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Structural Analysis and Evolution of the Kashan (Qom-Zefreh) Fault, Central Iran

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Abstract: The main objectives of this research were to identify the geometry and structure of the Qom-Zefreh fault and to determine the extent of its effects on stratigraphy and facies changes. The identification of movement mechanism of major faults in basement, extent and time of their activities are important effects for evaluation of paleogeography of the Iran plateau. In the Orumieh-Dokhtar volcanic band, there are nearly parallel faults to the Zagros Zone. These faults were formed during closure of the Neothetys and collision of the Arabic plate with crust of Iran. The Qom-Zefreh fault is one of these faults, which is known as having four different trend faults. The result indicates that, this fault is not divided in four segments with different trends but the major trend is of Central section, which is the Kashan segment with AZ140 trend and other segments are just related faults. Thus the name of the Kashan fault is recommended for this fault. The mechanism of the Kashan fault is dextral transpression and other related faults in the region are in good correlation with fractures in a dextral transpression system. The stratigraphic studies conducted on the present formations show the effect of fault movements in Upper Cretaceous sedimentary basin. Lack of noticeable changes in Lower Cretaceous sediments and before that indicates that, the fault system activity has been started from the Upper Cretaceous. Thus, based upon these results, the effect of the Neothetys sea closure in this region could be considered at least from the Upper Cretaceous.

Key words: Qom-Zefreh fault, Kashan fault, Orumieh-Dokhtar zone, cretaceous sediments, Iran

INTRODUCTION

The Iran plateau is bounded on the North by the Alborz and Koppeh Dagh deformed zones adjacent to the Turan platform and on the South by the Zagros fold-thrust belt and Makran accretionary wedge adjacent to the Arabian platform (Berberian *et al.*, 2001). The convergence between the Eurasian and Arabian plates is about 35 mm year^{-1} NE-SW (DeMets *et al.*, 1994; Jackson *et al.*, 1995).

The precise identification of major faults movement mechanism, extent and time of their activities of foundation rock could effectively help to evaluate the paleogeography of Iran plateau. One of the major fault systems in Iran parallel to the Zagros zone is the Qom-Zefreh fault.

This study has two aims. One is to understand geometry and structure of the Qom-Zefreh fault. The other aim is to determine how they have evolved during the passage of time by stratigraphy and facies. Since movement on the fault system is the dominant control on the drainage and geomorphology, a sense of motion can be determined. The research procedure may divide into three stages. In the first stage the tectonic and geological setting of the Qom-Zefreh fault system are summarized. Secondly, the actual situation and structural analysis in this fault system are introduced. Finally, the stratigraphy and sedimentology evidences for strata next to the mentioned fault system are revealed which can help to determine the history of this fault system.

Tectonic and geological setting of the Qom-Zefreh fault: The Mesozoic and Cenozoic Alpine-Himalayan system represents a classic continental collision orogen (Jackson, 1992; Jackson *et al.*, 1995). The Zagros suture zone that extends from the Turkey-Iran border to north of the straits of Hormuz constitutes a significant part of this orogenic belt (Talbot and Alavi, 1996) (Fig. 1).

Some of the Arabia-Eurasia convergence is accommodated in the Zagros Mountains (Walker and Jackson, 2002; Boulin, 1991; Sengor, 1990). The overall Arabian-Eurasia convergence is known from a combination of Africa-Eurasia and Arabia-Eurasia motions to be approximately N-S in eastern Iran, with rates of about 30 mm year^{-1} at 50E and 40 mm year^{-1} at 60E (Jackson, 1992; De Mets *et al.*, 1994; Jestin *et al.*, 1994; Chu and Gordon, 1998). At the present time, the Zagros accommodates about 10-15 mm year^{-1} shortening

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(Jackson and Mckenzie, 1984, 1988; Jackson, 1999). Central Iran is a mosaic of various tectonic blocks once separated by minor ocean basins (Berberian and King, 1981) that started to close in the Mid-Tertiary (McCall, 1996). Much of the broader collision zone, however, did not start to deform until the Mid-Miocene or even later (Dewey *et al.*, 1986).

