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Tectonic controls on the morphometry of alluvial fans around Danehkhoshk anticline, Zagros, Iran

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ABSTRACT

Alluvial fans are important landforms where their morphology and morphometry reflect changes in tectonic, climate, base level, and drainage basin characteristics. Along the margins of tectonically active mountain ranges like the Zagros Mountains, alluvial fans are generally assumed to act as useful landforms for identifying the level of tectonic activity. The purpose of this paper is to evaluate the relationship between active tectonics and morphometric characteristics of alluvial fans around Danehkhoshk anticline in the Simply Folded Belt of Zagros. Morphometric characteristics of alluvial fans, such as area (FA), slope (SF) length of base (BF), width/length ratio (W/L), radius (R), sweep angle (SA) and entrenchment (E) as well as valley floor width-to-height ratio (Vf) and strata dips of anticline limbs (DAL), were measured. The study area was sub-divided into eight tectonic zones and then the mean values of the above-mentioned parameters were calculated in each zone. Result reveals that values of SA, BF and E are directly proportional to DAL. The poor relationships between catchment characteristics (slope and area) and fan parameters are probably due to extensive karstic landforms of catchments having complex hydrologic systems and, hence, result in complex catchment/fan relations. The highly entrenched fans with high sweep angles and long bases are characteristic of tectonically active fronts of Danehkhoshk anticline, having V-shaped valleys (higher Vf values), steep triangular facets and more rotated limbs (higher DAL values). Apart from the tectonic control on fan development, the fan head entrenchment and negative accumulation spaces on most alluvial fans can be attributed to decreased sediment load and discharge the drier the present-day climate regime.

1. Introduction

Alluvial fans are depositional landforms characterized by cone-shaped deposits of boulders, gravel, sand and fine sediments that have usually been eroded from mountain catchments, and then deposited at the outlets of mountain valleys. Depositional processes, morphology, morphometry, and the development of alluvial fans are controlled by a number of factors such as tectonic activity (Whipple and Trayler, 1996; Calvache et al., 1997; Li et al., 1999; Viseras et al., 2003; Harvey, 2005; Goswami et al., 2009; Harvey, 2012), climate (White et al., 1996; Pope and Wilkinson, 2005; Salcher et al., 2010; Waters et al., 2010), lithology (Lecce, 1991; Blair and McPherson, 1998), base level change (Koss et al., 1994; Harvey, 2002; Storz-Peretz et al., 2011) and the morphometric properties of catchments (Oguchi, and Ohmori, 1994; Sorriso-Valvo et al., 1998; Crosta and Frattini, 2004). Tectonics and climate are of the most significant parameters affecting the situation of deposition and entrenchment of alluvial fans (Pepin et al., 2010; Salcher et al., 2010).

Climate change can shift the locus of aggradation and entrenchment on alluvial fan surfaces. For example, an increase in water discharge without an accompanying increase in sediment flux will tend to cause entrenchment of the fan head (Burbank, and Anderson, 2001). Tectonic setting is also an important variable affecting alluvial fan aggradation and degradation. If the rate of uplift exceeds the rate of stream-channel downcutting at the mountain front, deposition will tend to be focused near the fan apex (Bull, 1977; Burbank, and Anderson, 2001). Tectonic controls on fan aggradation and degradation have been studied widely. For example, incised fans and their relation to tectonics have been interpreted in Central Valley, (Bull, 1964), Death Valley (Hooke, 1972; Hooke and Dorn, 1992; Blair, 1999), Ventura, California (Rockwell et al., 1985), southwestern Montana (DeCelles et al., 1991; Ritter et al., 1995), Spain (Calvache et al., 1997; Stokes and Mather, 2000; Viseras et al., 2003; Nichols, 2005), Argentina (Sancho et al., 2008), Gobi-Altay, Mongolia (Vassallo et al., 2007) and Australia (Quigley et al., 2007). Although tectonism may be the first-order control on sedimentation at mountain fronts by providing accommodation space for sediment accumulation (Fraser and DeCelles, 1992), the geomorphology of alluvial fan reflects interactions between the tectonic setting, Quaternary climatic changes and base-level changes (Harvey, 2005).

The creation and development of accommodation space (vertical space available for sediment accumulation) on alluvial fans are closely linked to uplift the source area (along basin–margin faults), base-level elevation changes, basin subsidence rates, the degree of

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change in sediment supply to discharge ratios due to climate variability and basin geometry (Weissman et al., 2002, 2005; Viseras et al., 2003). At tectonically active mountain fronts, where the mountains are rising with respect to the adjacent basin, alluvial fans tend to aggrade vertically and vertical accommodation space is high (Ferrill et al., 1996; Harvey, 2012).

Although several works have been carried out on the tectonic effects on alluvial fan development, little research has considered the tectonic effect on the morphometric characteristics of fans, such as sweep angle, radius and width/length ratio (Viseras and Fernandez, 1994; Viseras et al., 2003). According to Viseras et al. (2003), fans that have developed at tectonically very active mountain fronts in the Granada and Bajo Segura basins (Betic Cordillera, Spain) tend to aggradate vertically and have plan-view morphologies of an open fan, with a steep slope, high width/length ratio and sweep angle, lacking incised channels and headward-eroding gullies.

Only a few authors have studied the geomorphology of alluvial fans in Iran. Beaumont's (1972) studies on 26 alluvial fans situated to the southeast of Tehran along the foothills of the Elborz Mountains showed the direct relationship between the fan area and the drainage basin area, and the inverse relationship between fan area and the mean slope of the fan. Most of the fans studied by Beaumont were characterized by the presence of varnish on stone pavements, which, along with archaeological evidence, suggested that the fans had not experienced widespread flooding and associated sedimentation for at least several hundreds of years. Arzani (2005) studied the fluvial megafan of Abarkoh basin (Central Iran) and concluded that “episodic thundershowers” resulted in periodic high magnitude runoff and created flash floods toward the feeder channel at the fan apex. His study revealed that the general geomorphology and facies distribution of studied megafan have been formed by flash floods and sheetflood-channelized flows. Arzani's (2012) study on alluvial megafans, along the flanks of the Kohrud Mountain range in central Iran, revealed that the limited sediment supply of the Soh fan has resulted in a deep incised channel. He suggested that sediment supply, as a function of climate and source lithology, is a dominant control on the development of alluvial megafans.

The Danehkhoshk anticline was chosen for this study because the rate of uplift and limb rotation varies greatly along its mountain fronts. Moreover, various alluvial fans with different morphometric characteristics have been developed around its fronts. This area provides a good opportunity to evaluate the effect of tectonic activity on the fans' morphometric parameters. The principal objective of this study is to evaluate the tectonic controls on fan characteristics. To achieve this goal, first, the morphometric characteristics of fans were obtained, i.e. base length, width/length ratio, fan radius, sweep angle, fan entrenchment, as well as the basin's area and topographic slope. Limb rotation (dips of strata at mountain front) and Valley floor width to valley height ratio (Vf), as proxies for tectonic activity, were also measured for every fan. Finally, quantitative relationships between fan characteristics and active tectonic indexes were examined.

2. Study area

The study area is located to the south of the town of Sarpole-Zahab, Kermanshah province, in the western part of Iran. The studied alluvial fans have been formed around the uplifting Danehkhoshk anticline. The highest elevation is about 1358 m a.s.l., while the minimum elevation is about 600 m a.s.l. in the northwestern part (Fig. 1). Structurally, the study area is part of the Zagros belt in southwest Iran. According to Berberian (1995), the Zagros belt is divided into five morphotectonic units on the basis of topography, seismicity and exposed stratigraphy. These five parallel units, from northeast to southwest, are the High Zagros Thrust Belt, the Simple Folded Belt, the Zagros Foredeep, the Zagros Coastal Plain and the Persian Gulf–Mesopotamian lowland. Geomorphologically, Zagros belt is divided into two adjacent belts: the High Zagros Belt and the Zagros Simply Folded Belt, separated by the High Zagros Fault (Falcon, 1974; Berberian and King, 1981). The Zagros belt is tectonically active and has been shortening and uplifting. For example, Lees and Falcon (1952) showed that the course of a Sasanian canal on the Shaur anticline between Shushes and Ahwas has been uplifted approximately 4 m in the last 1700 years. This implies an uplift rate of 2.35 mm/yr in the Shaur anticline. Blanc et al. (2003) suggested that, if the Simple Folded Zone deformation has taken place since c. 5 Ma, this corresponds to a shortening rate of c. 10 mm/yr, which is a substantial part of the present Arabia–Eurasia convergence rate. Vernant et al. (2004) showed that the rate of shortening increases from 4 ± 2 mm/yr in the NW to 9 ± 2 mm/yr in the SE Zagros. GPS measurements and analyses of the 35 stations in and alongside the Zagros Mountain belt also showed that the current rate of shortening across the SE Zagros is about 9 ± 3 mm/yr, whereas in the NW Zagros it is about 5 ± 3 mm/yr (Hessami et al., 2006). The Zagros Simply Folded Belt is composed of a large number of elongated whaleback or box-shaped anticlines which generally trend NW-SE. The uplifting of Zagros is migrating from the suture zone (northeast) toward the foredeep or southwest (Berberian, 1995). The morphometry of the drainage system and the geomorphic indexes reveal the effect of tectonic activity and its spatial differences in Zagros Mountains (Ramsey et al., 2008; Dehbozorgi et al., 2010; Alipoor et al., 2011; Piraste et al., 2011; Bahrami, 2012).

