Journal of Earth Science, Vol. 25, No. 5, p. 932–938, October 2014 *ISSN 1674-487X*
Printed in China
DOI: 10.1007/s12583-014-0474-y

Tectonic Setting of the Barm Firuz Lake, Zagros Mountains, Iran: Inferred from Structural and Karstic Evidence

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ABSTRACT: This paper presents the role of tectonic and karstic processes in the formation and evolution of Barm Firuz Lake within the Zagros Mountains of Iran. This lake with elevation of 3 340 m from sea level is located in the crest of the Barm Firuz anticline. Results show that the structural evolution of the Barme Firuz Lake is related to both tectonic and karst processes. Therefore the term of tectono-karstic has been used for structural evolution of the lake. Structural studies especially on the stylolite structures revealed the occurrence of an important component of simple shear deformation in the study area. Based on structural and karstic evidence around the lake, the fault-dissolution sink model with oblique pure shear component is suggested as kinematic model of the Barm Firuz Lake evolution in the Zagros Mountains of Iran.
KEY WORDS: tectonic, karst, Barm Firuz Lake, Zagros Mountains, Iran.

0 INTRODUCTION

Sinkholes form by dissolution of carbonate formations by influence of surface and underground waters and rocks collapse due to gravity force (Filipponi et al., 2009). In many cases the effects of tectonics for increase of fractures density is very important for evolution of karst features. Therefore tectonics can be act as complementary phenomenon for formation of karst features. Sometimes a tectonic shock such as earthquake generates driving force for tumble down of the rocks. Anyway, the role of water in generate of karst cavities is the most important factor. So that in many cases, independent of the tectonic effects and only with operation of acidic water the formation of a karst sinkhole is possible. But in some cases the evidence of tectonic effects can be seen around the sinkholes (Neal, 2004). In such cases the terms of tectonokarstic sinkholes can be used. Determination of transposition of dissolution or tectonic operation in the formation of sinkholes is very difficult and sometimes simultaneous operation of these two phenomena forms a tectonokarstic sinkhole. There are many tectonokarstic structures in the world. San Gregorio Magno and Dasht Arjan in Italy and Iran are the examples of two known tectonokarstic features. This work investigates the importance of structural analyses in the characterizing of tectonic and karstic processes on the evolution of the Barm Firuz Lake.

1 REGIONAL GEOLOGICAL SETTING

The Zagros fold-thrust belt is part of the Alpine-Himalayan orogenic belt (Berberian and King, 1981) and lies on the northeastern margin of the Arabian Plate. This belt contains 8–14 km thick Cambrian–recent succession, which lie on a Precambrian basement. These sediments were deposited on a platform that was relatively stable from the Cambrian until the collision between the Arabian and Iranian plates in the Late Cretaceous to Tertiary (Berberian and King, 1981; Falcon, 1974). Shortening across the Zagros fold-thrust belt in the Phanerozoic rock cover, which is estimated to be about 30–85 km (McQuarrie, 2004; Blanc et al., 2003; Falcon, 1974), occurred by thrusting and folding above various decollement horizons. Postcollisional crustal shortening is still active (Allen et al., 2004; Tatar et al., 2004; Talebian and Jackson, 2002; Jackson and McKenzie, 1984) with an N-S oriented convergence rate of approximately 20±2 $mmyr^{-1}$ (Molinaro et al., 2005; Vernant et al., 2004). Shortening in the basement occurs dominantly by faulting. The thick Cambrian Hormuz Salt, at the base of the sedimentary succession, and other evaporite horizons (e.g., the Dashtak and Gachsaran formations) within the succession (Sepehr and Cosgrove, 2005; Talebian and Jackson, 2002), prevented these basement faults from rupturing the cover rocks and reaching the surface. As a result of these decoupling horizons, the deformation in the basement and the sedimentary cover occurred independently. This fold-thrust belt is approximately 1 800 km long and 200–300 km wide. It runs from eastern Turkey to the Strait of Hormuz, where it terminates against the Minab fault (Fig. 1), which separates the Zagros belt from the Makran accretionary prism (Molinaro et al., 2005). The study area is located in the Barm Firuz anticline near Ardekan Town 110 km northwestern of Shiraz. The Barm Firuz anticline such as many anticlines in the Zagros fold-thrust belt shows an axial trend with NW-SE orientation. The anticline shows doubly plunging geometry. The main part of this anticline consist of the Cretaceous Sarvak Formation composed mainly of carbonate rocks that is one of the main hydrocarbon reservoir rocks in Southwest Iran. In the study area, the

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Manuscript received October 21, 2013.
Manuscript accepted May 27, 2014.

