Evidence of Neotectonics along Dehshir and Anar Faults in Central Iran by Using Remote Sensing Data

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Abstract:
We used remote sensing data and fieldwork observations to detect geomorphological and geological evidence of neotectonic deformation along the Dehshir and Anar Faults in central Iran. The utilized satellite data include Landsat, SRTM90 m, Aster data, QuickBird, and IRS images. Fieldworks show along the Dehshir Fault; the activity of tectonic has displaced perpendicularly travertine deposits ~190 m since Quaternary and also alluvial fan 7-55 m horizontally since Holocene. Perpendicular displacement along the Dehshir and subsequent erosion of hanging-wall has scatteringly created erosion surfaces in Quaternary. Oldest fan displacement of the Dehshir strike-slip Fault can be documented ~1000 m in Marvast part. Along the Dehshir and Anar Faults the existing springs can be regarded as a witness of the fault activity since they are stretched as linear trend. The Anar strike-slip faulting has displaced border of Anar playa ~1000 m and caused sharp scarp similar to wall-like feature ~40 m. We estimate 11.5 m (Mean) offset in the north of Anar that is a new evidence of morphotectonic in Late Holocene. The results show the rate of offsets is different but the patterns of displacements along the faults play in the same structure. Despite ample geomorphological evidence of recent tectonic activity along these faults, there is no evidence of high-magnitude earthquakes (M≥4.5).

Keywords: Neomorphotectonic; Strike-Slip Fault; Dehshir Fault; Anar Fault; Central Iran

1. Introduction

Study and evolution of neotectonic has attracted a great deal of attention during the last decade (Burbank and Anderson, 2000; Zanchi et al., 2006; Walker et al., 2010). Special Quaternary landforms are assigned to specific processes of active tectonic. Active faulting causes a variety of landform features, including fault scarp and traces, warped and tilted slopes, fault springs, vegetation lineation, and offset features such as stream channels (Keller and Pinter, 2001). Furthermore, deformation of Playas, Travertine deposits, drainage patterns and alluvial fans can also be implicated for dynamic landscape. Considering each major category of faulting—strike-slip, normal and reverse—may be discussed in terms of a characteristic assemblage of landforms, therefore, studies of these landforms can be used for estimation active tectonic type and patterns of faulting.

The paper first presents and reviews briefly the tectonic setting, dynamics, present-day distribution of active faulting and seismicity of the Iran (Fig.1). After that, places the Dehshir and Anar Faults of the central Iran. It describes main faults and morphostructural features of the area under study. An overview of the geomorphology is presented and highlights the tectonic influence on the landscape.
In the two sections, we present the data utilized for our interpretations and the methodology for the extraction from each layer of its information. In the later sections, we summarize geomorphological evidence for active tectonic in Quaternary. We use an analysis of the neotectonic evidence to show that the most Quaternary landforms are supported by active tectonics in the area of interest. Finally, it is followed by the discussion of the results and a general conclusion.

The main part of the paper focuses on the tectonic landforms and their evolution during the Quaternary. This allows us to discuss (1) geomorphological consequences of the active faulting in the study area, and (2) the patterns of faulting.

2. The general background

2.1: Tectonic and Geodynamic setting

The Iranian plateau extends over a number of continental fragments welded together along suture zones of oceanic character (Nadimi, 2007). Due to the Arabian–Eurasian collision (Falcon, 1969; Berberian and King, 1981) and their dynamics (Jackson and McKenzie, 1984; Nifluoushan et al., 2003; Vernant et al., 2004) (Fig.1), the Iran territory may be considered as one of the most tectonically active regions of the world. The central Iranian interior plateau (herein referred to as central Iran) is surrounded by fold-and-thrust belts, within the Alpine–Himalayan orogenic system of western Asia (Fig.1).

Central Iran is located among the Turkish syntax (TS) to the west and the Alborz and Kopeh–Dagh Ranges to the north, the Zagros and Makran Ranges to the west and south, and the East Ranges of Iran to the east. Being situated to the northeast and north of the Zagros–Makran Neo-Tethyan suture and its sub-parallel Cenozoic magmatic arc (Urumieh–Dokhtar Magmatic Arc), the Central Iranian terrain is an area of continuous continental deformation in response to the ongoing convergence (~22 mm/yr) between the Arabian (Gondwana) and Eurasian (herein referred to as Turan plate) plates (Vernant et al., 2004) (Fig. 1).

Whereas the central Iran includes regions with little internal relief, such as Central Iran (C) and Sanandaj-Sirjan (SS), and regions with more pronounced topography such as the Urumieh-Dokhtar magmatic arc (UD), therefore, it comprises a triangular area limited by the Lut Zone to the east, the Alborz Mountains to the North and Sanandaj-Sirjan Belt to the west-southwest. Central Iran is separated from the Sanandaj-Sirjan Belt by a continuous zone of depressions, including the Lake Urumieh-Tuzlu Gol-Gavkhuni-Taghistan-Abarkooch-Marvast and Sirjan depressions (Berberian, 1979) (Fig. 1). Overall it consists, from east to west of five major crustal domains: the Lut Block, Tabass Block, Kalmar block, Poshtabadam block and Yazd (Goorabi, 2009). The boundaries between these blocks are delineated with major and active faults (Stoecklin, 1968; Berberian, 1976). The Lut Block (lowland block) is located between the Nehbandan Fault to the east and Nayband Fault to the west. The Tabass Block is surrounded by the Nayband Fault to the east and the Kalmard, Kuhbanan and Anar Faults to the west and south. The Yazd Block is located between the Kuhbanan Fault to the east, the Biabanak Fault to the north and the Raftanjan, Shahr-e-Babak and Dehsir Faults to the south and west (Fig.1).

Tectonic studies indicate that the Iranian plateau has a very high density of active and recent faults, where large scale horizontal motion occurs on narrow zones of major strike-slip faults, the active deformation in Iran is spread out over a large area along many reverse faults (Ambraseys, 1968; Wells, 1969; Ambraseys and Tchalenko, 1969; Stocklin et al., 1972; Haghipour and Amid, 1980; Berberian, 1981b, 1981c; Farhoudi and Poll, 1992; Alavi, 1994; Ambraseys and Jackson, 1998; Berberian and Yeats, 1999; Koyi et al., 2000; Berberian et al., 2001; Ajen et al., 2001; Hessami, 2002, 2002; Tatar et al., 2002; Ambraseys and Bilham, 2003; Allen et al., 2004; Regard et al., 2004, 2005; Vernant et al., 2004; Walker and Jackson, 2004a, 2004a; Bachmanov, 2004; Agard et
This background presumably due to the fact that the Iranian plateau is, on one hand, confined between the convergence movements of the Arabian and the Eurasian plates, and on the other hand, is laterally trapped between the Arabian plate with eastern Asia-minor in the west and the Indian plate with Eurasian in the east. Because of entrapment, none of the continental blocks forming the Iranian plateau can easily move sideways from the collision zone, along major strike-slip faults (Fig.1). Entrapment of Iranian plateau and the motion in the eastern part of the Arabian impinging zone are first taken up by several reverse faults with large strike-slip component (dextral-reverse oblique slip close to the impinging zone) and then by pure thrusting towards central Iran (Berberian, 1981a). For these reasons it has attracted the attention of geomorphologist, tectonicians and seismologist for several decades (Falcon, 1969; Freund, 1970; Berberian, 1981c; Nowroozi and Mohajer-Ashjai, 1985; Baker, 1993; Jackson et al., 1995, 2002; Goorabi, 2009).

