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Basement Faults and Salt Plug Emplacement in the Arabian Platform in Southern Iran

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Abstract: The Arabian Platform containing the Zagros Mountain Ranges (ZMR) is located to the Northeast of the Arabian Shield. There are nearly 200 salt domes on the Arabian Platform. In the ZMR, structural anomalies are frequently associated with similar facies distribution patterns. In the eastern portion of the region, emergent salt plugs of Infra-Cambrian age exhibit the same alignment patterns. Such trends bear no apparent genetic relationship to the Tertiary folding responsible for the present Zagros fold belt but rather indicate their affinity with linear basement features which are readily observable on Landsat imagery and aerial photographs. Bending of anticlines in the competent cover rock, combined with minor strike-slip faults and horizontal displacements of parts of folded structures, strongly point to the presence of these basement faults. The salt plugs, which have pierced cover rocks of up to 10000 m thick, are distributed on the Arabian Platform along regional basement faults. The area of diapir outcrops is bounded by the Oman Line to the East and by the Kazerun Fault to the West. Pieces of the basement have been brought up to the surface on some of the salt domes. The fragments were transported by rotational ascent of the Hormuz Salt Formation to the present and former land surfaces. The recognition of features related to basement tectonic and realization of their implication in the control and modification of geological processes in an important adjunct to the search for hydrocarbon accumulations in this region. To our best knowledge, data of basement faults in the study area is scarce. Therefore, this study was carried out to determine basement faults and their relation to salt dome distribution. Considering the fold axis bending, the trend of the salt plugs and also the distribution of epicenters of the last century, numerous new basement faults are introduced in this study.

Key words: Morphotectonics, Iran, Saudi Arabia, tectonics, fault, geology

INTRODUCTION

Although the salt domes in Southern Iran, especially those around Bandar-Abbas which could be called geologically salt dome province, have been a matter of investigation resulting in numerous publications since 1908, this study has following innovations:

- There have been vague ideas that salt domes are outcropped along basement faults. Most of basement faults that have not been mapped before, is mapped in this study for the first time
- This study uses the accurate location of all earthquake epicenters of the complete last century to find their relation to the basement faults

Moreover, this study explains the relation between some basement faults and the bending of the folds and develops criteria for recognizing some faults in the basement according to the fold and salt morphology. Photogeological and satellite imagery studies of the ZMR have led to the recognition of lineament pattern. These linear features persist with constant alignments throughout the region. In common with findings from other areas worldwide, the pattern of surface lineaments is considered to be related to basement structure. The present surface manifestations of basement discontinuities can also be related to structural and stratigraphic patterns and anomalies. The emplacement pattern of emergent salt domes in the ZMR is related to basement structures.

GEOLOGICAL SETTING

The NW-SE trending Zagros Mountains, part of the Alpine-Himalaya chain, extend for 2,000 km through Iran (Fig. 1). Together with its equivalent in the Arabian foreland, the Neoproterozoic to Neogene cover sequence of the Zagros fold-thrust belt hosts two-thirds of the World's proven oil reserves and one-third of the World's

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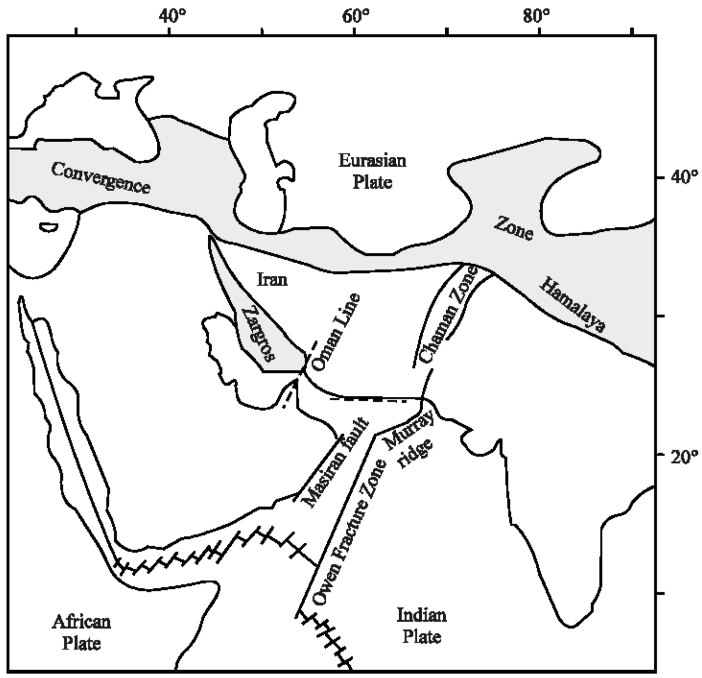

