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Folding pattern in the Fars province, Zagros folded belt: case study on the Karbasi and Khaftar anticlines, interior Fars, Iran

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Abstract

The anticlines in Fars region, which are located in Zagros fold-thrust belt, are valuable because they possess several hydrocarbons and this area is easily recognized by the NW–SE trending parallel anticlines that verge to the SW. According to the geological classification, the study area is located in Interior Fars region. Due to increasing complication of structural geometry in Fars region and necessity to explore activities for deeper horizons especially the Paleozoic ones, the analysis of fold style elements, which is known as one of the main parts in structural studies, seems necessary.

The Karbasi and Khaftar anticlines are case study anticlines in the interior Fars subbasin (Fassa area). These anticlines have an asymmetric structure and some faults with large strike separation are observed in these structures. Due to increasing complication of structural geometry in Fars region and necessity to explore activities for deeper horizons especially the Paleozoic ones, the analysis of fold style elements, which is known as one of the main parts in structural studies, seems necessary. Description of fold geometry is important because it allows comparisons within and between folds and also allows us to recognize patterns in the occurrence and distribution of fold systems. The main aim of this paper is to determine fold style elements and folding pattern in the study area. This paper presents a part of the results of a regional study of Fars province in the Zagros Simply folded belt, based on satellite images, geological maps, and well data.

In the Interior Fars area, it seems that folding pattern is controlled by structural elements such as the Nezamabad basement fault and Dashtak formation. In fact, as a middle detachment unit, Dashtak formation plays an important role regarding folding geometry and fold in style in the study area.

1 Introduction

The Zagros fold-thrust belt in Iran lies on the northeastern margin of the Arabian plate. This fold thrust belt with northwestern–southeastern strike extends from Tarus mountain in the northeast of Turkey and Kurdistan in north of Iraq up to Strait of Hormuz in southwest of Iran (Fig. 1). More than 65 % (~ 107.5 billion m^3) of the remaining prove oil resources (~ 159.6 billion m^3) and nearly 34 % (~ 49.5 trillion m^3) of the total gas resources (~ 146.4 trillion m^3) of the world are accumulated in numerous giant and super giant hydrocarbon fields of the Middle East. Clearly, the accumulation of hydrocarbons in the Middle East has been intricately related to the stratigraphy and structural evolution of the Zagros fold-thrust belt (Alavi, 2007). As one of the valuable oil-rich provinces, this belt provides approximately 2/3 of oil-resources and 1/3 of gas-resources of the world.

The anticlines in Fars region, which are situated in Zagros fold-thrust belt, are valuable because of possessing numerous hydrocarbons and this area is easily recognized by the NW–SE trending parallel anticlines that verge to the SW in a 6–12 km cover sequence (Colman-Sadd, 1978; Dehbozorgi et al., 2010). According to the geological classification, this understudy area is located in the Interior Fars region (Fig. 1).

So far, a large number of studies have been done in the study area based on stratigraphy and geophysical exploration, but no studies have been conducted based on folding geometry and folding style in order to indicate structural oil traps with emphasis on basement complexities and basement faults activity. On the other hand, a few studies should be done on understudy area based on kinematics pattern of folding in this fold-thrust belt.

Fold geometric form and mechanical stratigraphy evolution are affected by thickness, detachment unit's ductility, and stratigraphy sequence of formations. Moreover, fold geometric form and mechanical stratigraphy evolution depend on the above-mentioned cases (Ehsani and Arian, 2015; Arian and Aram, 2014; Qorashi and Arian, 2011; Alavi, 1994). Numerous studies have been conducted according to variation of structural style

SED
7, 2347–2379, 2015

and effects of detachment folding on folding pattern (Sherkati and Letouzey, 2004; Sherkati et al., 2005). These investigations mentioned above confirm the effects of mechanical stratigraphy on folding geometry in Zagros but did not study the relationship of folding patterns with middle detachment horizons in the Paleozoic horizons based on the relationship of kinematics with main folds.

Other researchers such as O'Brien (1957) mentioned the effects of detachment layers on folding process for the first time. On the other hand, in the recent years, geologists have presented different types of geometric and mechanical models and the obtained results of these studies have increased researchers' information. Other researchers such as Jamison (1989) and Mitra (2002, 2003) have presented papers which have brought about an increase in geologists' information about cases mentioned above.

Geometry of anticlines in Zagros is affected by type of deformation and mechanical behavior of stratigraphic units. Detachment units such as Dashtak formation in Zagros are important in controlling folding pattern especially in Fars region. Dashtak formation with Triassic age belongs to Kazeron group and this formation have evaporates units such as shale and dolomite. On the other hand, other detachment formations in this area are Kazdomi and Gachsaran formation.

Based on Maleki et al. (2014) the Khaftar anticline is an asymmetric structure and activity of the Nezamabad sinistral strike slip fault has caused main changes to the fold style characteristics in the study area. One of the case study anticlines in Fars region is Karbasi anticline. These anticlines have asymmetric structures and their stratigraphic units are affected by many faults in this region. Some of these faults may affect the Dehram horizon in this region. As the result of the effects of these faults that exist in stratigraphic units, faults activity may affect gas reservation in this horizon (based on geological map of the Karbasi anticline, 2001c). Due to increasing complication of structural geometry in Fars region and necessity to explore activities for deeper horizons especially the Paleozoic ones, the analysis of fold style elements, which is known as one of the main parts in structural studies, seems necessary.

SED
7, 2347–2379, 2015

Specific features are important in describing folds and understanding how they develop (Twiss and Moors, 1992). According to the cases mentioned above, we tried to analyze and investigate the complications in the study area with fold element style analysis, structural map, modified structural sections.

Description of fold geometry is important because it allows comparisons within and between folds and allows us to recognize patterns in the occurrence and distribution of fold systems. The main aim of this paper is to determine fold style elements and folding pattern in the study area.

2 Material and methods

This paper presents part of the results of a regional study of Fars province in the Zagros Simply folded belt, based on satellite images, thin sections, geological maps, well data and original fieldwork. Our fieldwork in the study area and some data such as geological maps (Jahrom and Kushk, 2001) and geological regional data were prepared and provided by the National Iranian Oil Company (NIOC). In the study area, there are no seismic data provided by Oil Companies in this region to analyze and discuss the structural features. All geological reports have been studied and all the elements of fold style have been calculated and analyzed. We used fold style elements analysis methods (description of folds) base on Twiss and Moors (1992), Rickard (1971), Ragan (1985) and Ramsay (1967). We used Tectonics FP software to prepare and analyze stereoplots of the Karbasi and the Khaftar anticlines. In addition, we used Global Mapper Software to prepare 3-D SRTM of the study area and 3-D Path Profile (along cross sections) based on Global Mapper Software. 3-D SRTM has been prepared base on Digital Elevation Model (DEM) and geological map of study area (in scale 1 : 100 000, 1 : 250 000 and 1 : 1 000 000 – published by the National Oil Company and the Geological Survey of Iran).

3 Geological and geographical setting

In this paper, the study area is located in the Zagros Simply Folded Belt of Iran and Fars region (Fig. 1). The Zagros fold-thrust belt is home to one of the largest petroleum producing reservoirs in the world. Based on geological facies, Fars region consists of three sub-basins; Interior Fars, Coastal Fars and Sub-Coastal Fars (Beydoun et al., 1992) and the study area is located in the Interior Fars sub-basin. This area is easily recognized by the NW–SE trending parallel anticlines that verge to the SW in a 6–12 km cover sequence (Colman-Sadd, 1978).