Danehkhoshk anticline is composed of only one lithological unit (Asmari; limestone and dolomite). The stratigraphic column of Zagros is divided into the five structural divisions (Colman-Sadd, 1978): the Basement group, the Lower Mobile group, the Competent group, the Upper Mobile group and the Incompetent group (for stratigraphic details of Zagros, see Colman-Sadd, 1978; Bahrami, 2012). According to Colman-Sadd (1978), structures in the competent group of Zagros Simply Folded Belt are typical of parallel folds formed by buckling and developed by a combination of flexural-slip and neutral-surface mechanisms. The length of Danehkhoshk anticline is 21 km and its width is 6400 m in the southeast, 5000 m in the center and 1300 m in the northwestern part. It plunges toward the southeast and northwest and its southwestern limb is steeper than northeastern one. There is a main reverse fault in its southwest limb and some minor faults with different directions (Fig. 5). The area of alluvial fans varies from 0.0021 to 0.305 km^2 and the areas of corresponding basins vary from 0.0377 to 7.368 km^2.

The mean annual precipitation at Sarpole-Zahab synoptic station (in the northwestern border of study area) is 468 mm (during the period of 1987–2000) and is highly concentrated between December and February. The mean annual temperature of Sarpole-Zahab Synoptic station is 20 °C (during the period of 1987–2000). The climate of the study area is of semi-arid to Mediterranean type with cool winters and dry summers (Karimi et al., 2005).

3. Materials and methods

To evaluate the relationship between quantitative characteristics of alluvial fans and active tectonics of Danehkhoshk anticline, the boundaries of 103 alluvial fans were delineated based on Quickbird satellite imagery (with a resolution of less than 1 m) and fieldwork as a supplementary validation data. Several field surveys were carried out to identify the landforms and processes of alluvial fans and their basins. Morphological characteristics of alluvial fans such as base length (BF), width/length ratio (W/L), radius (R) and sweep angle (SA) were determined based on Quickbird Satellite image. After digitizing the 20-m contour lines from topographic maps of the Iranian National Geography Organization, at a scale of 1:50 000, a Digital Elevation Model (DEM) of study area was prepared in ILWIS (Integrated Land and Water Information System) software. All information relating to the

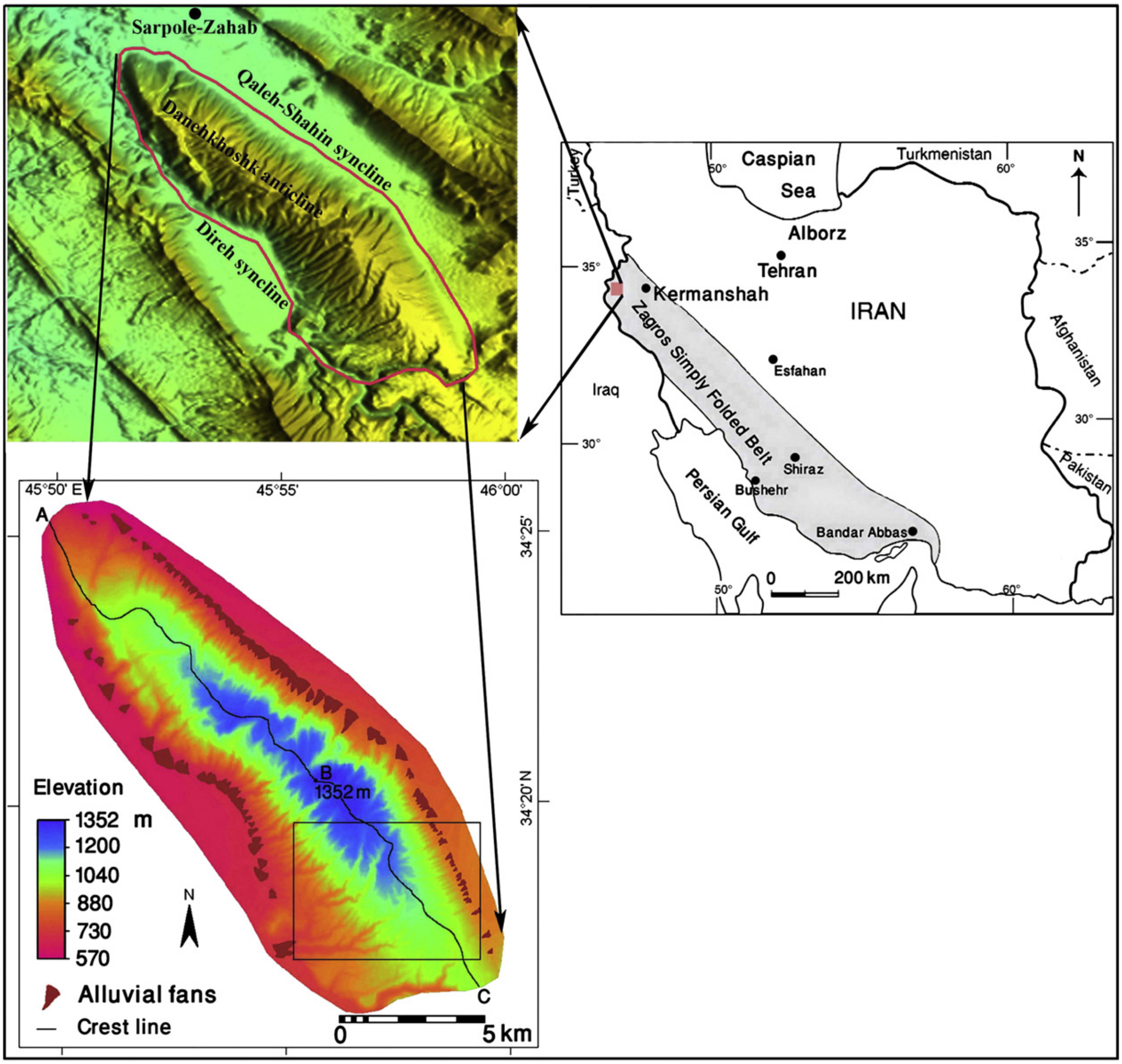

Fig. 1. Location map and topography of Danehkhoshk anticline in the Zagros Folded Belt. A–B–C is the topographic profile along the fold crest, shown in Fig. 8. The black rectangle is the location of Fig. 9.

fans was transferred to topographic maps and then basin borders were determined in ILWIS software. The borders of fans and their basins were converted to polygons and thereby basin areas (BA) and fan areas (FA) were obtained. To calculate topographic slope of fans and basins, the DEM of study area was crossed with polygons of fans and basins and subsequently the mean topographic slope for each fan and its basin were obtained, again in ILWIS software. The sweep angle (SA) of fans was obtained through measuring the angle between the two outermost positions of the channels (Fig. 2A12) of a fan (Viseras and Fernandez, 1994).

To determine fan entrenchment, the deepest channel on every fan was identified by fieldwork and then the maximum entrenchment was obtained using a theodolite. The maximum entrenchment (E) for each fan was calculated as the difference in elevation between a channel bed and the maximum elevation of the fan surface to the right and left sides of channel:

$$E = \frac{(A - C) + (B - C)}{2} \tag{1}$$

where A is maximum elevation of fan surface in left side of channel, B is maximum elevation of fan surface in right side of channel and C is the channel bed elevation (Fig. 2B).

In order to discriminate between V-shaped and U-shaped flat-floored valleys, valley floor width-to-height ratio (*Vf*) was calculated as the width of the valley floor divided by the average height of the valley divides (Bull and McFadden, 1977; Figueroa and Knott, 2010):

$$Vf = Vfw/(((Eld - Esc) + (Erd - Esc))/2) \tag{2}$$

where *Vfw* is width of valley floor, *Eld* is elevation of the left valley divide, *Erd* is elevation of the right valley divide, and *Esc* is elevation of the valley floor. The low values of *Vf* are characteristic of tectonically active areas undergoing relatively rapid uplift and valley incision, whereas high values of *Vf* are related to low tectonic activity (Azor et al., 2002).

The *Vf* index was calculated for every fan 100 m upstream from the mountain front. The *Vf* parameters were determined using QuickBird satellite images (with a nominal resolution of 0.6 m) archived by Google Earth™.

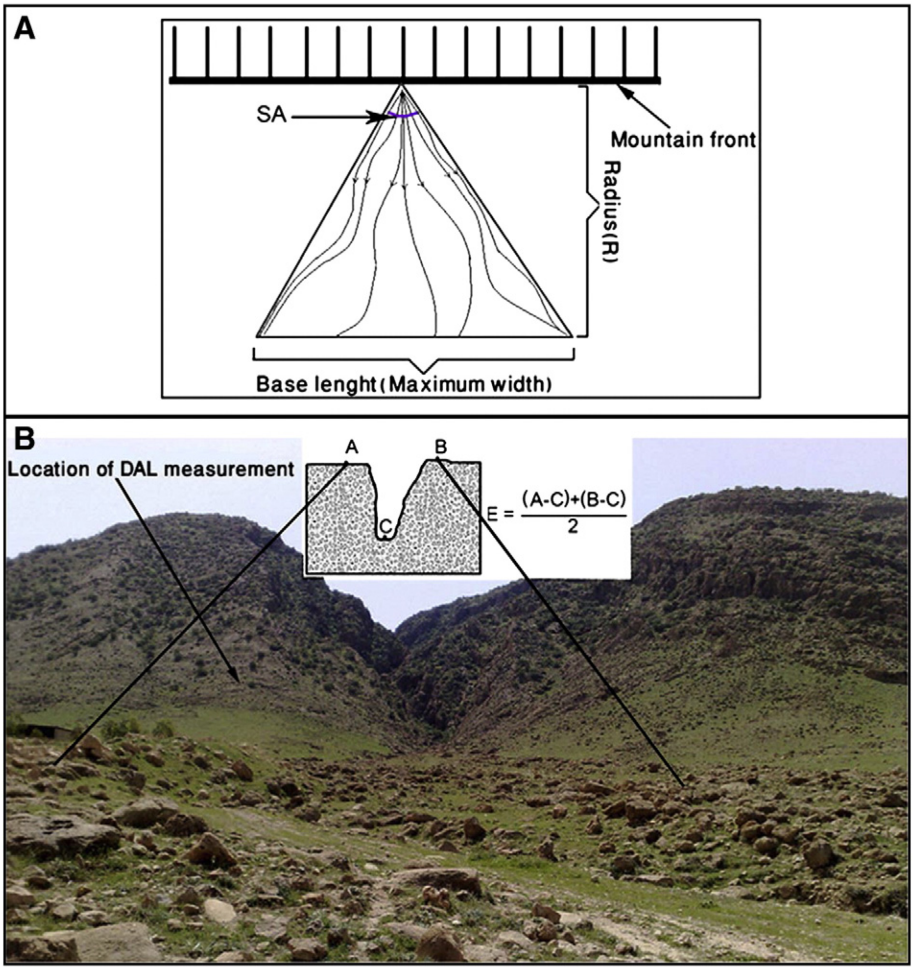

Fig. 2. (A) Schematic representation of sweep angle (SA), base length (BL), and radius (R) of fans. (B) Procedure for the measurement of fan entrenchment.