Fig. 1: Location of Zagros and plate tectonic setting of the area (modified from Derakhshani and Farhoudi, 2005)

reserves of gas (Beydoun, 1991). The Zagros Basin is defined here as lying between the central Iranian plateau in the NE, the Arabian Shield to the SW and the Taurides of Turkey to the NW and Makran Subduction to the East (Alsharhan and Nairn, 1997; Bahroudi and Talbot, 2003; Regard *et al*., 2005).

The Main Zagros reverse fault at the northeastern limit of the ZMR is the suture between the colliding plates of central Iran and the Arabian passive continental margin (Berberian, 1995) where, the fastest shortening seems to be occurred (Hessami *et al*., 2006). This Alpine orogenic grain masks and modifies earlier patterns of structural deformation (McQuillan, 1991). Three structural belts with intensity of deformation increasing in a northeasterly direction have been defined (Falcon, 1969).

The Zagros basin is defined by a 7-14 km thick succession of cover sediments deposited over an extraordinary wide and long region along the north-northeast edge of the Arabian plate (Fig. 1), since the end of Precambrian (Bahroudi and Koyi, 2004; Sepehr and Cosgrove, 2004).

Paleozoic sedimentation was mainly epicontinental; from Permian to Miocene time it consisted chiefly of carbonates. The Tethys Ocean began to subduct under the Iranian Plate in the Late Cretaceous. Cessation or slow subduction resulted in carbonate sedimentation in Early Cenozoic time as well as the deposition of 400 m evaporatic materials in the Miocene. Orogenic movements began in middle or upper Miocene when sedimentation became clastic. The opening of the Red Sea intensified folding and uplifting of ZMR which are still active in a roughly N-S direction at a rate of approximately 25-30 mm year^{-1} at the Eastern edge of the Arabian plate (Sella *et al*., 2002). This direction is oblique o the NW-SE trend of the orogenic belt. Earthquake focal mechanisms and the GPS velocity field (Talebian and Jackson, 2002) suggest partitioning of this oblique shortening along the faults in the ZMR (Sherkati and Letouzey, 2004). Most of the salt diapers are located in Hormozgan and the Southeastern part of Fars Provinces. The diapir field, as well as Hormoz salt basin (Fig. 2) is bounded by the Oman Line to the East, the Kazerun Fault to the West and the Main Zagros Thrust to the North (Derakhshani and Farhoudi, 2005; Sepehr and Cosgrove, 2005). Only a few salt diapirs reach the surface Northwest of the Kazerun Fault near the Main Zagros Thrust. They occur in great number also in the form of small islands in Persian Gulf, South of the boundary of the Zagros Folded Belt.

