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The Effect of Fracture Intersection on Drilling Mud Loss in Iranian Gas Fields

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Abstract

Kangan and Dalan formations are one of main reservoir rocks in Fars structural province in Iran south. in XXP gas field available fractures in Kangan formation have main effect on drilling mud loss. Although shale rate change of reservoir rock units is a key factor in control of fractures distribution in upright direction. But lateral distinction in reservoir rock leakage is affected by opening amount of intersection fractures. During 31 wells drilling in TBK, drilling mud loss has occurred in 12 wells. Drilling mud loss in these wells has been observed in Kangan formation and in anticline axis range. On the basis of surface studies and EMI images' interpretation, two major groups of fractures with non tectonic origin have been recognized in XXP anticline. These fractures have geometric characteristics including Dr. 150/80, Dr. 240/80. Two desired fracture groups are crossover and vertical on layered surface. These fractures are co-direction and intersection type with main fractures of southern Pars field. Desired fractures have evolved by the effect of upper layers' weight before folding. Fracture Intersection have been stretched in fold axis range by folding effect and extra opening has been occurred on their surface. Extra opening of fractures intersection in fold axis range has caused drilling mud loss increase in this part of the field.

Key words: Zagros Fold Belt, Iranian Gas Field, Drilling Mud Loss, Fracture Intersection.

1. Introduction

The The Zagros Mountains form a broad orogenic domain in Iran, approximately 2000 km long and 100–200 km wide in front of the Turkish-Iranian plateau. The Zagros fold belt and its foreland are one of the most prolific petroleum provinces in the world. This mountain range results from the still active collision of the Arabian plate with the continental blocks of Central Iran (Stocklin 1968). The Main Zagros Thrust (MZT) is considered as the suture, currently inactive, between the Arabian and Central Iran plates. GPS studies suggest that about one third of the active Arabia–Eurasia shortening (ca. 7 mm yr-1) is taken up in central Zagros (Vernant et al. 2004). Folding (and thrusting) of the Zagros sedimentary cover occurred mainly during the Mio-Pliocene by the end of deposition of the syntectonic upper Agha Jari Formation, about 7–3 Ma ago (Berberian & King 1981, Homke et al. 2004), while the Arabia-Eurasia continental collision culminated. The timing of the onset of this continental collision is, however, poorly constrained (estimates range from Late Cretaceous to Pliocene times, e.g., Berberian & King 1981, Sherkati et al. 2006) and has remained a matter of debate.

The Zagros orogen is known for its spectacular fold trains, believed to be detached on lower Cambrian salt. Resistant limestone anticlines control the characteristic morphology of the region. Widely distributed earthquakes that are similar in magnitude (mb , 5–6), depth (11^4), and geometry (40–508 NE-dipping nodal planes) (Ni & Barazangi 1986) combined with preserved sedimentary cover rocks with thickness ranges of 6–15 km (Stocklin 1968), have lead to a deformation model comprising distributed basement shortening in conjunction with, but decoupled from, folding of sedimentary cover rocks (Ni & Barazangi 1986, Berberian 1995).

In this research, according to surface and deep fractures, effective factors on drilling mud loss have been examined in TBK gas field. Surface studies have been done by fractures' measure in different spots of anticline and characteristics of reservoir rock fractures have been carried out by pictorial logs and information of drilling mud loss in 31 wells.

2. Tectonic Evolution of the Zagros Fold Belt

The Zagros fold belt is located along the north-eastern margin of the Arabian plate. It forms a 200–300 km-wide series of remarkable folds extending for about 1200 km from eastern Turkey to the Strait of Hormuz. The sedimentary column in the Zagros is estimated to be up to 12 km (Falcon 1974, Huber 1975) and comprises the Cenozoic foreland sequence and the underlying Paleozoic-Mesozoic deposits of the Arabian margin and platform. The sedimentary column, ranging from Cambrian to Plio-Quaternary, is embedded between two main detachment levels (mobile group), namely the Hormuz Salt Formation (Infra-Cambrian) at the base and the Gachsaran Formation (Lower Miocene) at the top (Falcon 1969).

The present morphology of the Zagros is the result of the structural evolution and depositional history of the northern part of the Arabian plate including a platform phase during the Paleozoic; a Tethyan rifting phase in the Permian-Triassic; a passive continental margin phase (with sea-floor spreading to the northeast) in the Jurassic-Early Cretaceous; subduction to the north-east and ophiolite-radiolarite obduction in the Late Cretaceous; and collision-shortening during the Neogene (Falcon 1974, Berberian & King 1981).

From a geodynamic point of view, different models for the evolution of the Zagros mountain system in southern Iran have been proposed (Stocklin 1968, Alavi 2004, Berberian & King 1981, Ni & Barazangi 1986). In almost all of them, northward movement of the Arabian plate relative to the Central Iran during Tertiary times resulted in thrust faulting and overfolding in the Imbricated Belt adjoining the trench zone and gentler folding in the Simply Folded Belt to the southwest. Despite this, the beginning of compression in the Zagros fold belt is poorly dated. The initial Arabian-Central Iran continental collision is considered to be Late Cretaceous (Berberian & King 1981, Alavi 1994), Eocene-Oligocene (Hooper et al. 1994), Oligocene-Miocene (Berberian et al. 1982) or late Miocene in age (McQuarrie et al. 2003). Berberian and King (1981) proposed that folding in the Zagros foldbelt started around 5 Ma and coincides with the second phase of extension in the Red Sea and Gulf of Aden. Based on the unconformity between the Agha-Jari and Bakhtyari formations, Falcon (1961) suggested that the deformation was initiated in the Early Pliocene.