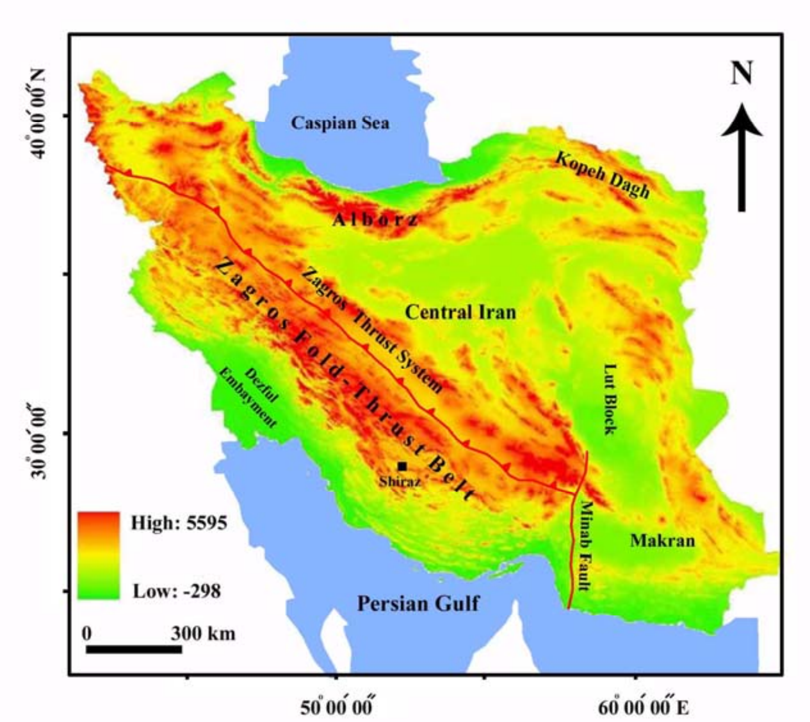

Figure 1. The tectonic setting of the Zagros fold-thrust belt and its location in Iran.

Sarvak Formation consists of light to grey calcareous breccia and medium bedded limestone. Figures 2 and 3 show the oblique satellite image and the geological map of the study area.

2 STRUCTURAL AND KARSTIC EVIDENCE

Because of the unique position of the Barm Firuz Lake it is interest subject for many geologists. Several hydrogeological studies have been done on the lake (Eftekhari, 1993; Pezeshkour, 1991). These studies mainly concentrated on the hydrological relationships of the lake with the sprigs around the Barm Firuz anticline. In this research a possible kinematic model for the evolution of the Barm Firuz Lake is investigated using stylolite structures. Satellite images analyses and detection of linear elements show several main fault systems around the lake. It seems that two fault systems dominated in the area. Faults with parallel trend and faults with attitude of 30° to 40° in respect of the fold axis of the Barm Firuz Anticline (Fig. 4). Related to the faults vertical movement components along the long axis of the lake especially in the south rim, the lake area identified as a low elevation between the fault planes (Figs. 5a, 5b). Limestone scarp surfaces around the lake show numerous of dissolution cavities, karrens and fault slickensides features. In some cases the fault planes show a smooth surface with clear scratch-slip and in another places exhibit a rough and dissolution surface. Slickenfibres on the fault planes mainly show high plunge angles which confirm predominant of vertical