The presence of numerous salt domes, mainly of Hormuz Formation, indicates tectonic activity of the ZMR. Although salt domes have been reported in many places of the world, e.g., to the North of the Gulf of Mexico in the USA and in the Northern part of Germany, most of them are not outcropped and have been detected by geophysical methods. In contrast to them salt domes in the ZMR and in the Persian Gulf, are not only high

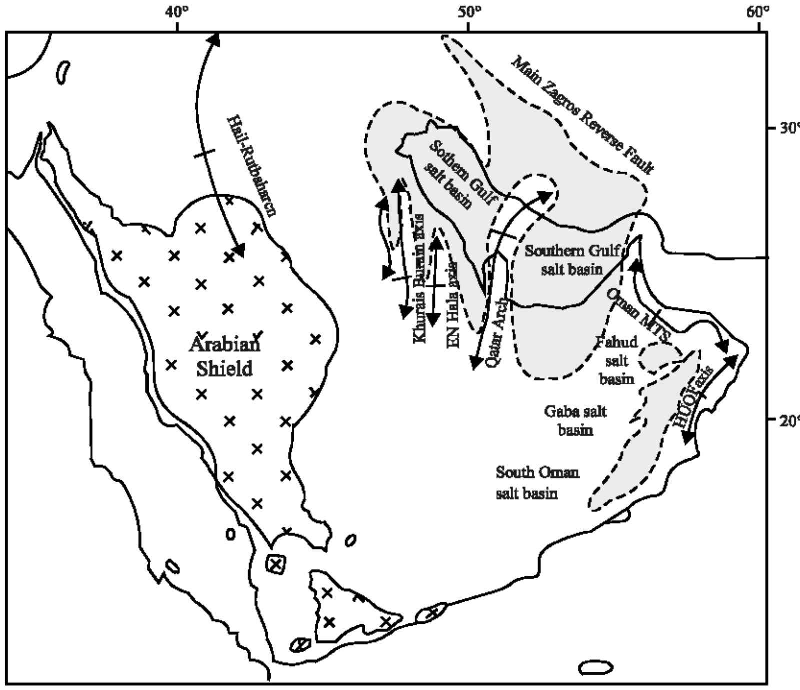

Fig. 2: Hormuz salt basins. The eastern boundary of Southern Gulf Salt Basin seems to have been controlled by a lineament crossing them northeastward along its boundaries (Derakhshani and Farhoudi, 2005)

elevated domes, but also in many cases the salt is flowing down the flanks as Salt Glacier.

Some of the salt domes are more than 1000 m higher than the surrounding area, e.g., Kangan salt dome. Some of them have been used as open cast mines. It's more soluble than limestone and in contrast to the latter; it has plastic behavior and impedes the flow of fluids. The Tertiary Gachsaran Formation, consisting mainly of salt, anhydrite and marl layers, acts as one of the best cap rocks of hydrocarbon in the Middle East.

ZMR structurally consist of numerous, mostly northwest trending, synclines and anticlines. Steep flanks on most individual structures face southwest (Falcon, 1969). Dextral displacements have been reported on faults parallel to the Main Zagros Thrust between 33°-35°N (Tchalenko and Braud, 1974) and also on Kazerun Fault (Falcon, 1974; Baker *et al*., 1993). The near-basement salts play major role in the morphology and structure of the Zagros Thrust and Fold Belt. These salts cause disharmonic folding and do not permit sub-salt structures to continue upward.

DISCUSSION

A variety of structures with different trends in the surface geology have been attributed to repeated reactivation of basement faults (Falcon, 1974; Kent, 1979; McQuillan, 1991; Berberian, 1995; Alsharhan and Nairn, 1997; Hessami *et al*., 2001; Bahroudi and Talbot, 2003). Nevertheless, the number, distribution and interrelation of basement faults are still poorly constrained. Many active faults in the basement are clearly recognisable by their seismic activity. However, GPS measurements emphasize that most Zagros deformation is aseismic (Hessami, 2002) or relatively low level of seismic activity (Regard *et al*., 2004) and other faults have been attributed to the basement on the basis of surface evidence alone.

About two hundred emergent Hormuz salt plugs are known in southwest of Iran. Characteristic dome-shaped swellings on elongate surface anticlines indicate the presence of many more intrusive salt masses at shallow depths. The majority of these unusual and spectacular diapirs are located in Fars Province. Kent (1958) in commenting that the Zagros fold belt owes its Jura-type folding mode to a basal plastic or incompetent layer, implies a thick and widespread Hormuz evaporate presence. Regional location of the plugs shows no relation to upper tertiary folding though it is interesting to note that not all, but most, plugs are associated with Zagros fold axis. In some cases active plugs in some positions appear to have previously inflated the anticlines. Following on the extrusion of salt from the fold, collapse folds have resulted. Such structures possibly associated with axial fold displacements.