On the basis of several unconformities at different stratigraphic levels, Hessami et al. (2001) proposed that deformation has occurred by pulses since the end of the Eocene, and reached the front of the folded belt during an end-Pliocene phase. All these estimations are based on ages of unconformities and sediment formations mostly defined by James and Wynd (1965).

Documented Holocene anticline growth (Vita-Finzi 2001) and recent seismicity (Jackson & McKenzie 1984) indicate that deformation in the Zagros belt is still active, especially at deep crustal levels. Homke et al. (2004) defined the beginning of the deformation in part of the Zagros foreland basin (Push-e Kush Arc) at 8.1 to 7.2 Ma based on magnetostratigraphical study of Miocene-Pliocene sediments.

3. Geological Setting

XXP gas field is located in Iran south, in geological province of coastal Fars parallel to Persian Gulf beaches (Fig. 1). Available gas reservoirs have been stored in an asymmetric anticline in this field and they have been saved in the form of upper Sanpermin and lower Triassic in Dalan and Kangan formations. This anticline has two culminations separated from each other and one saddle located in the position of well number 25 (Fig. 3). This anticline dimensions on Kangan's reservoir rock have length of 44Km and width of 4 to 6.5 Km. north limb of anticline has 36 dip and south limb has 18 dip. Bakhtiyari, Aghajari, Mishan, Gachsaran, and Asemari formations have outcrop on anticline surface. In this field, about 70% of gas reservoirs have been stored in Kangan formation and the rest of them have been reserved in Dalan formation. This gas field cap rock is evaporative sediments of Dashtak formation.

Dashtak formation is a succession of anhydrite thick and dolomite thin layers which act like an efficient cap rock.

The XXP folds are asymmetric, verging southwest with a typical wavelength of about 10 km. Oligocene–Lower Miocene Asmari carbonates in this domain are shortened by folds with wavelengths of 1–2 km on the flank of the main structures, which are locally breached by thrust faults.

4. Fars Structural Province

According to Haynes & McQuillan (1974) classification, XXP gas field locates in Fars geological province. Fars area is located in continental margin of Arabian platform that has been separated by faults of neighbor zones. These faults played an important role in control of area sedimentation (Sepher & Cosgrove 2004).

Fars structural province is limited from west to Kazeron fault and from east to Zendan fault. Fars structural province from northeast to southwest has been divided into three subdivisions including: Interior, Sub-coastal Fars, and Coastal Fars. XXP field has been located in coastal Fars part in this division (Fig. 1). One tectonic feature of this zone is the existing of anticlines with wavelength of 15 to 20 Km that have formed with buckling mechanism on basal decollement level of Hormoz formation salts. In developed stages, folds have been cut by thrust faults (Sherkati & Letouzey 2004). This area anticlines have various direction. Existence of salty domes and their effect on Fars zone anticlines are important tectonic features of this area.

In general, Fars region oil system has different features from other Zagros regions. Characteristics of origin rocks are in Fars region so that, huge resources of liquid Hydrocarbon (oil) like Zagros southwest have not been seen in this region. But because of gas resources this region has great importance. So that, Dalan and Kangan formations have huge gas resources. Gahgam formation shale with lower Silurian are gas origin rock in these reservoirs (Alsharhan & Nairn 1997).

The huge gas reserves accumulated in the Permo-Triassic carbonates (Kangan/Dalan formations) are assumed to have the same origin. This is applicable to fields such as North Pars, Mand, Kangan, Nar, Varavi, Shanul, Tabnak, and Homa, to the North Dome field and its South Pars extension in the Iranian waters, and to several major gas fields found in the Abu Dhabi offshore.