In the Zagros fold-trust belt, the oldest known stratigraphic unit with 2000–1000 m thickness is estimated to be Hormuz Series (Ala, 1974) and is exposed in the form of salt domes in Fars region. Structures in this area have complications and the oldest stratigraphy unit that outcropped in the Khaftar anticline on the surface belongs to Hormuz Series (salt plug). The age of Hormuz Series is Pre-Cambrian–Cambrian (Fig. 2).

Anticlines which outcrop stratigraphic units in most structures in Fars region often include Upper Cretaceous stratigraphic units (Campanian to the present) and in the sub-coastal Fars region, includes the Lower Cretaceous stratigraphic units (Neocomian to the present). The youngest formations that outcrop in the study area are Aghajari and Bakhtiari and Razak formations. Also, in the study area, the oldest outcrop is Hormuz Series which are observed in the Khaftar, Kuh-e Qazi and Surmeh anticlines (e.g. Beydoun et al., 1992; Dehbashi Ghanavati, 2008).

The Khaftar and Karbasi anticlines are located in the Interior Fars region (Fasa area). Trend of the Khaftar anticline has three orientations consisting North–Northeast, East–West and South–Southwest. This anticline is bounded from north by Kuh-e Qazi anticline, from north–northeast by Qutbabad anticline, from south–southeast by the Karbasi anticline and from southwest by Sim anticlines (Fig. 1).The trend of the Karbasi anticline is N60° W. This anticline is bounded from south by the Chaghal, from southwest by the Noura, from north–northeast by the Khaftar and from north–northeast by the

SED
7, 2347–2379, 2015

Jahrom anticlines (Fig. 1). The Karbasi anticline is an elongated structure with 40 km length and 7.5 km width in the Asmari horizon. The Khaftar anticline is an asymmetric structure with 45 km length and 12.5 km width in the Asmarihorizon on the surface (Fig. 3).

The Mund River flows towards a northern–southern path in this area and in the western part of anticline; this river has changes in its flow path. By running towards the western part of anticline, finally Mund River continues its path to south.

4 Structural setting

The Karbasi and Khaftar anticlines are an asymmetric structure (Fig. 1). This anticline is located in Interior Fars province. This structure is an elongated structure. Eastern part of anticline ends to the city of Jahrom and in the western part ends to mountains. The oldest formation that outcropped on the surface of this anticline is Gurpi formation which exists in the Gurbid strait. In this anticline, some parts eroded on the surface and then caused the oldest formation such as Pabdeh–Gurpi to outcrop on the surface. In the southern flank of the location which Asmari formation covered surface, some cliffs exist with vertical walls. The highest part of The Karbasi anticline has an elevation of 2013 m.

A large part of the surface of anticline is generally covered with Asmari–Jahrom formation. This anticline is an asymmetrical anticline in which the dip of southern flank is greater than that of the northern flank (Fig. 4). On the other hand, the plunge values in western part of anticline more than eastern part. Based on Setchell et al. (2007) Khaftar anticline is a detachment fold and in the middle part of southern flank of this anticline, salt diaper has cropped out.

The structure of the Karbasi anticline has been complicated due to some faults with high lateral displacement. The activity of these faults could be divided into different parts. By activity of faults, western part of anticline has plunged to north. This anticline in the western part has a complicated structure but in the eastern part, the structure has a subtle change.

Because of Karbasi and Khaftar anticlines, have complicated structures, the analysis of element fold style is necessary. Then, for further studies in this structure, changes of fold style elements will be analyzed and investigated from east to west of anticline in the different structural cross sections.

5 Faulting in the study area

Fault system in the study area comprises two type of faults. One type is longitude fault and the other type is transverse fault. The longitude faults are located in the hinge line zone of anticlines in the study area. On the other hand, some longitude faults are located parallel with fold axis. Transverse faults are situated in a high angle to fold axis.

The Nezamabad fault is one of the strike slip faults with northeast–southwest trend in the Gavbandi High which has separated Gavbandi High from central Zagros (Setudehnia, 1978). This fault has 265 km length and sinistral displacement. Regarding the fact that, the first time Barzegar (1992) introduced Nezamabad fault, he introduced this fault based on satellite images. This fault has 2.5 km strike slip displacement and begins from the southern flank of Shahini anticline to southeast of Neyriz. The major parts of displacement of the Nezamabad fault can be easily observed in the satellite image of the Khaftar anticline. This fault has caused change and rotation of anticlines plunge (Dehbashi, 2008).The Nezamabad sinistral strike slip fault is the main fault in this area which affected the western plunge of the Karbasi anticline. In addition, based on Maleki et al. (2014) activity of this fault has caused main changes to the fold style characteristics of the Khaftar anticline.

According to fold style elements analysis results, it became clear that in the eastern part of anticline the type of fold is horizontal and moderately inclined and in the western part it is upright moderately plunging, so west evaluation of anticline is affected by more deformations. It seems that, the Nezamabad fault may be located between G–G' and

F–F’ structural sections, moreover a second order fault introduced in relationship with the Nezamabad fault. In different parts of the Karbasi anticline, Dashtak formation, as a middle detachment unit, plays an important role regarding folding geometry, which may be affected by the Nezamabad main fault and the second order fault. According to Maleki et al. (2014) folding analysis of the Khaftar anticline, reveals that folding pattern in the study area may be affected by Nezamabad.

6 The description of folds

Descriptions of fold geometries are important because they allow comparisons within and between folds and allow us to recognize patterns in the occurrence and distribution of fold systems. For example, orogenic belts contain characteristic fold systems: along their flanks are large fold and thrust belts, with little metamorphism, but underlain by décollements; and in core zones where intense folding has been accomplished, accompanied by high-grade metamorphism under high temperature and pressure.

Top formations tested in the analysis of folds are top formations of Kazeron group, i.e. Neyriz–Dashtak formation, and also those of Bangestan group. According to given results, limbs in the Karbasi anticline are of unequal length.

Twiss and Moors (1992) described the geometry of folded surface by specifying three style elements: aspect ratio, tightness and bluntness. Based on these cases we will analyze the geometry of fold style of the Karbasi anticline. As some parts of anticline are affected by faults and fault effects were observed on surface, we were not able to measure and calculate some parameters in these parts. There are three chief descriptors of a folded surface: aspect ratio: the ratio of the fold amplitude to the distance between two adjacent inflection points, tightness: or the interlimb angle, bluntness: a measure of the curvature of the surface in the zone of closure. In this part, we mentioned methods of calculation and measurement of this parameters in the studied area. Finally, given results are illustrated by comparable diagram (Table 1).

SED
7, 2347–2379, 2015

7 Elements of fold style

The style of a fold is the set of characteristics that describe its form. Over years of working with folds, geologists have identified certain features as particularly useful in describing folds and understanding how they develop (Twiss and Moors, 1992).

Since the Karbasi anticline, has complicated structure, the analysis of fold style elements seems necessary. Therefore, for more studies on this structure the changes of fold style elements will be analyzed and investigated from east to west in the different parts of this anticline. As the Nezamabad fault may produce effects on the Karbasi anticline, we have evaluated and calculated elements of fold style in this structure. In this respect, cylindricity and symmetry have been evaluated in the geometry of axial plane and Folding Mechanism.