No basement rocks are exposed anywhere within the Zagros orogen and it is generally assumed that the Zagros basement is a NE ward continuation of the Precambrian shield exposed in Arabia (Falcon, 1969; Berberian and King, 1981; Husseini, 1988; Alsharhan and Nairn, 1997) which is similar to the basement exposed West of the Tabas block in central Iran (Alavi, 1991). However, recent maps of Gondwana show that the basement beneath Iran comprises not only Pan-African (900-600 Ma) rocks extending northwards from East Africa (Haffman, 1999); but also older rocks (>1,000 Ma) extending westward from India (De Wit *et al*., 1999). The occurrence of a Pan-African suture between Arabia and these older basement rocks along the SWward projection of the Oman line could account for structural trends to the east being oriented NE-SW, a trend not exposed in the Arabian Shield but characteristic of the older basement before the dispersal of Gondwana (de Wit *et al*., 1999; Derakhshani and Farhoudi, 2005).

An Infra-Cambrian age has been assigned to evaporates and polygenetic assemblage of rocks which comprise the Hormuz group (Kent, 1979). These rocks are seen only in small, scattered, emergent plugs associated with thrust faults in the imbricated belt of Khuzestan Province and more abundantly throughout Fars Province. These large plugs and salt glaciers contain rafts of Cambrian sediments and a mixed assemblage of dominantly intrusive rocks grouped under the general term of greenstones (McQuillan, 1991). These exotics provide the only indications of possible basement composition.

The pattern of surface lineament is thought to relate to discontinuities in the basement surface. Studying of Landsat images, aerial photographs of the study area and distribution of earthquake epicenters (Fig. 3), combined with field checking has revealed abundance of surface linear features. These include stream alignments, subtle topographical patterns, tonal variations, faulting and structural modifications which do not appear to relate to the late Tertiary folding episode.

The major lineaments of the Kazerun Fault and Oman Line form obvious boundaries to distinct structural regimes. An examination of individual folds exhibits the frequent occurrence of marked structural anomalies in the form of abrupt axial bends or transcurrent disruptions. Regionally such anomalies are seen to lie along trends which correspond to one or more of the major lineament directions. This indicates the ongoing influence of deep seated basement structural features and their modification of later folding modes.

12 strike slip faults are recognized in the study area (Fig. 4). Some of these faults could have important role for salt uplifting. They are as follows:

Fault No. 1: This dextral strike slip fault with 147° azimuth, deviated the axis of Forgun, Neyzeh and Kushkuh anticlines as well as displaced some features and caused linear outcropping of salt plugs specially in Kushkuh.

Fault No. 2: This dextral strike slip fault with 139° azimuth has caused deviation of the axis of Muran, Finu, Baz, Handun and Namak anticlines. The rotation of Muran anticline is an interesting feature of the previous activity of this fault. Several salt plugs are outcropped in this fault's trend such as Handun and Namak salt plugs.

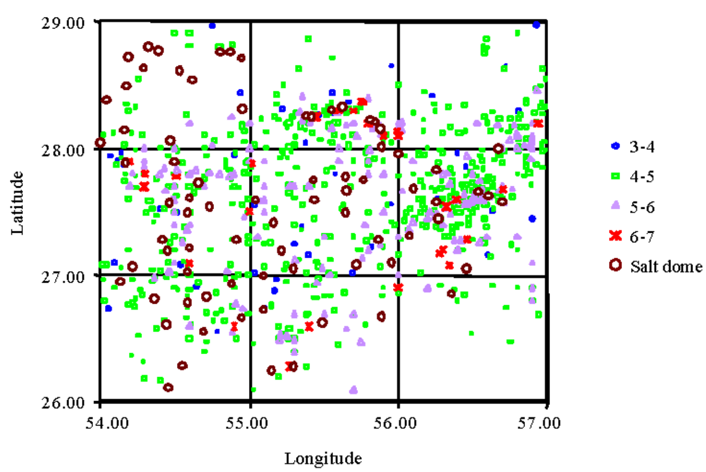

Fig. 3: Earthquake epicenters and salt domes distribution in the study area. Earthquakes are divided and shown in 4 distinct colors according their surface magnitudes