Fig. 1: Simplified topographic (derivative from SRTM30) and tectonic map of Iran and adjacent regions, including the zone of interaction of the Indian, Arabian and Eurasian plates. Simplified active fault traces highlight the main structural features accounting for the Arabia-Eurasia convergence zone. The Main Zagros Thrust (MZT) that separates the Iranian Plateau from the Zagros Mountains (Z) indicates the suture between Central Iran and the former margin of Arabia (AB). Sanandaj-Sirjan Zone is located northeast (NE) of Zagros and south of Lake Urumieh-Tuzlu Gol and Gavkhuni-Sirjan depressions (Marked with Ur-Tu-Ga-Ta-Ab-Ma-Si, dotted line). Ophiolitics outcrop (adjust of Urumieh-Doktar sequence, Marked UD), Eocene pyroclastic volcanic belt, is positioned southwestern central Iran. The Dehshir Fault cuts across the overall structure and morphology of the plateau and vanishes north of a prominent bend of the Main Zagros Thrust. The LUT Block is marked by L, the Alborz by AL, and the KoPeh Dagh by KP and the Holmand block by H. It shows two Inactive platforms of TUran in the NE and ArAlBia in the SW. Turkish syntax is marked by TS. Satiation of Dehshir and Anar faults mark by “Deh” and “An”. Black square refers to inset and approximate location of Fig.3. The inset at the lower left is an enlargement of major strike-slip fault systems in central Iran that marked by black square.
2.2: Seismicity

The existence and a relative excess of the active faults in the central Iran have been caused along series of large damaging earthquakes, many of them occurring within the 20th century (Fig. 2A). There have been roughly 126,000 deaths attributed to 14 earthquakes of magnitude ~7.0 (one 7.0 earthquake/7-yr), and 51 earthquakes of 6.0-6.9 (one/2-yr) that have occurred in Iran since 1800. During this period nine (9) cities were devastated (one city/10-yr). These earthquakes represent a mix of urban and rural events, with levels of documentation varying from one earthquake to another. Unfortunately, actual human and financial loss estimates are not available for the most Iranian earthquakes. On Iran earthquake map, Dehshir and Anar Faults reveal to be an aseismic area with negligible earthquakes (Fig. 2A). Although, base on earthquake map, Dehshir and Anar Faults have not had considerably earthquakes (M≥4.5) but there are many notable evidence of neotectonic in Quaternary landforms around it (see Discussion and also Figs. 5 to 19). In this research, we have considered historically (Berberian and Yeats, 1999) and instrumentally earthquakes for our explanations.

![Fig. 2. (A) Faults and Epicenter earthquakes of Iran. Seismicity of Iran 1900–2008 (International Institute of Earthquake Engineering and Seismology). Earthquakes data was imported through GIS environment. It shows two Inactive platforms of TUR in the NE and Arab in the SW (Fig. 1). The relatively aseismic Central Iran block is shown by C, (see Figs; 1 and 3 for morphology). Most activity is concentrated along the Zagros active fold-thrust belt at the northern margin of the Arabian and less activity in Central and east Iran (characterized by surface ruptures with earthquakes larger than M=5.5). No earthquake larger than M=7.0 has been experienced in the Zagros during the 20th century, but shocks of magnitude over M=7.0 have occurred in Central Iran. Note that negligible marks around Dehshir and Anar Faults as there are much evidence of very fresh neotectonic features along it (As described in Discussion). (B) Velocity field for Iran shows how the NNE motion of Arabia relative to Asia is absorbed in Iran (The GPS velocity vectors begin to shorten from S to N). The distribution of velocities within Iran is estimated from the spatial variation in the style of strain rates indicated by earthquakes (GPS velocity data read from National Cartography of Centre-NCC- of Iran, 2008). ”Dh” and ”An” on Figs refer to Dehshir and Anar Faults respectively.

2.3: Geomorphology

The geomorphology of the study area is dominated by a pattern of sub-parallel mountain ranges and intermontane plains (lowlands) (Fig. 3). The central Iran landforms are strongly influenced by the recent faults movements (particularly strike-slip faults). The piedmont areas are covered with broad alluvial fans (predominantly Holocene alluvium) composed of coarse gravel deposits, which originate from the mountain channels and spread for kilometers towards the lowlands. The bottom of the medial plains, known as "Kavir" (Persian for playa), is covered with playa-type mudflats, evaporate (salt) lakes (e.g. Abarkooh, Marvast and Anar Kavirs; Fig. 3) and, only locally, mobile...
sand dunes (e.g. along Dehshir fault at east of Abarkooh playa). Bedrock exposures are limited to the mountain ranges and fault scarps.

2.4: Active tectonics

Numerous studies in the central and eastern Iran domain have recorded geomorphic expressions like displaced, deformed and warped late Pleistocene and Holocene landforms along active faults. The basic contributions to studies of active faulting in Iran were made by geologists and geomorphologist scientists (Ambraseys and Tchalenko, 1969; Tchalenko et al., 1973; Tchalenko, 1975; Tchalenko and Berberian, 1975; Berberian, 1976, 1981c; Atwater and Atwater, 1987; Atwater, 1992). The latest compilations of available data about active faulting are from Berberian et al., 2001; Bachmanov et al., 2004; Talebian et al., 2005; Hessami et al., 2006; Jackson, 2006; Goorabi, 2009). Few studies have been undertaken to understand the active tectonic of Dehshir and Anar faults (Kristell Le Dortz; Meyer et al., 2006). Based on these studies, Dehshir and Anar fault have been active since Quaternary.

