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ACTIVE DEFORMATION DELINEATED BY GEOMORPHIC AND SEDIMENTARY RESPONSE OF RIVERS, CENTRAL ZAGROS FOLD – THRUST BELT, SW IRAN

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Abstract. The mountain generation in Iran is because of continental collision between the Arabian and Eurasia plate. Southwestern Iran shows active shorten that its evidences is deformation of crust and frequent earthquakes. At depth, active basement of the Zagros fold-thrust-belt in southwestern Iran, which are covered by folding of the Phanerozoic sediments, affected by some blind thrusted faults that have seismic nature.

The Zagros fold-thrust-belt can be divided into 4 lithotectonic units including Sanandaj-Sirjan Zone (SSZ), Imbricate Zone (IZ), Zagros Fold Belt (ZFB), and Molasse Cover Sequence (MCS); this dividing and classification is based on geomorphology landscape, drainage pattern, rate of tectonics and stratigraphic records.

Each tectonic unit characterized by especial abnormal forces in river systems. Active tectonics has the most important role to control the river systems by changing of channels incline.

Change in the drainage pattern, channels cut, longitudinal profile, anomalous changes of sinuosity, changing of the side form and forming of terrace, change of river direction, compact meanders, cutting of meanders and geomorphology features of the rivers are responds to the active tectonics of region that are studied using remote sensing, DEM and field observations. These parameters are used to understand the vertical movement in the study area.

Existing structures, especially growing anticlines and blind thrusted faults in the Zagros fold-thrust-belt, which cut the river channels and sometimes put them in parallel, are used in the study of their effect on the longitudinal and transverse tilt of morphological changes.

Keywords: active tectonics, geomorphology, DEM, Dez River, Zagros belt, SW Iran.

Introduction

The Zagros mountain belt in Iran is a part of the Alpine-Himalaya system that is extends from northwestern to southwestern Iran. This orogenic belt is continental collision between the Arabian plate and a part of Eurasia plate that is called the Iranian plate (Berberian, King 1981).

It can be concluded that the first phase of compression in this belt, during the lower Cretaceous, has caused uplifted ophiolite in the northeastern margin of the Arabian plate. This compression movement continued to occur continental-continental collision during the Miocene (Falcon 1969). At the present, this convergence is activated so that the pressure direction in the eastern edge of the Arabian plate is NS, the rate of motion is almost 25–30 mm/y (Sella *et al.* 2002), and in the Zagros orogenic belt, the pressure direction change to NW-SE. The focal mechanisms of earthquakes and field GPS data also show this oblique shortening along the faults of Zagros (Talebian, Jackson 2002).

The Zagros fold-thrust-belt is divided into four units as follows:

1 – Sanandaj – Sirjan Zone (SSZ),
2 – Imbricate Zone (IZ),
3 – Zagros Fold Belt (ZFB),
4 – Molasse Cover Sequence (MCS).

This division has been established based on geomorphology and active tectonics patterns (Rangzan 1993) that will be discussed in this research.

Mountain topography is caused by interaction between tectonics and surface processes.

The ZFB are formed on the thrust and strike-slip faults. One of the main methods for analyzing the evolution of such orogenic belt is studying the active tectonics and neotectonic of region.

The most common evidence of regional neotectonic are geomorphic features such as length and gradient of channel, the channel stage number and the aspects of geomorphic such as network and texture of drainage. Therefore, the study of river systems due to their high sensitivity to changes of tectonic is a suitable method for the evaluation of tectonic activity and the evolution of studied region.

In this research, by using of GIS and RIVERTools software and field observation have detected the evidence of active tectonics in the Dez River basin that is a part of the ZFB.

1. Geological setting

The studied region is located in southwestern Iran, between the Dezful city in the northern Khuzestan province and the Khorramabad and Doroud cites in the north of Lorestan Province. These two provinces are very important in terms of geology and geomorphology, as well as hydrocarbonic reserves. This region is a part of the Zagros fold-trust-belt. The studied region has a high variety of the stratigraphy and geomorphology patterns. In this region, altitude than sea level varies between 142 to 4200 m.