This study is concerned with the Qom-Zefreh fault system that is one of the important faults in Iran. The Zagros Orogenic Belt consists of four parallel tectonic zones from the southwest to northeast (Fig. 2). (1) The Mesopotamian-Persian Gulf foreland basin, (2) The Zagros fold-thrust, (3) The Sanandaj-Sirjan zone and (4) The Urumieh-Dokhtar Magmatic Arc (Berberian and King, 1981; Alavi, 1994). The Sanandaj-Sirjan Zone is a metamorphic belt (greenschist-amphibolite) that was uplifted during the Late Cretaceous continental collision under dextral transpression. This zone is between the Afro-Arabian continent and the Iranian microcontinent (Mohajjel and Fergusson, 2000). The Urumieh-Dokhtar magmatic Arc is mainly faulted adjacent to the Central Iran block. The Qom-Zefreh fault system is an important fault system between the Urumieh-Dokhtar zone and the Central Iran block (Fig. 3).

The Urumieh-Dokhtar zone may be considered as an active axis from volcanic point of view in late Cretaceous and Eocene and from aspect of pulotonism in Oligocene and Miocene. This zone is approximately 100-150 km width, which its wide decreases towards SE. The length of this zone is about 1700 km and is located about 150-200 km far from the Zagros zone.

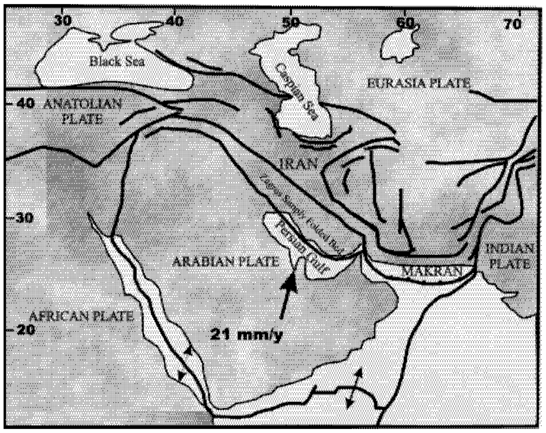

Fig. 1: Structural frame of the Middle-East of the Alpine collision belt (Baker *et al.*, 1993)

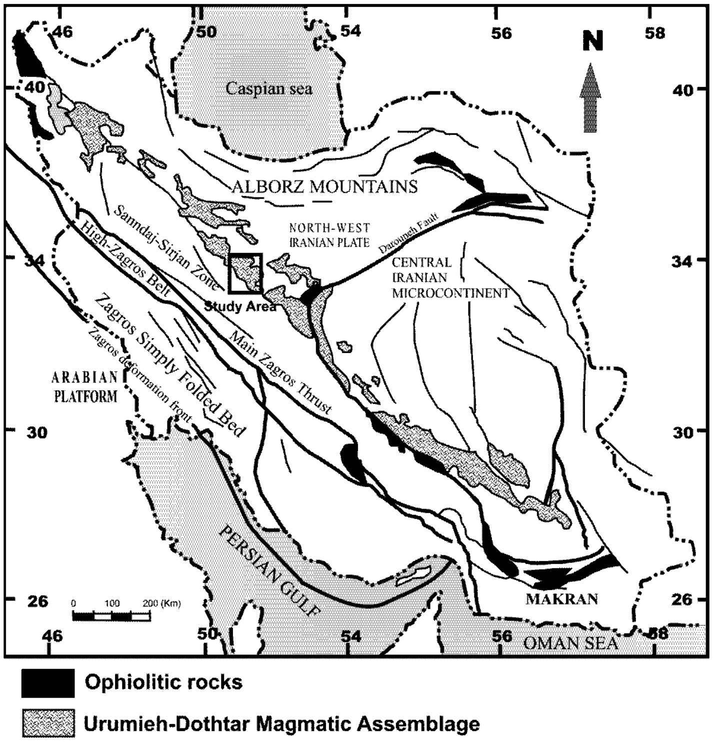

Fig. 2: Summarized tectonic map of Iran with Major faults (black lines) and the location of study area