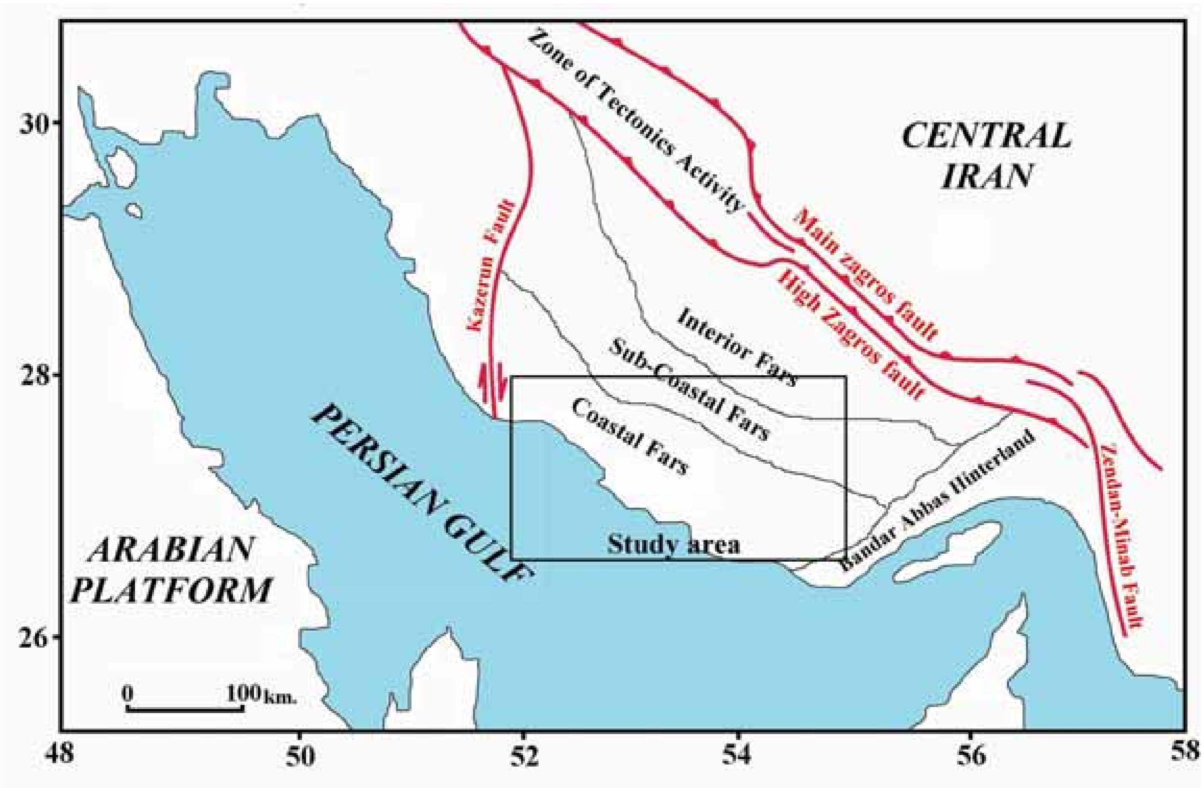

Fig. 1 Location of study area in Fars Structural Province

5. Stratigraphy

The sedimentary column of the Zagros fold–thrust belt comprises a, 12-km-thick section of lower Cambrian through Pliocene strata without significant angular unconformities (Stocklin 1968). The oldest sedimentary unit believed to be involved in the fold–thrust belt is the late Proterozoic to early Cambrian Hormoz Salt (Falcon 1969). The Hormoz Salt is overlain by 6–10 km of platformal deposits that are predominantly sandstone, shale, and dolomite in the Cambrian through Triassic section and limestone (with subordinate shale and evaporite) in the Jurassic through Lower Miocene section (Stocklin 1968). Strata thickness in the Jurassic through Pliocene section was obtained from map pattern and borehole data. Thickness variations within Paleozoic section were derived from exposures in the high Zagros, adjacent to the suture. The total thickness of Cambrian strata in the region of the Zagros is unknown; however, the Cambrian strata in the Zagros is most likely similar to the, 2-km-thick section in the Alborz Mountains N. McQuarrie/ Journal of Structural Geology 26 (2004) 519–535 521 (Stocklin 1968). Thickness changes of mapped strata on National Iranian Oil Company and Iranian Geological Survey maps suggest an original sedimentary basin taper of, 0.58. The mid-Miocene and younger rocks in the section include gypsum, limestone, sandstone, shale and conglomerate. The thickness of these formations varies significantly through the fold–thrust belt, perhaps due to synorogenic deposition on, and erosion off of growing structures. Provenance data and interpretations of isopach-facies maps suggest that the Agha Jari and Bakhtiyari formations are synorogenic sedimentary rocks derived from a growing fold–thrust belt to the NE (Hessami et al. 2001).

1.5 Upper Permian- lower Triassic

During upper Permian and lower Triassic Dalan and Kangan formations have been sediment in Iran and its regional equal, Khuff formation has been sediment in Saudi Arabia Island (Ziegler et al. 2001). The deposit of Dalan and Kangan formations in Iran contemporaneous to Neototis and subsidence ocean floor spreading and its transgression caused a Epiric platform shelf development that has been spread from Iran south to Saudi Arabia. This regional Epiric platform has a few relief, so that it has caused facieses with extremely development and expansion of tens to hundreds kilometers (Sharland et al. 2001). Carbonate regime dominance in east part of Arabian platform has caused formation of shoal sea carbonate facieses to open sea (Ziegler et al. 2001). In this large and little energetic platform, suitable conditions prepared for reservoir development with high thickness and quality. Because of these conditions stability, gas huge reservoirs would be formed on this platform. But falling of sea water level has separated the iner regions of platform and reservoir development has been stopped in these regions (Insalaco et al. 2006). So that, gas reservoirs have only been constructed in some regions of this huge platform. Upper Dalan and Kangan formations in Iran and equal to them upper part of Khuff formation in Arabian plate are examples of gas reservoirs that have been formed during this stage (Fig. 2). These formations have a lot of the most important gas reservoirs in Middle East region (Kashfi 1992). These gas fields include Ghatar northern gas field and Iran southern Pars field that is the largest world gas field.