2.5: Climate

The complex physical conditions of Iran including: topography, vegetation cover and landscape have created a diverse climate pattern. The very hot and arid climate of the interior areas changes suddenly to the wet and moderate coastal climates of the Caspian coastal areas to the north of the Alborz mountains. The cold climates of Zagros are replaced by the warm and dry desert climates to the east (e.g. LUT desert; Fig.1). As we know that the present and paleo-climate are very important factors in the development of Quaternary landforms, it is important that they should be recognized, understood and considered any investigations and evolutions of landforms. The arid to semi-arid climate of central Iran is characterized by very hot summers. The sparse human
population is all densely concentrated around natural fault springs and Qanats. Qanat is a chain of manually excavated wells interconnected by a subsurface canal, which is designed to carry underground water from the piedmonts (aquifer high areas) to the lowlands. Some Qanats have swayed by active tectonic of Dehshir fault. Almost all of the streams (drainages) in the area are dry throughout most of the year. Nevertheless, the presence of broad stream channels floored with boulder-size fluvial deposits make plain to the enormous torrential currents caused by seasonal, drastic flash-floods. Thunder-showers may last only for a few minute in study area. Most of rivers beds are crossed by Dehshir and Anar faults. Mostly rivers beds are displaced by faults active tectonic.

The Kavir (playa) basins turn into transient lakes and the plains flourish with vegetation during the rainy season. The combination of arid climate and dramatic temperature fluctuations (daily and/or seasonal) has significant impact on rock weathering and erosion in the area. In this environment, the inhomogeneous, crystalline (poly-mineral) rocks, such as granites and gneisses, undergo pervasive mechanical weathering and disintegration. In contrast, the homogenous, fine-grained rocks such as carbonates (e.g. Travertines) tend to resist mechanical disintegration and remain by and large intact.

Based on geological and biological evidence, one of the Geologists has suggested a more humid climate for Iran in the early to middle Holocene (Moatamed, 1988). Furthermore, one of the geomorphologists believes that, during the period of glaciations, central and southern parts of Iran were experiencing a climate with more rainfall than today, whereas in interglaciation periods the climatic conditions were rather the same as today (Mahmudi, 1987). Bobek, while indicating clearly that in Iran we are still far from a satisfactory knowledge about climate changes, questions the presence of any pluvial periods in any way comparable with those of near-Eastern countries (Bobek, 1963). However, he agrees on the existence of a more humid type of climate in Iran in the Pliocene. Krinsley pointed out that the Pleistocene climatic patterns of Iran were similar to those of the present (Krinsley, 1970). Stable isotope composition of the gypsum hydration water from the soils showed the preservation of isotopically lighter water which is an indication of an environment with more precipitation (Khamedi, 1997). In spite of arid to semi-arid climate study area in present-day, existing Travertine deposits imply on wet climate in former period. Travertine are secondary carbonates originating in spring areas of groundwater saturated with Ca(HCO₃)₂. Since carbonate formation depends on the warmth of climate or active tectonic, the carbonate growth record may be useful in reconstructing the regional climate or tectonic activity in the past (Mallick and Frank, 2002). Travertine deposits have mostly formed around Dehshir fault and its tributaries in study area.

2.6 : Case study

For this study, we focused on the two active strike-slip faults, which cut large-scale Quaternary landforms. The NW-trending, right-lateral Dehshir Fault and NNW-trending right-lateral Anar Fault are major faults in middle and western central Iran respectively (Figs: 1, 2 and 3). The Dehshir Fault has cut main part of Iranian plateau (Fig. 1). It is about 400 km long and trends NNW–SSE between 29.5°N and 32.5°N (Berberian, 1981a; Walker and Jackson, 2004b; Goobab, 2009)(Fig.3). It is made of several linear portions, described from NW to SE in the following: First portion N170; 75-km-long segment cuts the eastern part of Nain-Baft suture and Urumieh-Doktar magmatic arc. This segment is located between Ardestan playa in the extreme north of the fault and Urumieh-Doktar magmatic arc (Nain-Baft suture) to south. The next segment is elongated along N150 and 80-km-long and terminates N of Dehshir. Activity of Dehshir Fault in this segment has caused displacement of Central Mountains (Urumieh-Doktar magmatic arc) about 65-70Km since Eocene-Oligocene (Berberian, 1976). The third portion of the fault is about 220 km long. It starts from Dehshir city and after cuts the western part of the Nain-Baft suture (see "UD" on Fig.3) and ponded lakes, marshes, Quaternary salt flats and alluvial fans connecting to
Sanandaj-Sirjan belt. Finally; Dehshir Fault terminates at ENE of the Main Zagros Thrust (MZT) in the end (Berberian, 1981c; Meyer et al., 2006; Goorabi, 2009).

The Anar Fault, as defined by authors, about 345 km long and NNW–SSE structural feature, has developed from northern part (Kharanaq, 32° 30' N, Yazd province located in the midst of Iran) to southwards (south of Anar city, 30° N, Kerman province, at the Kuh-e Mosahem Mountains). It is probably elongated along Chapedony Fault (Parallel to Posht Badam and Kalmard Faults in the east) that is located in northern with NE-SE structural feature (Overall, it makes several linear portions, characterized from north to south (Figs; 1, 2 and 3). Northern part with abundant tributaries starts from NE Kharanaq towards south till north of Anar playa (31° 30' N), about 120 Km long segment cutting the Quaternary sediments along itself. The further portion (mid part) is elongated along N-S striking and is about 90 Km. It begins from NW of Anar city toward south to alluvial fans on foothills of the Kuh-e Mosahem Mountains. The last part of Anar Fault, about 35 Km, cuts geology formations at the Kuh-e Mosahem Mountain and finally links to Rafsanjan Fault in southeast (Fig.3). Based on Berberian studies (Berberian, 1981a, 1981b) the Dehshir fault is older than the Anar Fault.

3. Materials and Methods

An active tectonic area on remotely sensed images including Landsat, Aster and Radar images with its large scale synoptic coverage - all extracted from satellite, topographic features and models—due to good exposures of morphotectonic indices in arid regions can be identified (Fig. 4). This work is essentially based on interpretations made on satellite imagery, DEMs in conjunction with fieldwork observations. Data obtained from five different sources: (1) Optical; (2) Radar; (3) DEMs represent three types of remote sensing data besides; (4) Geodynamic and Earthquake Maps and (5) Geology and Topography Maps.

Remote sensing data are based on Landsat (Thematic Mapper or TM and Enhanced Thematic Mapper Plus or ETM*), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), QuickBird, IRS (P5), Shuttle Radar Topographic Mission (SRTM90m) and Aster DEMs data.

Landsat data were acquired on path 161-163 and row 039-041 June 24, 1989. Landsat 7 data were taken by an Enhanced Thematic Mapper plus (ETM+) instrument on the same path and row on May-August, 2000 (http://glcf.umiacs.umd.edu/index.shtml). Landsat data were utilized for extraction neotectonic evidence. Many researchers have used Landsat data (Jackson and McKenzie, 1984; Novak and Soulakellis, 2000; Sauro and Zampieri, 2001; Kaul and Pandit, 2004; Jordan et al., 2005; Kervyn et al., 2006; Thurmond et al., 2006).
Aster is a high-resolution imaging spectrometer on board the satellite TERRA launched in December of 1999. ASTER has separate VNIR, SWIR, and TIR subsystems (Thurmond et al., 2006). The VNIR subsystem collects data with a spatial resolution of 15m using a nadir-looking telescope with three spectral bands detector (band 1, 2 and 3N) and a backward-looking telescope with one spectral band detector (3B). The backward-looking telescope provides a second image of view of the target in band 3 for stereoscopic observation and DEM generation. These bands (VNIR, DEM) are used in this study. ASTER imageries were acquired in Mars-July 2007(http://edcims.ww.cr.usgs.gov/pub/imswelcome). These multispectral images helped us to validate and to interpret the information extracted from the DEMs.