Folded surface forms a symmetric fold if in profile, the shape on one side of the hinges a mirror image of the shape on the other side, and if adjacent limbs are identifiable in length (Twiss and Moors, 1992).Based on previous studies in the Karbasi and Khaftar anticlines, these anticlines are asymmetric. The Karbasi anticline is an asymmetric anticline that the dip of its southern flank is greater than the northern flank. Southern flank is changing from 15 to 75° and in northern flank dip value is changing from 3 to 57°. In the southern flank, dip of layers is greater than the northern flank on the Asmari formation horizon. The Southern flank layers have dip changes from about 60 to 88° and dip value in the northern flank ranges from about 35 to 50° (Maleki et al., 2014).

8 The description of folds

Descriptions of fold geometries are important because they allow comparisons within and between folds and allow us to recognize patterns in the occurrence and distribution of fold systems. For example, orogenic belts contain characteristic fold systems: along their flanks are large fold and thrust belts, with little metamorphism, but underlain by décollements; and in core zones where intense folding has accomplished, accompanied by high-grade metamorphism under high temperature and pressure.

Top formations tested in the analysis of folds are top formations of Kazeron group, i.e. Neyriz–Dashtak formation, and also those of Bangestan group. According to given results, limbs in The Karbasi anticline are of unequal length.

Twiss and Moors (1992) described the geometry of folded surface by specifying three style elements: aspect ratio, tightness and bluntness. Based on these cases we will analyze the geometry of fold style of the Karbasi anticline. As some parts of anticline are affected by faults and fault effects were observed on surface, we were not able to measure and calculate some parameters in these parts. There are three chief descriptors of a folded surface: aspect ratio: the ratio of the fold amplitude to the distance between two adjacent inflection points, tightness: or the interlimb angle, bluntness: a measure of the curvature of the surface in the zone of closure In this part, we mentioned methods of calculation and measurement of this parameters in the studied area. Finally, given results are illustrated by comparable diagram (Table 1). In this research, due to the Nezamabad fault effect on the middle parts of the Khaftar anticline, we have evaluated and calculated some elements of fold style, measurable in this structure. An important reason that some fold element analyses are not measurable in the Khaftar anticline is absence of well data and seismic lines in this area. In this respect, symmetry, cylindricity, Geometry of axial plane, and folding mechanism have been evaluated for the Khaftar anticline. According to previous studies by Maleki et al. (2014) folding style analysis of the Khaftar anticline, position of salt plug, changes of fold type and main structural changes (rotation of fold axis and 2.5 km displacement in this anticline) show main changes in the middle parts of the Khaftar anticline. It seems that, these changes are formed by activity of the Nezamabad fault and activity of this fault, the same as fault zone. The effect of Nezamabad fault on the dip direction of axial plane can be clearly observed in the Fig. 5. Thanks to available well data in the Karbasi anticline, other fold style elements in this part are calculated.

8.1 Aspect ratio

The aspect ratio P is the ratio of the amplitude A of a fold, measured along the axial surface, to the distance M, measured between the adjacent inflection points that bound the fold (Twiss, 1988). In the Karbasi anticline, aspect ratio (P) or ratio of amplitude is measured to half of fold wavelength in seven parts of structural cross section of this anticline.

According to calculated values of aspect ratio, this parameter varies from −0.847 to −0.322 for top of Bangestan group formations (Table 1) and values of aspect ratio varies from −1.08 to −0.156. This variable result is obtained for tested top of folded surface from eastern part to western part. Based on aspect ratio, fold type in different parts of the Karbasi anticline has been defined in Table 2.

Based on logarithm P and description term of folds in the Karbasi anticline just between three parts of folds (E–E' to G–G') description term of fold is broad and in the other parts is wide for top of tested surface formations of Bangestan group. It seems that these changes have affected some faults in the mentioned parts of anticline. As most changes observed in the western part are the same as one domain of deformation (from E–E' to G–G' sections), operation of the Nezamabad Fault in this area may be the same as fault zone that specific states especially observed in top of tested surface formations of Bangestan group.

8.2 Tightness

The tightness of Folding is defined by the Folding angle (ϕ) or the interlimb angle (I) (Twiss and Moors, 1992). As the degree of folding increases, the folding angle increases and the interlimb angle decreases. Based on interlimb angle calculated in seven parts of fold from A–A' to G–G' sections, the minimum of interlimb angle is 62° degree for western part of anticline which is located in the G–G' structural cross section (for top of tested surface formations of Bangestan group). In addition, the maximum of interlimb angle is 136° for Eastern part of anticline which is located in the A–A' structural cross section (for top of tested surface formations of Bangestan group), (Table 2). The minimum of interlimb angle for top of tested surface Nz–Dk is 84° for G–G' structural cross section in western part and maximum of interlimb is 152° for A–A' structural cross section in eastern part. Ramsey (1967) classified folds based on folding angle that is used in this paper and the given results are presented in Table 2.

According to the given results, based on folding angle, only in one part of the Karbasi anticline, fold type is close in G–G' structural cross section. In this part, fold type of anticline is rabbit ear fold (in southwest flank of rabbit ear fold). This complication of structure may be affected by operation of the Nezamabad Fault. In this area, it seems that faults affect folding style and complications of structures.

8.3 Bluntness

The bluntness b measures the relative curvature of the fold at its closure. It is defined by Twiss (1988). In seven parts of fold from A–A' to G–G' sections b is calculated based on bluntness for tasted surface of Bgp formations (Ilam–Sarvak formations) and Nz–Dk formation this parameter. Given results showed that folds in different parts are angular, sub- rounded, rounded and blunt and just in E–E' section, fold is angular (Table 2).

9 Geometry of axial plane

In the Karbasi anticline, it seems that geometry of axial plane is planner. In Fig. 5, based on analysis and calculations of some parameters, given locations of axial plane in the seven structural cross sections of anticline are shown. Based on results, it seems that activity of the Nezamabad fault is the same as fault zone. On the other hand, based on Fig. 6, the Karbasi anticline is a horizontal fold. The given results and output of Tectonics FP software for seven parts of Karbasi anticline, presented seven stereoplots that showed the location of axial plane (AP) and cylindericity (AC) for seven parts of the Karbasi anticline (Fig. 6) (also structural cross sections are shown in Fig. 10).

SED
7, 2347–2379, 2015

10 Results and discussion

In the eastern and western part of the Karbasi anticline rabbit ear folds are observed (G–G' and A–A' cross sections). In the western part most of changes are observed. In this part of fold there is a specific style which based on folding angle, fold has a close style. Probably the operation of the Nezamabad fault and some other faults in this anticline caused these changes. In the proposed pattern of folding model for the Karbasi anticline, we will represent changes in different parts of the Karbasi anticline.

Based on classification of Rickard (1971) in the Karbasi anticline, the type of fold is different (Fig. 7 and Table 3). In the eastern part of anticline (A–A' section) the type of fold is moderately inclined horizontally and in the western part of anticline (G–G' section) type of fold is moderately inclined moderately plunging. According to these results, it seems that the western part deformed greater than the eastern part. Nezamabad fault may have affected this case. Based on classification of Ramsay (1967), in most parts of the Khaftar anticline, axial plane of fold is upright but in D–D' and E–E' sections axial plane is steeply inclined. According to Maleki et al. (2014), the Khaftar anticline has been cut by sinistral displacement of the Nezamabad fault.