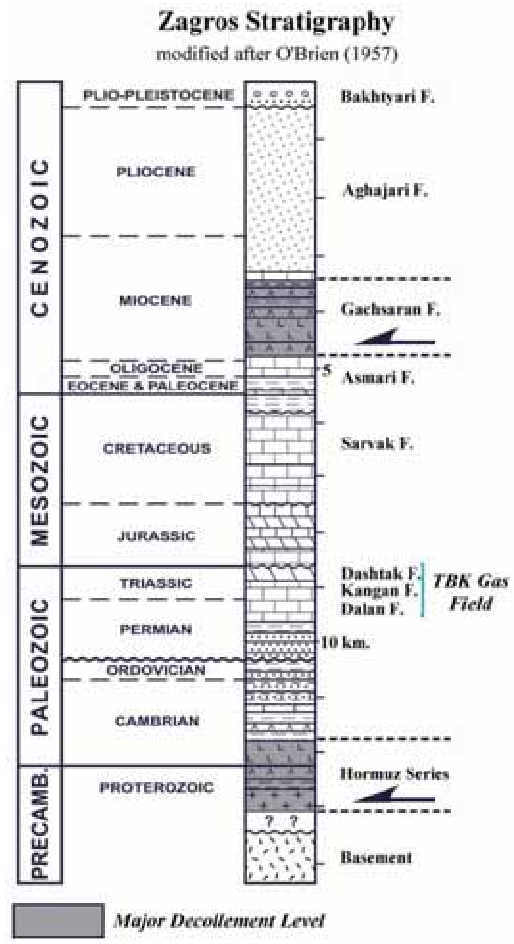

Fig. 2 Location of Dalan, Kangan and Dashtak formations in Zagros Stratigraphy

6. Drilling Mud Loss

Well collision to an open and conductive fracture causes mud loss drop. This process that is caused because of mud loss infiltration to fractures inside called mud loss. this can be determined by diagram of input and output flow difference of mud rather than time .in most cases ,because of high care of flow test losses to 20 liter are distinguishable.

Mud loss in formation inside is one of indirect evidence that is used for interpretation of fractures development of reservoir. In order to this factor use to fractures interpretation At first stage equal conditions must dominant on reservoir that is during drilling, mud weight should be almost stable in well especially inside reservoir and doesn't change rapidly. Because mud weight increase causes high hydrostatic pressure and then some parts of formation are broken .this kind of mud losing increase was affected by induced fracture and it dose not relate to litho logy qualities and available fractures inside stone. Drilling mud loss is a very complex physical process and it details are unknown. Mud volume increase or decrease during drilling is a warning for probability occurrence of mud high volume loss or reservoir mobile flow well inside. During this process, one mobile penetrate into a set of fractures with asymmetric geometry shape. Hydraulic openness of cracks that encounter well during drilling. Cracks tangent angle with well's wall and physical characteristics of fractures have an effective role in drilling mud loss rate. These fractures' recognition provides more accurate model of reservoir. In addition, knowing these conditions with drilling operation control reduces damages due to mud loss.

Carbohydrate formation including hydrocarbon have many fractures. So ,distinction of conductive fracture gaps is one of the most important exploration priorities in these fields .moreover ,open and close cracks' recognition is not possible through image log and gaps with productive potential cannot be determined by it. Apparently, mud loss information is only reliable source for description of effective cracks' fractures in these reservoirs. Therefore during crack reservoir's drilling. examinating of mud loss and it's rate is a very useful method for examining the probability of effective fractures existence and nit is so suitable for exploitation interval' recognition. it is possible to determine fractures' features by helping mud loss rate by effective cracks' realizing in a depth distance and estimating of conductive rate. This method is not very careful that cracks' hydraulic features are separately realized by its help.

During drilling in XXP field, mud loss has had in Kangan formation provided rodding diagrams for 31 wells in XXP field indicate that drilling mud loss has occurred in Kangan formation and low part of Dashtak formation (fig.3). these condition of drilling mud loss have only seen in 12 wells which all of them were drilled in anticline axis range(fig.3)of course it should be noticed that collective loss rate in a depth gap not only depends on fractures' conduction but also relates to mud rheological features, cracks' compression, hydrostatics pressure mud obstacle taints and etc.