SRTM is capable of producing DEMs with an X–Y resolution of 1 arc-second (approximately 30 m) and a vertical resolution (Z) of 6–10 m. The data have been released at full resolution for the US and degraded to 3 arc- seconds to the rest of the world (90 m). SRTM data used in this research were obtained through the Jet Propulsion Laboratory (JPL) with 90 m spatial resolution (SRTM Project Office, 2003). SRTM data has been used in many active tectonic researches(Masoud and Koike, 2006; Grohmann et al., 2007). For digital ground elevation modeling, we used a SRTM data set with a resolution of 90 m and also Aster DEMs. 3D terrain models are based on the SRTM and Aster DEMs data combing with Landsat and ASTEr image overlays. Vertical exaggeration of the SRTM (Aster DEMs) ground information emphasizes the topographic conditions of the area observed. Image and terrain model (Topographic Models and Features) processing was carried out using ENVI 4.8 software.

All earthquake epicenters of instrumentally occurred in Iran (1900-2008, ≥5.5) are used for seismicity analyzing (Fig.2A). Geodynamic map of Iran is constructed on network of GPS sites (www.ncc.ir)&(Masson et al., 2006). This map shows north–south convergence between the plates of Arabia to the northeast and Eurasia to the southwest (Fig. 2B). Abarkooh (ABRK) in west of Dehshir Fault and Share-e-Babak (SBAK), Harat (HARA) and Ardakan (ARDA) sites in east of Dehshir Fault are represent orientation velocity of GPS, Robat (ROBA) and Kerman (KER) sites are located in the north and east of Anar Fault respectively (Fig.2, B).

The description of the methodology and its respective contributions to the study are presented below (Fig.4). In general, the research has been constructed at five stages. In the first stage; after reviewing literature of research about faults (Dehshir and Anar) and the exploratory fieldwork observations; an overview of the geodynamic and earthquakes around faults is presented. Furthermore fault traces on geology maps are digitized and imported to GIS software. In second stage; a geomorphological analysis of the study area has been undertaken based on the study of the relationships between the types of Quaternary landforms observed on digital elevation models and fieldwork data. One of the applications of DEMs used in this research is the utilization of three-dimensional (3D) perspective views for the visualization and analysis of morphologically defined structures. These perspective views have been effective in analyzing the relationships between topography and lithology (Thurmond et al., 2006), morphology and structures. These 3D perspective views are created by draping remote sensing images over DEMs and displaying the results in a two dimensional (2D) perspective view.

In the third stage; We apply analysis of the drainage network; drainage re-routing, channel pattern anomalies, avulsion,..., and search for complementary elements; analyzing the pediments, fans, plains, playas and the other evidence of active tectonics around faults. In the fourth stage and only in a limited of the study area; we have done the former stage but on imagery with upper resolution (2.5m and 60cm IRS, QuickBird data respectively). Analysis and overview of the regional drainage network constitute customarily the most important step of the search for evidence of active tectonics (Maruyama and Lin, 2000; Scheidegger, 2002; Murphy and Burgess, 2006; Goorabi, 2009).

Finally all evidence of neotectonic extracted from Quaternary landforms; fans, drainages,playas, pediments, faults, Channel slopes, channel trend changes and dry valleys are recognized in this
stage, we carried out fieldwork observations and acknowledged all evidence of neotectonic resulted from database and upper stages. At the end Concluding remarks are represented.

4. Discussion

There is very fresh evidence of faulting in Quaternary landforms (Burbank and Anderson, 2000; Keller and Pinter, 2001; Bull, 2007) in the study area. We surveyed some of them and analyzed neotectonic activities around Dehshir and Anar Faults. In this part, we followed and discussed some evidence of active tectonic in Quaternary landforms to evaluate study area from the viewpoint of tectonic geomorphology and also the effects of neotectonic on Quaternary landforms. By integrating these results, we can reveal the style, spatial extent and pattern of deformation along faults (Dehshir and Anar).

4.1: Active Surface faulting in study area

The aspects of some types of scarps and traces linked to tectonic structures, large, medium and small scale-sized are briefly discussed in the following. In this work four regions have been chosen.

4.1.1: Surface faulting of Dehshir area

One of the most spectacular neotectonic uplift and block faulting is recognized in the Dehshir area (Fig. 5). Numerous indications of active faulting are observed in Dehshir area. In the part of Dehshir geology map (Scale; 1:100,000) (Fig. 5, A), Dehshir Fault can be defined as the part of a much wider zone of late Quaternary deformation (e.g. Travertine, fans), which appears to link the Share-e-Babak right-lateral strike-slip fault in the southeast of the Dehshir region (Figs. 5) with a more distributed system of strike-slip faulting (e.g. Fig. 10).

![Fig. 5. Morphology and morphotectonic in Dehshir area; (A) a part of the geology map of Dehshir that aimed Dehshir fault and travertine deposits location. Travertine deposits (mark by Tr) have faulted and displaced across horizontal and perpendicular. Lines show location of profiles(C, D and E). (B) ASTER image (bands 1, 2 and 3n) of the Dehshir Fault at Dehshir. The fault trace is marked by black arrows. Alluvial fan and Travertine deposits appear to be displaced vertically and perpendicularly along a sharp line (marked by black arrows). (K) Geomorphology map of Dehshir Fault and Dehshir area. (C, E) After faulting of Travertine deposits in the early Quaternary, erosion process has filled foot-wall of Dehshir Fault by constitution of alluvial fan (see C, B). Travertine deposits may belong to the early Quaternary and it is displaced up to ~190m, therefore the rate of uplifting (depression) in this area can be ranged between 0.21 and 0.26 mm/yr-1. (F) ](image-url)
Beheaded, offset and deflection drainages along Dehshir Fault, ~2.5 km at the west of Dehshir (see F is in Fig. 5, B). (G, HiField photos of ravine displacements observed along the Dehshir Fault, the drainages channel are marked as a ragged line and the Dehshir Fault trace runs between white arrows. The magnitude of apparent right-lateral displacement was measured with a tape measure, at 31 38 27 N, 53 36 24, is about 11m that is shown at Fig.5H.

