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In-situ stress regime in the Asmari reservoir of the Zeloi and Lali oil fields, northwest of the Dezful embayment in Zagros fold-thrust belt, Iran

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ABSTRACT

This paper analyzes in-situ stress field in the Asmari formation with in the complex structures of the Zeloi and Lali oilfields located in the Dezful embayment, SW Iran. The orientation of the maximum horizontal stress, SHmax is determined on the basis of compressive borehole breakouts and drilling-induced tensile fractures observed in eight oil wells, in which we focus on well-log based methods and drilling data to estimate stress magnitudes. In situ stress magnitude in studied fields obtained from 1D mechanical earth modeling in key wells. The maximum horizontal stress trend in this area is NE–SW in accordance with the World Stress Map however a stress perturbation has been recognized in some wells of the Lali field which is approximately perpendicular to the expected direction of the maximum horizontal stress. In situ stress magnitudes in the Lali oil wells are consistent with a strike-slip regime, while in the Zeloi oilfield, normal faulting regime is estimated. The observed strike-slip and normal faulting regime in the Lali and Zeloi wells respectively, Supports the idea that the role of overburden stress magnitude is higher than the horizontal stresses. Undoubtedly, the structural position of the wells, structural framework, faults location, fold geometry, pore pressure changes and mechanical properties of rocks are main factors and have played an important role in stress condition and in situ stress regime in these two hydrocarbon structure.

1- Introduction

In-situ stress is a primitive stress which exists in the rock mass prior to any artificial disturbance. In the wellbore scale, in situ stress field along with the strength properties of rock and the wellbore orientation control the intensity and orientation of rock failures (Moos and Zoback, 1990). Stress magnitudes in the Earth's crust which contains faults, fractures and planar discontinuities at many different scales and orientations are limited by the frictional strength of these planar discontinuities (Zoback et al., 2003).

Tectonic stresses are those parts of the local stress state that deviate from the reference state of stress as a consequence of tectonic processes (Fossen, 2010). Tectonic stress distribution and heterogeneous stress field in tectonically active areas such as the Zagros fold-thrust belt is directly associated with plate movements and convergent boundary conditions which cause stress state variations from place to place (Gowd et al., 1992). In Oligocene – Miocene times compressional tectonic regime prevailed during the continental collision and folding of the sedimentary cover with a NE – SW trend of σ1 stress axis and the compression was followed by a strike-slip stress regime with an approximately N–S trend of the σ1 axis oblique to the mountain belt during inversion of the inherited extensional basement structures in Pliocene –Recent times in the west and east of the Iranian Zagros area (Navabpour and Barrier, 2012).

Gravitational body forces and tectonic loading change the geometry and thereby the stress distribution in sedimentary basins (Skar and Beekman, 2003). Tectonic stresses may be influenced by factors such as bending of layers, e.g. in front of a propagating fault, fault interference and other local effects. It can be mentioned that the most important factors to influence stress directions are faulting and fracturing, lithology, geologic structure and topography (Martin and Chandler, 1993; Tingay et al., 2003).

The main cause of horizontal stress anisotropy is tectonic stress, while structural in homogeneities affect both stress magnitude and direction (Zoback, 2003).

The overall trend of maximum horizontal stress in the Zagros region is N-NE-directed (Heidbach et al., 2010). The scatter in stress directions observed in some parts of the Northern Dezful Embayment determined from wellbore elongations has led some investigators to conclude that shallow stress directions are decoupled from the deeper regional stress field (e.g. Borgerud and Svare, 1995). In situ stress field cannot be measured directly, however it can be inferred indirectly by using different methods. A wide variety of techniques are currently used to determine the orientation of in situ stress in the upper crust. In order to assess factors that may influence the local stress distribution we need to consider aspects at different spatial scales. Numerical simulations show that the spatial variation in calculated horizontal stress are the result of many factors such as the magnitude of compressive stress applied to the edge of the model, the structural configuration on which the model is based and variations in the mechanical properties of the rocks (Skar and Beekman, 2003).

In the Zagros region, there was no precise estimation of in situ stress magnitude. Our analysis of stress magnitudes and orientations can be critical in designing successful exploration and production wells. By knowing the stress tensor we are able to plan drilling strategies that minimize wellbore failure during drilling and enhance producing the reservoir.

The orientation of maximum horizontal stress of the Asmari reservoir in northern Dezful Embayment structures previously have been studied in several drilled oil wells and such as other available information in the Zagros area indicates the NE-SW overall orientation, moreover, the relative estimation of the stress magnitude has been done (Talebi et al., 2013).

This paper investigates in-situ stress condition consist of orientation and estimation of in-situ stresses and finally determination of stress regime across the Zeloi and Lali oilfields in the northern part of the Dezful Embayment in the Zagros area, based on well-log data, interpreted seismic lines, reservoir structure maps and previous fundamental studies in the Zagros area. Analysis and determination of stress regime in the Asmari reservoir has been done for the first time in this area.

2- Regional Setting

The Zagros fold and thrust Belt (ZFTB) is actively deforming due to shortening between the Arabian and Eurasian plates Where tectonic stresses and strains arise from tectonic plate movement in this tectonically active area. The Zagros Foredeep (ZF) is bordered by the Main Recent Fault (MRF) to the northeast and to the southwest by the Zagros Foredeep Fault (ZFF), which marks the northeastern edge of alluvial covered coastal plain of the Persian Gulf (Berberian, 1995).

The Zagros Foredeep associated with elongate and en-echelon folds and consist the largest and most important hydrocarbon reservoirs in Iran. The shearing off from the subsurface Asmari limestone base along decollement thrust in the Gachsaran evaporites is principal in Zagros foredeep (Sherkati et al., 2005). Orientation of compressional axes which are perpendicular to fold axes in Central Zagros but exhibit changes in north Zagros (Walpersdorf et al., 2006). (Islam and Shinjo, 2010) found from calculation that strike-slip faulting is dominant in shallower depth (up to 10 km), while thrust faulting becomes significant with increasing the depth. The stress inversion results obtained by two different methods used by (Pourbeyranvand et al., 2011) showed that the stress tensor is almost compatible with NE -SW orientation which is identical to the trend of the Zagros collision zone between the Iranian and Arabian plates in the region.

The Dezful Embayment as a sub zone and oil-rich state in the Zagros region within the Zagros Simply Folded Belt, appears to be a discrete structural unit and associated with basement faults around it and bounded among three important structural elements consist of left lateral Balaroud fault (BF), Mountain frontal fault (MFF) and right lateral Kazeroun lineament (Fig. 1).

The Zeloi and Lali structures are located in north Dezful area and geologically are complex structures. Detachments layers have a principle role in structural relation between the Zeloi and Lali anticlines. Triassic evaporites, Albian shales and Eocene marls have acted as local intermediate decollement levels. They have a great similarity with the geometry of detachment folds with dual detachments as it has been mentioned by several researchers for many anticlines in the Zagros.

Interpretation of seismic profiles have revealed reverse faulting in border of these two anticlines and formed structures similar to duplexes consist of several fault blocks which are separated by thrust faults (Fig. 2).

Generally, structural geometry and folding mechanism of the Zeloi anticline is consistent with fault propagation fold mechanism although significant ambiguities could be observed in the northwestern nose.