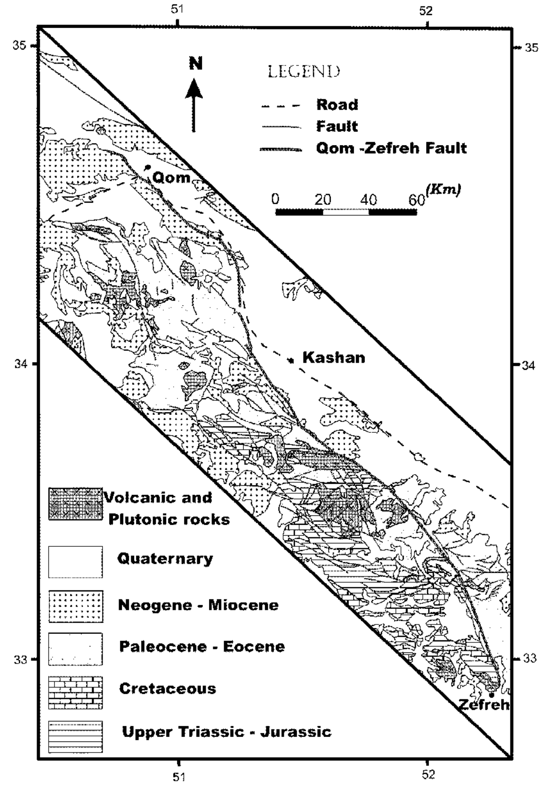

Fig. 3: Simplified geological map of the Kashan region (Nogol-Sadat and Almasian, 1993). Upper Triassic-Jurassic sequence mainly continental and clastics sediments. Cretaceous sequence mainly limestone and marl. Paleocene-Eocene sequence mainly conglomerates, limestones, volcanic rocks and tuffaceous sediments. Neogene and Miocene sequence mainly red beds of Neogene (Oligo-Miocene), shallow marine the Qom Formation (Oligocene), Miocene neritic/molassic. Unfolded Quaternary cover alluvium. Volcanic and plutonic rocks mainly granite, granodiorite, syenite and quartz-diorite (middle and late Alpine orogenic)

In the Kashan region, in addition to Eocene volcanic rocks, there are also younger volcanic rocks of Oligocene and Miocene age. Eocene volcanic rocks as pyroclastic accompanying lava and interbeds of tuffite, sandstone, shale and nummulitic limestone are overlain disconformably on Cretaceous limestone. It may be argued that this disconformity is due to the activity of equivalent phase of Laramide. Due to activity of equivalent phase of Pirnian, the Oligo-Miocene limestones (the Qom Formation) are overlain disconformably on Eocene units. The effect of equivalent orogenic phase of Pasadenian is a low degree angular disconformity between clastic formations of Pliocene (Upper-Red Formation) and Plioctocene (equivalent conglomerate of Baktiari Formation).

Geometry and structure of the Qom-Zefreh fault system: In order to study a fault, the first step is exact recognition of geometry and situation of the fault. In previous studies, it is supposed that the Qom-Zefreh fault with a length of over 250 km extends from highlands of the south of the Qom to highlands of the Zefreh village in 60 km NE of Isfahan (Berberian, 1976; Nogol-Sadat and Almasian, 1993). Such proposed situation for the Qom-Zefreh fault includes a few sharp curvatures and on the basis of these curvatures at least four segments can be considered for this fault (Fig. 3). The Qom fault is the first segment of the Qom-Zefreh fault, which its general trend is AZ 130 and it has about 60 km length and crosses 5 km in south of the Qom. The second segment is Ravand fault, which has a general trend of AZ 160-170 and a length of about 50 km. The Kashan fault is the third segment of the Qom-Zefreh fault, which has a general trend of AZ 140 and a length of about 60 km. The forth segment is the Zefreh fault, which is about 80 km long and its trend is AZ 170.