One of the best evidence of neotectonic in Dehshir area is travertine faulted deposits. Almost all of travertine deposits are being located along fault traces in Dehshir area. Distribution of main travertine masses is shown in the geological map of the Dehshir (Fig. 5, A). The fieldwork revealed that the travertine masses have been deposited along dip-slip normal strike-slip fault segments (e.g. Dehshir, Toranposht and Share-e-Babak faults and its tributaries). Presently, travertine deposits in all springs were elongated or Qanats dug along faults are still forming at the very low seepage. Initial time of apparent right-lateral displacement was measured with a tape measure, at 31 38 27 N, 53 36 24, is about 11m that is shown at Fig.5H.

One of the best evidence of neotectonic in Dehshir area is travertine faulted deposits. Almost all of travertine deposits are being located along fault traces in Dehshir area. Distribution of main travertine masses is shown in the geological map of the Dehshir (Fig. 5, A). The fieldwork revealed that the travertine masses have been deposited along dip-slip normal strike-slip fault segments (e.g. Dehshir, Toranposht and Share-e-Babak faults and its tributaries). Presently, travertine deposits in all springs were elongated or Qanats dug along faults are still forming at the very low seepage. Initial time of apparent right-lateral displacement was measured with a tape measure, at 31 38 27 N, 53 36 24, is about 11m that is shown at Fig.5H.

Dehshir faulting has been displaced ~190 m the travertine deposit perpendicularly near Dehshir city (Fig.5). Profiles (C, D and E) drown between uncoupling travertine deposits by Dehshir Faulting (Fig.5, A) represent the scarp of fault in Quaternary landforms. Since all profiles have cut Quaternary landforms, wherever the profiles are sagged and carved, faulting is active now. Figs.5, B, F (ASTER imageries) illustrates morphology and relocation of travertine deposits across Dehshir Fault. Although fault scarps in Figs.5, C and E have been filled by alluvial sediments since Quaternary (see Fig.8Aa2), Fig.5, D shows apparently fault scarp in travertine deposit (~190m). If travertine is deposited in mid Quaternary (828±93 ka, According to B. Engin and O. Guven, 1997) the rate of displacement across perpendicular can be ranged between 0.21-0.26-mm/yr⁻¹. Figs.8, A, B and C show reconstruction evolution history of alluvial fans and Travertine deposits caused by neotectonic deformation in Dehshir area. Simultaneous faulting along strike and slip of Dehshir fault has created beheaded, offset and deflection drainages along Dehshir Fault (see Fig.8A, B and C). Considering to suggestion dating of Travertine deposits, this suggests considerable rate of incision (0.21-0.26 mm/yr⁻¹) that is reflected by the geomorphic analysis.

Travertine deposits also provide valuable information regarding neotectonic activity because they are often associated with areas affected by intense deformation. Fault scarps, fault plans, tectonic cracks and tectonic veins are often had filled and cemented by calcite (CaCO₃) in Quaternary formations (Fig.8). In general, the terrains are covered by travertine deposits have been fragmented by faulting since Quaternary.
Fig. 7. (A) Outcrop of the alluvial fan in foot-wall of the Dehshir Fault (west of Dehshir, See location on Fig. 5A). Insects ; (a1) Qanat-well is dug in Harat alluvial fan; L (lake), Ls (lake-shallow) and F1,3 show different facieses recorded in different circumstances. (a2) Well drilling by farmers in alluvial fan (~70m), its depth has not meet water because Dehshir faulting. Figs. 8 a and a show Dehshir Fault traces across perpendicular (fault plan). Last of alluviums in fan are displaced ~70-80cm across fault plan in west of Dehshir. (B), (C), (E) and (F) show fault scarps, fault plans, tectonic cracks and tectonic veins are filled and cemented by calcite in Quaternary.

Furthermore, in this part, the results of the geomorphological study suggest that the drainage networks are consequent to the Dehshir Fault System activity. The organization and development of a drainage network is the result of a combination of factors such as climate, lithology and the attitude of the strata, as well as active tectonics, regional uplift and subsidence. It has been observed that, the major streams and ridges around Dehshir Fault are displaced by active tectonic (faulting). Herein, the travertine and alluvial fans deposits are incised within the present-day drainage network because of faulting. Sketch diagram shows three possible Dehshir Fault landscape evolutions leading to present-day observation (Figs. 7, A, B and C). 1-A; Initial configuration: Primary Travertine deposit before faulting on the Conglomerate deposit (Fig. 7, E) during raining period. 2-B; Tectonic and Climate forcing scenario: tectonic stage (Dehshir Faulting) has cut Travertine deposits causing to increasing slope characterized by incised rivers. 3-C, Final stage in continues of pervious stage, the rivers are being eroded at hanging-wall part and simultaneously alluvial fans are being deposited at foot-wall of Dehshir Fault. Travertine deposit is buried by alluvial fans at foot-wall part whereas they appear as pseudo-inselbergs at hanging-wall. All stages indicated above have been accompanied with right strike-slip fault forming a huge number of morphotectonic landforms such as; fault scarps (Fig. 5C, D and E), linear valleys and deflection, offset and beheaded streams along Dehshir Fault. Estimation of recent landforms (e.g.; drainage offsets are incised in fans or sediments belongs to Holocene) indicated that the total displacement could have accumulated over Holocene slip rate about 0.01 mm/yr$^{-1}$ (11 m).
Fig. 8. A, B and C show reconstruction of alluvial fan and Travertine deposits caused by neotectonics deformation (see Fig. 5A, along C, D and E profiles). (D) Travertine layers upon the Upper Red Formation (See Fig. 5B). (E) Remained deposit of Travertine upon the Pliocene conglomerate and Upper Red Formation (See Fig. 5B).

4.1.2: Surface faulting in the east of Abarkooh Playa area

In the eastern margin of Abarkooh Playa, one of the best-preserved scarps of surface faulting is well recognizable inside a depression morphostructure, about 78-km-long and 6–10-km-wide (Figs. 9, A-J, see Fig. 3 for location). The “Abarkooh Playa depression” appears as playadeposit surrounded by scarps with recent offsets at the east part. This depression is part of the Lake "Urumieh-TuzluGol-Gavkhuni-Sirjan" great tectonic depression, the main structural in the southwest of central Iran located between Urumieh-Doktar magmatic arc and Sanandaj-Sirjan zone (Figs. 1).