2. Geomorphology

Geomorphic studies of the Zagros Structural Belt (ZSB) was carried out as part of multi-phase studies of tectonic analysis of the ZSB.

The Zagros belt with a length of 1,500 km starts from the Taurus Mountains in southeast Turkey and after crossing southwestern Iran, ended in near the Minab strike-slip fault in the vicinity the Hormuz Strait in the Persian Gulf (Berberian 1976). The Zagros forms a natural barrier on the border of southwestern Iran. The Zagros Folded Belt (ZFB) is defined the main structural framework of the Zagros that its average altitude is about 3,000 meters (Jackson *et al.* 1981).

The lithotectonic units have clear geomorphological features in satellite photos that in this study, they have been used to estimate the morpho-chronology of the ZSB.

Morpho-chronology, landform analysis, drainage morphometry, and morphotectonics are studied in order to develop an evolution model of the studied region and its relationship with tectonic processes controlling it. The zoning geomorphology of the region was carried out based on these parameters. The geomorphological analysis shows the correlation between morpho-chronology and tectonics at the margin of the Arabian and Iranian plates.

2.1. Geomorphic elements

The current geomorphic surface of the studied region has four morphotectonics unit that are characterized by the landforms, drainage patterns and relief features. The Morpho-Chronology has not been carried out in the Zagros. The landscapes of region are young. The available information indicates immature topography that is in dynamic state. However, based on recent calculations of the vertical forces of the Zagros Structural Belt (Lees, Falcon 1952; Berberian 1981) was carried out relative morpho-chronology of the four morphotectonics units namely MCS, ZFB, SSZ, and IZ (Table 1) and described their elements (Rangzan 1993). A description of the geomorphic elements mapped in the Zagros Folded Belt follows.

a) IZ

The morphotectonics unit represented by the IZ shows development of four geomorphic elements that have been mapped as structural hills, cuesta zone, hogback zone and structural valleys. The IZ, as morphotectonics unit, is characterized from the SSZ in the North East based on relief variation and from the ZFB in the South West based on NW-SE dominant structural direction. The geomorphic elements of the IZ show structural discordance.

Table 1. Geomorphic zones of the Zagros Structural Belt

Zones	Morphometery of Watershed	Landform	Relief(Average) Meters
MCS	MBR = 4.88 DD = 1.72 SF = 0.83	Less deformed, folded sequence Cuesta & Fans etc	25–1267
ZFB	MBR = 4.63 DD = 3.89 SF = 4.01	Elongated dome & basin, Trellis drainage pattern	2500
SSZ	MBR = 4.05 DD = 3.89 SF = 3.17	Hill & Range Moderately-Dissected	1900
IZ	MBR = 3.64 DD = 2.73 SF = 2.20	Highly Dissected Terrain	2967

Note: MBR: Mean Bifurcation Ratio, DD: Drainage Density, SF: Stream Frequency.

b) SSZ

In terms of geology, the SSZ is the oldest lithotectonic unit in the region but in terms of geomorphology, it is younger than the IZ so that appears at lower geomorphic level that mainly dug by erosion processes. Based on the shape and relief characteristics, this unit can be divided into three geomorphic subunit: a) rolling rocky waste, b) structural hills and c) erosional hills

c) ZFB

The ZFB is the classical example of a folded mountain belt. In this zone, the structural direction of anticlines and synclines is consistent with the main direction of the Zagros Structural Belt in Iran.