Geological data such as lithology, faults and cross-sections were derived from 1:250000 scale geological maps of National Iranian Oil Company. The strata dips of anticline limbs (DAL) were measured at the mountain front using a clinometer (Fig. 2B). Danehkhoshk anticline was sub-divided into eight tectonic zones based on dip of strata and width of limbs. The mean values of the above-mentioned parameters of fans and their basins were then calculated in each zone. Subsequently linear relationship between parameter means were examined.

4. Results

4.1. Geomorphology

Danehkhoshk anticline is an asymmetric fold bordered by incised consequent streams. It is uplifted to a maximum height of 1280 m above the Direh synclinal plain located along its southwestern border. Due to the outcropping of carbonate rocks (Asmari Formation) in all Danehkhoshk anticline, karstic features are the dominant landforms of the catchments. Karrens, dolines and caves are the most typical karstic features. Karrens are very frequent landforms over the whole area and at all elevation levels, especially in northeastern limb (Fig. 3A). Dense fractures oriented parallel to the fold hinge have been developed on steep slopes of thrusted southwestern limb, especially in zone 4 (Fig. 3B).

It seems that the climate of Zagros was wetter and colder during glacial periods of the Quaternary. For example, Brooks (1982) suggested that crenulated and steep cliffs, bedrock slopes covered by taluses and continuous talus cones of Zagros are related to cryonival process of colder glacial periods. Further, he inferred that the most karstic landforms in Zagros have been formed during colder glacial periods of the Quaternary. As Fig. 3A shows, the extensive karstic features, especially the karrens of the study area, can be attributed to colder and wetter glacial conditions, corresponding with the study of Brooks (1982).

Numerous alluvial fans were recognized at piedmont zones around anticline. Due to the narrow spacing between catchments outlets, most fans are coalesced. Some solitary fans are formed along steep mountain fronts, such as zones 4 and 1, where spacing between catchments outlets is high. Several field surveys revealed that most fans are composed of inactive or degradational surfaces that have been abandoned for a long period. Because of the lack of inundation of fan surfaces during most flood events, currently inactive areas may have remained relatively unaffected by serious flooding for prolonged periods. This has allowed for the development of particular erosional and weathering features, such as pitting of carbonate clasts and the formation of varnish on stable rock surfaces. Since the catchments of all studied fans are underlain by limestone and dolomite, sediments deposited at the fans include calcareous boulders and clasts. Large boulders and blocks are observed (Fig. 4A) on fans formed along steep mountain fronts such as zones 4 and 1.

Pitting of calcareous boulders and the development of small-scale karren are prevalent on inactive surfaces (Fig. 4B). On active parts of fans, clasts are smaller and generally less angular than on inactive

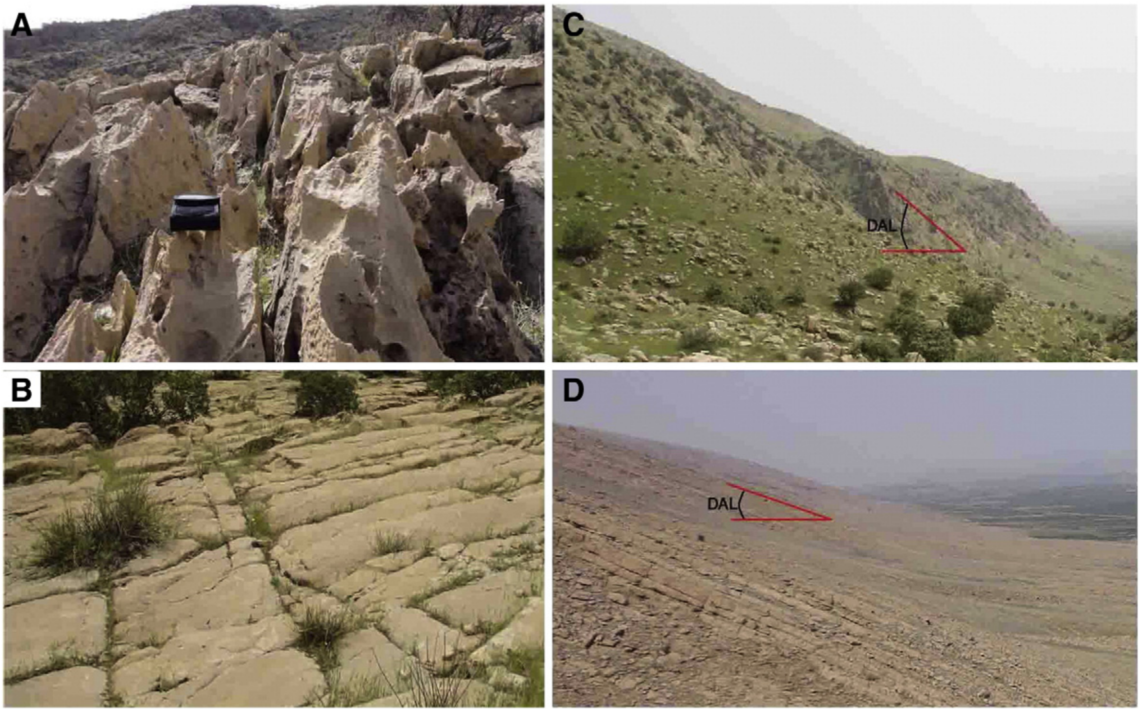

Fig. 3. (A) Karrens on the northeastern limb; (B) fractures oriented parallel to the fold hinge on the southwestern limb; (C) higher value of limb's strata dip (DAL) in tectonically active mountain fronts of zone 4 in the southwestern limb; (D) lower value of DAL in less tectonically active mountain fronts of zone 3 in the northeastern limb.

areas. The morphology of inactive fan surfaces is rougher and more crenulated compared with active fan ones. The incised channels often cross-cut the older fan surfaces, especially the fan head areas.

4.2. Fan morphometry

A total of 103 alluvial fans and their feeder catchments were delineated around Danehkhoshk anticline (Fig. 5). Fans 1 to 46 and 76 to 103 are located on the northeastern limb while fans 47 to 75 are located on southwestern limb. Morphometric parameters of fans such as area (FA), topographic slope (SF), length of fan base (BF), radius (R), width/length ratio (W/L), and sweep angle (SA), and morphometric parameters of basins such as area (BA) and topographic slope (SB) are given in Table 1. Data reveal that the dips of strata decrease from central parts toward southeastern plunge of anticline. The lowest values of DAL belong to the upstream parts of fans 74, 75 (8°), 103 (9°) and 102 (10°) in the southeastern plunge. In northeastern limb, the value of DAL decreases from center of anticline toward northwestern plunge. For example, the values of DAL are 55° and 50° respectively in the upstream parts of fans 3 and 4 in central parts of anticline, whereas the DAL value is 17° in upstream parts of fans 46 and 45 in northwestern plunge (Table 1). In the southwestern limb, the values of DAL decrease from central part toward southeastern plunge so that fans 50, 48 and 55 have the maximum values of DAL (respectively, 81°, 80° and 78°) and fans 74 and 75 have the minimum values of DAL (8°).

The means of FA and BA parameters in the southwestern limb are, respectively, 0.0765 and 1.493 km^2 whereas those of the northeastern limb are 0.0463 and 0.435 km^2, respectively, showing that the southwestern limb has larger fans and basins. The means of SF and SB parameters in the southwestern limb are, respectively, 10.3% and 39.1% whereas those of the northeastern limb are 12.2% and 34.9%, respectively. The means of DAL and SA parameters in the southwestern limb are respectively 34.5° and 56.4° whereas those of the northeastern limb are respectively 22.5° and 45.3°. The higher value of DAL in the tectonically active mountain fronts of zone 4 in the southwestern limb and the lower value of DAL in less tectonically active mountain fronts of zone 3 in the northeastern limb are compared in Fig. 3(C, D).

The means of R and BF in southwestern limb are 393.7 m and 314.4 m, respectively, whilst those of the northeastern limb are 294.1 m and 227.96 m, respectively. The mean of W/L is 0.8 in both the southwestern and northeastern limbs. Overall, results show that southwestern limb has higher values of means SA, R, BF and FA.