East of Abarkooh Playa is characterized by abundant landforms created by frequent displacement and offsetting (Figs. 9, A-B, b, c, d, e, f, g, h, I, j). For example; large areas of eastern Abarkooh Playa are covered by large late Quaternary alluvial fan surfaces, which are often abandoned and incised by drainages. Uplifted and abandoned alluvial fans are widespread to the east of the Dehshir Fault. These morphostructures are neotectonic displacement features, clearly resulted from reactivation of a Neogene inherited structure. In this area, the drainages reflect the morphotectonic patterns. Stream tributaries are dislocated along Dehshir Fault showing irregularity forms, such as; meandering and beheaded ravines. In view of this overall structural geometry they could probably be triggered by earthquake shocks as the measurement of offsets confirms anomalies. The complex fault scarps may be also interpreted as multi-phase tectonics (Figs. 9).
Fig. 9 shows evidence of neotectonic along the Dehshir strike-slip fault in the east of Abarkooh Playa. (A) Shaded SRTM digital topography of the Abarkooh Playa region (see Fig. 3 for location). The fault scarp (marked by black arrows) is clearly shown at Abarkooh Playa. There is a height change of up to 30–40 m along the Dehshir fault in alluvial sediment (see inset topographic profile). The drainage systems are incised and appear along the fault at the eastern margin of playa, indicating that the Abarkooh Playa is sagging coinciding with horizontal displacement to NW (Normal right-lateral strike-slip fault). The boxed region shows the location of Fig. 9B. (B) LANDSAT ETM image (band 1) of the eastern margin of Abarkooh Playa. A series of alluvial fans extend along the western side of the Dehshir Fault trace that are cut by the Dehshir Fault (marked by black arrows). (a) ASTER image (band 1) of faulting in alluvial fan along Dehshir Fault. Alluvial fan deposits have been displaced horizontally and vertically along a sharp line (marked by white arrows, see Fig. 9B for location). (b) ASTER image (band 3n). Uplifted and abandoned alluvial fans towards east of the fault indicating uplift relative to the west part of fault. Recent alluvial fans are forming along break-through on footwall. (c) Deflected, beheaded and offsets streams with shutter ridges are formed along Dehshir Fault. (d, e) ASTER images (band 1); recent alluvial fans are displaced along Dehshir Fault (marked by white arrows, see Close-up in Fig. 9h). (f) Close-up QuickBird image along Dehshir Fault trace (see Fig. 9b for location). Abandoned alluvial fan and drainage channels are broadly raised across the fault. (g) QuickBird image shows offset of drainage. (h) Close-up of Fig. 9e. (i) QuickBird image shows offsets, deflections and beheaded drainages along Dehshir Fault. Dehshir strike-slip faulting has shifted the depocenter of alluvial fan towards the Abarkooh Playa (see Fig. 10). Note: all the above evidence are settled in alluvial deposit that belong to Quaternary - Recent, therefore, Dehshir Fault is very active in this area. (J) Deflected and beheaded drainages show active tectonic of Dehshir Fault in the eastern of Abarkooh Playa.
One of the best evidence of active tectonic in east of "Abarkooh playa" are related to morphology of the alluvial fan. Nearly, all alluvial fans are faulted and displaced by Dehshir and Share-e-Babak Faults in early Quaternary (Fig.10). Successions of alluvial fans show consecutive and reactive faulting in early Quaternary. Fig.10 shows reconstruction and propagation of neotectonic in east of Abarkooh Playa that is located around Dehshir and Share-e-Babak Faults. An attempt is made to show the development of fan structure resulted in the present tectonic–geomorphic setting in Fig.10. Based on measurements on fieldwork and imageries, total drainages displacement in recent landforms (e.g.; fans or surface deposits belongs to Holocene) would have accumulated about 30-55 m since Quaternary (e.g. see Fig.17b). This rate is maximum dislocation in Holocene landforms Dehshir Fault-wide.

Fig. 10. Schematic diagram illustrates the geomorphic evolution of the alluvial fans and drainages around the Dehshir and Share-e-Babak Faults with the help of 3-D cartoon model, 2-D view and transverse and longitudinal cross-sections from left to right respectively. The faults marked in the model ("Sh", "Dh") do not represent the original dip of the structures. (a) Stage-I: Alluvial fan (F1) is placed at knick influenced by tectonics. The transverse profile shows no incision at the fan
head and also the longitudinal profile shows low gentle slope. (b) Stage-II: Share-e-Babak Fault is activated (active) and it has displaced footwall (hanging-wall) fault across horizontal and perpendicular. Therefore, fan (F1) head has been incised and shifted the fan (F2) depocenter towards the lower part. The transverse profile shows incision at the fan head and the terrace is formed only one side of river whereas the longitudinal profile shows high relief and high stream gradient. Deflected stream, offset stream and beheaded stream have formed around Share-e-Babak Fault trace. The rate of sedimentation is more than the subsidence rate by Dehshir Fault (c) Stage-III: Further uplift (by Dehshir and Share-e Babak) has imposed fans head incision and the river flows within the confined channel; consequently, shift the depocenter towards the Abarkooch Playa. Incision by the axial stream has led to the formation of terraces in the distal part. The transverse profile shows present day cross-section near the fan head and the present day surface and the stream longitudinal profile is also shown.

4.1.3 : Surface faulting in Marvast alluvial fan

There are typical examples of neomorphotectonic evidence at the eastern part of Sanandaj-Sirjan zone in Marvast-Harat area (Figs; 11, 12 and 13). The typical one of neotectonic deformations can be observed on the Marvast alluvial fan. Marvast alluvial fan has been displaced along Dehshir Fault since Quaternary. There are many offsets of rillwash on the last alluvial fans (belong to Holocene). It shows that active deformation along the Dehshir fault on Marvast fan is accommodated both drainages and alluvial fans. One of the ridge displacements in alluvial fans that belong to early Quaternary illustrates in Fig.11d, the horizontal offset is around 1000 m based on fieldwork measurement and according to Meyer (2006) 900 m. In this part, the horizontal offset of recent terrace along Marvast River was measured around 30 m based on fieldwork survey and according to Meyer (2006) 20 m.

Fig. 11. Evidence of neotectonics in Marvast area; (A) fault trace, beheaded river, shutter ridge, displacement of the Marvast fan depocenter towards the Marvast playa and dislocation of Marvast alluvial fan (ETM image, band2). Dehshir Fault traces runs between arrows. (b, c) Morphotectonics pattern of Dehshir strike-slip Fault; stream channels found on Marvast alluvial fan (Aster images, band 3n). (d) Misalignment of single channels directly related to amount of fault displacement that is enlarged at d1 and d2 (IRS.P5 images, 2.5m) (see Fig.12). (e) Compound offset of ridge, offset and deflection of channel; both right and left deflection. (F) Picture of Dehshir Fault scarp, folding of Quaternary sediments and magnitude of apparent right-lateral displacement was measured at 30 26 55 N, 54 o7 08, is about 30m that show at Fig.11F (View NW from approximately position white arrow in Fig.11d).
4.1.4: Surface faulting between Marvast and Harat area (West of Marvast playa)