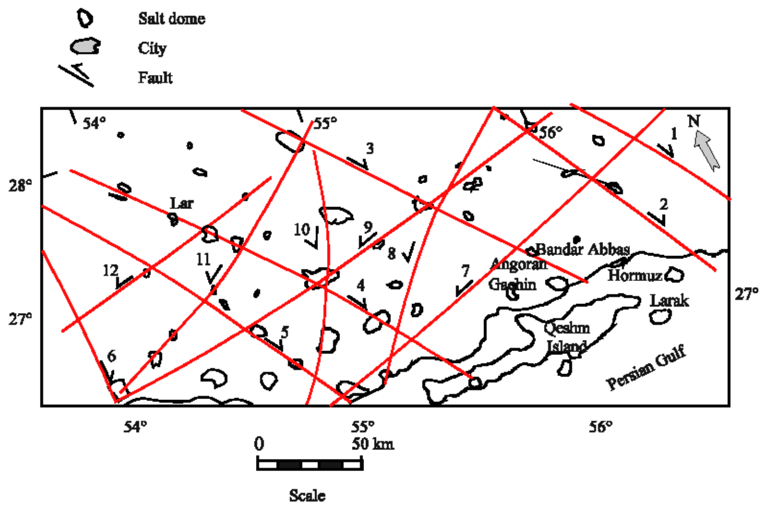

Fig. 4: Trends of postulate basement faults in the study area

Fault No. 3: This strike slip fault with 135° azimuth causes deviation in the axis of Gachin, Gashu, Guniz, Muran, Bundasht, Shemilu and Shab anticlines. There are six salt plugs such as Anguran in the trend of this fault. Minor thrust faults that could be seen in Bundasht anticline probably are formed by this fault.

Fault No. 4: This fault with 135° azimuth has caused right lateral offset of the axis of some of anticlines such as Kuh-e Kohneh, Pishavar, Gach, Burkh, Nakh and Champeh. There are seven salt plugs such as Kermostaj in Gach anticline, Bam and Namakdan in Qeshm island, which are outcropped in the direction of this fault. To the southeast, this fault may cross Tonbe Bozorg salt plug. In Kohneh anticline, it creates some minor faults parallel to itself and some of them to the axis of Kohneh anticline. Because of the activity of the minor faults, recognition of the anticlinal axis is very hard at this part of the anticline. This fault has created some minor faults parallel to itself by crossing Nakh anticline.

Fault No. 5: This dextral strike slip fault has caused deviation of the axis of Bostameh, Champeh, Herang, Nakh, Gavbast and Paskhand anticlines. It also displaced the axis of Nakh syncline, which is located between Gavbast and Nakh anticlines. This right lateral displacement is very clear in Asmary, Jahrom, Gachsaran and Guri Formations at the northwest limb of Nakh anticline. Exposure of salt domes at the East and Northeast of Bastak could be related to this fault's activity. There are several salt plugs such as Kildun, which are outcropped on this fault in 140° azimuth. Kildun salt plug has a sharp fault boundary parallel to the fault direction. Cutting of Bakhtiari and Aghajari formations and forming sharp scraps in the salt plugs are also evidence of fault activity. To the southeast, this fault may cross Tonbe Bozorg salt plug.