Based on dip of strata (DAL) and width of limbs, the studied anticline was sub-divided into eight tectonic zones. Zones 1, 2, 3, 7 and

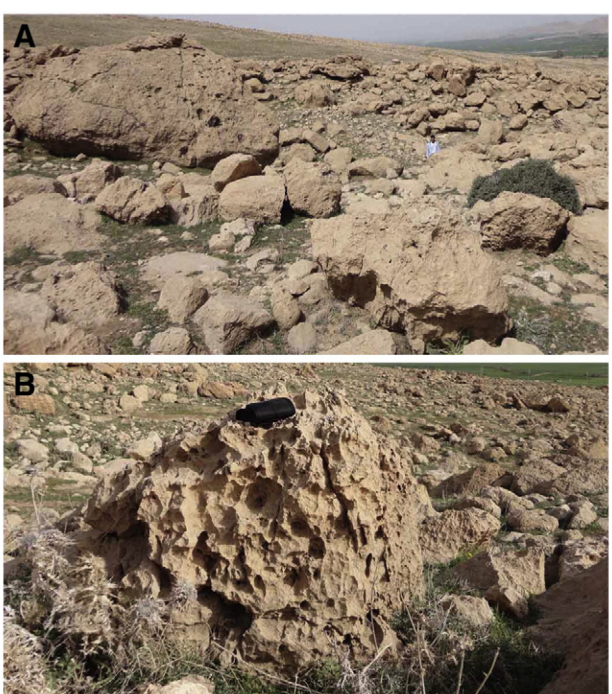

Fig. 4. (A) Large boulders and blocks on fan 6 in a steep mountain front. (B) Development of small-scale karren on calcareous boulders on fan surfaces.

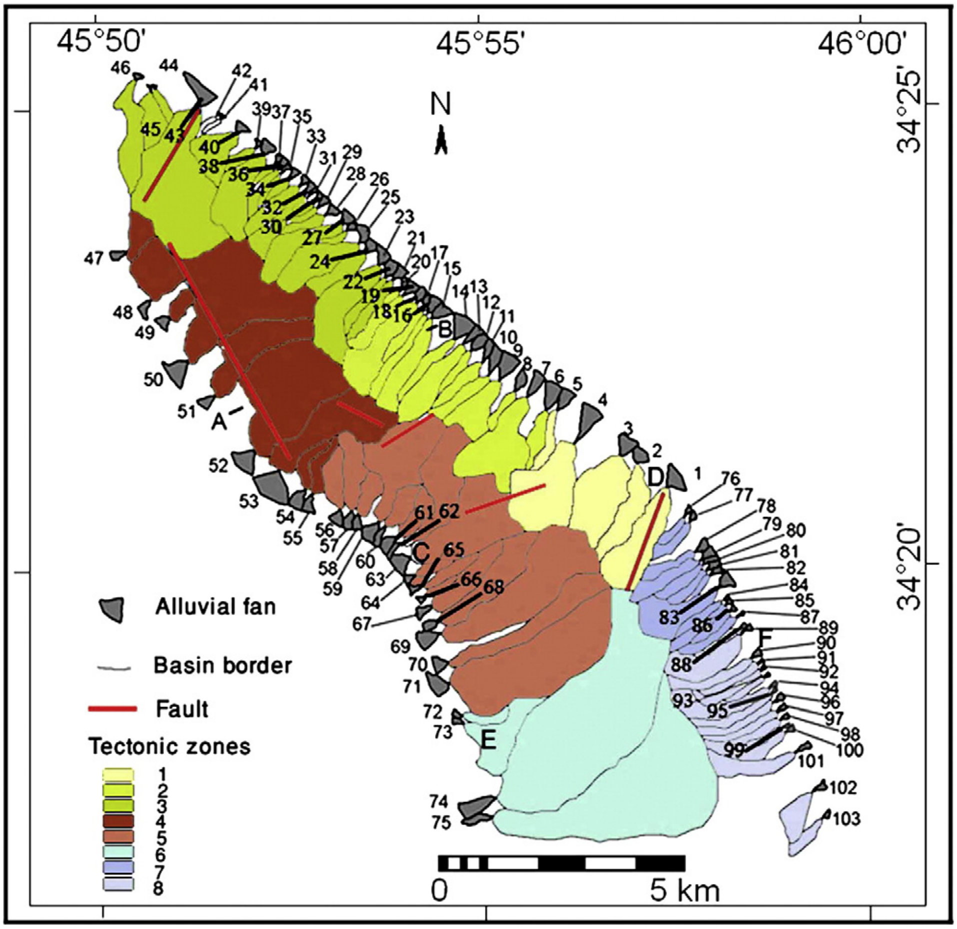

Fig. 5. Borders of alluvial fans and their basins, tectonic zones and faults of study area.

8 are in the northeastern limb and zones 4, 5 and 6 are in the southwestern limb. The means of morphometric characteristics of the fans and their feeder basins in tectonic zones are given in Table 2. Data show that zones 8, 7 and 3 (in southeastern and northwestern plunges of anticline) have the lowest values of mean FA, respectively 0.0152, 0.0266 and 0.0381 km^2. Zone 1 in central part of anticline has the highest value of mean FA (0.1257 km^2). The means of basin areas are higher in zones of the southwestern limb than zones of the northeastern one (Table 2). Zones 1 and 5 have almost the same values of mean BA. The minimum value of mean SF belongs to zone 6 in the low-gradient slopes of the southeastern plunge, whereas the highest value of mean SF belongs to fans of zone 4 with steep slopes. Zones 1 and 5 in the central parts of anticline have high-gradient basins, while zones 6 and 8 in the southeastern plunge have the lowest values of mean SB, 23.1% and 25.1%, respectively. Zones 4 and 1 have the highest values of mean DAL (71.2° and 40.2°, respectively). The mean of DAL decreases from zone 1, in the central parts of anticline, toward zones 3 (in the northwestern plunge) and 8 (in the southeastern plunge). In the southwestern limb, the highest value of mean DAL belongs to zone 4, and the rate of mean DAL decreases toward zone 6 in the southeastern plunge. The mean of BF is higher in zones 4 and 1 than other zones. The lowest rates of mean BF are associated with zones 8 and 6 in the southeastern plunge. Results show that steep-gradient zones such as 1 and 4 have fans with higher values of width/length ratio. The minimum value of W/L belongs to zone 6 (0.48), with the lowest value of mean DAL. The maximum value of mean R is associated with zone 1 (469.4) in the central part of anticline and the minimum value of mean R (205.3) belongs to zone 8 with low value of mean DAL. Fans with high sweep angle belong to zones with higher rates of strata dip (DAL) so that the zone 4 with highest rate of mean DAL has the highest value of SA (70.78°). The minimum value of SA is related to zone 6 (31°) with the lowest value of DAL. The lowest value of mean Vf index is associated with zone 4 (0.68) indicating deep V-shaped valleys and active uplifting. The highest values of mean Vf in zones 6 and 8 (6.06 and 5.49, respectively) showing U-shaped valleys indicative of lower tectonic activity. Overall, the results of Table 2 show that fans in zones with high-gradient slopes have higher values of SA, R, W/L, BF, FA and FA.

The Pearson's correlation coefficient (R) and probability (P) values between means of morphometric parameters are given in Table 3. Strong positive correlations exist between pairs DAL-SA and DAL-BF (Fig. 6A, B). Although there are positive correlations between DAL-W/L, DAL-R, DAL-SF and DAL-FA pairs, these are rather weak correlations (Table 3). The relatively strong negative correlation between DAL and Vf (Fig. 6C, Table 3) indicates that higher DAL values are associated with low Vf values (i.e. the V-shaped valleys of zones 4 and 1). Since lower values of Vf are characteristic of tectonically active mountains fronts, the higher values of DAL can imply the higher tectonic activity and active uplifting. There are no meaningful correlations between BA-SA, BA-BF, BA-W/L, BA-R, and BA-FA pairs (Table 3). A relatively strong negative correlation exists between BA and SF parameters (Fig. 6D), and weak positive correlations exist between SB-SA, SB-SF, SB-BF, SB-W/L, SB-FA and SB-R pairs (Table 3).

4.3. Fan entrenchment

The values of fan entrenchment are given in Table 1. The rates of fan entrenchment vary from 0.45 to 14 m. Data reveal that higher values of fan entrenchment are associated with slopes with higher

Table 1
Morphometric characteristics and entrenchment rates of alluvial fans and their corresponding basin areas and slopes of study area.