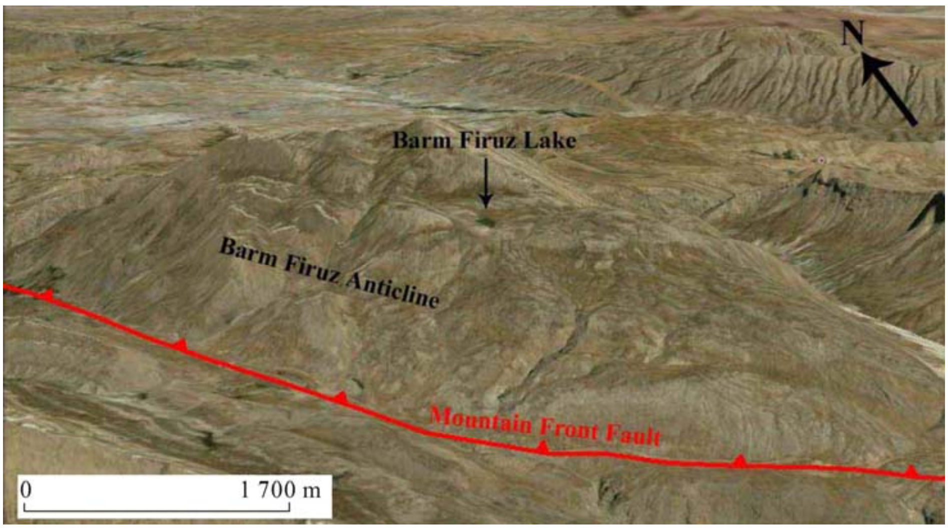

Figure 2. Oblique satellite image of the study area.

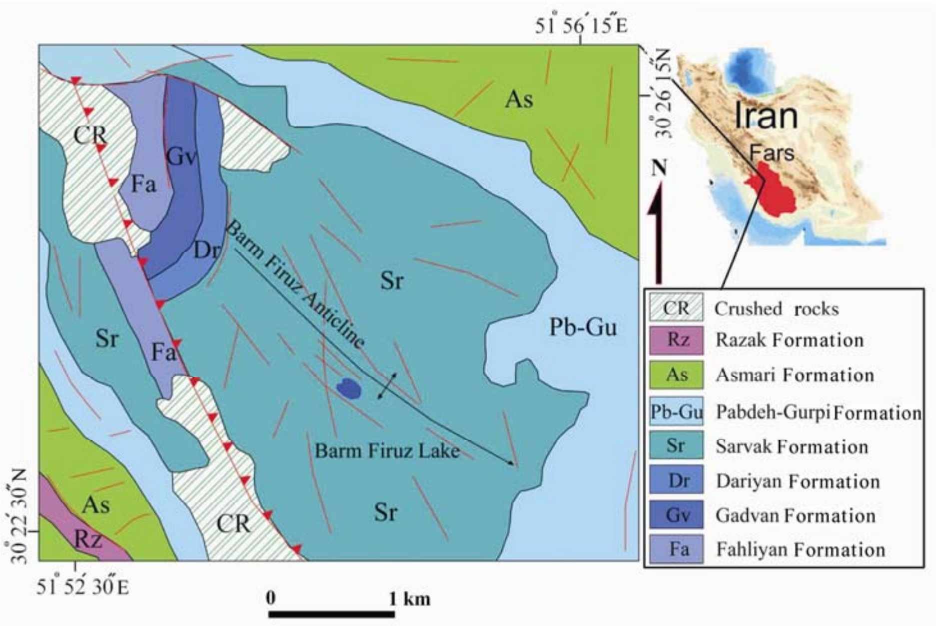

Figure 3. Geological map of the study area.

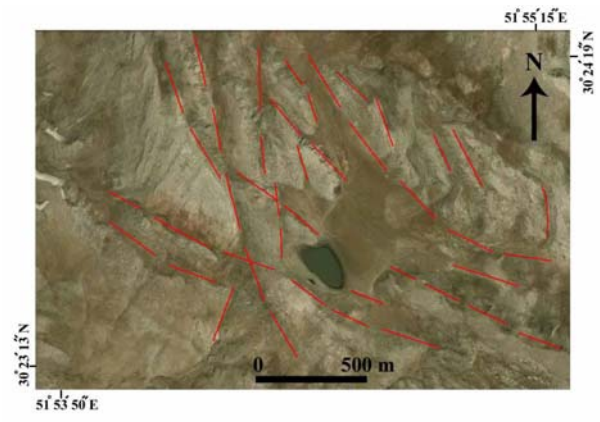

Figure 4. Main faults and joint around the lake.

movement on the fault planes. As mentioned above, karren features have formed on the carbonate surfaces around the lake. These dissolution grooves mainly have vertical mode and no visible on the all of carbonate surfaces so it can be deduced that vertical faults and joints have played an important role to control of the water flow directions. Young fault movements have caused to cut karstic grooves and formed carbonate surfaces with both karren and slickenside features (Fig. 6). Due to the local lithology and climate similarities in the study area differential dissolution on the fault surfaces cannot be related to the erosional processes after faulting. In order to introduce a structural evolution model for the Barm Firuz Lake, stylolite structures in the area were studied. Stylolites are serrated surfaces at which mineral material has been removed by pressure dissolution, in a process that decreases the total volume of rock. Insoluble minerals like clays, pyrite, and oxides remain within the stylolites and make them visible. Sometime host rocks contain no insoluble minerals, in which case stylolites can be recognized by change in the texture of rock. They occur most commonly in homogeneous rocks, carbonates, cherts, sandstones,