Based on the geomorphological evidence, the ZFB is younger than the IZ and SSZ and older than the MCS. This unit is separated from other units by its rugged and dissected topography, alignment of ridges, drainage pattern etc. The differential erosion of the massive and resistant formations has developed complex geomorphic landscape so that there are hills and valleys of anticlinal close together and the valleys and hills of synclinal side by side. This symmetry shows the uncertain geomorphological conditions. In the rugged landscape of the Zagros, the broken limp of anticlines seen as hogbacks and cuestas that are dominate the eroded valleys.

d) MCS

Structurally, the MCS, which is the youngest geomorphic unit, is as thrust sheet over the ZFB. This unit is composed of clastic formations such as the Aghajari and Bakhtiari formatuin with Mio–Pliocene age. The sequence topography is included cuesta and alluvial fans. The alluvial fan formed by rivers that are in motion from raised areas due to tectonic activity to the plains leading to the Persian Gulf.

Hard and resistant nature of the clastic formation in the MCS is formed synclinal hills and cuesta flanks which in some places rises up to 100–500 meters above the valleys floors. The Karkheh and Dez are two main rivers, which flow from the northeastern and northwestern regions. These rivers have compact meandering with morphotectonics landscape due to neotectonics in the MCS. The development of the fans at the frontal margin of the cuesta and synclinal hills shows that alluvial fans are the youngest geomorphic features in the region. The southwestern margin of the MCS contains the flat plains that continue to the coastal zone of the Persian Gulf.

2.2. Landscape evolution

The geomorphological study of the Zagros collision zone reveals that the Zagros morphogeny is the morphotectonics expression of the Alpine – Himalayan subduction cycle and collision of the Arabian and Iranian plates. The Iranian and Arabian lithospheric plates were separated by an oceanic crust up to the Cretaceous. During the Cretaceous, the subduction started as a global event that led to the closing of the Neo – Tethys (Berberian, King 1981), in Iran. This event is recorded as IZ where the subduction related ophiolite and colored mélange were accreted to the Zagros sediments in the late Cretaceous time. The IZ remained negative tectonics topography from Paleocene to Mio – Pliocene and formed part of Zagros trough that received sediments from SSZ on the Arabian plate in the north and probably from the Arabian plate in the south. The deformation of the IZ started in Eocene (55–25 Ma) and continued up to Miocene. Collision related compressional tectonics resulted in the upliftment of the IZ and the formation of the ZFB and the sedimentary environment changed from marine to continental in the Zagros trough. During early Miocene the Gachsaran evaporates were deposited over which the MCS was deposited in front of the newly raised tectonics lands of ZFB and IZ and isolated patches in the inner part of the belt.

The Zagros trough closed around Miocene (25–5 Ma) concomitantly with the opening of the Red Sea.

The collision of the Arabian and the Iranian plates led to the annihilation of the subduction below the IZ. This process of collision generated morphogeny in the SSZ, IZ and ZFB. The closing of the foreland basin generated vertical tectonics in the Zagros Folded Belt and decollement in the MCS.

The morphogeny in the Zagros Mountains has taken place during the last 4–5 Ma/1mm year that generated a relief of about 4 km above MSL and resulted in the development of erosional cycle. The collision resulted in tectonics jumbling and juxtaposition of different lithotectonic units that resulted in the structural discordance of the internal fabric of IZ with the regional NW–SE grain of the ZFB. This internal fabric is geomorphologically expressed as hogback ridges of IZ.

In response to opening of the Red Sea the SSZ, IZ underwent vertical tectonics and acted as areas of positive relief. Later geomorphic processes resulted in extensive erosion of the SSZ so much so that its present day disposition at lower altitude than the IZ has exhumed the deeper levels of the older rocks in the area. The ZFB together with the MCS are rising 1mm/year. The tectonics activity in these zones is well documented by the development of anomalous drainage and compressed meanders in the study area.

The fluvial erosion of the newly raised tectonics lands during the humid cycles in the Quaternary has generated the cuesta and hogback ridges and structural and erosional hills and valleys.

