3.64	26.95	22.81	260
Al5	3.86	1.96	4.31	4.31	29.05	26.86	290
Al6	3.33	0.86	4.02	4.02	24.56	21.57	220

*Fan no.13 in the northern margin of Jazmouriyan Plain is not of structural type. Thus, it was disregarded in the investigation of the region's tectonic activities.

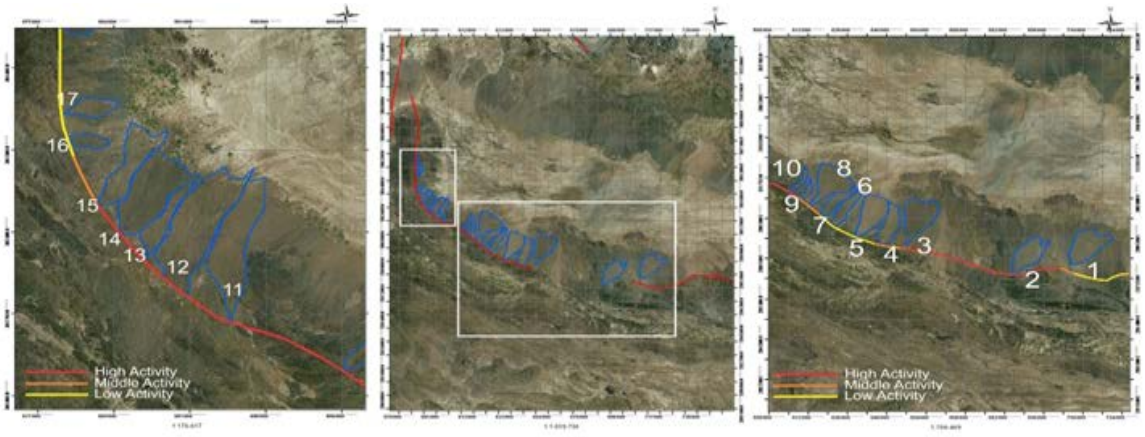


Figure 8: satellite images showing the active regions in the northern margin of Jazmouriyan Plain

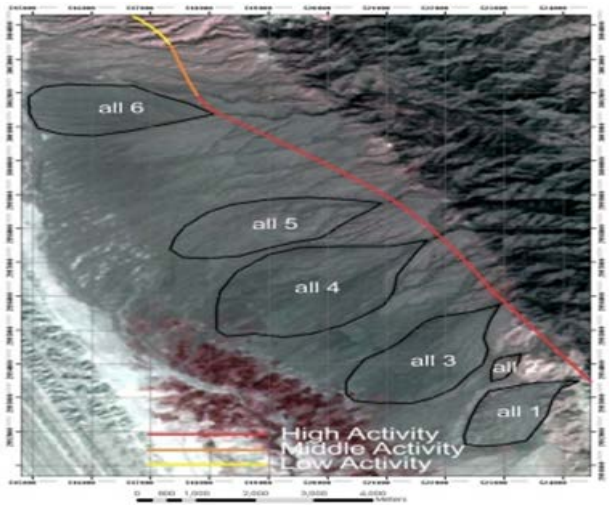


Figure 9: satellite map demonstrating the active regions in the western side of Palami Fault

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