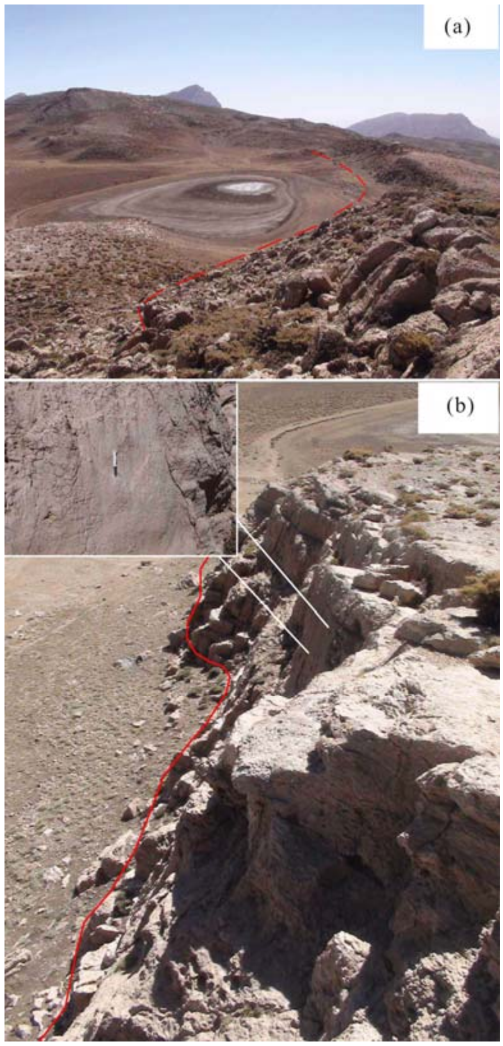

Figure 5. Fault planes with vertical displacement in the lake margins.

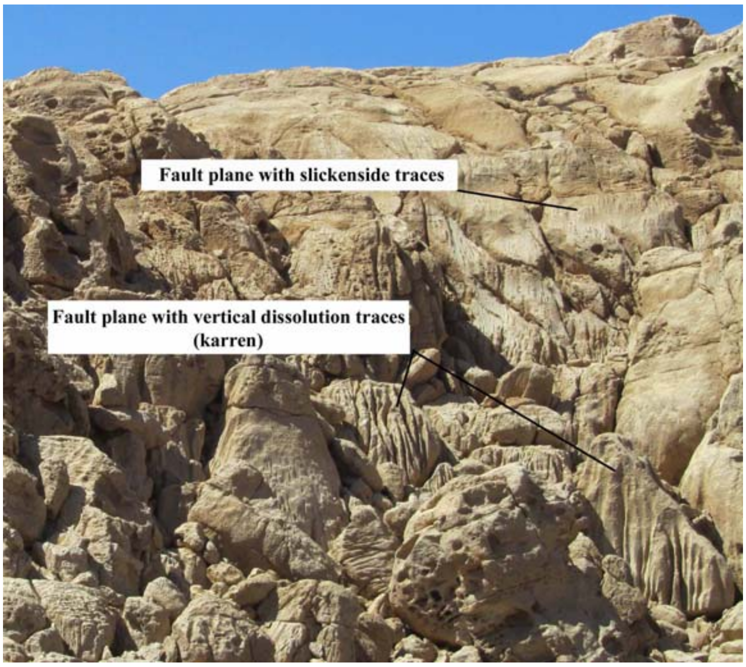

Figure 6. Karren and slickenside features on the vertical scarp around the Barm-Firuz Lake.