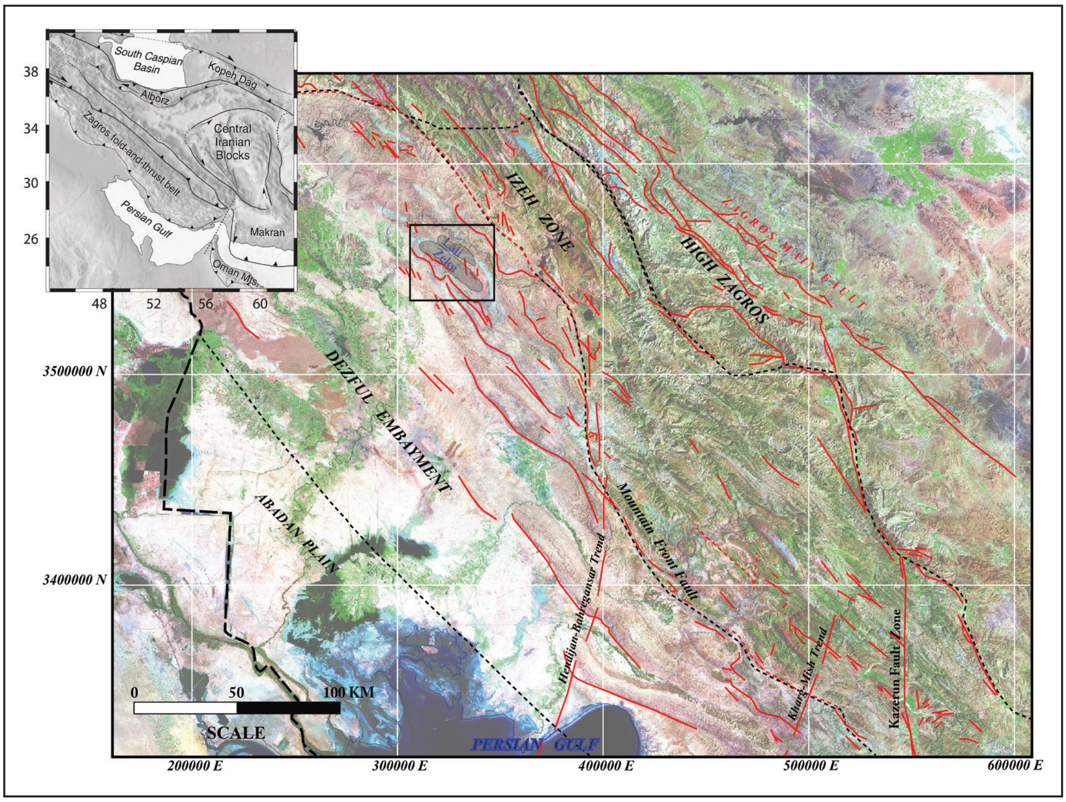


Fig.1- Simplified structural map of the Dezful Embayment and Izeh Zone-central part of the Zagros Fold. Thrust Belt in Iran. Studied oil fields in this paper are located in the north-west of the Dezful Embayment.

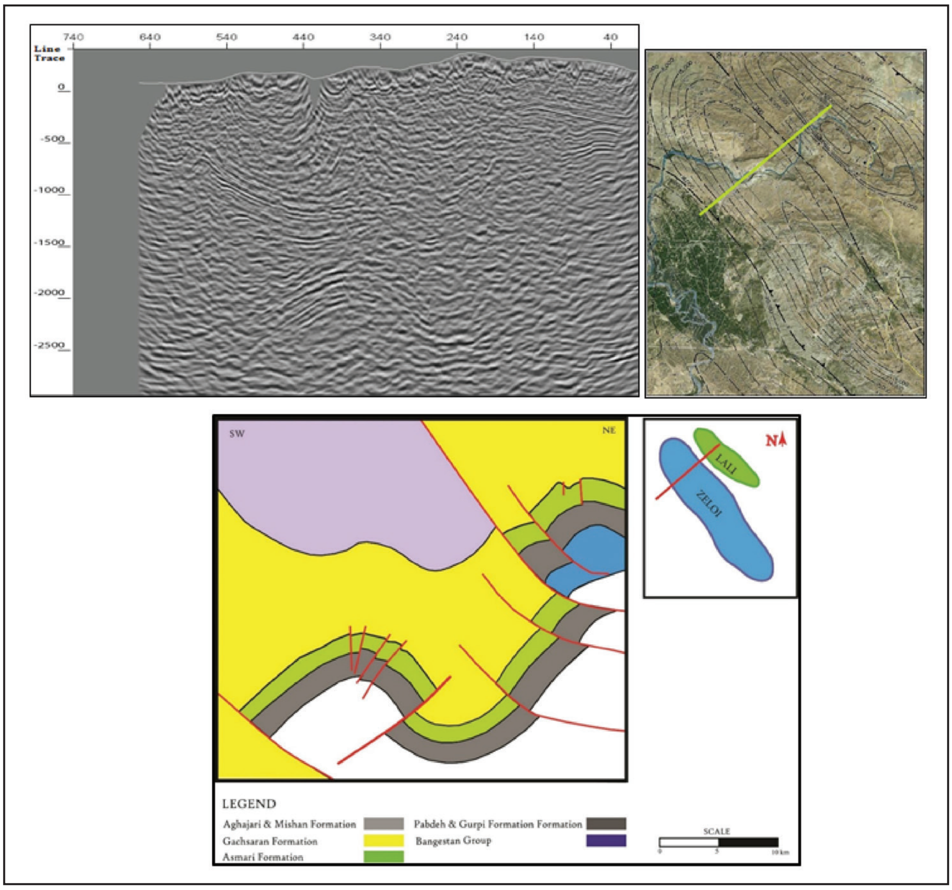


Fig 2- Interpreted seismic profile through the north western nose of the Zeloi and Lali structures. The ground surface is covered by Gachsaran, Mishan and Aghajari formation.

3- Methodology

3- 1. In-situ stress analysis

The potential of reservoir mechanical earth models in oil wells are used to predict stress magnitude and evaluation of stress regime. A mechanical earth model (MEM) is a repository of data- measurements and models- representing the mechanical properties of rocks and fractures as well as the stresses, pressures and temperatures acting on them at depth. The mechanical earth model is a description of rock elastic and strength properties, in-situ stresses, and pore pressure as a function of depth, referenced to a stratigraphic column and have built by integrating of data from various sources and the rock physics parameters have been derived. (Plumb et al., 2000).

There are different techniques for determination of in-situ stresses magnitude so in this study we focused on the well log based methods using several petrophysical log data consist of dipole sonic well logs, image logs and core data to estimate magnitude of stresses in five wells according to available data.

In parts there is not available sonic well logs data so we have used data extracted from vertical seismic profiles (VSP). In the Asmari reservoir section, pressure data points and pressure gradient from modular formation dynamic (MDT) or repeat formation test (RFT) were available. Static pressure was utilized where there is no enough data pressure to estimate pore pressure especially in the Lali field. In accordance with regional considerations and the lack of log anomalies pointing towards elevated pore pressures, hydrostatic pore pressures were assumed.

The velocity of the compressional and shear waves are measured, mechanical property of the rocks determined and by using poroelastic relations and considering the drilling events include lost circulation, kick, tight hole, stuck pipe and etc., extracted from drilling reports, in-situ stresses are calculated.

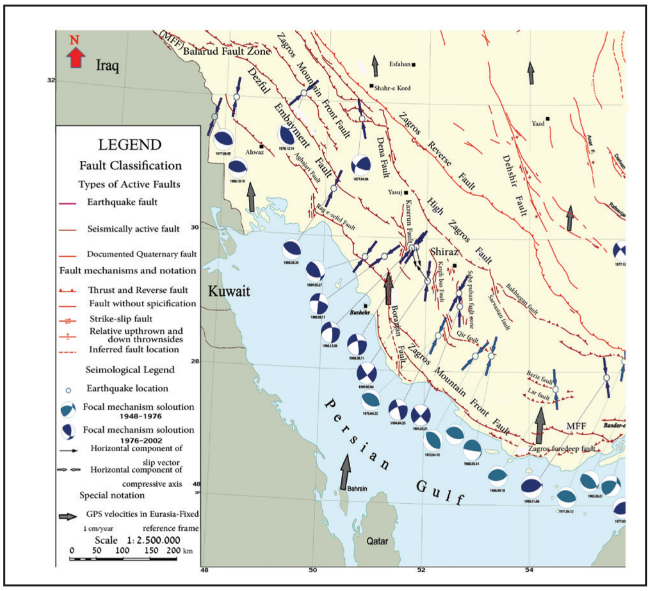


Fig 3- The orientation of present-day SHmax in the Zagros geological province of Iran based on seismological information. GPS velocities in Eurasia-fixed reference frame are shown by the large arrows (Major Active Faults of Iran Map-IIESS, Hessami et al., 2003).

Due to the impossibility of performing the leakoff test in the Asmari reservoir sequence in the absence of casing shoe in this formation, access to this data is not provided.

On the basis of the World Stress Map (WSM) (CASMO, 2008), present-day SHmax is oriented in NE-SW direction in the High Zagros, NNE-SSW and N-S orientation of SHmax in Fars arc (Fig. 3).