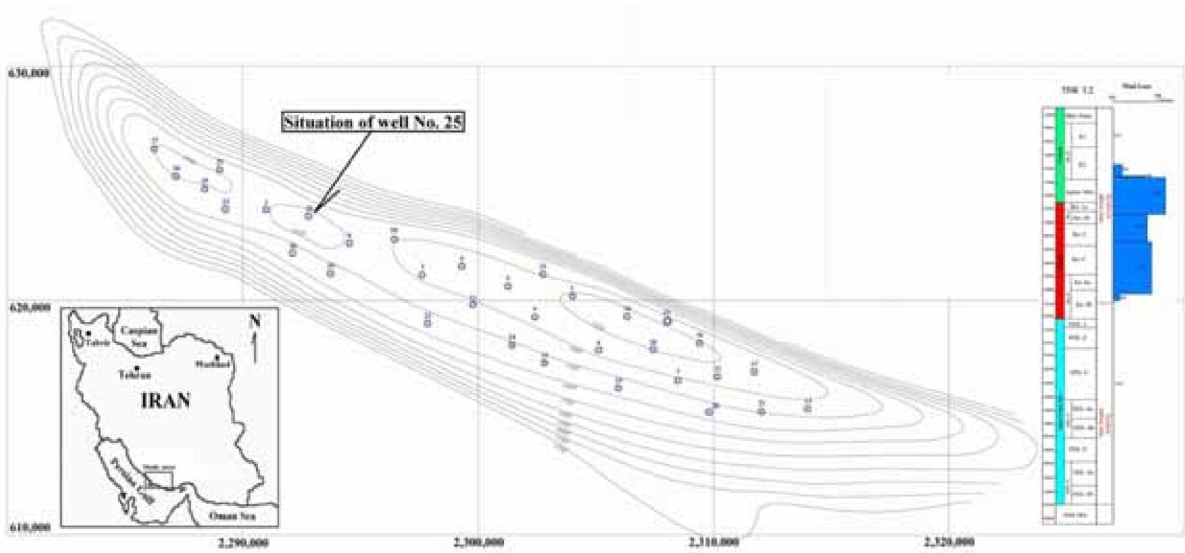

Fig. 3 Maximum mud loss in XXP gas field.

7. Fractures in XXP gas field

One of oil industry experts challenges is fracture systems recognition, modeling and determination of mobiles flow route in Middle East. Available reservoirs in this region are the most important world's natural broken reservoirs. That permeable and open fractures' emersion inside them is regarded to some factor's performance such as, folding nature and grade, faulting, stable tension nature and changing of stone features such as, porosity, bedding, lithology and shale percent (Akbar et al. 1993)

Available fractures in folding sedimentary stones are usually interpreted by folding influence. In fold – related fractures, it is supposed that joints affected by local stretch in external arc of folds are related .Although, many geologist believe that most Zagros oil reservoir fractures relate to folds. Nonetheless chronological relations of different fractures with folds are still debatable in Zagros (Ahmadhadi et al. 2008). generally, public plan recognition of fractures and their chronological relation with folds has a special importance. Kangan and Dalan formation is one of major reservoirs stone in Fars structural state in south of Iran. This reservoir stone has been divided into four units K1, K2, K3, K4.these two formations are similar to a carbonate fractured reservoir.

7.1. Non-tectonic fractures:

Done studies on Asmari formation fractures on deferent parts Zagros belt indicate that there is vast variety in fractures process and there is any relation between fractures density and folding intensity. The conditions show the emersion of a group of fractures before main block of folding in mio- Pliocene (MaQuillan 1974).therefore this region fractures can be separated to two groups of fractures before and after folding (Ahmadhadi et al. 2008).

The study of XXP gas fields' fractures has been done based on surface outcrops and EMI diagrams of drilled wells. Each of these cases provides certain scale of observations. Measurement of fractures' geometry condition on XXP anticline surface has provided 3dimensional information of fractures' geometry and pattern. unfortunately, superficial outcrop shortage of Kangan and Dalan reservoir stone units has eliminated this part information. 17 rings of drilled wells have EMI diagram. that most of them have been driven in Kangan and low part of Dashtak formation .in this research, EMI diagrams belong to six vertical wells have been selected and geological main damage such as, fractures, layered surfaces, and faults along Dalan and Kangan reservoir stone have been realized (fig.4) on the basis two groups of basic fractures have been recognized in anticline depth and surface. On the basis of stratigraphy methods for each group of fracture have considered a selected geometry position (Fig.5) that have Dr.150/80, Dr.240/80 geometric features. Two groups of fracture are crossover and vertical on layered surface.

Fractures presence in sedimentary class that doesn't have noticeable tectonic change in form. show non-tectonic factors' role in the fractures. South Pars gas field located in some part of Arabian platform has been still affected by Zagros field folding. So, fractures' position of Permo-triassic reservoir stone in this field is a suitable tool for recognizing of non-tectonic fractures' direction in the studied region .according to similarity of geometry position of two recognized fracture groups in XXP gas fields' with main fractures of south Pars field, non-tectonic origin probability of two groups of fracture will be strengthened.