but they can be found in certain igneous rocks and ice. Their sizes vary from microscopic contacts between two grains (microstylolites) to large structures up to 20 m in length and up to 10 m in amplitude. Stylolites can be classified by their geometry or their relationship to bedding (Park and Schot, 1968). Stylolites can be divided into two main groups, parallel stylolite to the bedding and the stylolites with oblique or perpendicular status to the bedding (Andrews and Railsbak, 1997). Stylolites usually form parallel to bedding, because of overburden pressure, but they can be oblique or even perpendicular to bedding, as a result of tectonic activity (Anderson and Railsbak, 1997). Stylolites are significant in several fields. In petrology, stylolites are important because they alter rock fabrics and create dissolved solids that precipitate as cement. In stratigraphy, weathering of stylolites generates apparent bedding in many stratigraphic sections and loss of material along stylolites can have a result similar to erosion, with significant stratigraphic thinning. In hydrology, stylolites prevent fluid flow and, in other settings, serve for fluid flow. Also, stylolites are indicators of compressive stress (σ_1) in tectonic studies. In this research with using stylolite structures, orientation of maximum principal axis of stress (σ_1) was determined. In order to determination of position of the maximum stress axis in respect of the mountain front fault approximately 80 stylolites were evaluated from the southern limb of the Barm Firuz Anticline (Fig. 7). For determination of true attitude of stylolite plane it is noted that use from stylolites that show track in two different surfaces. The poles of stylolite surfaces show the maximum principal axis of stress (σ_1), (Fig. 8). Equal-area lower hemisphere projection of the poles of stylolite surfaces revealed the orientation of the (σ_1) about the 205°∠30° (Fig. 9).

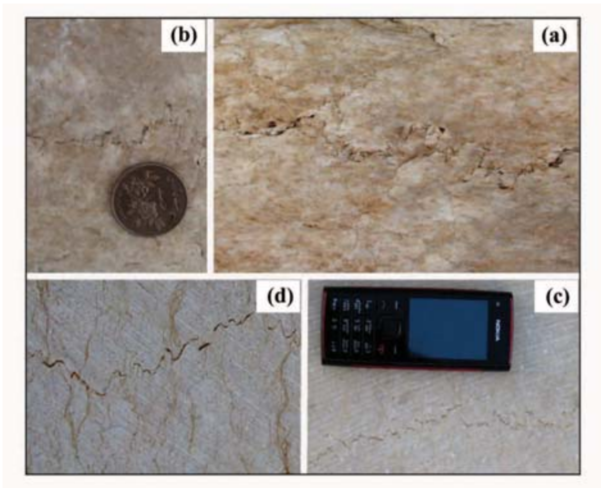

Figure 7. Stylolite structures in the study area.

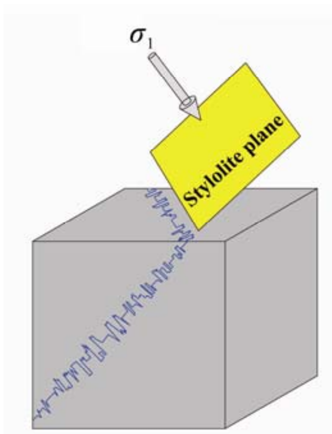

Figure 8. Schematic images for determination of principal maximum stress according to stylolite orientation.

3 DISCUSSION

In this research the effective parameters in the formation of the Barm Firuz Lake were studied and the possible models

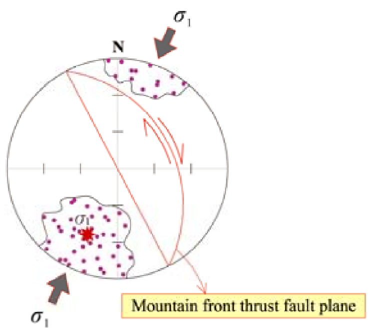

Figure 9. Equal-area lower hemisphere projection of the poles of stylolite surfaces, mountain front fault and dextral shear stress component in the area.