The results from finite element model suggests that most of the Zagros area displays NE-SW orientation for SHmax whereas Lurestan, High Zagros Fault ,Main Recent Fault and eastern part of Zagros fold thrust belt show different stress orientation (Islam and Shinjo, 2010). In order to obtaining the mean azimuth and standard deviation of the maximum horizontal stress for each well we have used statistical method that Wiprut and Zoback (2000) have suggested.

In this study, types of image logs which is the most reliable tool for determining of SHmax orientations are used. Orientation of the maximum horizontal stress determined totally in eight vertical oil wells, three wells in the Zeloi field and five wells in the Lali field (Fig. 4).

Drilled oil wells in here are mainly vertical and due to the presence of axial induced tensile fractures, confirms that the principal stresses are vertical and horizontal.

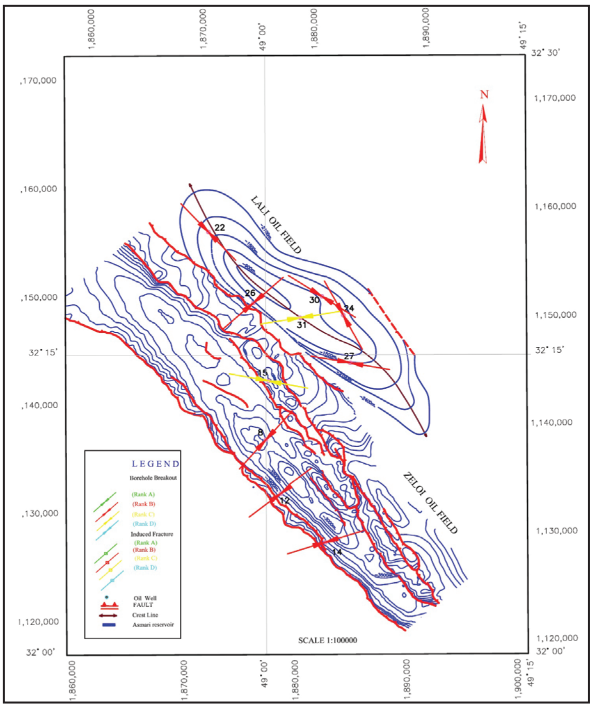


Fig. 4- Orientation of SHmax in the Lali and Zeloi oil wells in the Asmari Formation indicated by arrows from borehole breakouts and drilling induced tensile fractures. The color of arrows indicate the quality factor of data (Modified from N.I.S.O.C underground contour map-top of the Asmari formation).

All measurements are from 1550 to more than 4600 meters in depth which in general should remove near-surface influences such as topographic loading.

All studied wells were drilled to evaluate and produce the hydrocarbon from the Asmari formation and are nearly vertical wells or with low deviation although, Mastin (1988) has shown that for wellbore deviations up to 12° the azimuths of wellbore failures are approximately what they would be in a vertical borehole.

The Asmari reservoir in these area are mainly contains carbonate horizons and anhydritic lithology is relatively less in the Kalhor member, so natural and even induced fractures are intensely developed through carbonate intervals.

This issue should be noted that sometimes the regional stress is completely overprinted due to stresses localized to a certain area. Barton et al. (1988) proposed a methodology for determination of SHmax when the rock strength is known utilizing observations of breakout width. Consequently, the combination of unconfined compressive strength and breakout width allows the estimation of in situ stress magnitudes. This method has been successfully used by Zoback and his colleagues in many scientific studies

4- Elastic and Strength properties

Young's modulus and Poisson's ratio describe the stress or strain behavior isotropic elastic materials typically and therefore the rock mass can be characterized by these parameters (Harrison and Hudson, 2000). Rock mechanics analyses have been conducted assuming that the elastic moduli are the same in all directions the rock mass is completely isotropic.

The mechanical stratigraphy classification is used to calculate the mechanical properties of the rock or in-situ stresses differently in different rock types. The response of a rock to stress/strain is dependent upon rock type.

We calculated dynamic elastic properties by using density, compressional slowness and shear slowness data from density logs, dipole sonic measurements or even VSP data respectively.

Dynamic elastic properties (Young's modulus, Edyn and Poisson's ratio, υdyn) can be calculated using the following equations (equations 1and2), (Fjaer et al., 1992):

$$1)\quad \mathrm{E_d} = \frac{(\frac{\rho}{\Delta t_p^2})(3\Delta t_p^2 - 4\Delta t_s^2)}{\Delta t_p^2 - \Delta t_s^2}$$

$$2)\quad \upsilon_d = \frac{\frac{1}{2}(\Delta t_p^2 - 2\Delta t_s^2)}{\Delta t_p^2 - \Delta t_s^2}$$

The dynamic elastic properties can be calibrated against rock strength and measured static moduli. Static strains are always larger than dynamic strains and static moduli are always smaller than dynamic ones. The ratio of static to dynamic Young's modulus is dependent on porosity, confining pressure, degree of loading and other factors (Rasouli et al., 2011).

In order to convert the dynamic Young's modulus to static Young's modulus and calculate the UCS, a dedicated correlation related to Schlumberger was used in this study (equations 3and4). Because of the small difference of the Poisson's ratio in dynamic and static condition, it's assumed that their values are equal. The compressive strength of rock commonly is about ten times the tensile strength and tensile strength (T0) is in the range of 0.083 to 0.13 of the UCS.

In this study the tensile strength of rock derived in the basis of experimental results approximately is estimated 0.1 unconfined compressive strength.

$$3)\mathrm{E_s} = 0.4 * \mathrm{E_d}$$

$$4)\mathrm{UCS} = (3 + 4.1 * \mathrm{E_s})$$

5- Vertical Stress

The vertical stress (σV) at any point in a basin is equivalent to the weight of the overburden and is calculated by integration of the mean overburden density of the overlying rocks. Integration of a bulk density log taken after drilling will provide the vertical stress at depth according to (Zang et al., 2010):

$$5)\sigma_V = \int \rho g dz$$

Where ρ is the bulk density of the fluid-saturated rock. Density logs that are used for estimating σV should be as complete as possible and record little hole enlargement. In this study density log data were used to calculate vertical stress profile of reservoir.

In practically all wells there is an upper unlogged interval in Gachsaran, Mishan and Aghajari formations, so an average density for drilling cuttings of overlaying rocks, so an average density for drilling cuttings of overlaying rocks the Asmari reservoir have been used.

6- Horizontal Stresses

In order to model the magnitudes of the minimum and maximum horizontal stresses we used the poroelastic horizontal strain model (Erling et al., 1992):

$$6)\sigma_h = \frac{\upsilon}{1-\upsilon}\sigma_v - \frac{1-2\upsilon}{1-\upsilon}\alpha P_p + \frac{E_{static}}{1-\upsilon^2}\varepsilon_x + \frac{\upsilon E_{static}}{1-\upsilon^2}\varepsilon_y$$

$$7)\sigma_H = \frac{\upsilon}{1-\upsilon}\sigma_v - \frac{\upsilon}{1-\upsilon}\alpha P_p + \frac{E_{static}}{(1-\upsilon^2)}\varepsilon_y + \frac{\upsilon E_{static}}{(1-\upsilon^2)}\varepsilon_x$$

Where ε_x and ε_y are stress relaxation in the two horizontal directions, Estatic is static Young's modulus, P_P

and υ are pore pressure and Poisson's ratio respectively. For the biot's coefficient (α), value of 1 have been intended.

Two tectonic coefficients, ε_x and ε_y are horizontal strains, respectively in direction of maximum and minimum horizontal stresses and can be compressive or tensile. For applying a tectonic effect, we imposed a constant horizontal strain across in different zones of Asmari reservoir.

Often for calibration of the minimum horizontal stress, results of leak off test (LOT) or extended leak off test (XLOT) are used. For initiation of mud loss, creating or reopening of fractures is necessary and pressure must be equal or slightly higher than the minimum stress so the loss pressure of mud is controlled by minimum principal stress, as a result, mud loss data is used as one of parameters to calibrate the minimum horizontal stress.

ε_y The values of tectonics strain coefficients, ε_x and values were changed until to get most optimal mode and good match to recalculate the Shmin according to drilling evidences such as mud loss, flow of the fluid into the wellbore and also creating of shear and tensile fractures in the wellbore wall.

All deformations in the wellbore wall such as shear and tensile fractures are not necessarily dramatic from an operational point of view (Erling et al., 1992).