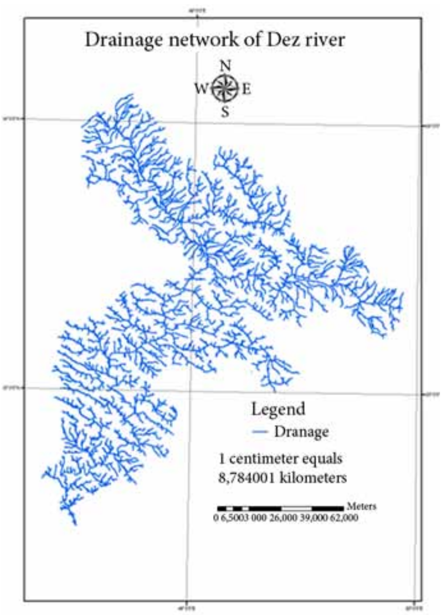

Fig. 1. Drainage pattern of the Dez River basin

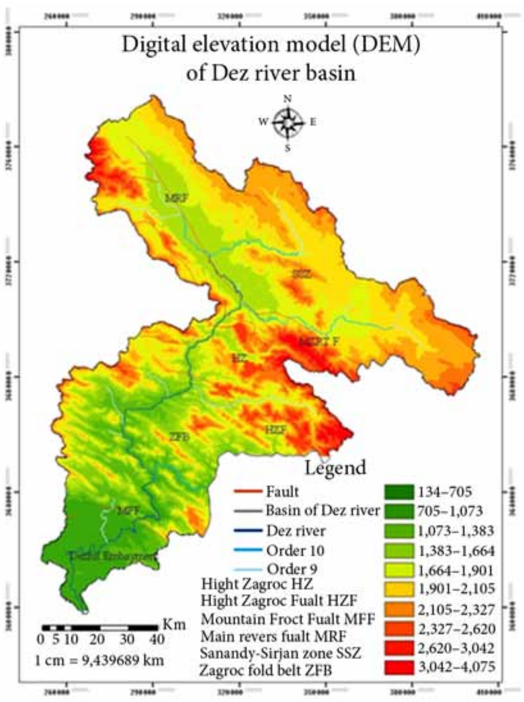

Fig. 2. DEM and profile of the Dez River

2.3. Drainage network

River systems consist of two main landscapes that are valleys and drainage networks (Jain, Sinha 2005). The drainage networks in the Zagros fold-trust-belt shows different pattern so that their study has a significant role in the analysis of the tectonic evolution of the region.

Drainage pattern immediately follows the pattern of the region structure. Therefore, active tectonics can be changed the rivers and drainage patterns.

The SSZ shows a dendritic drainage pattern with large texture on the Granite and Granodiorite rock.

The IZ shows an irregular and disorganized drainage pattern. This model refer to thrusting in the Zagros belt. The other parts of this zone has dendritic and tree branch-like drainage pattern.

The drainage network in the ZFB is dendritic that is indicative high tectonics activity in this unit. Some part of the ZFB and high Zagros (IZ) has trellis and sub-parallel pattern (Fig. 1).

In the MCS, drainage system development is obvious but is not evaluated like drainage network in the ZFB unit. However, approximately similar tectonic forces had affected the ZFB and MCS but their morphotectonics reaction had been different. The approximate dendritic drainage pattern in the MCS is due to the dominance of transitional deformation with minor deformation in this unit. In fact, the spread of the Gachsaran formation in these two units and its role as a slippery-separation surface had caused less deformation in the MCS than the ZFB.

It should be noted that the drainage pattern analysis is not enough alone to understand the deformation of studied region.

2.4. Stream gradient

Regions that are affected by rapid and periodical uplift show step gradient, high reliefs and high gradient (Burbank, Anderson 2001). The DEM of region are used to prepare the Dez River profile (Fig. 2). One profile is prepared for each lithotectonic unit (Figs 3a, b, c). Analyzing the profiles and nick point places can be determined the effect of faults and growth of anticline on the river system. The essential point is the concavity and or convexity of profile so that the convex profile shows uplift rapid rate and further activity of tectonic in the river direction.