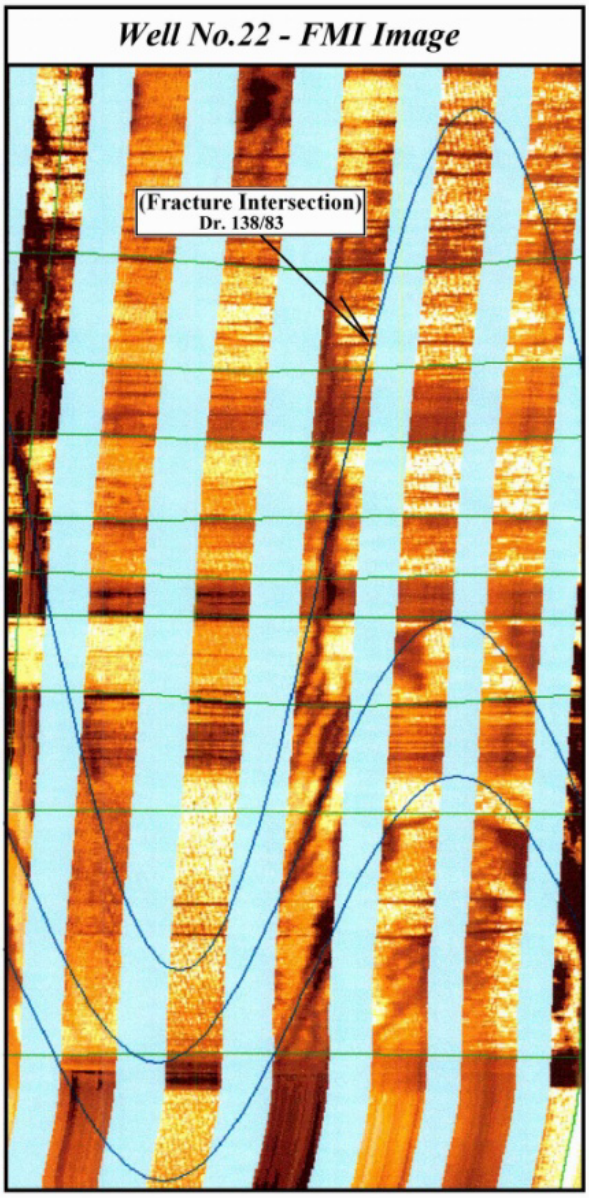

Fig. 4 FMI image, showing the fractures in well No. 22.

7.2 Fracture Intersection

A group of fractures limited to layered surfaces are called fracture intersection. These fractures are formed in conditions when tenacity in layered surface is low. Therefore, fracture intersection of two layers will be very frail and in resistant against section (cutting) or openness.(fig.6). The most controlling factors of layers' intersection fractures are interment depth,pressure stresses and fractures. Length (Renshaw & Pollard 1995). Moreover, in conditions that fracture development accompanies with fluids static pressures, we can see fluids injection in layer surface. Incases that fractures develop rapidly, some fractures that intersect layer's surface are formed at first stage. Then fluids under pressure are scattered through the fractures in layered surface and they cause layer's surface openness. Therefore, fluids pressure can cause preliminary fractures' stop and step –over fractures' formation.

In anticline XXP, most of reservoir stone sediments and other formations have layered surfaces with low resistant. Therefore, under the effect of tensional. energies due to openness upper classes' weight and slip occurred simultaneously on layer surface as a result, step –over fractures have been widely created in sediments(fig.7). formation of these buildings in Kangan and Dalan reservoir stone cause permeability of fluids in to fracture's network. results of superficial study and their a adaptation to underground data show two groups of intersection fracture with geometric features of Dr.150/80 , Dr240/80 respectively ,.both of them are vertical to layered surface and unrealistic to folding axis. Collision of this stretch fracture with wall increase drilling mud loss.

Generally, fractures that meet well wall and able to conduct drilling mud flow are called conductive fractures. Conductive fractures position and permeability have great effect on drilling operations, production rate and reservoir management in gap reservoirs. Recognition of conductive fractures position causes improving of reservoir modeling quality and its better exploitation. in addition, by considering opening, permeability and gaps obstruction process provide prevention of mud loss and its damages conductive fractures features can be realized by careful control of mud loss rate.

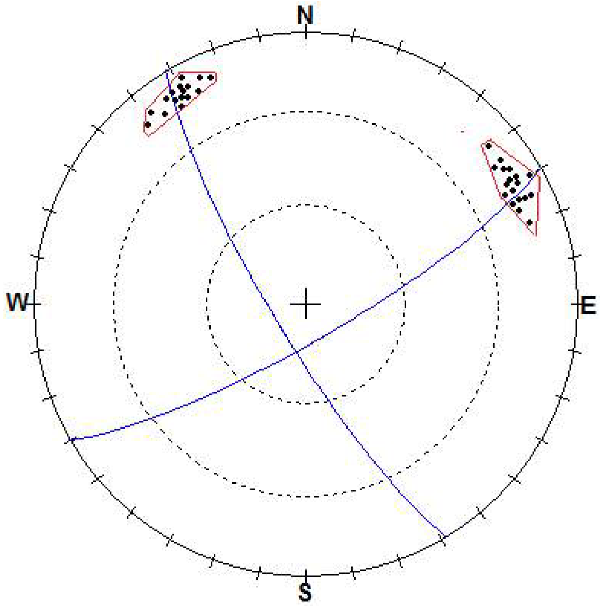

Fig. 5 Statistical plots of selection fractures in XXP gas field (surface study).