If the stress deviation somewhere exceeds the failure criterion for the rock, borehole failure will be occur.

For an intact linear elastic rock, the theoretical value for the fracture breakdown pressure is determined by Hubbert and Willis (1957) and has been used in numerous papers.

Theoretical models for breakout creation, suggested by Moos and Zoback (1990), these equations predict the initiation of the borehole breakouts along the azimuth of Shmin whenever the maximum effective circumferential stress, σθθmax at the borehole wall exceeds from compressive rock strength (Fig. 5).

In all of the mechanical earth models by using these rules and changing the amount of horizontal strains (ε_x and ε_y) related to condition of borehole wall for occuring the tensile and shear fractures, horizontal stresses are calibrated. It should be noted that this item will be intended simultaneously.

In-situ stress profiles of the Asmari reservoir for five wells was calculate in these two oilfields derived from integrated log data. In Lali-24 and Zeloi-15 oil wells, this definition has been shown in columns (10 and 11) in their related mechanical earth model (Fig. 6 and 12).

Tectonic stress reflects the amount of stress which is added to or subtracted from horizontal stress by tectonic plate movement. In the basis of poroelastic method for constraining of stress magnitude if tectonic strains are applied to rock formations, these strains add a stress component in an elastic rock. The poroelastic horizontal strain model, discussed by (Blanton and Olson, 1999) takes tectonic strains into account and therefore accommodates anisotropic horizontal stresses.

Generally for calibrating values for tectonic term a fracturing test data like a mini fracturing test must be available across different intervals of reservoir zones and unfortunately these data were not available for the Asmari reservoir. On the other hand, having looked in literature (Avasthi et al., 1971); (Sayers, 2009) reveals that for calculation of in-situ stress, tectonic term has relatively small value with respect to vertical stress and pore pressure and in despite of its importance is usually disregarded.

The amount of stress that tectonic activity adds to or subtracts from horizontal stress is mainly dependent on Young's modulus. In extensional area, tectonic often, subtracts from in-situ stress while in compressional area it adds to in-situ stress and causes to increase the in situ stress magnitude. Although in this study, any field measurements have not been performed for tectonic strain data but as it explained in previous paragraph, strain tectonics coefficients obtained after calibrating of horizontal stresses, indicate positive and negative values in X and Y horizontal directions which could be reason for tension and compression along two orthogonal directions. Structural position of the wells on these two oilfields is the main factor for different values of tectonics strains (Table 1).

Interpretation of new 3D seismic data indicates intensity of deformation and significant changes especially

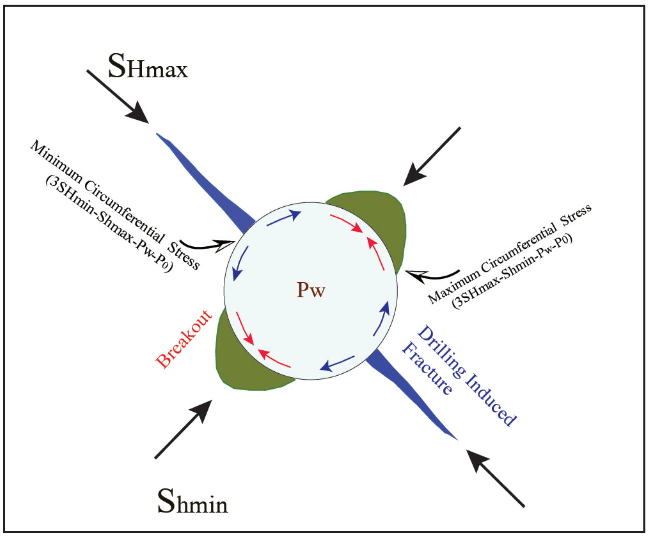


Fig. 5- Typical borehole breakout and drilling-induced fractures. The minimum and maximum hoop stresses are shown with related equations (Fjaer et al., 1992).

Table 1- Tectonics strain values in five oil wells of the Zeloi and Lali fields obtained from mechanical earth models.

Horizontal strain	ε_X	ε_Y
Well Number	**unitless**	**unitless**
ZE-15	**-0.7**	**0.52**
ZE-12	**-0.25**	**0.9**
LL-24	**-0.35**	**0.05**
LL-26	**-0.35**	**1.35**
LL-27	**-0.28**	**1.6**

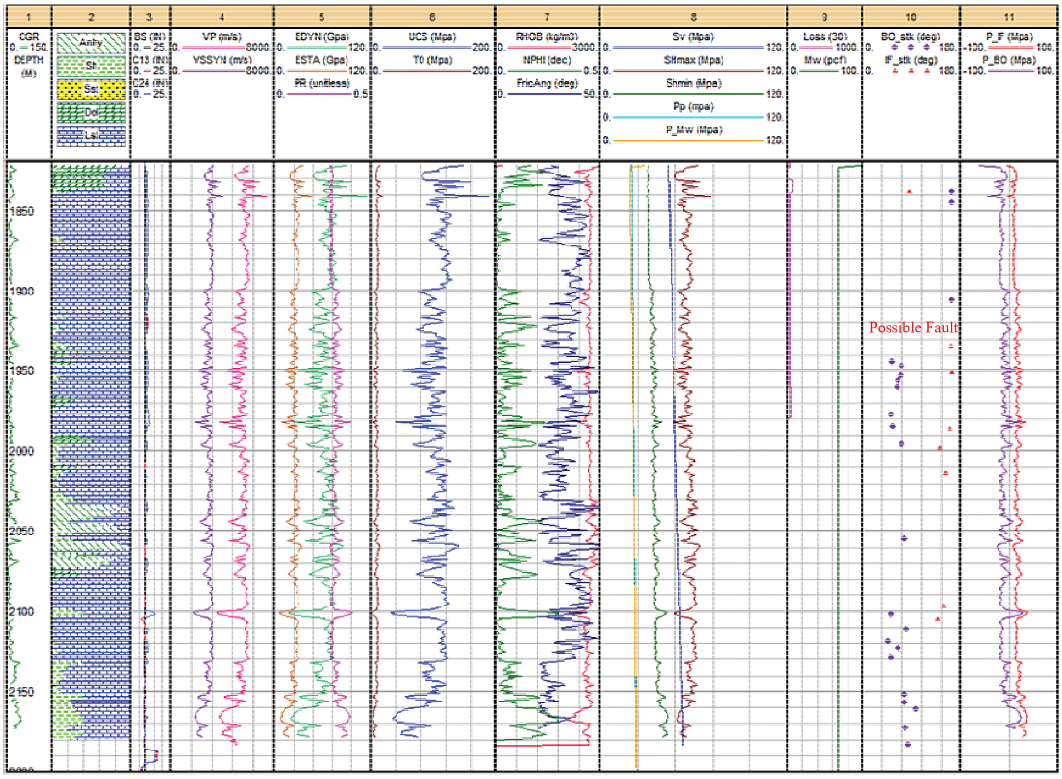


Fig. 6- Mechanical earth model of well LL-24 in main part of the Asmari reservoir.

7- Discussions

We proposed a method to use wire line log data and drilling documents or evidences to determine the elastic properties and magnitude of in situ stresses of the Asmari reservoir rocks and also the SHmax orientation.

The azimuth of SHmax on a subsurface structure as a hydrocarbon reservoir can vary significantly with depth or position and the orientation of local stresses may be changed abruptly over short distances in any area (Bruno and Winterstein, 1994). This phenomenon and along-depth stress rotations have been recognized in a wide variety of tectonic environments and rock types and have been explained by different processes that one of the most important of them is faulting the wells. The shear fractures intersecting the well, in some cases perturbing both the magnitude and the orientation of the wellbore stresses.

As well as possible the natural fractures give rise to perturbation of the stresses on the wellbore wall and causing induced tensile fractures to propagate non-axially along the borehole wall similar to what happened in the Well ZE-12. Non-axially Drilling-induced tensile fractures occur in vertical wells only if there is a significant difference between the two horizontal stresses (Fig. 7).

The occurrence of fractures intersecting or located close to the borehole may explain stress rotations such as these slip on faults causes the stress field surrounding the fault to be perturbed (Zoback, 2010) and (Barton and Zoback, 1994; Mariucci et al., 2002). As a consequence, faults and open fractures affect stress trajectories in the closer rock volume, so the smallest principal stress approaches the free surface at a right angle.