3. Imbalance forms of active tectonics

In Geomorphic systems, some events transform the output of the system elements that are landforms. It should be noted that a significant portion of the imbalances caused by accidents, which could have many reasons. Therefore, despite unchanged of the precipitation and the sun radiation rate an imbalance landscapes are formed. The uplift changes the local base level, increasing the incline of river and drainage network and finally after passing of balance threshold, creates the down cutting processes and imbalance forms that are as follows:

- Hilly landforms
- Deep valleys with low width
- Imbalance structure in the drainage network due to fault activity
- Head cut and shallow Gullies

The hilly landforms is visible in all uplifting region (Fig. 4). The uplift due to active tectonics and faulting has changed the down cutting erosion in the region and has caused the hilly landscape. The step forms at junction point of sub-channels and main channels show multi-stage uplift.

Water erosion has created the deep and narrow valley (Fig. 5). The deep of valleys shows the high rate of tectonics activity in a short time.

The fault activity caused reversed drainage to the mainstream (Fig. 6).

The head cut and shallow gullies are formed across the river that is evidence of youthfulness tectonics activity. In the other hand, in different regions especially uplifted hills, down cutting erosion has caused the gullies.

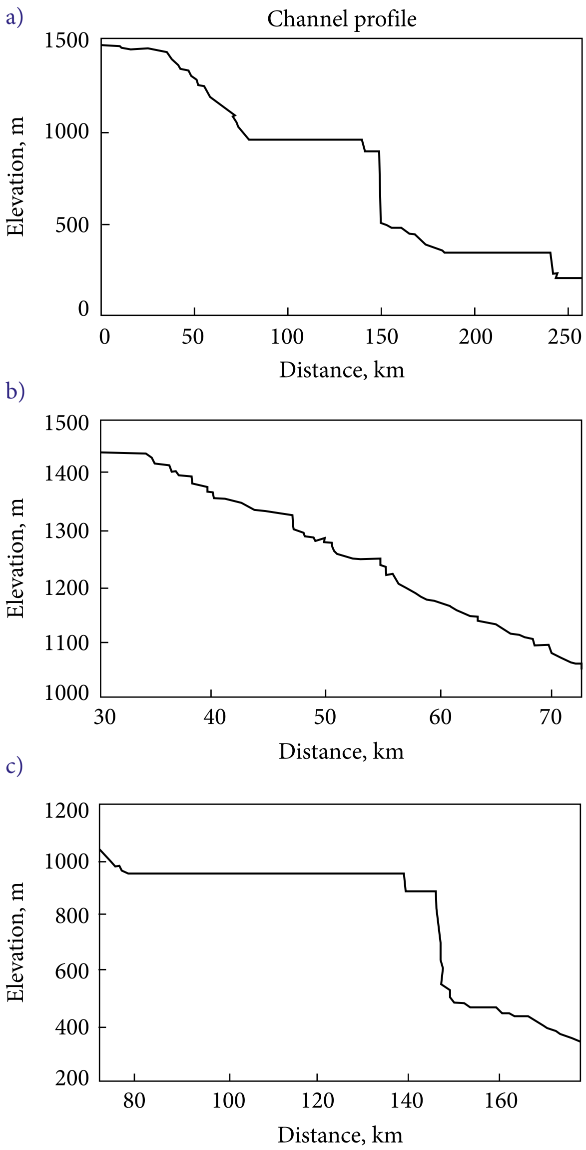

Fig. 3. Profiles of lithotectonic units
a) HZ, b) ZFB, c) Dezful embayment

Fig. 4. Hills landform in North of the Dezful and Haft Tapeh

Fig. 5. Deep valleys with low width in the Dez Dam

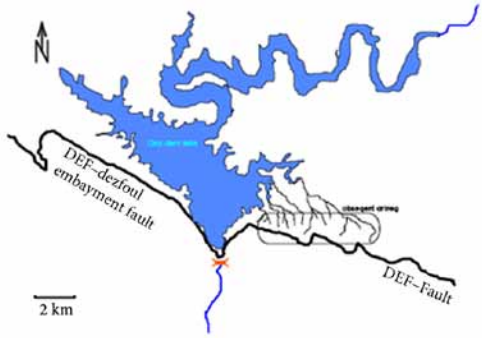

Fig. 6. Obcequent structure of drainage network due to of DEF function in the Dez Dam