Fan no.	FA (km^2)	BA (km^2)	SF (%)	SB (%)	DAL (degree)	BF (m)	R (m)	W/L	SA (degree)	E (m)	Vf
1	0.1330	1.3093	8.9	39.43	35	640	378	1.69	74	6.9	0.94
2	0.0782	0.7375	10.9	40.50	31	406	272	1.49	100	6.45	0.70
3	0.1237	1.4315	8.8	46.70	55	407	424	0.96	68	12.05	0.62
4	0.2019	1.7278	11.1	43.66	50	482	825	0.58	21	8.25	0.40
5	0.0917	0.2364	12.7	49.74	30	300	448	0.67	42	3.9	1.13
6	0.1343	0.2784	16.3	44.20	33	338	582	0.58	34	3.75	0.79
7	0.0937	1.4959	10.8	34.13	31	268	543	0.49	45	7	1.02
8	0.0750	0.1452	17.3	47.27	33	259	489	0.53	36	3.65	0.65
9	0.1460	0.6591	13.8	46.78	29	415	596	0.70	43	4.7	0.86
10	0.1063	0.3166	14.7	45.49	26	245	573	0.43	39	3.2	1.56
11	0.0666	0.2754	13.8	43.93	26	163	511	0.32	37	3.5	1.19
12	0.0712	0.1612	15.7	48.98	25	242	460	0.53	48	3.4	1.15
13	0.0699	0.7568	13.1	38.68	25	281	494	0.57	36	4.4	1.02
14	0.1614	0.3072	14.6	45.32	24	502	519	0.97	64	3.15	0.54
15	0.0881	0.6664	14.1	34.82	24	306	397	0.77	59	5.9	0.47
16	0.0595	0.3472	14.1	31.05	23	238	420	0.57	48	3	0.85
17	0.0353	0.2243	13.7	41.00	23	138	283	0.49	60	2.9	0.75
18	0.0519	0.9803	11.0	31.45	24	191	351	0.54	69	6	0.57
19	0.0542	0.3339	15.0	44.63	24	286	340	0.84	47	3.4	0.68
20	0.0319	0.0458	14.8	45.53	23	139	276	0.50	59	2.8	0.73
21	0.0554	0.3157	12.0	35.24	28	248	312	0.79	71	5.3	0.82
22	0.0695	0.2313	14.2	39.12	28	236	358	0.66	57	2.8	0.78
23	0.0722	1.2335	9.1	33.26	27	406	323	1.26	65	6.05	0.84
24	0.0536	0.3819	9.9	42.29	23	280	289	0.97	73	3.75	0.66
25	0.0649	0.8755	7.3	30.14	23	358	376	0.95	48	4	0.67
26	0.0324	0.0761	17.3	44.06	27	191	222	0.86	65	2.75	0.70
27	0.0534	0.715	9.3	32.35	26.5	294	251	1.17	83	4.15	0.78
28	0.0342	0.1579	18.4	42.93	26.5	253	281	0.90	28	2.7	0.92
29	0.0309	0.0796	17.4	42.75	26	202	289	0.70	35	2.7	1.21
30	0.0222	0.0575	17.9	44.96	26	134	270	0.50	32	2.45	1.10
31	0.0141	0.0394	16.8	45.95	25	92	290	0.32	17	2	2.95
32	0.0291	0.4217	14.8	21.93	25	165	296	0.56	48	3.7	1.34
33	0.0257	0.3778	13.6	37.21	25	190	250	0.76	42	3	2.44
34	0.0294	0.0973	16.9	41.64	24	184	275	0.67	40	1.7	2.90
35	0.0183	0.0895	15.5	37.64	24	153	206	0.74	43	1.7	1.53
36	0.0269	0.2009	13.2	32.29	24	170	291	0.58	34	1.45	2.46
37	0.0187	0.0707	13.0	40.67	23	108	238	0.45	39	1.15	1.86
38	0.0582	0.997	8.8	27.09	23	360	272	1.32	68	4.6	2.13
39	0.0145	0.1305	15.0	40.27	23	160	181	0.88	43	1.05	2.38
40	0.0435	0.6129	11.7	26.98	22	360	218	1.65	60	3.6	2.63
41	0.0096	0.0377	18.1	20.13	20	130	75	1.73	41	0.95	1.51
42	0.0081	0.0578	14.7	21.30	20	68	72	0.94	45	0.8	1.68
43	0.1759	3.3627	3.3	19.77	19	837	375	2.23	59	5.35	2.64
44	0.0021	0.1024	13.0	15.70	18	64	56	1.14	59	2.2	4.60
45	0.0102	0.3977	9.2	17.35	17	184	118	1.56	67	3.55	4.41
46	0.0184	0.7826	7.2	14.16	17	223	142	1.57	52	3.75	5.87
47	0.0396	0.3465	14.8	41.57	72	191	379	0.50	35	7.2	0.69
48	0.0533	0.8879	13.7	43.52	80	302	349	0.87	51	12.3	0.31
49	0.0473	0.1959	30.2	51.56	60	366	291	1.26	97	6.9	0.72
50	0.1564	3.4375	11.2	26.34	81	675	495	1.36	80	14	0.36
51	0.0447	1.383	16.2	28.78	60	272	376	0.72	40	7.5	0.34
52	0.1482	3.09	6.6	36.37	65	635	466	1.36	94	10.5	0.76
53	0.3055	1.7583	9.6	37.31	70	884	599	1.48	104	12.2	1.01
54	0.0914	0.2558	10.8	39.25	75	305	453	0.67	72	7.5	0.84
55	0.0645	0.2679	12.6	43.85	78	332	389	0.85	64	8.1	1.10
56	0.0690	0.3958	12.3	38.25	42	361	322	1.12	62	5.95	0.85
57	0.0668	0.5885	11.9	49.70	39	233	400	0.58	63	6.2	0.85
58	0.0403	0.2895	9.6	43.17	34	174	314	0.55	64	6	0.96
59	0.0937	1.7073	7.7	41.43	33	337	448	0.75	63	5.65	1.64
60	0.0506	0.3314	7.5	55.44	20	165	478	0.35	38	2	1.57
61	0.0700	0.3364	8.8	45.58	19	205	428	0.48	43	1.95	1.25
62	0.0379	1.3178	9.6	33.13	19	130	431	0.30	30	4.7	2.19
63	0.1046	2.0629	7.3	44.33	17	460	384	1.20	88	5.15	2.31
64	0.0236	0.1391	14.5	43.84	15	188	249	0.76	44	3.35	2.59
65	0.0288	0.2462	15.6	47.31	14	230	268	0.86	41	3.65	2.88
66	0.0168	0.1017	18.4	50.33	13	168	196	0.86	52	1.5	2.22
67	0.0405	0.6466	10.5	50.33	12	249	354	0.70	33	3.5	3.33
68	0.0457	1.0887	8.3	50.00	12	196	319	0.61	57	3.8	3.28
69	0.1051	2.7838	5.6	39.14	11	397	493	0.81	46	5	3.13
70	0.0633	1.2254	6.8	29.34	11	356	314	1.13	59	3.5	3.64
71	0.1181	3.8025	2.8	31.70	11	541	393	1.38	92	5.65	6.67
72	0.0195	0.1752	6.2	19.70	11	153	217	0.71	31	1.6	5.19
73	0.0237	0.988	6.0	17.61	10	136	255	0.53	34	3.7	8.21

(continued on next page)

Table 1 (*continued*)

Fan no.	FA (km^2)	BA (km^2)	SF (%)	SB (%)	DAL (degree)	BF (m)	R (m)	W/L	SA (degree)	E (m)	Vf
74	0.1753	7.3685	1.8	30.14	8	355	762	0.47	30	0.9	7.34
75	0.0752	6.0779	0.8	25.19	8	121	596	0.20	29	1.7	3.50
76	0.0138	0.1099	14.4	38.31	35	131	214	0.61	29	4.4	2.41
77	0.0178	0.1893	15.3	49.50	22	162	200	0.81	47	2.7	1.70
78	0.0428	0.2105	13.7	44.90	20	219	330	0.66	34	2.6	4.74
79	0.0454	0.3779	11.0	34.08	19	218	335	0.65	43	3.5	2.80
80	0.0332	0.2193	10.6	42.91	19	914	361	2.53	34	2.5	1.70
81	0.0336	0.1632	10.8	53.45	19	128	320	0.40	38	1.95	3.13
82	0.0318	0.0748	10.8	50.68	19	144	304	0.47	35	1.85	3.68
83	0.0653	0.8452	8.2	29.88	18	324	331	0.98	55	4	2.95
84	0.0096	0.1895	14.3	34.35	17	111	146	0.76	38	1.8	3.83
85	0.0084	0.2421	12.3	32.73	17.5	88	140	0.63	40	3.1	3.57
86	0.0091	0.154	13.4	36.53	17	123	115	1.07	59	1.6	4.36
87	0.0080	0.2198	11.1	44.65	17	91	175	0.52	27	1.6	3.72
88	0.0124	0.1349	10.2	39.40	17	108	197	0.55	30	1.55	3.68
89	0.0200	0.7389	8.9	28.93	16	147	276	0.53	19	5.1	6.50
90	0.0229	0.3384	13.5	28.70	16	184	243	0.76	38	3.9	4.12
91	0.0074	0.193	12.7	34.43	16	86	139	0.62	38	1.7	4.52
92	0.0078	0.2549	14.2	35.64	15	95	134	0.71	40	4.25	5.67
93	0.0064	0.1123	11.9	36.51	14.5	86	113	0.76	46	1.5	8.74
94	0.0106	0.5993	6.9	21.13	14	99	191	0.52	29	4.1	5.44
95	0.0104	0.2755	11.2	20.73	14	96	165	0.58	28	3.85	5.50
96	0.0209	0.2568	9.1	20.52	14	98	240	0.41	39	2.55	7.33
97	0.0150	0.2264	9.6	25.31	14	104	204	0.51	34	4	8.00
98	0.0139	0.1729	10.0	28.93	14	110	198	0.56	33	0.85	4.80
99	0.0069	0.0938	10.3	20.87	14	86	150	0.57	24	0.55	4.82
100	0.0150	0.4047	9.9	22.29	14	155	202	0.77	32	2.1	4.80
101	0.0287	0.5254	6.4	11.57	12	134	348	0.39	19	1.75	6.00
102	0.0328	0.3667	5.7	14.57	10	201	314	0.64	31	1.35	4.57
103	0.0121	0.173	6.7	11.72	9	131	171	0.77	52	0.45	3.31

values of DAL. For example, the highest rate of entrenchment (14 m) is associated with fan 50 having the highest value of DAL, and the lowest rate of entrenchment (0.45 m) belongs to fan 103 in the southeastern end of the anticline, with a very low value of DAL (9°). Overall, the high rates of entrenchment have occurred in fans located on high-gradient mountain fronts (i.e. fans 50, 48, 53, 3 and 52) whereas the low rates of entrenchment are associated with fans on gentle-slopes of anticline (plunges) with low DAL (fans 103, 99, 42, 98, 74). The mean value of E parameter is 5.57 m in the southwestern limb and is 3.33 m in the northeastern one. The values of mean E in tectonic zones are given in Table 2. The means of E vary greatly between tectonic zones; the highest value of mean E is related to zone 4 (9.58 m) whilst the minimum value belongs to zone 6 (1.97 m) in the southeastern plunge of anticline. Zone 8 in the southeastern end and zone 3 in the northwestern end also have the low rate of mean E (respectively 2.47 and 2.97 m). It is worth stressing that fans located in the southeastern plunge have lower rates of entrenchment compared with fans located in the northwestern plunge. For example, the mean value of fan entrenchment in zone 6 (1.97 m) in the southeastern plunge is much less than mean of E in zone 4 in the northwestern one. Overall, results demonstrate that the rate of E increases with increasing DAL of Danehkhoshk anticline.