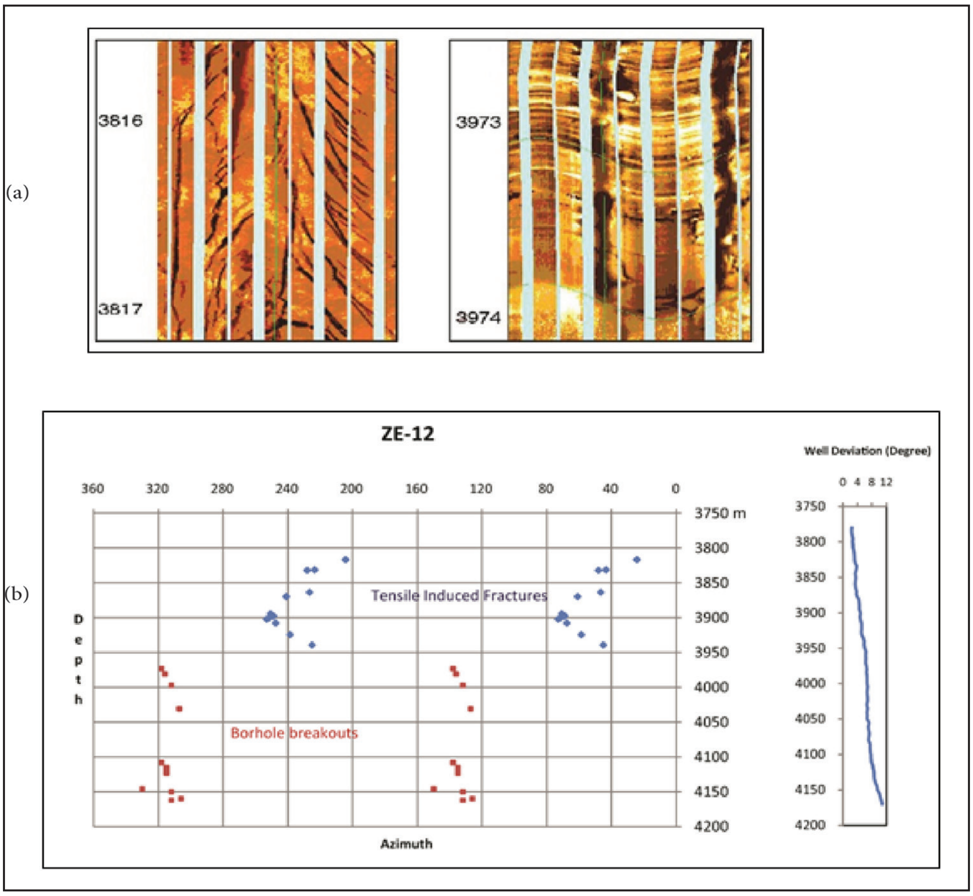


Fig. 7- Typical non-axially drilling-induced fractures and borehole breakouts in the left and right side in ZE -12 oil well respectively (a). Dramatic rotation of borehole failures at depth of 3900 m probably represents a fault performance. The maximum well deviation is less than 12º (b).

Fault slip may be induced by tectonics or may be enhanced by the increase of pore pressure on the fault during drilling (Carminati et al., 2010). The resulting stress perturbation to the wellbore stress depends on the borehole and remote stress orientations, the depth at which the fault intersects the wellbore, fault size and orientation. Although the effect of pore pressure changes on the magnitude of stress is well-known and relatively well understood but little is known about the reaction of stress orientations. (Skar and Beekman, 2003).

Case studies from normal, strike-slip and reverse faulting stress states indicate that nearly complete stress drop is required to match the observed breakout orientation anomalies, although in mechanical earth models constructed in this study it was not clearly observed. In the other hand, hydraulic fracturing data independently confirm the occurrence of near-complete stress drop on some faults penetrated by drilling.

Modeling of the observed interactions between breakouts and fractures can also be used to obtain information about the magnitude of in situ stress (Barton and Zoback, 1994).

There are significant stress orientations obtained in the Lali field appear to be quite heterogeneous with no overall obvious trend and follow the trend of possible faults in the region although on the structural map, any major faults have not been detected (Fig. 4). This may be due to the resolution of two-dimensional seismic data in this area. One way to readily determine if wells are being drilled in formations containing active faults is that fluctuations of stress orientation should be detected using observations of wellbore failure, such as breakouts.

In structurally complex reservoirs such as the Asmari reservoir of the Zeloi and Lali oilfields in Iran, direction of maximum stress vary significantly with both structural position and depth as it shown in several wells. There are stress orientation changes near faults in studied fields and probably follow the strike of faults which has not been recognized in the old maps.

The Lali structure is located in a faulted and complicated area where combination of reverse and strike-slip faults have crossed the anticline (Fig. 4, 8 and 11).

The effect of these faults in the studied wells (LL-22, 24 and 27) is an undeniable fact. In the Zeloi structure there are localized stress perturbations certainly due to slip on local faults where wells penetrate.

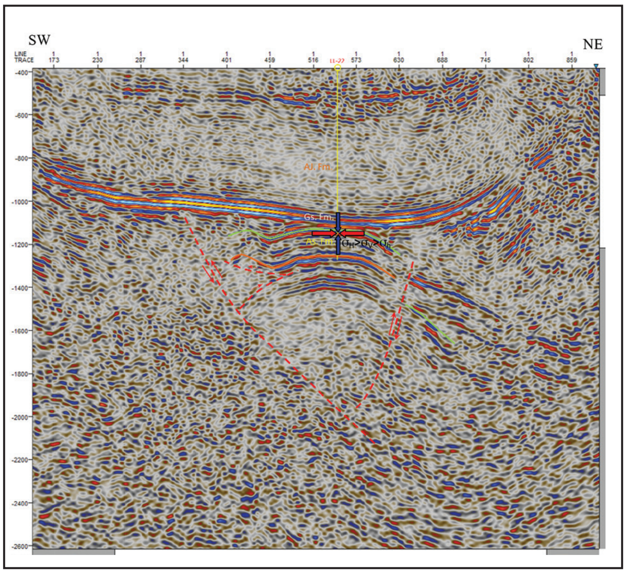


Fig. 8- 2D seismic line across the Lali field including well LL-22. The strike-slip stress regime in the Asmari formation (specified by green line in top) is estimated. In south flank, rabbit ear structures have been developed.

The stress anomaly in direction of maximum horizontal stress has been observed in four studied wells, ZE-15, Lali-22, 24 and 27. LL-24 and ZE-15 oil wells are case study of stress variation along depth which have been recognized by variations in borehole breakout and induced fracture directions (Fig. 6 and 15).

These perturbations are manifest as rotations of breakouts or drilling-induced tensile fractures azimuth along the wellbore as a function of depth and then turn to initial azimuth which cited in ZE-12 and 15 oil wells (Fig.7 and 9).

It is necessary to separate the referred wells according to the state of SHmax rotation. For instance, in well LL-22, SHmax direction in almost all logged interval indicates NW-SE direction which is relatively perpendicular to general well known direction of the maximum horizontal compressive stress in northern Dezful Embayment of the Zagros area, although In well ZE-15, 12 and 14, condition is different because SHmax direction indicates the significant local variations from top to total drilling depth in the Asmari formation (9 and 10).

In the other hand, maximum horizontal stress direction in three wells of the Lali field are completely different and unlike to regional stress direction in this area. It's may be due to the effect of the active faults near the referenced wells.

Well ZE-15 is one of the invoked wells for investigation of in-stress condition in studied area. This well is drilled with an inclination varying from 1 to 5 degrees toward NE. Carbonate layers show dominant dip azimuth of S62W and strike of N28W-S28E and average dip is dominantly 38 degrees however the spread of dip magnitude varies. However local variations in the dip magnitude are also observed.

In this angle ranges from a maximum 100 ± 20° at 4370–4450m to a minimum of 10 ± 10° at 4610 – 4630 m, because of although there is considerable uncertainty in our estimates of horizontal stress magnitudes. These variations in dip azimuth could be attributed to several reasons, high dip inclination which in this case is the consequence of the location of the study well near the possible fault has potential for variations in dip angle. Reservoir pressure from the initiation of production during almost three years, has dropped about 500 psi which is an important consideration. This evidence may prove existence of an important fault and it's performance.