In order to determine the location of the faults and for better identification of lithological and different structural units, the remotely sensed data (TM) from Landsat 5 were used. After geometric correction for statistical evaluation, seven data bands were processed for selection of the best possible three-band combination, thus Optimum Index Factor (OIF) was calculated by using the following formula (Chatterjee *et al.*, 1996).

$$\text{OIF} = \frac{\Sigma^{3}_{k=1}\text{sk}}{\Sigma^{3}_{j-1}\text{Abs(rj)}}$$

In this formula sk is the standard deviation for k band and Abs(rj) is the correlation coefficient which is evaluated between each two of three bands.

Combination of three bands of (7,5,4), (7,5,1) and (5,4,1) shows the highest values of optimized index factors. In the study area in respect to reflection spectra of different geological units, most of the information was extracted from the band combinations of (RGB = 754), (RGB = 541) and (RGB = 741). For better separation of lithostratigraphical units in different parts of area, the interactive image processing was mostly used.

For image enhancement of different geological phenomena in various parts of the study area, different data processing were used, but generally for identification of structural units such as faults, high pass filters and edges filters were used (Nash, 1992). For better separation

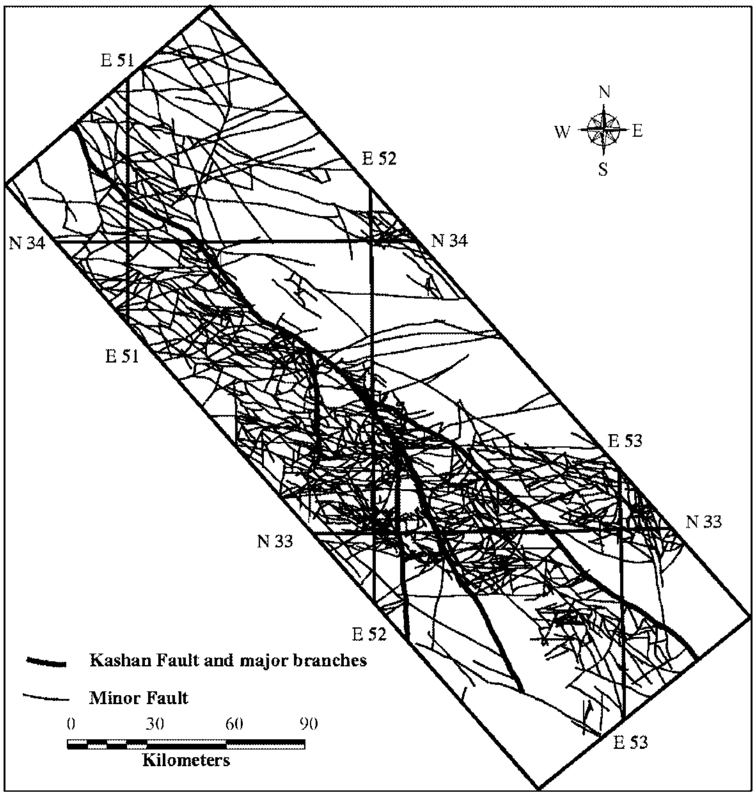

Fig. 4: Small-scale regional map of the Kashan fault with major branches and minor fault. This map recognized according to processing of satellite data and field study

of stratigraphic units different transforms such as histogram equalize and different formulas such as band ratios (7/1, 4/3, 1/2) were used.