There is strong positive correlation between DAL and E with an R^2 value of 91% (Fig. 6E). A relatively strong negative correlation exists between Vf and E (Fig. 6F), and there are no meaningful correlations between BA-E and SB-E pairs (Table 3).

5. Discussion

The increase in amplitude of the fold toward central parts of the Danehkhoshk anticline has resulted in the increase of the steepness of the strata dips and, hence, in the increase of the topographic slopes of the anticline. Fieldwork demonstrated that more rotated limbs (areas with higher values of DAL, such as zones 4 and 1) are characterized by V-shaped and perched valleys as well as by steep slopes and large triangular facets between narrow V-shaped valley (Fig. 7A) that are suggestive of tectonically active mountain fronts (El Hamdouni et al., 2008; Bahrami, 2012). In contrast, low-gradient slopes of the southeastern and northwestern plunges (zones 6, 7, 8 and 3) have wider and U-shaped valleys that are characteristic of less tectonically active mountain fronts (Fig. 7B). Therefore, V-shaped valleys and steep facets along with high vales of DAL in zones 4 and 1 can be associated with high tectonic activity and uplifting.

Lateral propagation of a fold produces characteristic geomorphic criteria in the direction of propagation, such as a decrease in dip of the forelimb, a decrease of drainage density in the direction of fold propagation, a decrease in relief of a topographic profile along the fold crest, the development of characteristic asymmetric drainage patterns, and the

Table 2
Means of morphometric parameters and fan entrenchment rate in tectonic zones.

Tectonic zone	Number of fans in zone	FA	BA	SF	SB	BF	DAL	W/L	R	SA	E	Vf
1	5	0.1257	1.0885	10.47	44	447	40.2	1.08	469.4	61	7.51	0.759
2	15	0.083	0.4663	14.2	41.55	267.4	26.2	0.59	455.6	48.27	4.05	0.856
3	26	0.0381	0.4578	12.98	32.58	232.70	23.46	1	243.30	50.54	2.97	1.99
4	9	0.1056	1.2914	13.97	38.73	440.2	71.22	1.01	421.9	70.78	9.58	0.68
5	16	0.0609	1.0665	9.83	43.31	274.4	20.13	0.78	361.94	54.7	4.22	2.46
6	4	0.0734	3.6524	3.69	23.16	191.3	9.3	0.48	457.5	31	1.97	6.06
7	12	0.0266	0.2496	12.16	41.00	221.1	19.96	0.84	247.6	39.92	2.63	3.22
8	16	0.0152	0.3042	9.82	25.1	120	13.97	0.6	205.3	33.25	2.47	5.49

Table 3
Pearson's correlation coefficient (R) and probability (P) values between morphometric parameters.

Morphometric parameters	R	P
DAL vs SA	0.89	0.003
DAL vs BF	0.86	0.006
DAL vs R	0.37	0.367
DAL vs W/L	0.67	0.071
DAL vs FA	0.65	0.08
DAL vs SF	0.56	0.152
DAL vs E	0.96	0
DAL vs Vf	−0.72	0.045
BA vs SA	−0.21	0.617
BA vs W/L	−0.37	0.365
BA vs R	0.57	0.138
BA vs BF	0.02	0.965
BA vs FA	0.35	0.388
BA vs SF	−0.81	0.015
BA vs E	−0.05	0.907
SB vs SA	0.69	0.057
SB vs SF	0.61	0.11
SB vs W/L	0.57	0.144
SB vs BF	0.67	0.071
SB vs R	0.29	0.48
SB vs FA	0.45	0.264
SB vs E	0.54	0.17
Vf vs E	−0.73	0.039

occurrence of a series of wind gaps with decreasing elevation in the propagation direction (Burbank et al., 1996; Keller et al., 1998, 1999; Azor et al., 2002; Bretis et al., 2011). The decrease in relief of a topographic profile along the crest (Fig. 8) as well as the decrease in limb rotation or DAL (Table 1) from the central part toward the southeastern and northwestern plunges reveals that Danehkhoshk anticline is growing laterally toward southeast and northwest. As Ramsey et al. (2008) and Bretis et al. (2011) noted, the presence of distinctive asymmetric forked tributary patterns shows the direction of fold propagation. The asymmetric forked tributary patterns on the southeastern plunge (upstream of fans 74 and 75) suggest the lateral growth of the anticline toward the southeast. The higher reaches of drainages are deflected northwestwards, signifying the growth of the anticline toward the southeast (Fig. 9). Although the above-mentioned geomorphic features are consistent with lateral growth of Danehkhoshk, the lack of at least two wind or wind and water gaps probably shows the slow rate of lateral growing.

Results show that among the morphometric characteristics of alluvial fans in the study area, sweep angle is more affected by rate of DAL, as evidenced by high R obtained (Table 3). It is worth stressing that increasing SA with an increase in DAL reflects the effect of tectonic activity in study area. In fans formed along steep slopes like zones 4 and zone 1, channels grow outward from center and hence the angle between the two outermost positions of the channels of a fan increases. The BF metric is strongly related to the sweep angle of fans (Table 2). Increase in the sweep angle has a direct effect on the length of a fan base so that an increase in the value of sweep angle can result in a corresponding increase in BF. Therefore, the values of SA are compatible with the values of BF in tectonic zones. Overall, the sweep angle and length of fan's base have strong relationships with tectonically active slopes of Danehkhoshk anticline. In

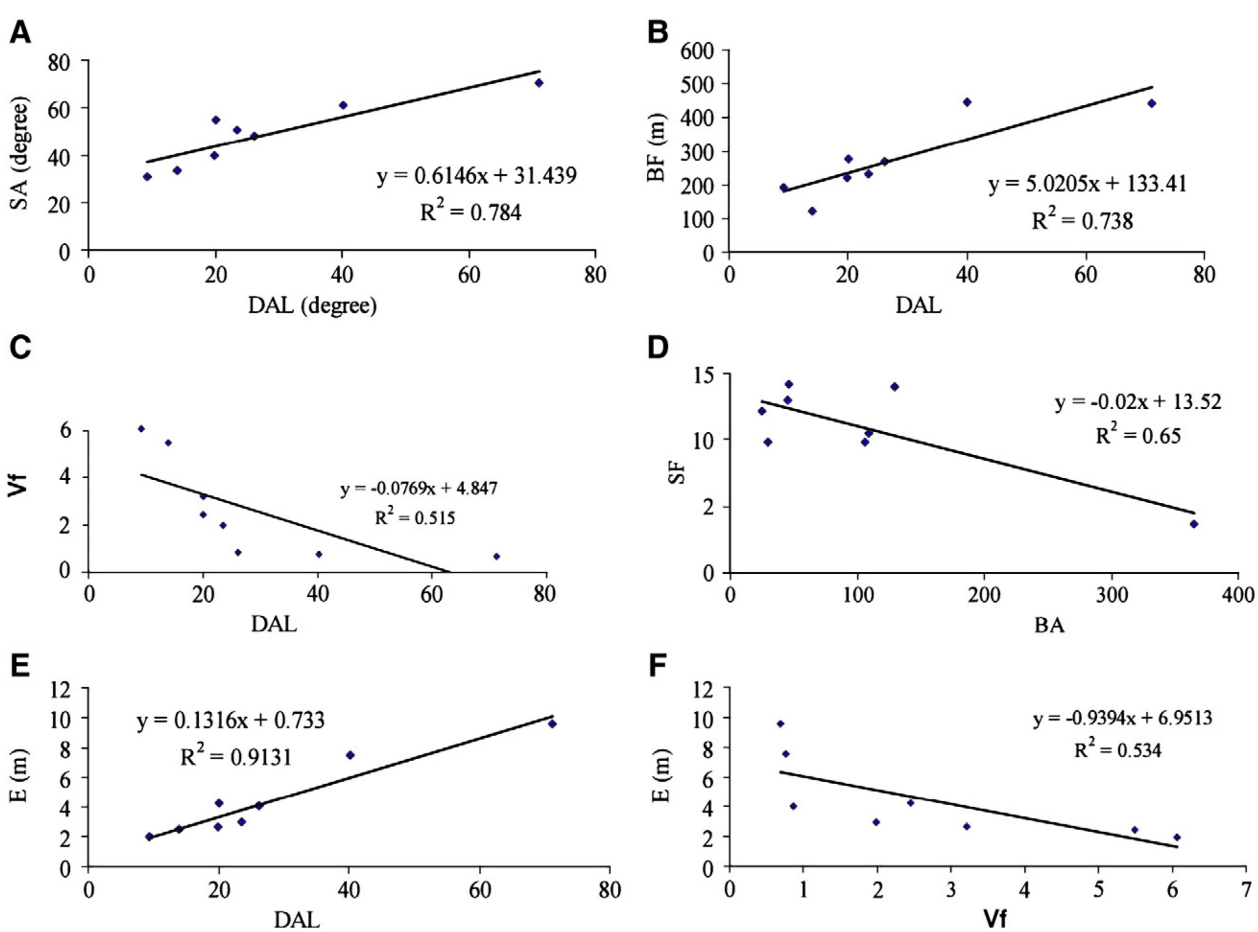

Fig. 6. Linear relationships and R^2 values between means of morphometric parameters: (a) DAL versus SA; (b) DAL versus BF; (c) DAL versus Vf; (d) BA versus SF; (e) DAL versus E; (f) Vf versus E.