4. Dez River reaction to active tectonics

The effect of active tectonics on incline parameter has changed the river systems in the Zagros fold-thrust-belt and has formed some river reaction over time. Analysis the effect of regional structure such as faults, anticlines, and synclines the river systems is important to understand these reactions and their relationship with active tectonics. The intersection of rivers and these structures is a key point in the analysis of their effect on the river system.

The first group is the reaction of drainage network in non-compliance with the general incline of studied region. The general incline is from the highlands to the thalweg of the region namely, the foreland of Persian Gulf. In the other word, this incline is from northeast to southwest. However, in many cases, the rivers due to effect of secondary incline of local uplift and subsidence flows in the direction other than the general incline. For example, the Dez River after passing the Dezful city and get to Haft Tapeh anticline, passes the way about 12 km along the anticline.

Other type of mismatch can be seen close to the uplifted faults and anticline, especially in the limps

Fig. 7. The Main axial of anticlines and rivers direction in the Khuzestan Plain. The red arrows show direction of rivers

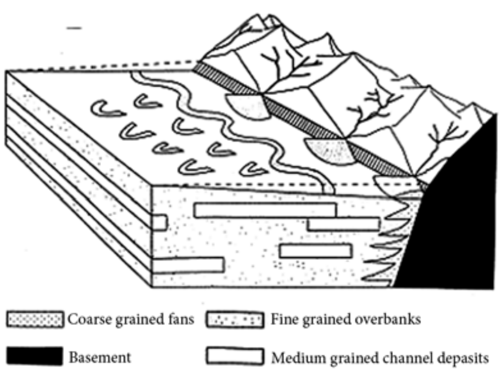

Fig. 8. Regular meander trace side main channel

toward to the folded Zagros. For example, in the Dezful embayment, the fault activity has made drainage network opposed to general incline of region (Fig. 7).

The Dez River has shown height sensitiveness to the tectonic activity such as immigration, terraces, and cut of Meander.

Although, periodical displacement of the river in the Khuzestan plain, which is a part of the MCS, is caused by high water and flooding in the region, but the main reason for this displacement is active tectonics of the studied region.

According to scholars, the basement of studied region is part of the Arabian plate and various studies have shown that this basement is none heterogeneous and with numerous longitudinal and transverse faulting (Berberian 1995).

The effect of these faults has created several blocks in the region such as Karkook and Mousel blocks in Iraq and multiple blocks in Iran (Rangzan 1993). The displacement of these blocks along the basement faults has caused some uplift and subsidence that have affected the sedimentary covers. An example can be cited the subsidence in southwestern Iran that is clearly visible in the geophysical analyzes and topographic maps with Post-Miocene age (Sepehr, Cosgrove 2004). General trend of river migration in the MCS mainly is toward west that shows effect of regional tectonics activity in these displacements.

The Dez River cut of meander are visible in the downstream of the MCS that these landforms shows continuous tectonics uplift in the region (Burbank, Anderson 2001). The meander concavity can be toward the down tilt of the region (Fig. 8).

The cross section analysis of the Dez River at the intersection with anticlines and faults clearly indicates the river terraces (Fig. 9). Most of these terraces in both sides of the river is not coincident. In fact, the river has created non-paired terraces at the intersection with these structures. As we know, none couple terraces show tectonics anomalous, therefore, they can be an evidence to uplift of anticlines and tectonics activity in the studied region.