According to processing of satellite data and field study, faults of the study area are carefully recognized (Fig. 4). Many faults were recognized in this research for the first time and the continuations of some faults reported in previous works were also recognized. According to the obtained results during analyzing satellite data and field observations, the Qom-Zefreh fault may be considered as a fault with a trend of AZ 140 and contrary to previous assumption, it does not include 4 distinct segments. Basis upon the findings of this work, it is proposed that this fault to be named as the Kashan fault. This fault is a basement fault and with minor changes, it can be observed on its trend surface. Briefly, the conditions of its different sections in the study area from northwest to southeast are defined.

In previous studies and maps, the Qom-Zefreh fault in northwest of the Kashan city was considered as the boundary of mountain and plain with more than 30° rotation and with a displacement of about 3 km toward East. The obtained results indicated that, the Kashan fault with the same trend of AZ140 had entered the altitudes and formed a fault valley. Previously due to this reason the fault trend was considered with direction change because another fault, which separated the mountain and plain with almost AZ170 trend, has dissected the Kashan fault in this area.

The continuation of the Kashan fault (the Qom-Zefreh fault) from west of the Kashan to Natanz has been previously introduced. The Kashan fault in this area is often the boundary of mountain and plain and its mechanism is dextral transpression (Fig. 5). The surfacial situation of the Kashan fault in this region rotates a few degrees in different sections, however the average of 140/75 SW may be considered for this fault from west of the Kashan to Ghamsar valley and also from Ghamsar to Natanz the average is 130/80 SW.

Previously, the situation of the Kashan fault was considered from south of Natanz towards the Zefreh. For this reason, this fault is called the Qom-Zefreh fault. Therefore, more than 30° rotation is considered for the strike of this fault. Based on this research, it may be

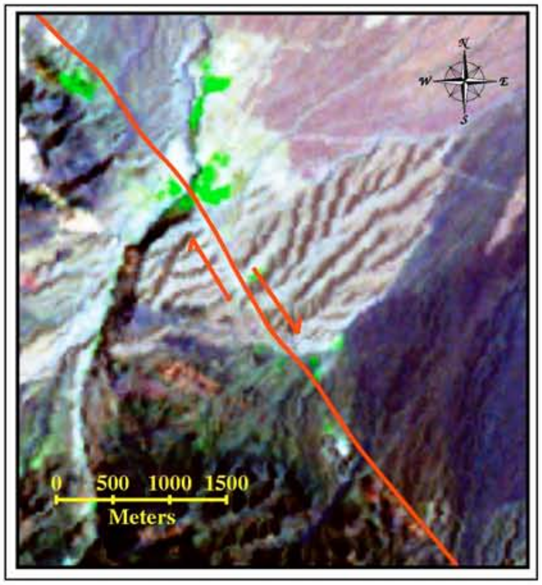

Fig. 5: Displaced alluvial fan (about 600 m) due to the Kashan right strike slip fault along Ghamsar valley