Some given results in the Khaftar anticline such as folding style analysis, position of Kuh e Khaftar salt plug in the middle part of Khaftar anticline, changes of fold type and main structural changes (rotation of fold axis and 2.5 km displacement in Khaftar anticline) show main changes in the middle parts of the Khaftar anticline. It seems that, these changes have been formed by activity of the Nezamabad fault and activity of this fault is just the same as a fault zone.

Based on classification of Ramsay (1967) the orientation of fold in the Khaftar and Karbasi anticlines are evaluated for all profiles (Fig. 8). Results show the orientation of fold in the Khaftar anticline especially in the D–D' and E–E' parts are different from other parts. It is possible that Nezamabad fault has affected the orientation of fold in these parts (Maleki et al., 2014).

SED
7, 2347–2379, 2015

In this research, model of the relation between folding and faulting has been prepared in the Dehram horizon and Bangestan group with emphasis on the Nezamabad strike slip fault (Figs. 9 and 10). The Dehram horizon and Bangestan group (stratigraphic units) are of utmost importance in hydrocarbon exploration in the Fars region. Based on given results and orientation of fold in the Karbasi anticline (Fig. 8) it seems that the Nezamabad fault is located between G–G' and E–E' structural sections and this fault in this area operated the same as fault zone. In the study area, Dashtak formation as a middle detachment unit, plays an important role in connection to folding geometry and it may be affected by the Nezamabad main fault. The relation between the Nezamabad fault and the Karbasi anticline is modeled by 3-D modeling based on structural cross section from A–A' to G–G' (Figs. 11 and 12).

Based on our investigation and map pattern of the Nezamabad fault related to surrounding structures (Fig. 13) and focal depth of instrumental earthquakes (Fig. 14), it is an active basement fault that has not yet completely visible at the earth surface.

11 Conclusion

In the Interior Fars area, it seems that folding pattern is controlled by structural elements such as strike slip Nezamabad fault and Dashtak formation. In fact, Dashtak formation, as a middle detachment unit, plays an important role in connection to folding geometry and fold style in the study area.

Some given results such as folding style analysis, position of Kuh-e Khaftar salt plug, changes of fold type, main structural changes in the study anticlines (such as rotation of fold axis of the Khaftar anticline and 2.5 km displacement in this anticline), show main changes in the middle parts of the Khaftar anticline and western part of the Karbasi anticline. Studied anticlines in these locations have greater deformation than other parts.

It seems that, these changes are brought about by the activity of Nezamabad fault and activity of this fault is just the same as a blind active basement fault zone.

SED
7, 2347–2379, 2015

Finally based on give results, it seems that orientation of fold and folding style in the study area are controlled by main strike slip fault in the area.

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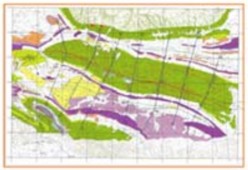
SED
7, 2347–2379, 2015

Table 1. Indicate style for tasted surface of Bgp formations (Ilam–Sarvak formations) and Nz–Dk formation.

Row	Structural Section	A (km)	M (km)	Log P	Descriptive Term based on LogP	Interlimb	Folding Angle φ	Descriptive Term based on φ	rc (km)	ro (km)	Bluntness	Descriptive Term based on b	Top of Folded Formation
1	A–A'	0.5	3.25	−0.815	Wide	136	44	Gentle	5.2	5.3	0.981	Rounded	Top of Bgp
2	B–B'	0.7	2.8	−0.602	Wide	118	62	Open	4.4	4.7	0.936	Rounded	Top of Bgp
3	C–C'	12	3.6	−0.785	Wide	123	57	Gentle	5.2	7.2	0.722	Sub rounded	Top of Bgp
4	D–D'	1	4.45	−0.649	Wide	131	49	Gentle	6	6.4	0.937	Rounded	Top of Bgp
5	E–E'	5	3.5	−0.847	Wide	96	84	Open	1.7	6.2	0.274	Angular	Top of Bgp
6	F–F'	15	3.1	−0.316	Broad	79	101	Open	2.4	6.3	0.38	Sub angular	Top of Bgp
7	G–G'	1.2	3	−0.397	Broad	62	118	Close	3.9	5.5	0.709	Sub rounded	Top of Bgp
8	G–G'	1	2.1	−0.322	Broad	75	105	Open	5.1	2.5	1.5	Blunt	Top of Bgp
Row	Structural Section	A (km)	M (km)	Log P	Descriptive Term based on LogP	Interlimb	Folding Angle φ	Descriptive Term based on φ	rc (km)	ro (km)	Bluntness	Descriptive Term based on b	Top of Folded Formation
1	A–A'	0.7	7	−1	Wide	130	50	Gentle	6.4	7	0.914	Rounded	NZ-DK
2	A–A'	0.6	7.2	−1.08	Wide	152	28	Gentle	6.8	6.6	1.02	Blunt	NZ-DK
3	B–B'	0.7	2.5	−0.552	Broad	118	62	Open	3.4	5.2	0.653	Sub rounded	NZ-DK
4	C–C'	0.6	2.5	−0.619	Wide	129	51	Gentle	3.4	3.5	0.971	Rounded	NZ-DK
5	D–D'	0.8	3.05	−0.581	Broad	125	55	Gentle	4.8	6.5	0.738	Sub rounded	NZ-DK
6	E–E'	2	4	−0.301	Broad	111	69	Open	1.3	6.2	0.171	Angular	NZ-DK
7	F–F'	0.6	1.5	−0.397	Broad	90	90	Open	1.5	2.9	0.502	Sub rounded	NZ-DK
8	G–G'	1.5	2.15	−0.156	Equant	84	96	Open	3.4	3.8	0.894	Rounded	NZ-DK

Table 2. In this table showed type of fold in seven sections of the Karbasi anticline. This classification based on classification of Rickard (1971) and Ragan (1985).

	A-A' P:9/ 110 AP:117/ 73 *Fold type: Moderately inclined horizontal*	B-B' P:3/ 286 AP:105/ 88 *Fold type: upright horizontal*	C-C' P:3/ 291 AP:111/ 83 *Fold type: upright horizontal*
D-D' P:1/ 105 AP:106/ 66 *Fold type: Moderately inclined horizontal*	E-E' P:2/ 303 AP:122/ 66 *Fold type: Moderately inclined horizontal*	F-F' P:8/ 107 AP:129/78 *Fold type: upright horizontal*	G-G' P:42/ 086 AP:088/ 89 *Fold type: Moderately inclined moderately plunging*

P: Plunge AP: Axial Plane

SED
7, 2347–2379, 2015

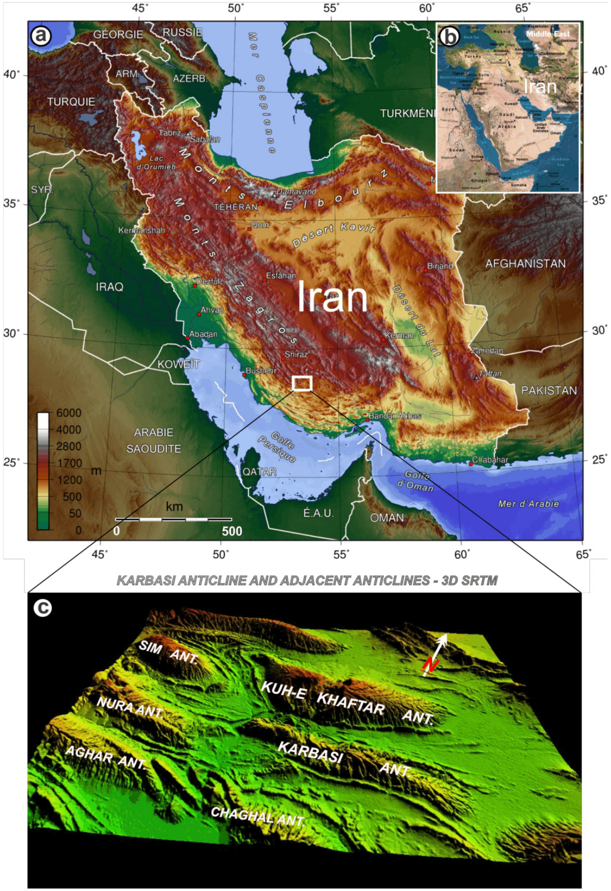


Figure 1. (a) shows location of the study area, **(b)** with white framework in the Middle East, **(c)** 3-D SRTM for the study anticlines (Karbasi and Khaftar anticlines).