The large tectonic scarp is directed towards the Marvast playa depression (Figs.13, see Fig.3 for location). Quaternary Bajada merged with a salt flat depression runs obliquely across Dehshir Fault (Marvast playa, Fig.13). The Bajada slope is oriented gently towards NE. The fault has been characterized by scarp whose height ranges between ~5-60m (Figs.13, a, b and c). The relative ages of the fans can be estimated based on their relative elevation and degree of incision by the active streambeds. Offset fans, shutter ridges do occur along fault of Dehshir and the margin of the Marvast salt flat, but the clearest morphologic offsets are found in the west of the salt flat along the road of Marvast to Harat (Fig.13). Profiles (Fig.13c, d and e) show the eastward scarp of Dehshir Fault along the Marvast playa depression towards the Mountain. These are strongly influenced by neotectonic force, with the evidence of deformations and morphostructure in the upper/lower parts on the numerous alluvial fans. Nearly, all of Qanats in Marvast area appear along fault scarp. Here, line-spring lineation is corresponded with vegetations lineation. Scarp are mainly resulted from vertical tectonics, and their styles are determined by the activity of normal faults (Fig.13F, G).
4.1.5: Surface faulting in Anar area

The surface faulting of the Anar area is a big tectonic scarp of the northeastern part of Dehshir-Anar region (Figs; 3 and 14). In this region, the Anar playa is limited by Anar Fault to the west and meets by the Mt. Bafgh minor Fault to the east. The faulting has created a scarp with about 40-m-high along more than 7.5-km-long (Fig.14). The scarp is modified by weathering and wind processes, but it is relatively well preserved. The average slope is about 80° (Fig.14-A, D). The upper rim is slightly undulated. Fieldwork observations showed the drainages offsets along Anar Fault and the rate of displacements in recent landforms are not equal. Fieldwork measurements show; the slip rates of the right-lateral along Anar Fault are different. In initial segment of Anar Fault in south of Anar city cumulative offsets alluviums (Holocene landforms) are measured between 4.5 m. But towards to NW, 10 km of Anar city, measurements of offsets show 8-12 m (Figs.15). Toward the north (N-NW) and segments of Anar Fault the rates of dislocations and offsets are decreased. It is documented about 4-5 m in alluviums.
Fig. 14. Morphotectonic of Anar Fault scarp (~10 km NW Anar): (A) Aster image (bands, 1-2-3) of Anar Fault scarp (mid part of Anar Fault), since the slope of fault scarp is very high, contour lines (1385 m) is elongated straightly across Anar Fault trace, arrows show the Hossin Abad (Marked farm on Fig. 14.A) canal. (B) Old canal is located probably on hanging-wall of Anar Fault. Western edges of Anar playa (hanging-wall of Anar Fault) are uplifting and has been caused to stopping old canal, farmers have (see farm is S) constructed new canal at lower elevation. (C) Photo of Kareem Abad spring. (D) Profiles are perpendicular of Anar strike-slip Fault.
Fig. 15. (A) Evidence of neotectonics and morphology of Anar Fault on Bad Bahat Koh pediment (TM imagery), the fault cuts the Quaternary piedmont. (a) Rillwash and drainages are uplifted (1-3 m) and displaced (mean 8.5). (b) Modern drainage is running along Anar Fault trace in Quaternary sediments, drainages on hanging-wall are terminated to Anar Fault trace. New basins (very small) are formed on footwall of Anar Fault. (C) Deflection drainages, offset drainages, beheaded streams, and shutter ridges are formed along Anar Fault, boxes indicate location of C1. (C1) Drainage offset shows that Anar Fault is displaced 11 m. Deflated drainage is shown in g (QuickBird imagery) and photo (p1). All landforms are settled in Quaternary sediment, therefore, it stands for reason Anar Fault is stirring now. Composition of deflection and offset drainages has formed OX-BOV landforms along Anar Fault strike-slip right lateral (e, f). Anar Fault is displaced 7.5(e1)-14 m (e2). (f) QuickBird mosaic of the Anar Fault.
4.2: Some other aspects of morphotectonic evidence

In addition to the above-mentioned, displacements of geomorphological and anthropogenic evidence are running and involves roads crack, offset on the qanat (duct) and destruction of wells. There are other geomorphological indications of recent tectonic activity in the region that some evidence can be extracted from DEMs and satellite imagery of study area. Some evidence is only searched by fieldworks.

4.2.1: Rupture on roads and displacement of Qanat route

Fieldwork observations in cross of Dehshir-Abarkooh and Marvast-Hanbarjan roads with Dehshir Fault show; there are many abnormal cracks on roads surface that can be created probably by active tectonic. Besides, active tectonic of Dehshir Fault zone has displaced Qanat route in south of Harat (Fig.16).
4.2.2 : Fault Springs, line-springs of Fault

After investigating on the satellite imagery and digital topography in conjunction with fieldwork, we found out spring or line-spring lineation to be really resulted from active fault. It is clearly distinguished by the vegetation, which in turn is sensitive to springs that occur along faults lineation. Springs are more common along active faults of Iran connected to spring line with an active fault. In this particular case, however, the line occurs precisely at the junction between major fan systems or playas coming off the mountains to the western and eastern respectively in Anar and Dehshir areas. Fig. 16.a shows a major drain influenced by neotectonics to be incised into fan deposit in Marvast area. Figs. 18.a,b1,c1 show perspective views of this junction, with Aster images draped over SRTM 90 m digital topography. The spring line is surely caused by faulting that has been relocated in both sides of horizontal and vertical directions. Two of them are seen in field work: Hossin Abad and Kareem Abad Springs at Figs.18.b2, c2.

4.2.3 : Erosional Surfaces

Isolated erosional remnants (monadnocks or pseudo-inselbergs) are generally located on the pediments in study area. For example, there are many erosional surfaces in Dehshir area that can be rexed in 150-250 m higher than its surrounding surfaces (Fig.19). The elevation remnant surfaces are extrapolated laterally to join others. These features are formed by both active tectonic uplift and subsequent erosional systems. Due to high sensitivity of travertine deposits relative to erosional processes, they appear as outstanding features incised by main channels. Probably, large of travertine deposits could be resulted from pluvial stages coinciding with active tectonic on the Dehshir area. Therefore neotectonic deformations are responsible for such landscape on footwall Dehshir Fault.

Fig. 16. Field observations of surface faulting features. Locations and orientations of the photographs (a, b and c) are given in Figure 13. (a) Surface rupturing on road of Harabarjan-Harat (the same effect is observed on Dehshir-Abarkoooh road ,~2.5 km W Dehshir); (b) Fluvial erosion of surface rupture on Dehshir Fault in north of Harabarjan; (c) Destructive effect of Dehshir Fault on Water well on near Harabarjan; (d) View of displacement Qanat route on QuickBird image; (e) Close-up at the locality shown in (d), with right lateral displacement in south of Harat.
Fig. 17. (A) view of Dehshir Fault scarp, because stream bed is elevated by faulting with respect to its downstream, ravine has incised bed its. (B) Field photo looking W, ~20 km S of Dehshir, showing deflected drainage (blue) along the line of the Dehshir strike-slip Fault (ragged red line). Along this segment of the fault, there are many ‘shutter-ridges’ reflecting recent right-lateral strike-slip motion. (b) Trenching site showing normal faulting in alluvium deposit near Dehshir Fault, looking SE ~ 2.5 km W of Dehshir. Fault gauge is shown in photo (ragged red line).