for the structural evolution of this lake were suggested. With application of stress analysis in the mesoscopic-scale the compatibility of the suggested models were compared with the general stress field in the study area. It seems that evolution of the Barm Firuz Lake is associated to both tectonic and karstic processes. In the rainy seasons the lake is filled with water and in the other times the lake water quickly penetrates in the soils and rocks of lake bed. According to the altitude and climate conditions in this region the evaporation rates were relatively low and the water less strongly is associated with the water escape into the underlying units. Figure 10 shows the general morphology of the lake in hydrated and dried seasons at 60-day intervals. Wetting and drying with frequent in the fine-grained bed sediments cause to form a general subsidence and deep cracks in the area (Fig. 11). Structural evolution of the Barm Firuz Lake probably can be explained with two models. In these models the mechanism of mountain front fault has an important effect on the other faulting in the hinge area and near the fold axis of the anticline. According to the first model formation of the Barm Firuz Lake is associated to extensional components of folding in the anticline hinge. In this model the reverse faulting on the mountain front fault only has a dip-slip component and because of the lack of strike-slip component shortening mainly occurred normal to the mountain front fault. Based on this model a graben depression occurs with walls almost parallel to the fold axis. Therefore this model was named as fault-dissolution sink with pure shear component perpendicular to the mountain front fault (Fig. 12a). According to the second model combination of dip-slip and strike slip components of the fault movement along the mountain front fault have caused to form shear fractures with oblique orientation in respect to the fold axis. Combination of extensional stress in the hinge of fold and shear stress components has caused to form a depression area between main fault and fractures. Based on the obliquity of pure shear component relative to the mountain front fault, this model was introduced as fault-dissolution sink with oblique pure shear component to the mountain front fault (Fig. 12b). Obliquity of pure shear component respect to a planar structure such as fault plane causes to form shortening with transpression geometry (Sanderson and Marchini, 1984). According to orientation of the maximum stress axis in respect to the mountain front fault it is possible to determine the fault kinematics. Based on the geological map, the mountain front fault in the Barm Firuz anticline shows the attitude N30°W and unknown dip to the NE. Lack of detailed information about the fault plane dip will not have significant effect on the results. According to the reverse behavior of the mountain front fault, the dip angle of 45° was assumed for the fault plane. Therefore based on position of the maximum stress, a dextral simple shear component is evident for the mountain front fault (Fig. 9). Hence it can be said that the fault kinematic shows the influence of transpression in the structural evolution of the Barm Firuz Anticline. Because of the occurrence of oblique shortening respect to the principal fault planes in the transpression, it seems that structural evolution of the lake has been occurred under the second model or fault-dissolution sink model with oblique pure shear component relative to the mountain front fault.

4 CONCLUSION

Structural evidence shows the significant role of karst and tectonic processes in the structural evolution of the Barm Firuz Lake. Therefore it can be introduce the Barm Firuz Lake as a tectonokarstic structure. Stereographic analysis of the stylolite structures displayed orientation of the maximum principal stress about 205º/30º. Obliquity of the maximum principal stress direction relative to the strike of mountain front fault

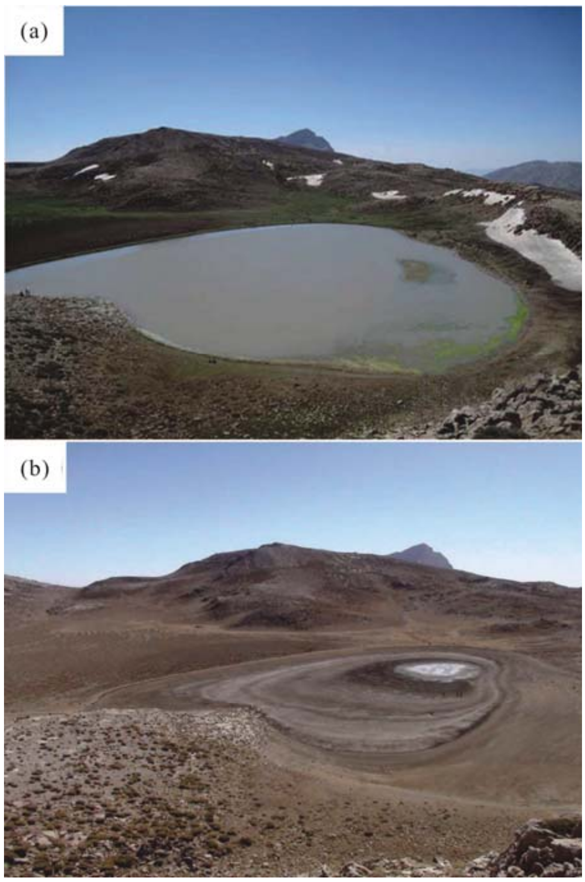

Figure 10. General morphology of the lake in hydrated and dried styles.