SED

7, 2347–2379, 2015

Folding pattern in the Fars province

Z. Maleki et al.

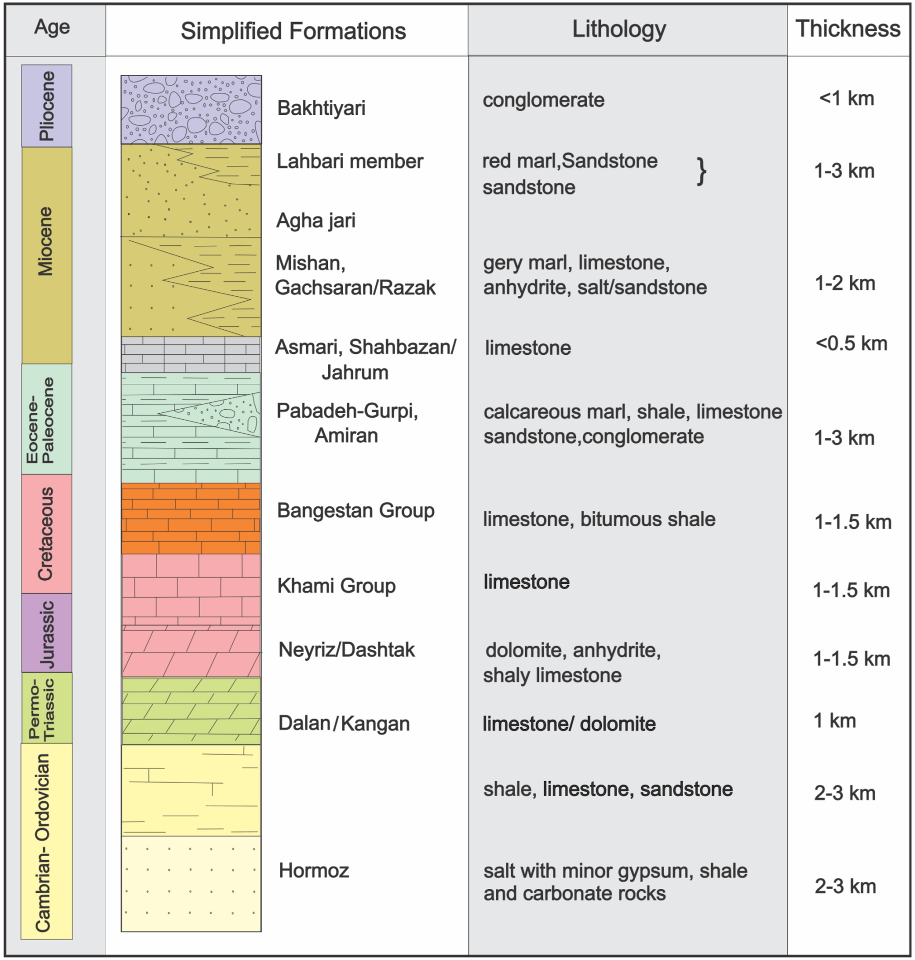


Figure 2. Generalized stratigraphic column through the Zagros fold-thrust belt (modified from McQuarrie, 2004).

SED
7, 2347–2379, 2015

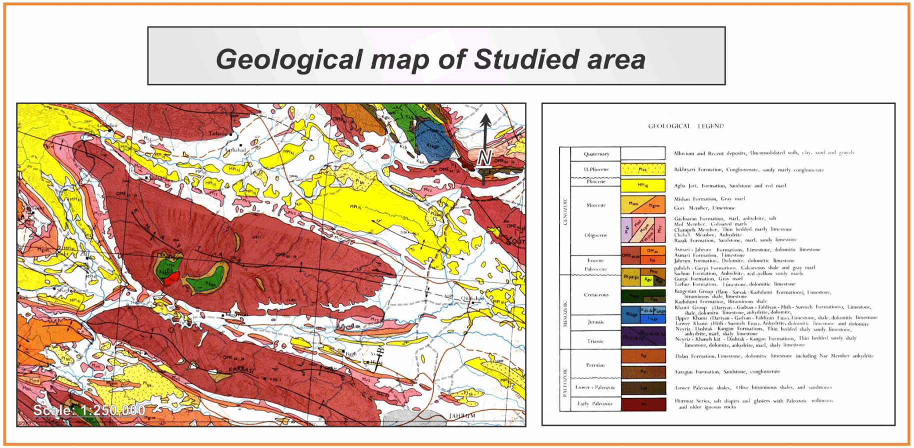


Figure 3. Geological map of the Karbasi and Khaftar anticlines (based on Geological map of Jahrom, 2001).

SED
7, 2347–2379, 2015

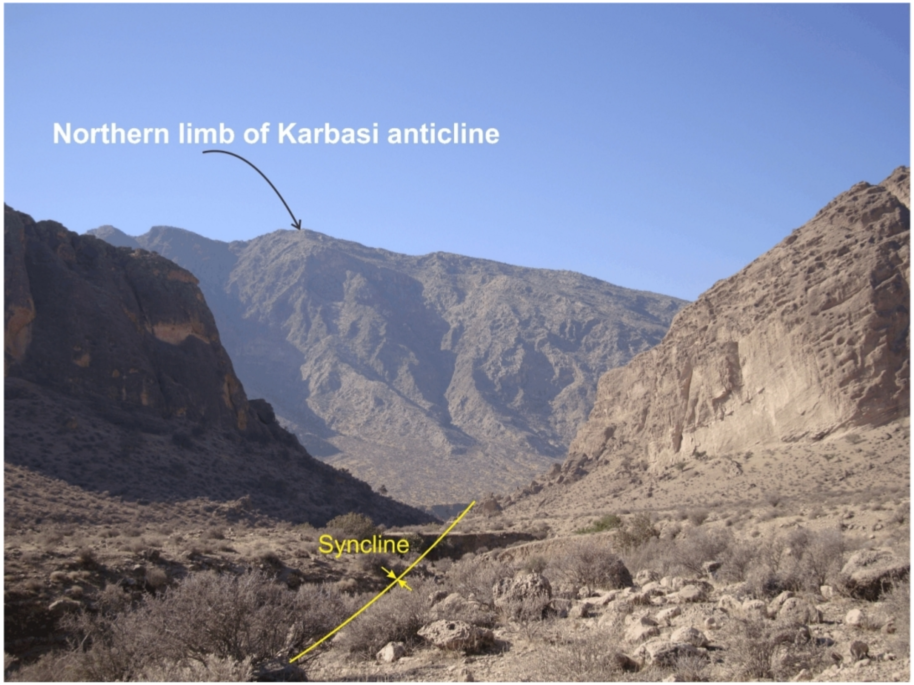


Figure 4. View to the south-west that shows Northern limb of the Karbasi anticline and syncline between the Karbasi anticline in northern limb and the Khaftar anticline in southern limb.