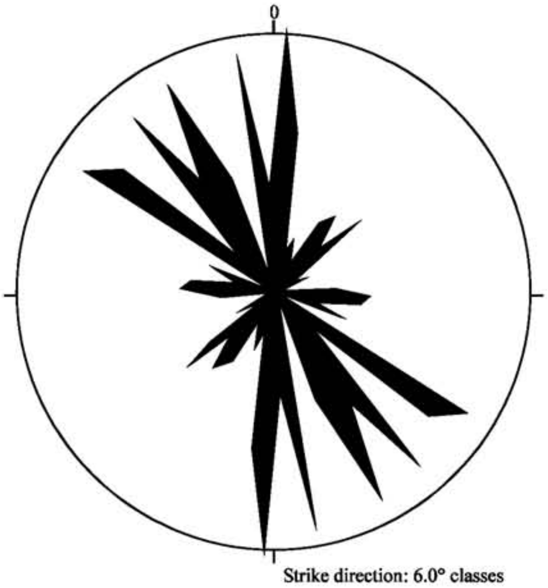

Fig. 6: Rose diagram of faults around study area

argued that the trend of this fault has not been rotated from south of Natanz and it approximately extends with previous trend towards southeast (Fig. 3). The Kashan fault after crossing from slice of the south of Natanz enters to plain and then thrusted Eocene andesite and andesite basalt in SW to Oligo-Miocene strata (the Qom Formation) in NW. As can be seen in Fig. 3, in addition to the Zefreh fault, this fault includes a number of important branches, which have the same situations. The branched faults include dextral components. On the basis of structural correlation of branched faults with the Kashan fault, it can be concluded that they have simultaneously started their activities with this fault. One of these branches is called the Abbas-Abad fault, which has affected Mesozoic sedimentary formations and has special importance in this research. For this reason its effect on Mesozoic sedimentary basins can be considered simultaneous with the Qom-Zefreh fault movements.

A large number of faults related to the Kashan fault have been recognized in image processing of satellite data and then traversed in the field. Most measured faults with general trend of 135° have thrust mechanism with dextral component and their average dips is 50-60 SW. However, the dip direction of some faults is northeast. A number of faults with trend of 155° like the Zefreh fault, include dip direction of NE and sometimes approach to vertical position whereas some other faults with the same trend include dip directions of SW. Faults with N-S trend, dextral component and sometimes normal mechanism are observed. Faults with E-W trend often include thrust mechanism with dextral component. The dip direction of some of these faults is toward south and toward north for some other faults.

Seismic activities: The number of earthquakes in Central Iran, unlike other areas of Iran (the Zagros in particular), is less but their magnitudes are usually more intense. The Kashan fault is one of the major and active faults in the west of Central Iran, which a number of historical and instrumental events have been recorded in its direction. Historical earthquakes dated on 1577.08.00 with magnitude of Ms = 5.5, 1775.06.07 with magnitude of Ms = 5.0, 1778 with magnitude of Ms = 6.2, 1890.02.07 with magnitude of Ms = 5.3 and 1895 with unknown magnitude, have been recognized on or around of the Kashan fault (Ambraseys and Melville, 1982). Also the epicenter of earthquake occurred on 1963.12.21, with magnitude of Ms = 4.5 was in the vicinity of the middle part of the Kashan fault.

Structural analysis: In order to structural analysis of the study area, at first, the rose diagrams of recognized faults based on their lengths were drawn for each part and also whole of study area. Such that based on the length of fault, a weight was considered for each fault (Fig. 6). As can be seen in Fig. 6, there are three major classes of fractures, which their trends are AZ 120-125, AZ 140-155, AZ 170-185, respectively. Two more classes of trends E-W and AZ 35-50 are in second priority. According to

Table 1: Trend of the Kashan fault and other related faults

Fracture type	Trend of faults in area	Expected trend
Primary 1st-orther wrench (right lateral) (Y)	AZ 140-145	AZ 140
Riedel fracture (R)	AZ 150-155	AZ 150
P-shear (P)	AZ 120-125	AZ 125
Extension fracture (E.F.)	AZ 170-185	AZ 180
Anti-Riedel fracture (R')	AZ 35-50	AZ 35