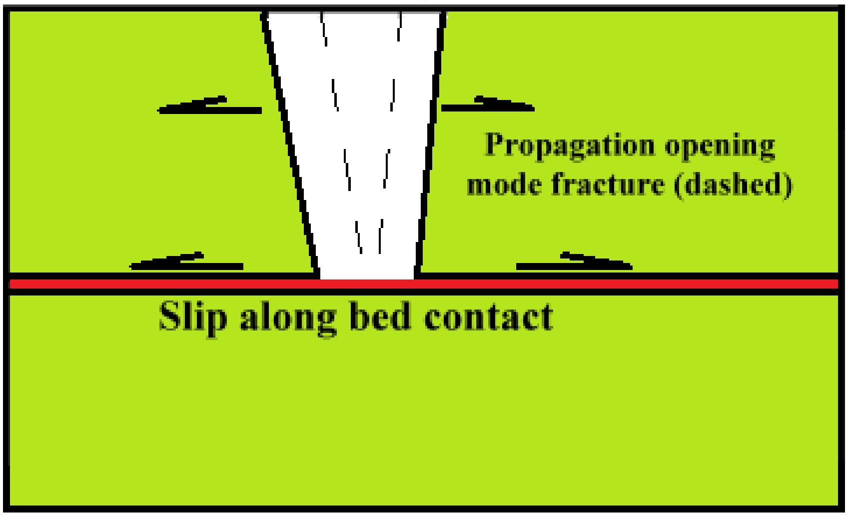

Fig. 6 Postulated mechanisms for fracture intersection at a bedding contact due to Slip along the contact (Cooke & Underwood 2001).

Fig. 7 Fractures intersection outcrops on layered surface in south of XXP anticline.

3.7 Difference of fractures density

As for thickness change of reservoir rock units is little in XXP gas field, so it can't control fracture. but available difference in shale rate of reservoir stone units is key factor in fractured distribution up right. so that shale rate increase in K3 and K1 reservoir stone units has caused decrease of fractures' density in two units of K4 and K2 reservoir stone is because of shale horizons lack in them.

In XXP gas field fractures of Kangan formation have main role in gas storage .although fractures density in lateral way don't show any considerable changes.

But difference in permeability of fractures in different part of field has caused exploitation and drilling mud loss increase. most openness of fractures has been seen in anticline axis range that has been caused by stretch forces' effect due to folding though, fractures geometric position in XXP anticline surface and underground data show that in most cases fractures general plan dose not adapt fractures pattern related to folding , it seems that intersection fractures (before folding) have been stretched in fold axis range by folding effect and openness has been created on their level excessively (Fig.8) while while these fractures have been affected by shear force on fold limb sand they lack openness excessive openness of intersection fractures in fold axis range has caused drilling mud loss in crease in this part of field.

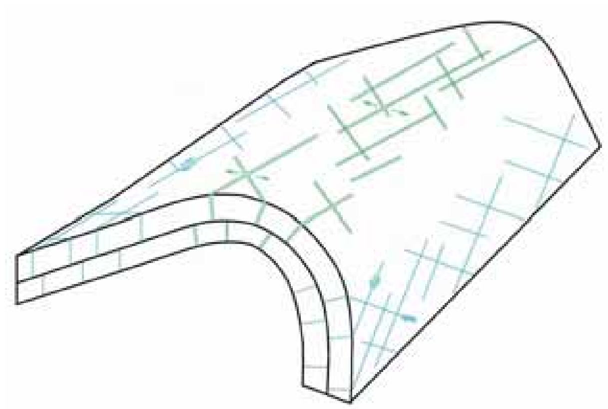

Fig. 8 The effect of stretch forces in fold axis range on excessive openness of intersection fractures.

Conclusion

In XXP gas field, available fractures in Kangan formation have main role in drilling mud loss. Geometric status of fractures in this anticline shows that in most cases fractures general plan does not adapt to fractures pattern related to folding. In other words, XXP gas fields fractures can be divided in two groups before and after folding fractures. In this anticline openness and lapse occurred simultaneously because of stretch forces effect due to upper classes weight. As a result, intersection fractures have widely been made in sediments. Formation of this building in Kangan and Dalan reservoir stone has caused fluids seepage in fracture network. Both groups of fracture are vertical on layered surface and adaptive to fold axis .during folding, layers of axis part of fold was affected by extension and inordinate openness has been created in intersection fractures. Drilled wells in this part of anticline have most potential of drilling mud loss because of contact to opened intersection fractures.

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References

Ahmadhadi, F., Marc Daniel, J., Azzizadeh, M. & Lacombe, O., 2008, "Evidence for pre-folding vein development in the Oligo-Miocene Asmari Formation in the Central Zagros Fold Belt Iran", *Tectonics, Vol. 27: 22 pp.*

Akbar, N., Dvorkin, J. & Nur, A., 1993, "Relating P-wave attenuation to permeability", *Geophysics, Vol. 58: 20-29.*

Alavi, M., 2004, "Regional Stratigraphy of the Zagros fold-thrust belt of Iran and its proforeland evolution", *Am. J. Sci., Vol. 304: 1–20.*

Alsharhan, A.S. & Nairn, A. E. M., 1997, "Sedimentary basins and petroleum geology of the Middle East", *Elsevier: 843 pp.*

Berberian, M. & King, G.C.P., 1981, "Towards a paleogeography and tectonic evolution of Iran", Canadian Journal of Earth Sciences 18: 210– 265

Berberian, F., Muir, I.D., Pankhurst, R.J. & Berberian, M., 1982, "Late Cretaceous and early Miocene Andean-type plutonic activity in northern Makran and Central Iran", *J. Geol. Soc. London, Vol. 139 (5): 605–614.*

Berberian, M., 1995, "Master “blind” thrust faults hidden under the Zagros folds: active basement tectonics and surface tectonics surface morphotectonics", *Tectonophysics, Vol. 241: 193–224.*