In this well, the largest horizontal stress along a nearly 200 m of the Asmari interval have been rotated to the trend of major reverse faults or longitudinal normal crestal faults in the region which are known to be almost parallel to the Zagros structural trend (Fig. 9).

The wells drilled in areas subjected to such kind of unbalanced stress system often exhibit two types of well known borehole failures.

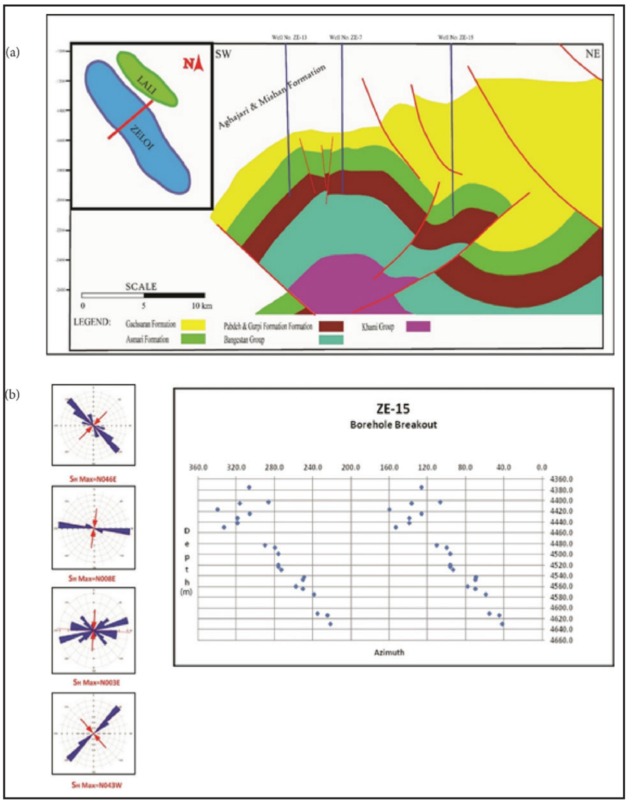


Fig. 9- Structural cross section in direction of NE-SW across the Zeloi field consist of ZE-7, 13 and 15 wells. The Asmari formation has been marked with green color (a). Azimuth of borehole breakouts vs. depth and mean orientations of SHmax in four discrete zones in the well ZE-15 (b).

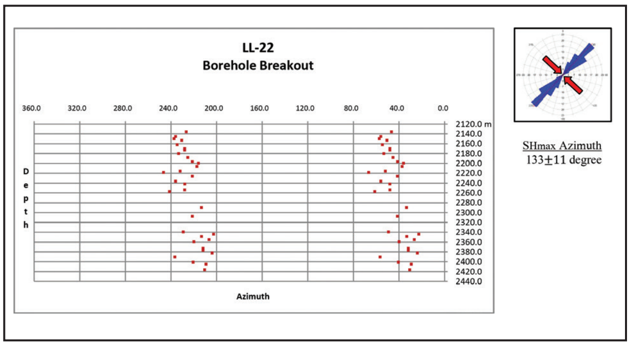


Fig. 10- The maximum horizontal stress direction in well LL-22 using the borehole breakouts indicates that the stress orientation in the well is completely different with well known trend in this region.

In order to achieve the desired results, mechanical earth models and available evidences from image logs in several oil wells are used to estimate the magnitude of stress and stress regime. Zoback (2010) by using a coefficient of sliding friction (0.6) has shown that the conditions for the occurrence of drilling induced tensile fractures around a vertical wellbore in the absence of excess mud weight are essentially identical to the values of Shmin and SHmax associated with a strike-slip faulting regime in frictional equilibrium.

As discussed former, breakouts form around a wellbore where the stress concentration exceeds the rock strength so we used breakout observations to estimate stress magnitudes.

Theoretical models for breakout formation, predict that borehole breakouts will initiate along the azimuth of Shmin whenever the maximum effective circumferential stress, σθθ max at the borehole wall exceeds the compressive rock strength, C0.

In LL-24 and ZE-12 oil wells which drilled into carbonate strong rocks, breakout's azimuth and width is measured in several desired. Fig. 13 is a plot of the magnitudes of horizontal stresses consistent with failure occurrences as a function of compressive (red contours) and tensile (blue contours) strength of the rock for a given depth (1944 m) in the well LL-24.

Altogether, Shmin resulted from mechanical earth models and these upper bounds to SHmax is consistent with strike-slip faulting stress regime (SHmax >Sv >Shmin). In other studied wells in the Lali field, similar condition have been considered.

The prepared stress models indicates that the stress regime in three wells of the Lali oilfield is strike-slip (σH>σv>σh) while in the Zeloi field, normal stress regime is prevailed (Figs. 14 and 15).

From a geologic perspective, the strike slip faulting stress state in compare with normal stress state in two adjacent fields implied that the most important factor is difference in reservoir depth which leads to considerable differences between the reservoir overburden stress.

Numerous strike-slip faults that occurred across the Lali field (well. LL-21) which have been interpreted in seismic sections (Fig. 11) indeed their influence on rotation of stress direction could change the stress regime.

Pre-existing faults in crest region in the Asmari reservoir of the Lali field in current stress field may also exhibit a strike-slip performance.gnitude measurement. Journal of

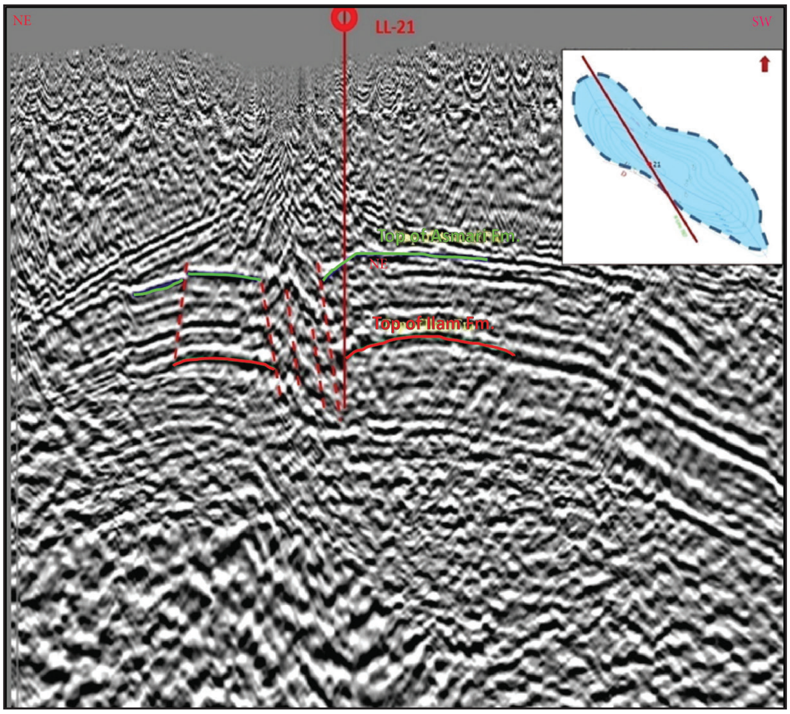


Fig. 11- Strike slip faulted zone near the well LL-21 in the Lali oil field in a random seismic line. Top of the Asmari and Ilam reservoirs have been shown.