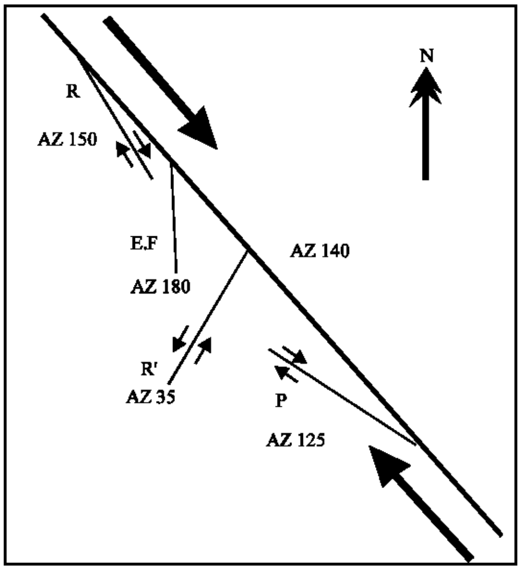

Fig. 7: Expected faults in a dextral transpression system with AZ140 strike

the above-mentioned characteristics regarding the Kashan fault and other related faults the mechanism of this fault system may be considered as dextral transpression (Price and Cosgrove, 1990) (Fig. 7). In this system, the general trend of the Kashan fault is AZ 140 and other faults have good correlation with fractures in a dextral transpression system (Table 1).

Stratigraphical evidences of the Qom-Zefreh fault activity: The most important problem for determining the beginning time of activity of the Kashan fault is the lack of lithological outcrops in most parts of the NW flank of this fault, which is located on the boundary between mountain and plain. In most branches of this fault, which enter to the highlands, different pyroclastic units are outcropped next to each other. Therefore, it is not possible to compare them for determining the commencement time of this fault activity.

With recognition of the Kashan fault system and giving a more comprehensive evaluation of this fault system the region around the Abbas-Abad fault was selected as the most appropriate region for comparing the changes of formation caused by this fault system.

As previously mentioned, this fault is a main branch of the Kashan fault, which has affected Mesozoic formations. Therefore, the beginning time of activity of this fault and its effect on sedimentary basins may be considered equivalent to the activity of the Kashan fault system. As can be seen from the satellite images in the east flank of this fault, there is an extensive outcrop of the Upper Cretaceous. Limestones are in an anticline with light tune, while these limestones do not outcrop in the west flank of this fault (Fig. 8). Several faults have affected the southern flank of this anticline, but the general stratigraphic sequences are still well recognized. Field studies over these sequences are as Upper and Lower Cretaceous carbonates, Jurassic shale and sandstone (Shemshak Formation) and Triassic clastics (Naiband Formation) and their thin sections were also repaired and examined. Due to intense faults activities, in western part of the Abbas-Abad fault, extensive displacement of Formation sequences are observed. The important point is the lack of distribution of the Upper Cretaceous units, in the area.

Stratigraphy of the Upper Cretaceous sediments along the Abbas-Abad fault: In the Upper Cretaceous sediments of the North the Zefreh two units are recognized based mainly on lithological characters. These are:

- Glouconitic sandy limestone in the base
- Inoceramous marly limestone on the top (Fig. 9).

The Glouconitic sandy limestone is a condensed bed only a few centimeters in thickness and contains abundant ammonites of the Upper Albian-Cenomanian. This unit overlies unconformably green shale (Boudantyceras shale) and is conformably overlain by Inoceramous marly limestone. The Inoceramous marly limestone is a gray, thin to medium bedded unit.

According to the following fauna, the age of Toronian-Santonian may be considered for the *Inoceramous* marly limestone (Bolli *et al.*, 1985; Sliter, 1989).

- *Marginotruncana marginata*
- *Marginotruncana pseudolinneiana*
- *Dicarinella hagni*
- *Hedbergella* sp.
- *Globotruncana lapparenti*
- *Dicarinella algeriana*
- *Praeglobotruncana stephani*
- *Pithonella ovalis*
- *Stomiosphaera sphaerica*
- *Calcisphaerulla innomminata*