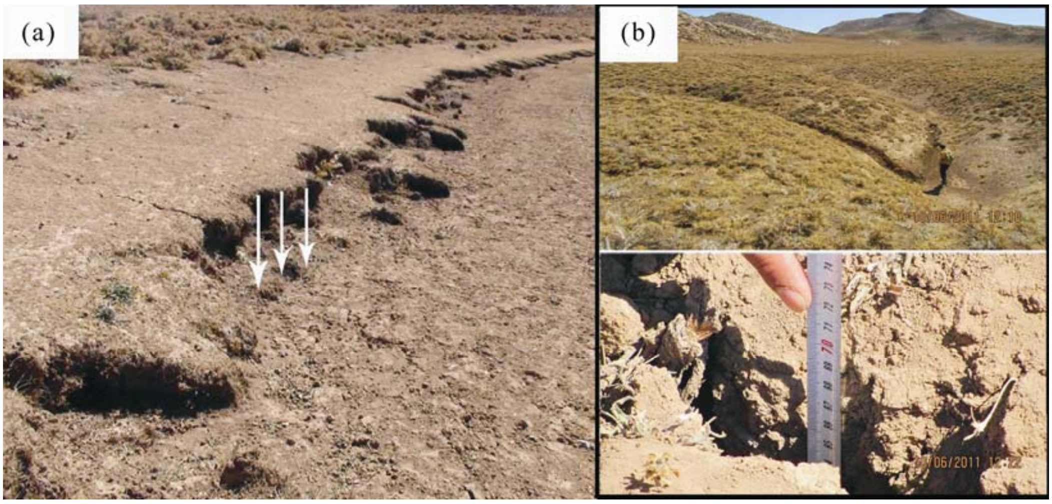

Figure 11. Occurrence of general subsidence and deep cracks in the study area.

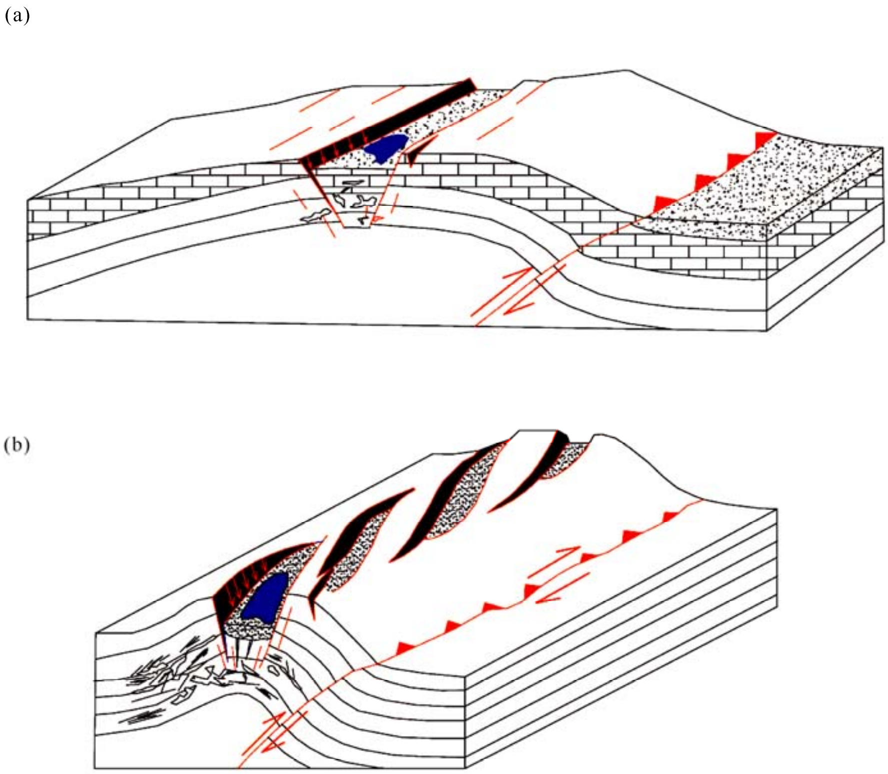

Figure 12. (a) Schematic images of fault-dissolution sink with perpendicular shortening to the mountain front fault and (b) fault-dissolution sink with oblique shortening to the mountain front fault.

confirms the occurrence of a dextral shear stress component along the Barm Firuz mountain front fault. Therefore it can be proposed that the structural evolution of the Barm Firuz Lake has been taken under the condition of the fault-dissolution sink model with oblique shortening to the mountain front fault.

ACKNOWLEDGMENT

The author would like to thank the editor of the Journal of Earth Science for the editorial authority. I am grateful to anonymous reviewers for helpful and valuable reviews of the manuscript. The Research Council of the Shahid Chamran University of Ahvaz has supported this study, which is gratefully acknowledged.

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