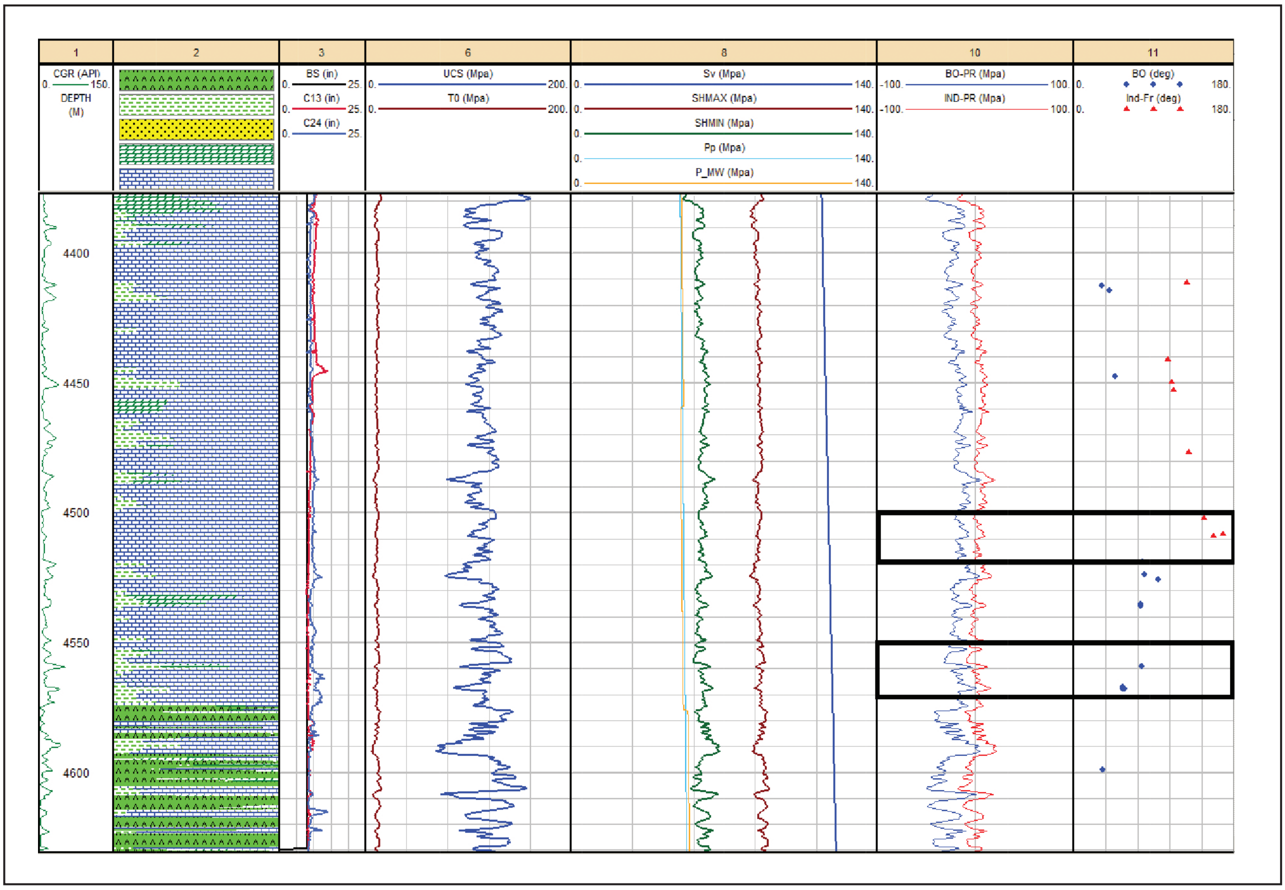
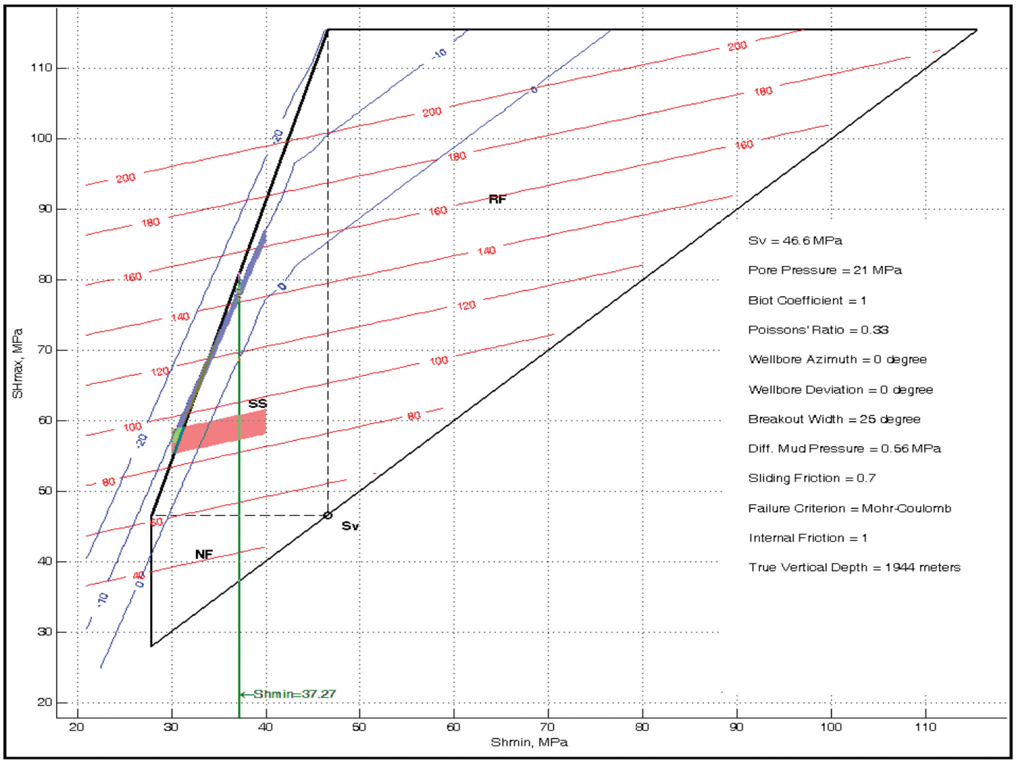


Fig. 12- The simultaneous use of shear and tensile fractures failure criteria created in the wellbore wall of well Zeloi-15 (4500 and 4560 m) for estimation and calibration of the magnitude of horizontal stresses.



Sv = 46.6 MPa
Pore Pressure = 21 MPa
Biot Coefficient = 1
Poissons' Ratio = 0.33
Wellbore Azimuth = 0 degree
Wellbore Deviation = 0 degree
Breakout Width = 25 degree
Diff. Mud Pressure = 0.56 MPa
Sliding Friction = 0.7
Failure Criterion = Mohr-Coulomb
Internal Friction = 1
True Vertical Depth = 1944 meters

Fig. 13- Output window of CSTR_1 module from GMI•SFIB software for a given depth in Lali-24 well. Strike-slip faulting stress regime has been inferred in depth 1944m.