Conclusions

One of the best and most applied tools in order to study active tectonics and regional tectonics evolution is the river systems analysis based on geomorphology and tectonics geomorphology evidence. The GIS and remote sensing science can be used to evaluate these parameters in order to study tectonic activity in a large

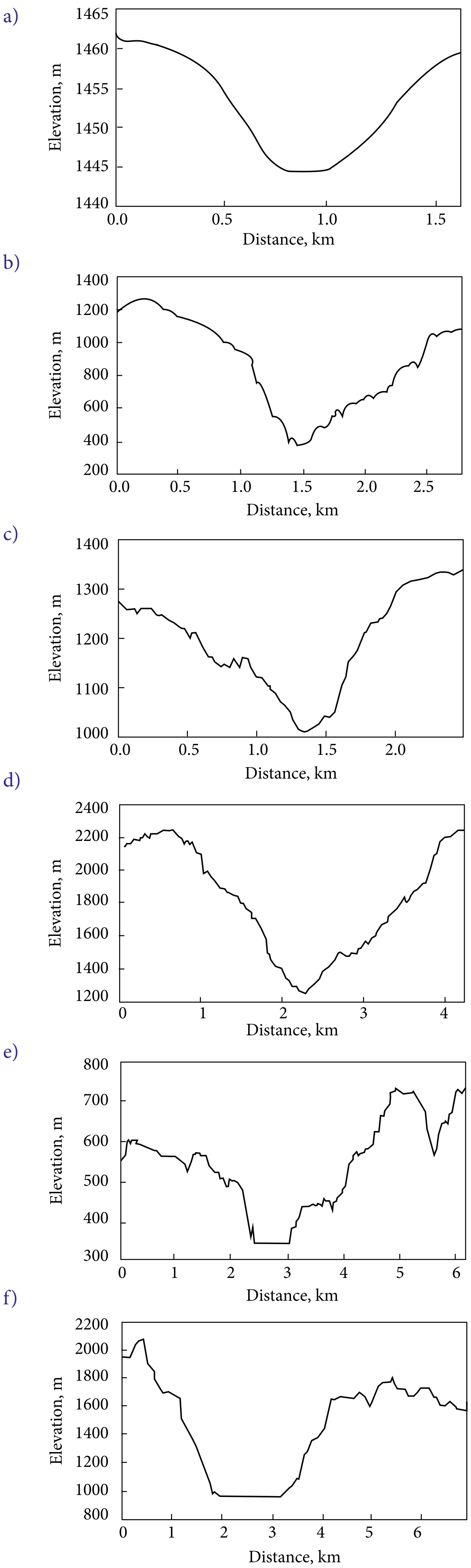

Fig. 9. The cross section in a) MRF, b) HZF, c) MFF, d) HZ, e) ZFB, f) Dezful Embayment

region. The special analysis of DEM and its adaptation with field observation in the Dez River basin presents acceptable and reasonable analysis of tectonics activity and its role in the tectonics development of Zagros fold-thrust-belt in southwestern Iran.

Based on geomorphological and morphometric analysis, the studied region is divided into 4 lithotectonic units. In addition to special geomorphological forms and features, each unit has special tectonic features that are clearly visible in the Dez River system.

The drainage network analysis of river systems shows the current tectonic activity in the region, for example, it can be noted the dendritic pattern of drainage in ZFB.

The meander position and changes in longitudinal profile clearly indicate effect of different tectonic structures such as faults and folds on the Dez River so that it can be concluded the growth of anticlines and fault activity in this region. In addition, analysis of longitudinal profile in each lithotectonic unit shows high rate of tectonics activity in the ZFB and MCS.

The Dez river cross sections at the intersection with faults and anticlines show non-placental river terrace that is evidence of the changes and tectonic uplift in this region. The tectonic disturbances is higher in the ZFB and Dezful Embayment units.

In general, it can be concluded that because of pressure from the Arabian plate, front of the Zagros fold-thrust-belt is propagation to southwestern. This propagation has caused the development of several highlight anticline axis and multi-axis fallen synclines in this region, especially in the Khuzestan plain. Rivers response to active tectonics and the creation of the axis, especially in the plains, is degradation and frequent movements over time. The current events in the Dez river system can be considered as a model for the evolution of the Zagros fold-thrust-Belt.

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