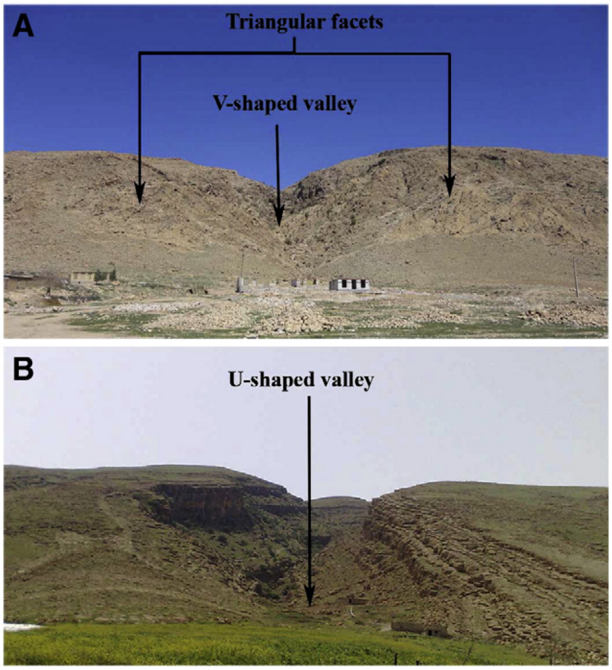

Fig. 7. (A) A perched and V-shaped valley and steep triangular facets in zone 4, upstream of fan 48. (B) A wide and U-shaped valley in zone 7, upstream of fan 83.

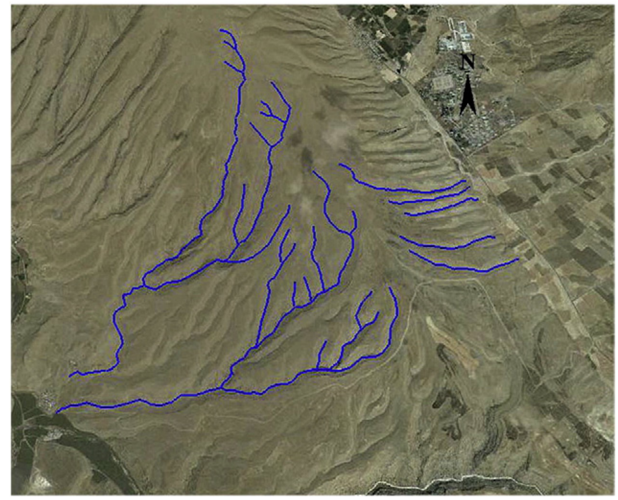

Fig. 9. The asymmetric forked tributary patterns in the southeastern plunge of anticline. The upper reaches of drainages are deflected towards the NW showing the lateral growth of anticline towards the SE.

other words, fans with high sweep angle and longer bases are useful landforms for distinguishing tectonically active zones from inactive zones of the uplifting Danehkhoshk anticline.

Analysis of the relationship between basin area and morphometric characteristics of fans shows that the basin area has more effect on fan slope than other characteristics of fans. Results reveal that mean slopes of basins in tectonic zones do not have a profound effect on the morphometric parameters of fans. The weak relationships between catchment characteristics (BA and SB) and fan morphometric parameters (Table 3) can be attributed to the presence of extensive karstic landforms of catchments (Fig. 3A). There are complex relationships between surface runoff, groundwater and rainfall characteristics in karstic environments, with their complex and unique hydrologic systems (Majone et al., 2004; Chalikakis et al., 2011). The sub-surface drainage in studied karstic catchments may be more important in terms of water discharge to the fan than the surface catchment area. Hence, the poor relations between catchment/ fan morphometric parameters are probably due to complexity of hydrologic systems of karstic features.

The higher value of DAL in southwestern zones is probably due to the effect of a thrust fault formed in the southwestern limb (Fig. 10) that has led to the steepening of the southwestern limb, especially in its northwestern part (zone 4).

For a better understanding of the tectonic effects on fan characteristics, three geological cross-sections were prepared from Danehkhoshk

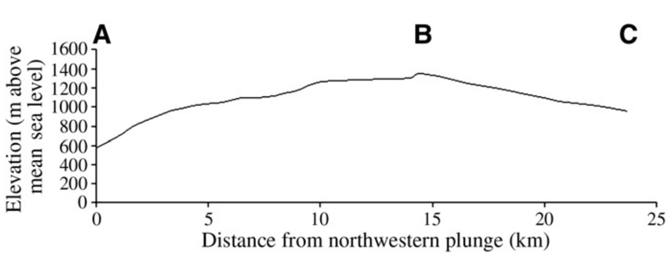

Fig. 8. Topographic profile along the fold crest of Danehkhoshk anticline showing decrease in relief from the central part (B) toward the northwestern (A) and the southeastern (C) plunges. Location of the profile is shown in Fig. 1.

anticline (Fig. 10). Cross-section A-B (Fig. 10) represents that, in northwestern part of anticline, the southwestern limb with a thrust fault (zone 4) is steeper than northeastern one (zone 2). Results show that fans in zone 4 with steeper slope have higher sweep angles as well as higher values of base lengths than zone 2 with gentler slopes. In addition, fans located in zone 4 have experienced higher rate of entrenchment compared to fans of zone 2. Cross-section C–D (Fig. 10) reveals that, in central part of anticline, the northeastern limb (zone 1) is steeper than southwestern one (zone 5). Table 2 shows that fans of zone 1 (with steeper slopes) have higher sweep angles and base lengths than those of gentler zone 5. Entrenchment rate of alluvial fans is higher in zone 1 than zone 5. Cross-section E–F (Fig. 10) shows that the southeastern plunge of anticline has low-gradient slopes, in which southwestern limb (zone 6) is a little gentler than the northeastern one (zone 8), as evidenced by the lower value of mean DAL in zone 6 (9.3°) and higher value of mean DAL in zone 8 (13.97°). Gentle slopes in zones 6 and 8 have resulted in the lower values of entrenchment, sweep angle, base length and slope of fans in two mentioned zones. Nonetheless, the values of mean entrenchment, sweep angle and slope of fans are a little lower in zone 6 than zone 8, due to lower rate of mean DAL in zone 6.

The mean basin area in zone 6 is much higher than those of zone 8 (Table 2). This is probably due to the fact that the southwestern limb is wider than northeastern one. The higher values of basin area in zone 6 have resulted in the formation of larger fans (with a mean FA value of 0.0734 km^2) compared to smaller fans of zone 8 (with a mean FA value of 0.0152 km^2).

Overall, geological cross-sections and values of DAL (Table 1) reveal that the dips of strata, as well as the degree of tectonic activity, vary greatly within the study area so that, in the northwestern plunge (cross-section A–B), the southwestern limb is steeper than the northeastern one. In the central part (cross-section C–D) and the southeastern plunge (cross-section E–F), the northeastern limbs are steeper than southwestern ones. Data reveal that the morphometry and entrenchment rates of alluvial fans are influenced by variations in slope gradient and strata dips of Danehkhoshk anticline.

To evaluate the effect of anticline plunges on fan entrenchment rates, several alluvial fans with virtually the same catchment areas were selected. Values of fan entrenchment from the central part toward the northwestern and southeastern plunges (Fig. 11) were then plotted. As Fig. 11A shows, the rate of fan entrenchment decreases from the central parts of the anticline (fan 5) toward the

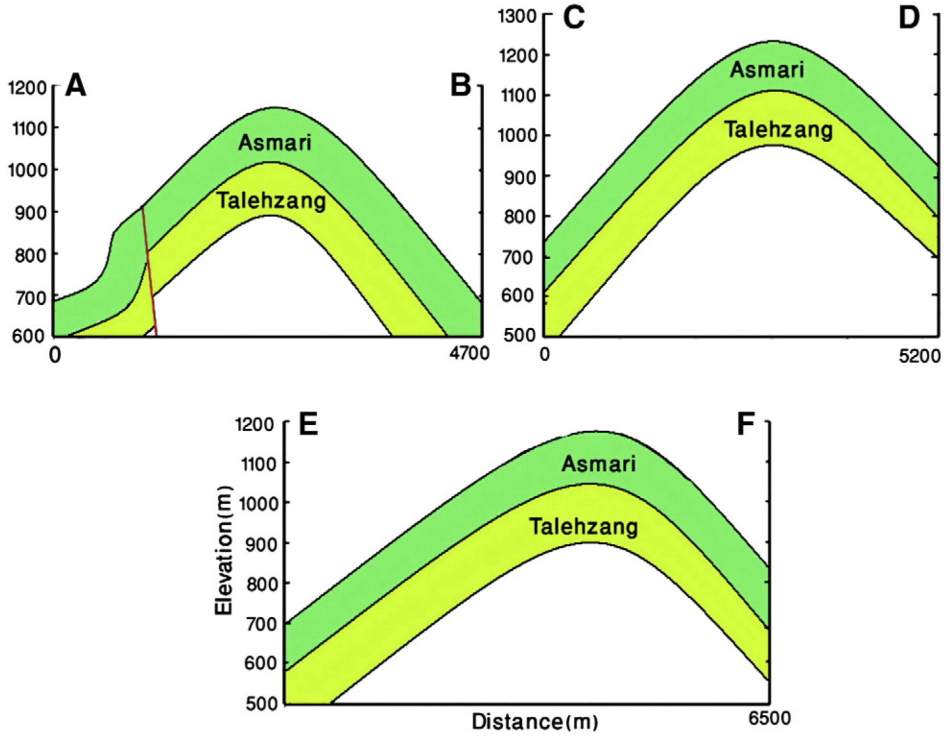

Fig. 10. Geological cross-sections of study area. Cross-section A–B in the northwestern part of Danehkhoshk anticline shows a thrust fault in the more rotated southwestern limb. Cross-section C–D demonstrates that, in central part of anticline, the northeastern limb is steeper than southwestern one. Cross-section E–F shows that the southeastern plunge of anticline has low-gradient slopes, in which southwestern limb is a little gentler than the northeastern one. Location of cross-sections is shown in Fig. 5.

northwestern plunge (fan 42) because of the decrease in DAL values. The rate of fan entrenchment also decreases from the central parts of the anticline (fan 76) toward the southeastern plunge (fan 103) due to a decrease in the DAL value (Fig. 11B).