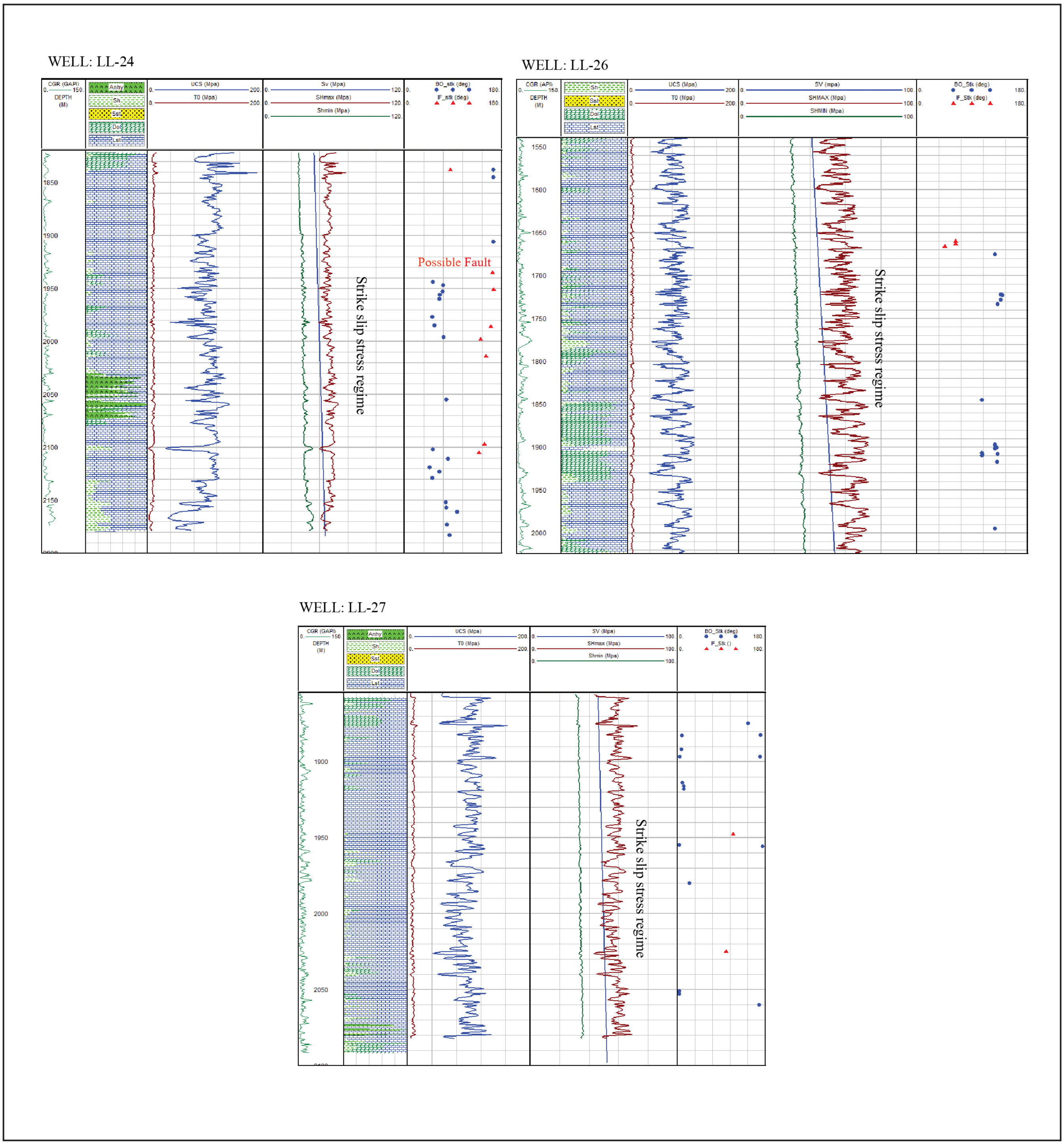


Fig. 14- Stress magnitudes profile. SHmax, Shmin and Sv represented by brown, green and blue lines respectively in the Lali oilfield wells (LL-24,26 and 27) which confirm strike-slip stress regime.

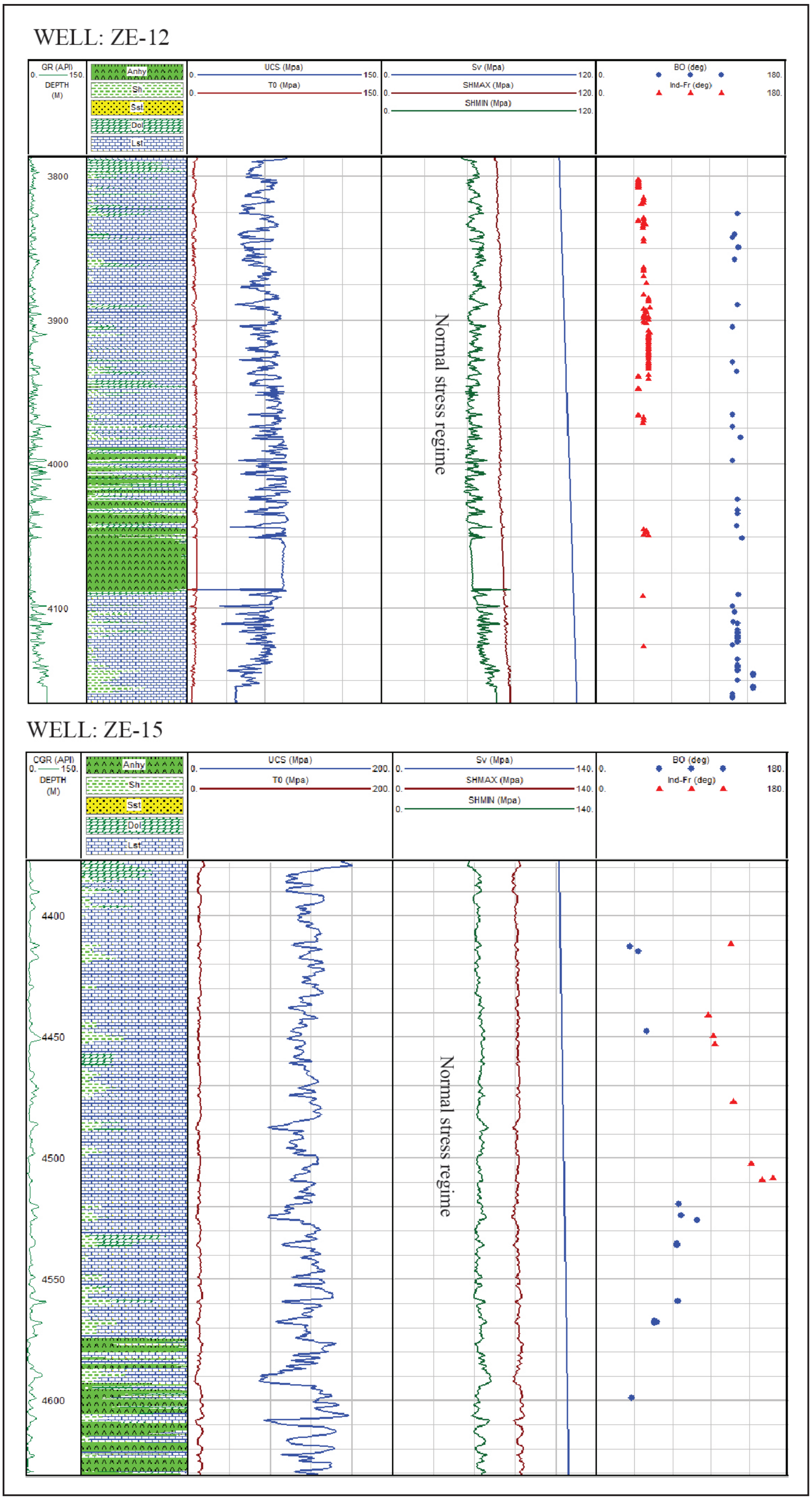


Fig. 15- Stress magnitudes profile. SHmax, Shmin and Sv represented by brown, green and blue lines respectively in the Zeloi oilfield wells (ZE-12 & 15) which confirm Normal stress regime.

8- Conclusions

In this paper the in situ stress field constrained in selected wells mainly using well data obtained from two development hydrocarbon fields in the south west of Iran as a case study. Integration of well log data, lab tests results and drilling data sets for appropriate geomechanical modeling of rocks is key in producing correct results. We demonstrated in the Zeloi oilfield, the vertical stress is the largest principal stress (σV= σ1) and significantly larger than maximum horizontal stress but in the Lali field, overburden stress is equivalent to intermediate stress (σ2).

The stress magnitudes calculated by using mechanical earth models are consistent with a model of strike-slip deformation in the Lali and normal stress regime in the Zeloi oilfield. Compressive borehole breakouts and drilling-induced tensile fractures are well-developed and imaged in several types of borehole image logs. The occurrence of near vertical induced fractures suggests that one principal stress is vertical and nearly parallel to the borehole axis. The maximum horizontal stress direction is known in the region is NE-SW in accordance with the general maximum horizontal stress trend on the basis of world stress map results in Zagros area.

The case study reveals that in particular, 1D mechanical earth modeling can be applied successfully utilizing the data sets typically available during the appraisal stage to prediction of stress magnitudes and integrate with structural elements such as structural position or faulting for assuming of stress regime.

The results of the study can be summarized as follows: (1) There are different stress regimes in the two adjacent fields in the Asmari carbonate reservoir consistent with the faulting observed in the area and depth difference of the reservoir formation. (2) Estimation of stress magnitude with Poroelastic method using well log data, tensile and shear fractures resulted from image logs in several oil wells can be useful for analyzing of in-situ regime in hydrocarbon reservoir formations. (3) Overburden stresses in compare with tectonic stresses which apply horizontally, plays more prominent role in determining the stress regime. (4) The analysis of dominant stress condition in studied fields which obtained from 1D mechanical earth modeling in key wells indicate that various phenomena including structural framework including both faults location and layers geometries, pore pressure changes and mechanical properties are main factors and have noticeable influence on stress state and in situ stress regime. (5) A comprehensive analysis of the three-dimensional stress state in the scale of an oilfield or specific formation, however requires the use of more complete data such as prestack geophysical data, seismic AVO inversion, extended leak off tests (XLOT) and etc., to be used to achieve increasing oil recovery, well trajectory planning and finally optimal management of hydrocarbon reservoirs.

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