Cooke, M.L. & Underwood, C.A., 2001, "Fracture ter mination and step-over at bedding interfaces due to frictional slip and interface opening", *J. of Struct. Geol. 23: 223-238.*

Falcon, N. L., 1961, "Major earth-fl exuring in the Zagros Mountains of south-west Iran", *Quarterly Journ. of the Geol. Soc. of London, Vol. 177: 367–376.*

Falcon, N.L., 1969, "Problems of the relationship between surface structures and deep displacements illustrated by the Zagros range", *In: Kent, P., Satterhwaite, G. E. & Spencer, A. M., (Eds.), Time and place in orogeny. Geol. Soc. London, Vol. 3: 9–22.*

Falcon, N., 1974, "Southern Iran: Zagros Mountains", *In: Spencer, A. (Ed.), Mesozoic-Cenozoic Orogenic belts. Geol. Soc. London, Vol. 4: 199–211.*

Haynes, S.J. & McQuillan, H., 1974, "Evolution of the Zagros suture zone, southern Iran", *Geological Society of America Bulletin, Vol. 85: 739–744.*

Hessami, K.H.A., Koyi, C.J., Talbot, H. & Tabasi, E., 2001, "Progressive unconformities within an evolving foreland fold-thrust belt, Zagros Mountains", *Journal of the Geol. Soc., Vol. 158: 969–981.*

Homke, S.J., Verges, G., Garces, H.E. & Karpuzc, R., 2004, "Magnetostratigraphy of Miocene–Pliocene Zagros foreland deposits in the front of the Push-e Kush Arc (Lurestan Province, Iran)", *Earth and Planetary Science Letters, Vol. 225: 397–410.*

Hooper, R. J., Baron, I. R., Agah, S. & Hatcher, R. D., 1994, "The Cenomanian to recent development of the Southern Tethyan Margin in Iran", *In: Al-Husseini, M.I. (Ed.), Middle East Petroleum Geosciences GEO, Vol. 2: 505–516.*

Huber, H., 1975, "Geological map of Iran 1:1000, 000 scale NIOC, Exploration and Production".

Insalaco, E., Virgone, A., Courme, B., Gaillot, J., Kamali, M., Moallemi, A., Lotfpour, M. & Monibi, S., 2006, "Upper Dalan Member and Kangan Formation between the Zagros Mountains and offshore Fars, Iran: depositional system, biostratigraphy and stratigraphic architecture", *GeoArabia Vol. 11 (2): 75-174.*

Kashfi, M.S., 1992, "Geology of the Permian "supergiant" gas reservoirs in the greater Persian Gulf area", Journ. Petrol. Geol., Vol. 15: 465-480.

McQuillan, H., 1974, "Fracture Pattern on Kuh-e-Asmari anticline, Southwest Iran", *AAPG Bull., Vol. 58: 236–246.*

McQuarrie, N., 2003, "Crustal scale geometry of the Zagros fold-thrust belt, Iran", *Journal of Structural Geology, Vol. 26: 519–535.*

Ni, J. & Barazangi, M., 1986, "Seismotectonics of the Zagros continental collision zone and a comparison with the Himilayas", *Journal of Geophysical Research, Vol. 91: 8205–8218.*

Renshaw, C.E. & Pollard, D.D., 1995, "An experiment tally verified criterion for propagation across unbounded frictional interfaces in brittle, linear elastic materials International", *Journal of Rock Mechanics and Mining Science and Geomechanics, Vol. 32: 237-249.*

Sherkati, S. & Letouzey, J., 2004, "Variation of structural style and basin evolution in the central Zagros (Izeh zone and Dezful Embayment), Iran", *Marine and Petroleum Geology, Vol. 21: 535–554.*

Sepehr, M. & Cosgrove, J.W., 2004, "Structural framework of the Zagros Fold-Thrust Belt, Iran", *Marine and Petroleum Geology, Vol. 21: 829-843.*

Sharland, P.R., Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., Horbury, A.D. & Simmons, M.D., 2001, "Arabian Plate Sequence Stratigraphy", *GeoArabia Special Publication, Vol. 2: 371 pp.*

Sherkati, S., Letouzey, J. & Frizon de Lamotte, D., 2006, "The central Zagros fold-thrust belt (Iran): New insights from seismic data, fi eld observation and sandbox modeling", *Tectonics, Vol. 25, TC4007.*

Stocklin, J., 1968, "Structural history and tectonics of Iran; a review", *American Association of Petroleum Geologists Bulletin, Vol. 52: 1229–1258.*

Vernant, P.F., Nilforoushan, D., Hatzfeld, M.R., Abbassi, C., Vigny, F., Masson, H., Nankali, J., Martinod, A., Ashtiani, R., Bayer, F., Tavakoli, J. & Chery, j., 2004, "Present-day crustal deformation and plate kinematics in the Middle East constrained by GPS measurements in Iran and northern Oman", *Geophysical Journal International, Vol. 157: 381–398.*

Vita-Finzi, C., 2001, "Neotectonics at the Arabian plate margins", *Journal of Structural Geology, Vol. 23: 521–530.*

Ziegler, M.A., 2001, "Late permian to holocene paleofacies evolution of the Arabian plate and its hydrocarbon occurrences", *GeoArabia, Vol. 6: 445–503.*