The results of this study reveal that an increase in limb rotation has resulted in the increasing sweep angle and base length of fans. Fig. 12 shows the comparatively high value of SA (104°) and BF (884 m) in fan 53 located on a high-gradient limb, and the low

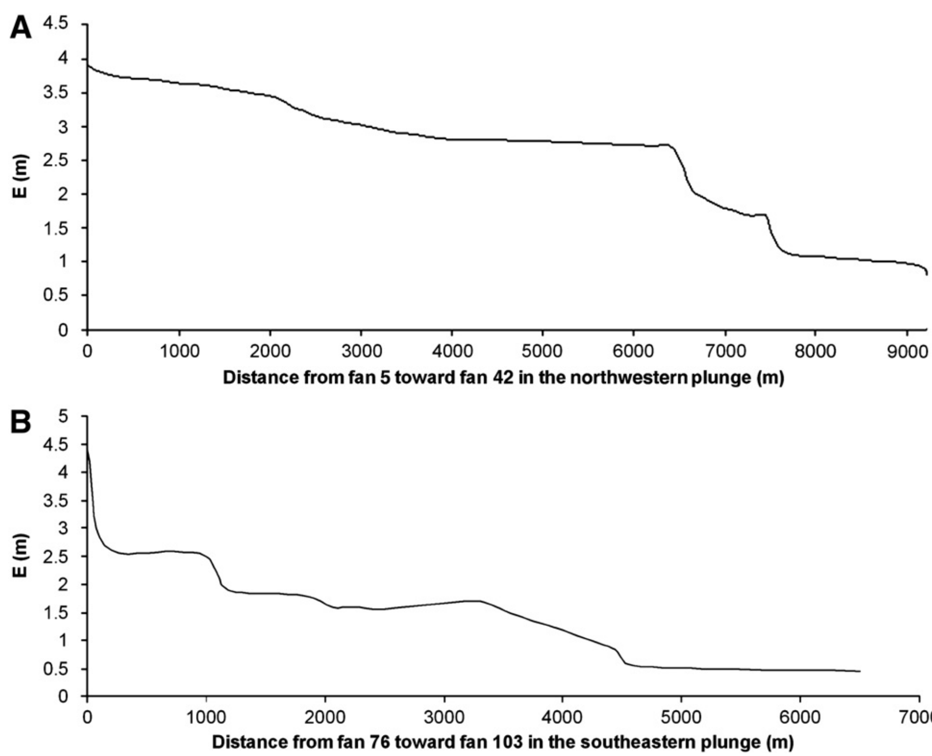

Fig. 11. Decrease in the entrenchment (E) rate from fan 4 in the central part of anticline toward fan 42 in the northwestern plunge (a) and from fan 76 in the central part toward fan 103 in the southeastern plunge of anticline (b).

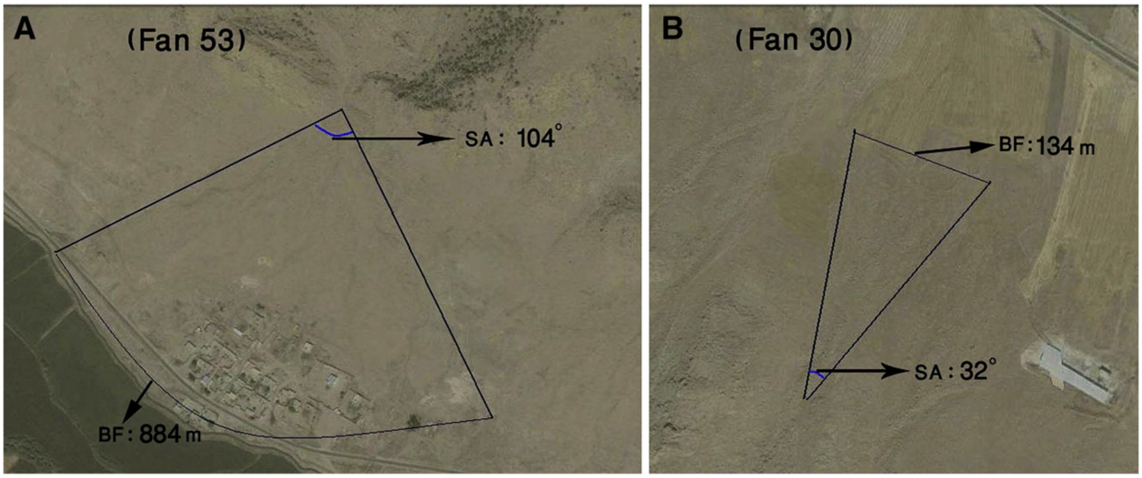

Fig. 12. Comparison of the high values of SA and BF in fan 53 located on a high-gradient limb and the low values of SA and BF in fan 30 formed on a low-gradient limb.

value of SA (32°) and BF (134 m) in fan 30 located on a low-gradient limb of the anticline.

Basin area has more effect on fan slope (SF) than the other characteristics of fans. Results show that the morphometric properties and entrenchment rate of fans are not greatly influenced by basin slopes. Overall, change in the morphometry of studied fans, especially in sweep angles and base lengths, is due to differences in the degree of tectonic activity, corresponding with the results of Viseras and Fernandez (1994) and Viseras et al. (2003) implying that fans developed at tectonically active mountain fronts have high width/length ratios and sweep angles.

Results show that the development and location of accommodation space on alluvial fans are influenced by tectonic and climatic variables, according with Weissman et al. (2002, 2005) and Viseras et al. (2003). Fans in tectonically inactive areas (zones 6, 7 and 8) are incised with negative accumulation space. Low uplift rate has resulted in fan head degradation, and downward shifting of the intersection point. In contrast, accumulation space in fans located on tectonically active mountain fronts (i.e. zones 1 and 4) is positive, and incision and intersection point are developed in the down-fan areas.

Apart from tectonic controls, climatic change is also responsible for change in the sediment supply and stream power and hence in the location of accommodation space. Fieldwork shows that most of fans are characterized by inactive (flood-free) surfaces. The presence of karrens and pitting of calcareous boulders, varnished clasts and some soil development on most fans reveals that they have remained unaffected by flooding for prolonged periods. It seems that the formation of most studied fans is associated with glacial periods when increased sediment load and water discharge resulted in the deposition of large boulders and blocks, and increased accumulation space. Due to the decrease in sediment load and discharge during the drier present-day climate regime (interglacial period), fan surfaces experience degradation and incision, and accumulation space is restricted to the distal parts of fans.

6. Conclusion

Danehkhoshk anticline and numerous alluvial fans developed around its fronts are part of the uplifting Zagros folds, indicating the interaction of active tectonics and alluvial fan processes. This study has focused on the morphometric characteristics of alluvial fans and their relationships with tectonic activities. Decrease in the crest height and in the limb rotation (DAL) toward the southeast and northwest, as well as the asymmetric forked tributary patterns, show that the studied anticline propagates laterally toward the southeast and northwest. Danehkhoshk anticline was sub-divided into eight tectonic zones and the means of morphometric parameters of fans and their catchments were obtained. Tectonically active areas (zones 4 and 1) are characterized by V-shaped valleys, steep triangular facets and higher rates of strata dip along the mountain fronts. Data show that zones with higher DAL coincide with zones having lower Vf values. Since a lower Vf index is considered as indicative of tectonically active mountain fronts (Silva et al., 2003; Figueroa and Knott, 2010), it can be concluded that high DAL values (i.e. in zones 4 and 1) are suggestive of high tectonic activity.

Results reveal that, among the various morphometric indexes of fans, sweep angle, base length and entrenchment rates are strongly related to the strata dip and Vf of the anticline. The highly entrenched fans with high sweep angles and long bases are characteristic of tectonically active fronts of Danehkhoshk anticline. The greater fan entrenchment in the central part of the anticline reflect longer uplift histories while lower entrenchment values in the northwestern and southeastern ends reflect relatively recent uplift, in agreement with Azor et al. (2002) and Ul-Hadi et al. (in press), implying that the values of fan entrenchment decrease in the direction of lateral fold growth. The poor relationships between catchment characteristics (slope and area) and fan characteristics are probably due to the complexity of karstic hydrologic systems of the studied catchments.

Although the sweep angle, base length and entrenchment rate of fans are strongly influenced by tectonic activity of the Danehkhoshk anticline, climate change has also considerable effect on the fans entrenchment and accommodation spaces. The fan head entrenchment and negative accumulation spaces on most alluvial fans can be attributed to decreased sediment load and discharge during the drier present-day climate regime. Corresponding with Ritter et al. (1995), the role of tectonics in the development of the studied alluvial fan characteristics seems to be long term.

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