SED
7, 2347–2379, 2015

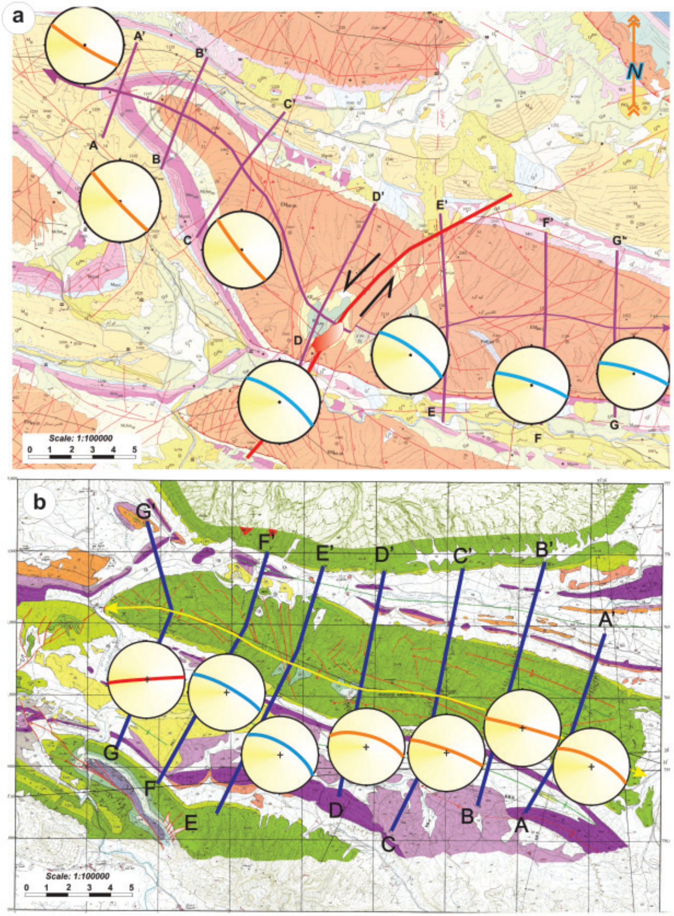


Figure 5. (a) Axial plane of the Khaftar anticline and **(b)** axial plane of the Karbasi anticline based on gave results in cross sections.

SED
7, 2347–2379, 2015

Folding pattern in the Fars province

Z. Maleki et al.

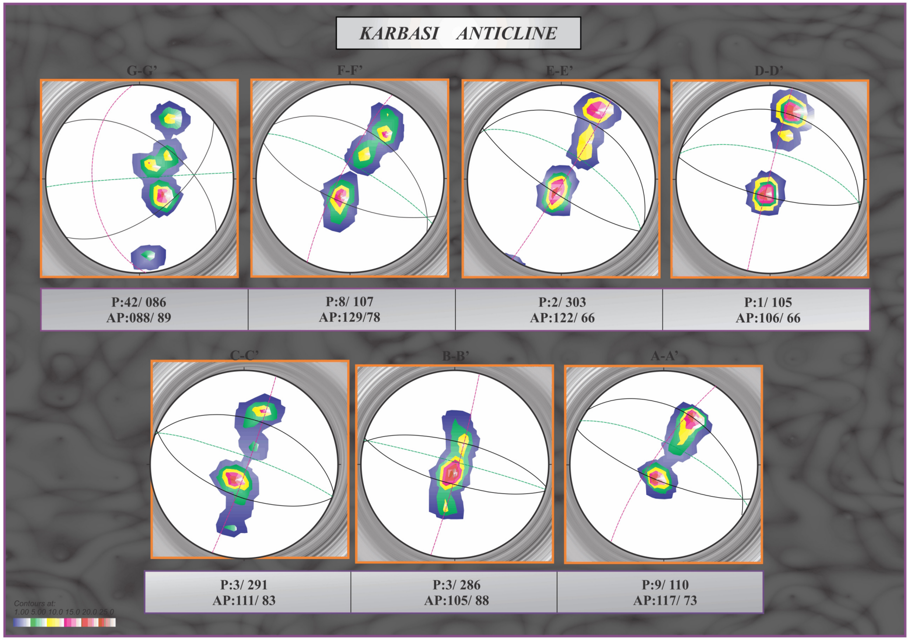


Figure 6. Stereoplots showed axial plane (AP), cylindericity (AC) for seven sections of the Karbasi anticline.

SED
7, 2347–2379, 2015

Folding pattern in the Fars province

Z. Maleki et al.

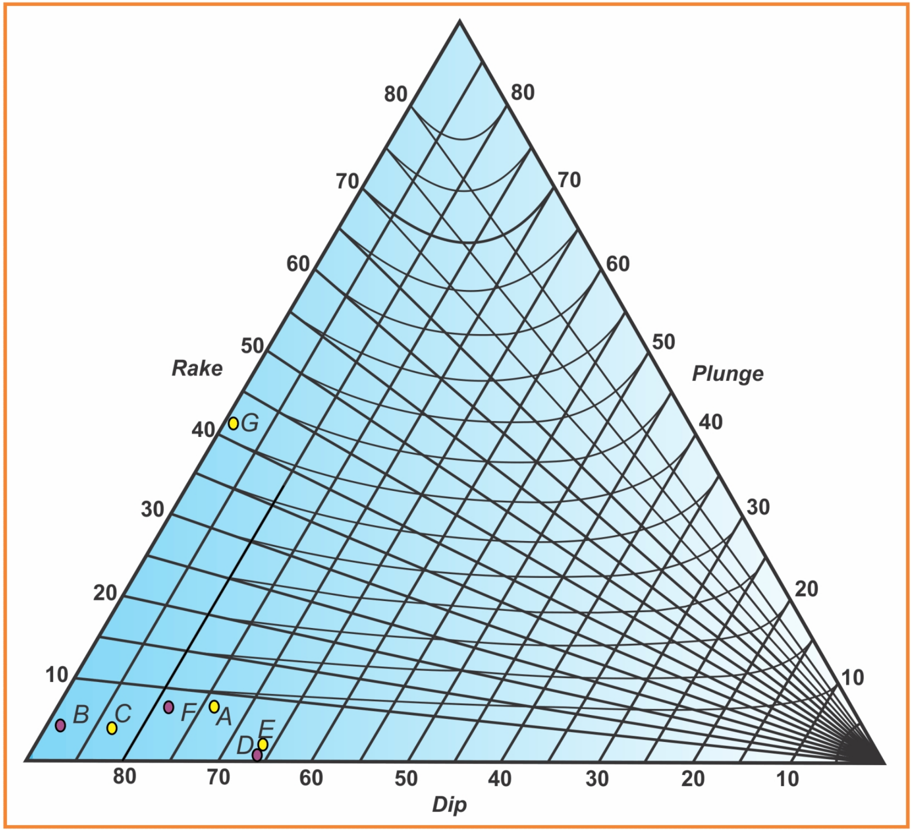


Figure 7. Triangle form diagram showed type of fold in seven sections of the Karbasi anticline, based on Rickard (1971). This Diagram gave based on Rickard classification. Type of fold in Part G (G–G' section) is different to other section completely.