Fig. 18. ASTER images (bands 321-CIR) draped over the 90m SRTM topography, to illustrate the tectonic geomorphology of the tectonic line-springs, along the lineation that might be a continuation of the Dehshir and Anar Fault system to the NW and N respectively. The vertical scale has been exaggerated six times. (a) Perspective view from the SE respect to Dehshir Fault near Marvast, looking along the lineation marked by white arrows. Note the vegetation lineation. (b1) View of Hossin Abad spring near Dehshir from the S. Note the farms associated with fault terrace. Black arrows show the lineation fault. (b2) Picture of farms along Dehshir Fault at view b1. Inset; as springs percolate very little water, farmers have connected it. (c1) Kareem Abad spring that is formed at conjunction Anar Fault, View from SE. (c2) photo filed work from Kareem Abad spring. Note the amount of vertical offset.
5. Concluding

Fieldwork measurements of drainages offsets and other neotectonic features in the Quaternary landforms along Dehshir and Anar faults show the rates of displacement are different along each segments of strike-slip faults in the study area (Dehshir and Anar Fault). In this study, we have focused on three segments of Dehshir Fault and two segments of Anar Fault due to much more evidence of neotectonics. In initial segment of Dehshir Fault in the south of Harat, cumulative offsets on alluviums were measured between 4-5 m in Holocene deposits. But towards to NW (SW of Marvast alluvial fan), near Harabarjan, it showed 8-10 m (Figs; 11 and 12). The east of Abarkooh playa (Fig.9), the rates of offsets is increased. Here, we have measured the rate of offsets in the recent deformed alluvium about 55 m (maximum of offset along Dehshir fault, Fig.17). Of course, in the later segment and the north of Dehshir, the rates of offset decreased (11 m. Fig.5). As Dehshir fault, along Anar Fault the rate of offset in recent deformed landforms are different indicating the maximum of offset in middle segment of Anar Fault (Figs. 14, 15). Overall, it seems the rate of offset along strike-slip faults from initial part to middle segment is being increased and finally it is decreased at final segment.

This can be observed on the west of Marvast playa where it begins 25 to 60 m high whereas in the east of Abarkooh Playa it is 200 m high.

Indications of offsets variety along strike-slip fault in study area are widespread. Perhaps one of the most neotectonic evidence of strike-slip fault can be found around Dehshir Fault in central Iran. The geomorphological expression of strike-slip Dehshir Fault is as the result of long-term strain accumulation. Vertical displacements and horizontal translation along the Dehshir Fault can be detected using high resolution satellite image. Over long time intervals, strike-slip faulting typically leads to some well-known geomorphologic features. A linear trough commonly is formed along the principal displacement zone, because structural blocks are slipping past each other along this zone and also the fractured materials are more readily eroded along the fault zone. Irrespective of how the troughs are generated, within them, seasonal sag ponds formed in low-lying regions on upthrown (+) of Dehshir Fault where river or ravine watercourse is relocated. Here along Dehshir fault, fault scarps can be seen clearly on other side of the Dehshir Fault. Linear features like drainages and ridges become offset along the Dehshir Fault.

Wherever a ridge that has been translated along the Dehshir Fault blocks of drainage, it is termed a shutter ridge. On the downslope side of Dehshir strike-slip faults, beheaded stream valleys are preserved (Figs. 9, 10). They are abandoned valleys that have been relocated laterally to rightward of the course the stream formerly flowed through them.
On both of the upstream and downstream sides of Dehshir Fault, uplifted-river (ravine) terraces and offsets appear systematically. Commonly, stream crossing a strike-slip Dehshir Fault will exit from a mountainous terrain into a gentler one. Upstream, their valleys have been more confined (due to erosion of), whereas downstream of the fault, has built alluvial fans in the less-confined topography. Offsets of the margins and the crest of a fan are used to determine fault displacements (Figs. 9, 10 and 11).

The examples illustrated above represent the most typical morphotectonic of surface faulting found in the area under study. A few small features of recent surface faulting destroying anthropogenic phenomenon i.e. roads and Qanats are also described. The forms-produced tectonic here is relatively fresh and shows neotectonic deformations.

From the morphotectonic point of view, neo-morphotectonic landforms are located mostly on upthrown and footwall sides of faults. Among the most convincing evidence that the evolution is driven by tectonic episodes in fault zones of study area, the following are worth of note: (1) the dry rivers are displaced or beheaded, (2) alluvial fan that is beheaded, (3) spring or line spring lineation alongside vegetations lineation, (4) fault scarps, (5) succession of alluvial fans, (6) erosional surfaces, (7) deformation of travertine deposits.

On the basis of geomorphological evidence of recent surface faulting one can evaluate whether the periodicity of the intense tectonic episodes is regular, or whether there are alternating periods of the rest followed by paroxysmal phases. However, forms like the complex east of Abarkooh and west of Marvast playas and offsets of valleys indicate alternating rest periods of the phases.

In any case, the time-scale pattern should be considered within the complexgeodynamic model of the recent evolution of the area. In our view, the present-day evolution is the result of prolonged compressive tectonics, which has caused convergences in the vary parts of the morphostuctures. Since tectonic episodes are resulted from compressive stresses they induce tectonic processes and episodes of surface faulting.

Morphotectonically, the following points are noteworthy: (a) the large forms are generally consistent with the tectonic structure (e.g. mountains, Plains); (b) most of the plateau surfaces are controlled by the bedding of Cenozoic units; (c) the main forms coincide with important tectonic lines and often with tectonic depressions (playa or fault angle depressions); (d) many anthropogenic features are influenced by the neo-morphotectonic processes.

Many scarps are linked with faults or more complex structures. Their morphological features can provide enough elements to distinguish the role of selective erosion of recent tectonic movements in their development. In general, it is clear that the largest forms are mostly of tectonic origin (Abarkooh, Marvast and Anar playas) and the medium-sized forms are the result of mixed origin, the small scarps are mostly due to lithology and selective erosion; but small forms on main features are created by erosional processes.

Morphotectonic structural and geomorphological records of late Quaternary age are the expression of very active offset and uplift resulted from tectonic activity.

The super abundance of geomorphic futures seems seldom to match historical data on earthquakes and recent geological records (Fig.1.B), but we concentrate on the neo-morphotectonic evidence and neotectonic processes to analyze landform evolution.

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7. References