Fault No. 6: This strike slip fault in 167° azimuth crosses Chiru salt plug and deviates the axis of some anticlines such as Chiru, Lavarestan, Gavbast (also, there is about 10 km right lateral offset in this anticline axis) and Bavash. Also, there is some minor faults parallel to the major fault which is formed as the result of this fault activity. These minor faults specially could be seen in the Lavarestan, Gavbast and Bavash anticlines. Existence of erosion and collapse structures parallel to this fault trend, in Gavbast and Bavash anticlines could be related to this fault activity too. Minor faults trends and the pattern of erosion in Gavbast anticline, increase the possibility of a hidden salt plug in this area.

Fault No. 7: This fault with 80° azimuth, has caused deviation of the axis of some anticlines like Bostameh, Ashuru, Champeh, Khamir, Shab, Genow, Guniz, western end of Namak, eastern end of Handun, Neyzeh and eastern end of Furghun. Eight salt plugs outcropped in its trend.

Fault No. 8: This sinistral strike slip fault with 36° azimuth, has a concavity in its trend, to the east. It has deviated Muran, Shab, Iicheh, Champeh and eastern end of shemilu anticlines axis. Outcropping of several salt plugs such as Homeiran in the trend of this fault and creating minor faults special in Muran and Iicheh anticlines, are considerable.

Fault No. 9: This fault with 76° azimuth, causes laterally displacement in the axis of Baz, Shab, Bam, Nakh, Herang, Namaki and Chiru anticlines and crosses in its southwestern end to Hendurabi island. Seven salt plugs are outcropped in its trend such as Bam and Shab salt plugs. This fault has created several minor faults in Baz, Shab, Bam and namaki anticlines. It has deviated the axis of Shab anticline and has created some clear minor faults there. Also, outcropping of shab salt plug in this anticline could be related to this fault activity. Five kilometers displacement in the axis of Nakh anticline and creating several minor faults in circular form maybe resulted to a hidden salt plug there.

Fault No. 10: This sinistral strike slip fault with 14° azimuth is concave to the west. It has started in the North from the Western end of Dasht-e Kanar and has deviated the axis of Qaleh Shur and eastern end of Chahal anticlines. Seven salt plugs have outcropped on its path. This fault controlled edge of a salt plug located in Herang anticline. It also formed some minor faults in Bam salt plug. This fault may pass through Farur Bozorg and Farur Kuchak islands.

Fault No .11 : Deviation in eastern end of Gach anticline axis and also the axis of Burkh, eastern end of Gavbast, eastern end of Gezeh, Kuh-e namaki and Chiru anticline, outcropping of seven salt plugs on the trend of this fault, creating of several minor faults specially in Burkh and Gavbast and sharp cutting of Bakhtiari and Aghajari formations between Gavbast and Gezeh anticlines are some evidences for this sinistral fault with 50° azimuth, which is ended to the northeast to Dasht-e namak anticline.

Fault No. 12: This sinistral strike slip fault with 67° azimuth is started from the eastern end of Kurdeh anticline. It has deviated the axis of some anticlines such as Kurdeh, Gach, western end of Burkh, Eastern end of Paskhand, Gavbast and Dehnow. Sharp and linear edge of Kurdeh salt plug, displacement of Gach anticline axis, clear deviation between Paskhand and Burkh anticlines and outcropping of a salt plug there, forming minor faults specially in Kurdeh, Gach and Dehnow anticlines and outcropping of six salt plugs are some evidences for the activity of this fault.

CONCLUSION

Displacement and bending of anticlines and synclines, location of salt domes and concentration of earthquake epicenters indicate a close relationship between basement faults, salt plugs and epicenters. By means of all these features, location and trend of basement faults have been mapped. These basement faults could be strike-slip faults regarding the displacement of landforms (anticlines, synclines and etc.) in their paths. Also there is a rectilinear pattern of salt plug emplacements. These implied lines of weakness are almost certainly related to basement structural trends. However, preferred orientations which correspond to the major basement lineament trends described earlier result when other lineament associated surface anomalies are taken into consideration. Thus basement structure controls plug emplacement through its continued influence of the sedimentary cover.

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