SED
7, 2347–2379, 2015

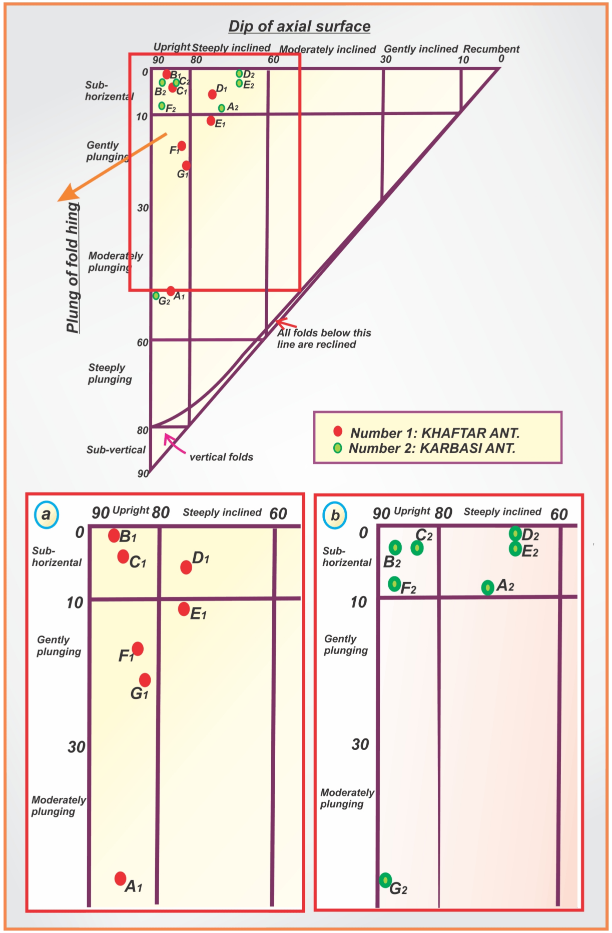


Figure 8. This figure showing the classification for orientation of the Khaftar and Karbasi anticlines based on Ramsay (1967).

SED
7, 2347–2379, 2015

Folding pattern in the Fars province

Z. Maleki et al.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◄◄ ►►
◄ ►
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

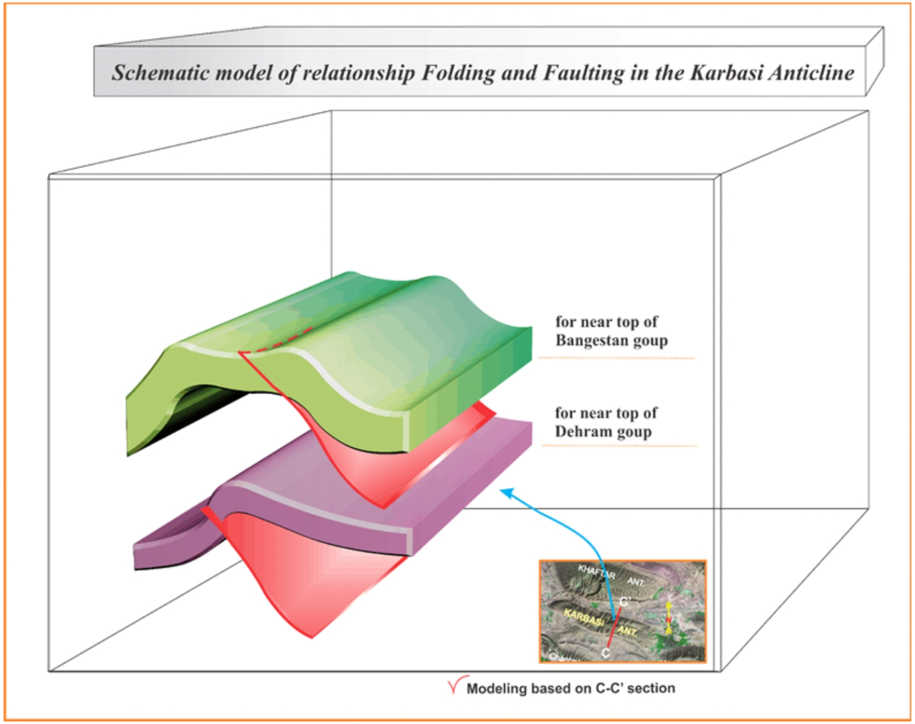


Figure 9. Schematic model for relationship between folding and faulting for near top of Bangestan group and near top of Dehram horizon in C–C' part of the Karbasi anticline that observed fault rapture in surface. This modelling is based on information of C–C' structural cross section with 3-D modelling software.

SED
7, 2347–2379, 2015

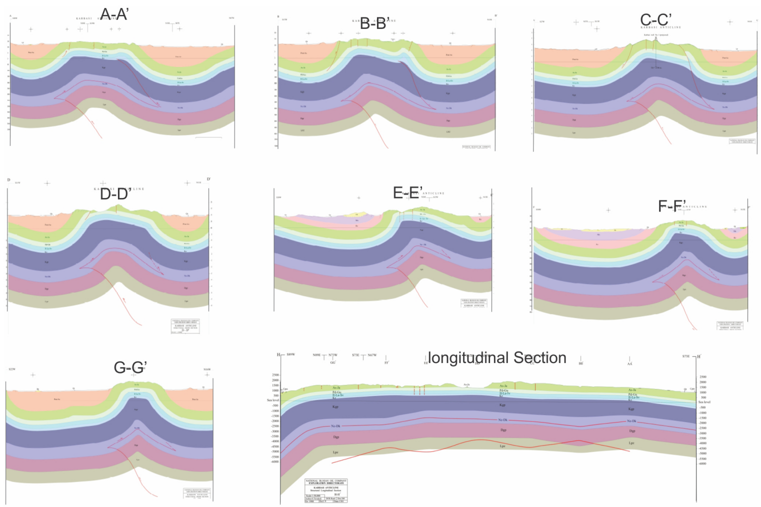


Figure 10. Structural cross sections of the Karbasi anticline (based on Geological map of the Karbasi anticline, 2001).