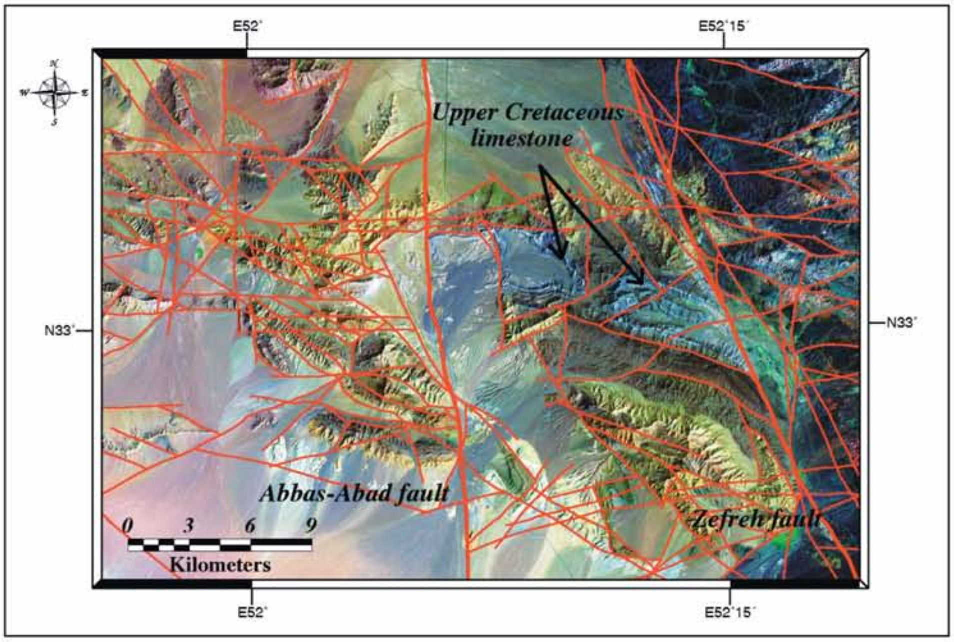

Fig. 8: Landsat image (TM data, RGB = 741, after histogram equalize stretch and high pass filter for each bands) of the Abbas-Abad fault area. At east side of the fault extensive outcrop of Upper Cretaceous limestone with light reflection is observed, but at west side of this fault no outcrop of limestone is present

Fig. 9: Sequences of Upper Cretaceous units such as *Boudantyceras* green shales (1), *Glouconitic* sandy limestone (2), *Inoceramous* marly limestone (3) in anticline core

This unit is next to the Lower Cretaceous calcareous sediments. The following microfossils are recognized within the Lower Cretaceous deposits.

- *Orbitolina* cf. *discoida*
- *Orbitolina* sp.
- *Dasycladacean*
- *Miliolids*
- *Textularids*

This assemblage reflects Aptian in age (Shakib, 1990).

As a result of the stratigraphic studies it seems that depositional environment of the Upper Cretaceous units (Albian) was affected by the Zefreh and the Abas-Abad faults, as had been spread out between these two faults. As the latter faults are branches of the Kashan fault (the Qom-Zefreh fault) they were active during Albian. Lower Cretaceous lithology and thickness similarity in both sides of Abas-Abad fault reflect that these environments were affected by the Kashan fault system from Albian.

CONCLUSION

The conclusions based on structural and paleogeographical studies of the Qom-Zefreh Fault (suggested by this study the Kashan fault) are as follows:

- The Qom-Zefreh fault (Kashan fault) is not made up of four parts with different trends, where its trend is similar to middle part trend (AZ140), the Northwest part (Ravand fault) and southeast part (the Zefreh fault) previously called the Qom-Zefreh fault, are separated faults, related to the Kashan fault.
- The Kashan fault is an important inter-continental fault, with dextral transpression mechanism. Other faults related to this system are present.
- Stratigraphical studies between the Zefreh fault and the Abas-Abad fault (branches of the Kashan fault) reflect that the Upper Cretaceous units were widespread. However, no Upper Cretaceous strata are present in west of the Abas-Abad fault. The Kashan fault system was active during Upper Cretaceous and has affected the depositional environment. No facies and thickness change in Lower Cretaceous in both sides of the Abas-Abad fault, reflects that depositional environment was not affected by the Kashan fault system activity.
- Activity of The Kashan fault system that is one of the important inter-continental fault systems parallel to the Zagros is after Albian.

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