Geomorphology 180–181 (2013) 217–230

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

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

Shahram Bahrami *

Department of Physical Geography, Faculty of Geography and Environmental Science, Hakim Sabzevari University, Sabzevar, Iran

ARTICLE INFO

Article history:
Received 18 December 2011
Received in revised form 11 October 2012
Accepted 14 October 2012
Available online 23 October 2012

Keywords:
Alluvial fans
Tectonic activity
Entrenchment
Morphometry
Danehkhoshk anticline
Zagros mountains

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

* Tel.: +98 5714003231; fax: +98 5714003270.
E-mail addresses: s.bahrami@sttu.ac.ir, shahram_bahrami2003@yahoo.com.

0169-555X/$ – see front matter
http://dx.doi.org/10.1016/j.geomorph.2012.10.012

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