SED
7, 2347–2379, 2015

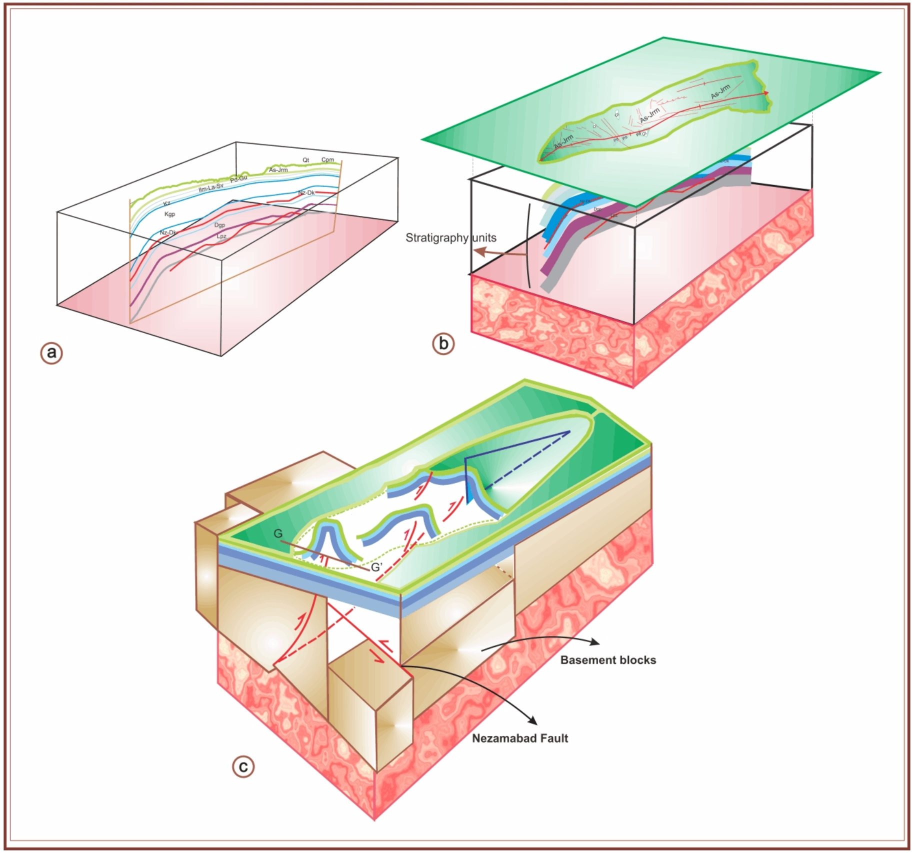


Figure 11. (a) 2-D model of longitude structural cross section of the Karbasi anticline. **(b)** Forms of fold with location of longitude structural cross section. **(c)** Relationship between the Nezamabad Fault and the Karbasi anticline, 3-D model (based on structural cross section from A–A' to G–G').

SED
7, 2347–2379, 2015

Folding pattern in the Fars province

Z. Maleki et al.

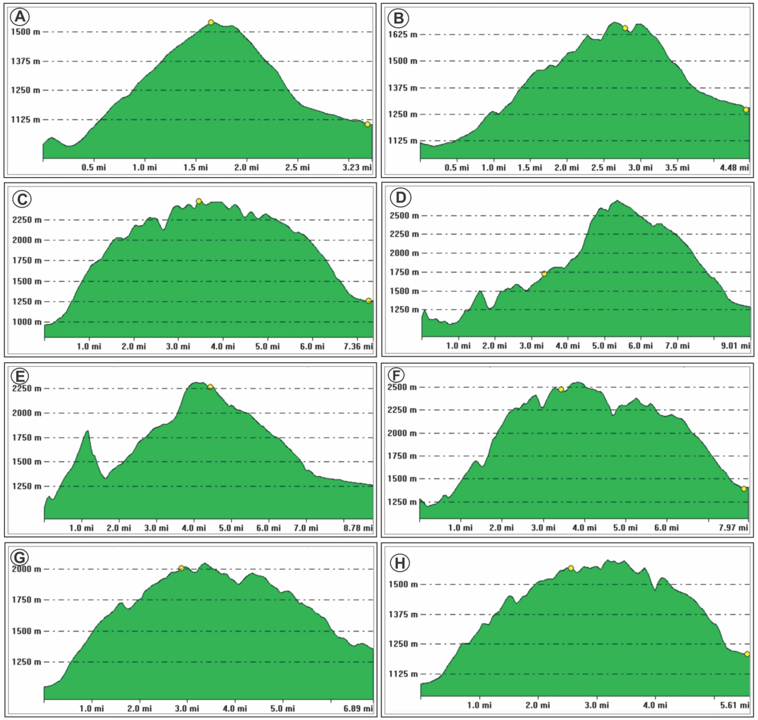


Figure 12. These diagrams showing 3-D path profiles of the Khaftar anticline (location of these profiles is located along the cross sections A–A' to G–G' in the Fig. 5). The horizontal axis and vertical axis showing distance (mile) and elevation (meter).

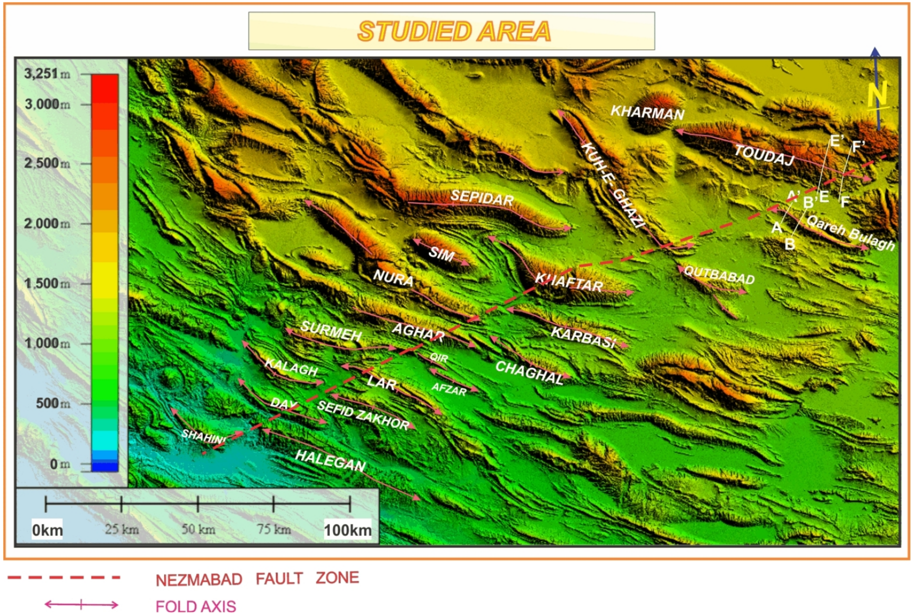


Figure 13. The map pattern of the Nezamabad fault related to surrounding structures.

SED

7, 2347–2379, 2015

Folding pattern in the Fars province

Z. Maleki et al.

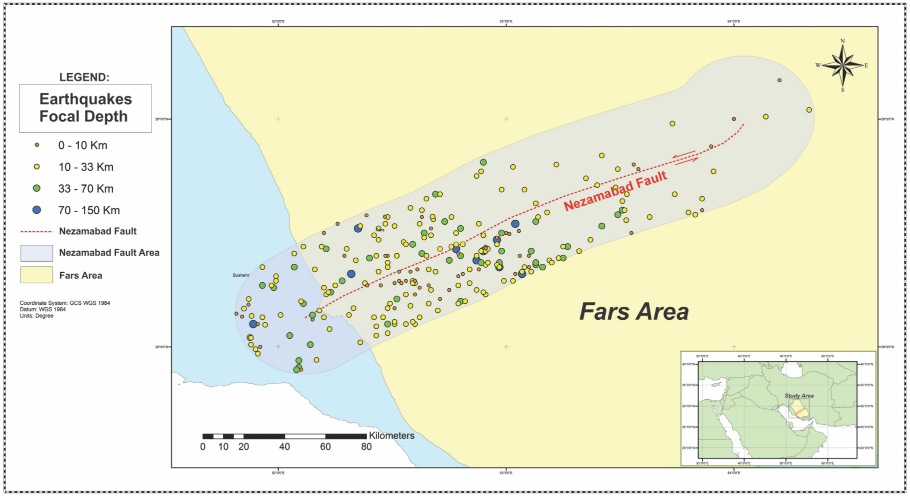


Figure 14. The distribution map of epicenters and focal depths of instrumental earthquakes along the Nezamabad fault.

SED
7, 2347–2379, 2015

Folding pattern in the Fars province

Z. Maleki et al.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion