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The Determination of In-Situ Stress Impacting on Field X by Well Logging Data

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Abstract: *In petroleum industry, the drilling process creates an external force impacting on the rocks at drilling at drilling position and adjacent area, then there is an elastic force from within the rock to balance the external force. Therefore, determine the in situ stress axis in order to predict the direction of the collapse in the borehole, the fracture generated by drilling ... Then using methods to minimize the impact of stress on the borehole by solutions while drilling, pipe and cement sealing techniques to improve the quality of wells.*

The method and researched data are proposed as follows: Determining the direction of maximum horizontal stress, minimum horizontal stress by image of collapse, fracture along the borehole by FMI geophysical data, CAST-V. Determine the intensity of vertical stress, maximum horizontal stress, minimum horizontal stress using data of depth, well pressure, pressure in hydraulic fracturing process.

The results of researching the in situ stress impacting on the field X show that the rocks is under maximum horizontal stress in the North-Northwest – South-Southeast direction, the minimum horizontal stress in the East-Northeast - West Southwest direction with the intensity value at the depth of about 3500m - 4500m respectively of the stress axis as follows: σv> σH> σh. Proposing to design the well orbit in the direction of North-Northeast – West-Southwest, so that the well can cut through many fractures caused by the in situ stress. Then the measurement results, which is include many parameters through fractures, will support for specific and detailed research.

Keywords: *In-situ stresses, collapse direction, maximum and minimum horizontal stresses, FMI and CAST-V documents, fractures and faults, well orbit, etc…*

1. INTRODUCTION

In the oil and gas industry, the drilling process creates an external force affecting rock at the drilling location and the vicinity, that results in an existance of elastic force from rock to balance with the impact external force. The influence level of elastic force (current stresses) is divergent in different directions, causing collapse of wellbore (breakout), longitudinal cracks ... reducing quality and technical requirements, that results in quality and accurate measurements reduction in the wells.

Therefore, determination of the current stress axis is to predict the direction of collapses in boreholes, cracked caused by drilling ... then giving measures to minimize the effect of stresses accross the borehole by placing solutions during drilling process, casing and cementing technique to improve the quality of wells.

There are many different methods to study current stresses, based on the collected data, this paper only uses geophysical data analysis. Borehole geophysical data analysis method is a visual method that detaily reproduces the depiction of the underground layers. Thereby, using the image data of the borehole collapse, the longitudinal cracks' zone generated by the drilling process in order to determine the horizontal stress axes qualitatively. Besides the pressure data of the various processes, hydraulic fracturing experiments were used to quantify the current stresses intensity affecting on the underground layers of the study area through calculating equations.

The main objective of this paper is to determine the azimuth and intensity of the current stresses field impacting on the X field where oil and gas exploration and production take place.

2. METHODOLOGY

2.1. In this Study, Two Main Contents are Presented

- Determine the azimuth of maximum horizontal stress, minimum horizontal stress by the depiction of wellbore collapse, longitudinal cracks across the wellbore on FMI, CAST-V geophysical data.
- Determine the intensity of vertical stresses, maximum and minimum horizontal stresses by using data of depth, bottom hole pressure (BHT), pressure during hydraulic fracturing process.

Proceed as follows:

2.2. Determine the Qualitative of the Direction and Direction

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The vertical stresses axis is considered to be obviously determined in the vertical direction. In the case of determining azimuth and direction of existing horizontal stresses, borehole geophysical data was used, however due to objective reasons, such as actual data is only measured at some depths and certain wells, therefore in this paper, only FMI data is used for reproducing depiction of cracks and fractures along the wellbore generated during and after drilling process in order to determine maximum horizontal stress axis. In addition, CAST-V data showed a collapse of wellbore that allows determining the minimum horizontal stress axis.

2.3. Determine the quantitative value of the current stresses

2.3.1. Determine Value of Vertical Stress

In order to determine the vertical stress, the Karota data of density **Rhob** is used. Based on rock density and the research depth, the vertical stress intensity can be determined according to the theoretical formula. However, this paper only uses experimental equations, therefore it is required to determine the depths with simultaneous display of other parameters such as pressure data which used to calculate the horizontal stress strength, collapse phenomenon, ... therefore the current stress model according to the main axes is fully determined.

2.3.2. Determine value of horizontal stress

In case of maximum horizontal stress, it is impossible to directly determine from any hydraulic fracture azimuth. The needed data is used to determine the maximum or minimum horizontal stress strength consisting of the wellbore pressure, the hydraulic fracturing breakdown pressure, or pressure from pilot test.

In addition, in order to apply the related equations or the experimental equations to determine the strength of the stresses, other data is needed to provide the necessary data for the calculation of the auxiliary parameters, for example □s (measured constant during slow wave propagation), □ (Poisson's coefficient), effective stress coefficient, vertical and horizontal wave propagation time corresponding with the equation for determining the coefficient of non-drainage ν_u to calculate the maximum horizontal stress in the equation proposed by Detournay (1998).

However, due to objective factors such as: within the underground layers, Rhob density data cannot be obtained, or it is obtained without accuracy, FMI CAST-V only shows collapse or fracture at certain depths or drilled wells, moreover some data could not be collected, such as data of Karota density, or core sample 's density analysis to determine vertical stress; data of the wave propagation velocity, drainage coefficient, ... Since the lack of data and materials, the papers only analyzed the current stress in the rock layer from 3500m to 4500m in term of depth, where existed the best and clearest collected data. These rock layers have enough corresponding data in order to conduct the calculation of the intensity value of the main stresses: vertical stresses, maximum and minimum horizontal stresses, azimuth and direction of the main stress axes.

3. RESULTS AND DISCUSSION

3.1. Basis Materials

The materials include:

1. Borehole geophysical data: FMI, CAST-V depictions from more than 15 wells in typical positions in the X field.

2. Hydrostatic pressure data, soil pressure surrounding wells in hydraulic fracturing pilot test.

3. The main equations for calculating stress intensity.

Due to objective reasons such as FMI, CAST-V measurements at some depths or some wells are not qualified as well as in the same well, the FMI measurement results meet requirement while CAST-V do not. Therefore, the study document only included FMI data from 14 wells, CAST-V data from 3 wells, pressure data from hydraulic fracturing of 12 wells with measured result at corresponding depths between wells meet requirements for research purposes.

In order to perform the current stress field model of the X field, the method of analyzing data from wells at different specific locations is used to give a relatively complete depiction. It also give the general view for the impact of current stress on wells, thereby, the properties of the current stress field of the X field are studied.

In order to determine minimum horizontal stresses, the analysis of FMI, CAST-V data gives depiction of longitudinal cracks in boreholes as well as borehole collapse is used to perform the horizontal stress direction. Determining the strength of horizontal stress, the value of fracture closure pressure in hydraulic fracturing and the hydraulic fracturing pilot test's pressure are necessary and high accuracy data.

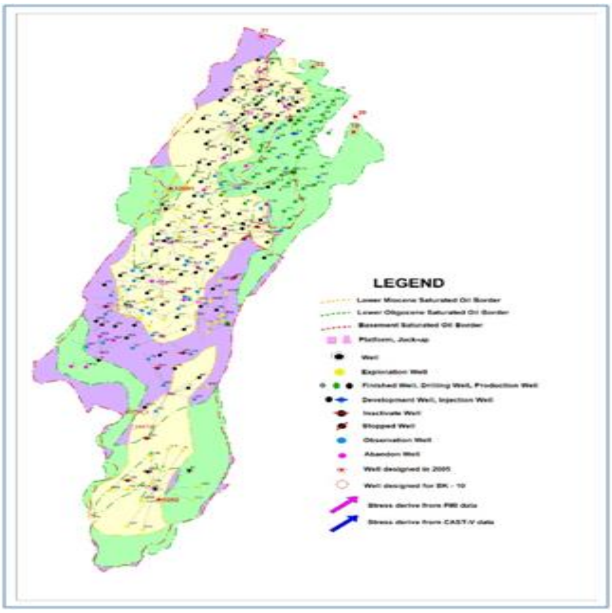

Fig1: Distribution of wells in X field

3.2. Model of Maximum Horizontal Stress

The method of analyzing FMI and CAST-V is based on the alteration of color on the recording tape, thereby determining the crack axis generated by the drilling process and the borehole collapse axis. Accordingly, the minimum (current) horizontal stress axis coincides with the borehole collapse axis, while the direction of the fracture generated by the drilling process is the maximum (current) horizontal stress axis.

3.2.1. Analyze the FMI Data to Determine the Direction of Maximum Horizontal Stress

Based on FMI data from these wells: X1, X2, X3, X4, X5, X6, X8, X9, X10, X11, X12, X13, X14, and X17, the fractures generated by the drilling process also coincides with maximum horizontal (current) stress axis. (Figure 2-3-4-5).

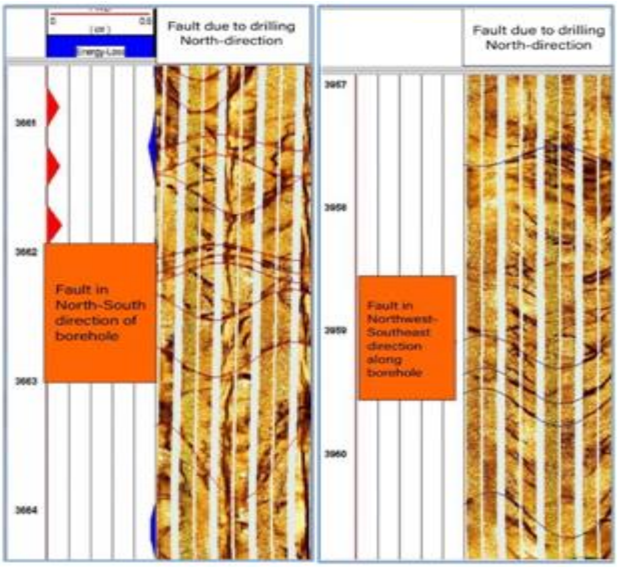

Fig2: Fault along boreholes: well X1 and X3

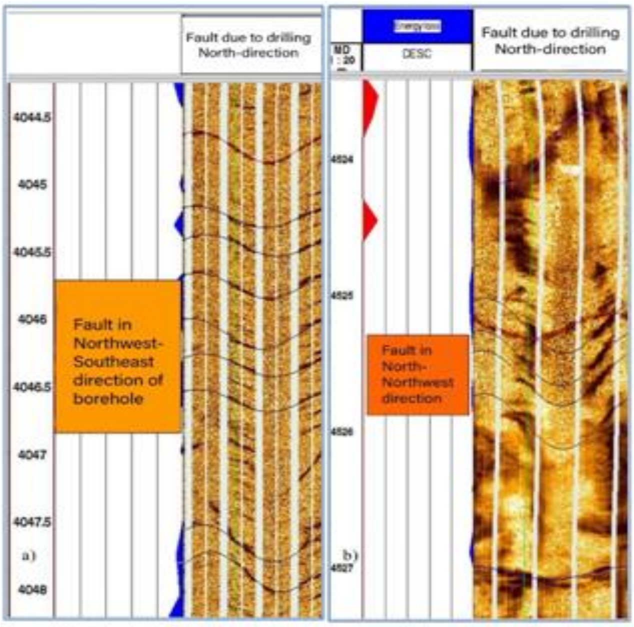

Fig3: Fault along boreholes: well X8 and X9

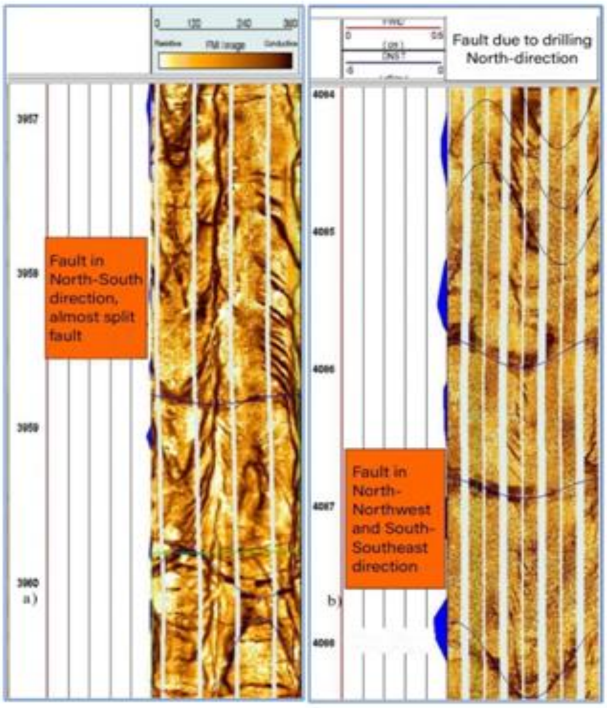

Fig4: Fault along boreholes: well X10 and X11

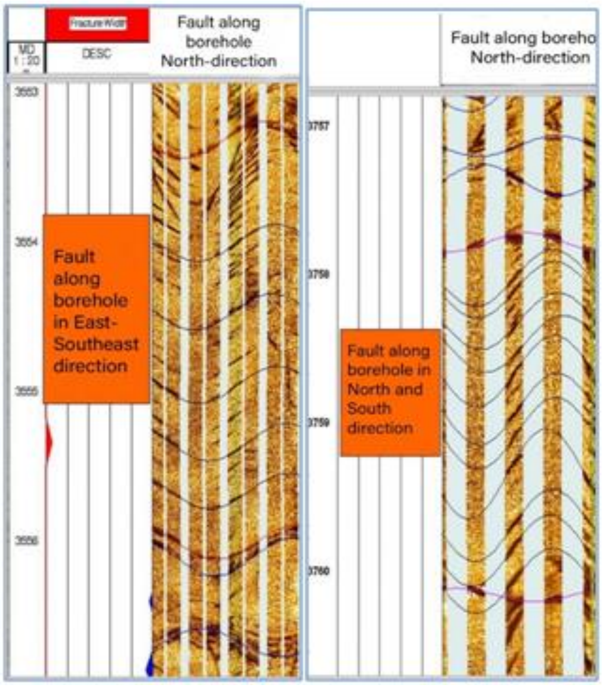

Fig5: Fault along boreholes: well X12 and X13

3.2.2. Model of Maximum Horizontal Stress from Analysis of Longitudinal Fracture Wells on FMI Data

By the analysis from FMI data in wells located at specific positions of BH field ranging from 3500m to over 4500m in term of depth i.e. in the basement rock, the current stress model with the maximum horizontal stress axis is recommended as North Northwest - South Southeast direction for X field. (Figure6).

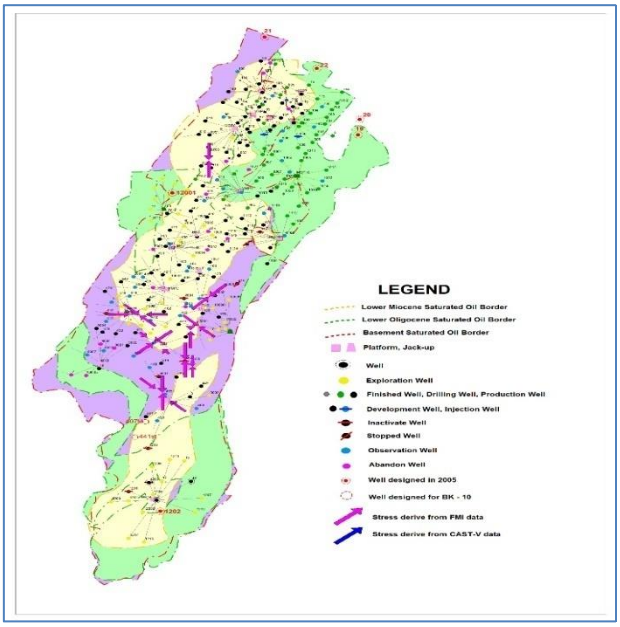

Fig6: The model suggests of maximum horizontal stress axis in the Xfield area

3.2.3. Model of Maximum Horizontal Stress from the Analysis of Borehole Collapse on CAST-V Image

In order to make the proposed maximum horizontal stress model of the X field more accurate, in addition to the database from the FMI image, the analysis of CAST-V data makes the recommended current stress axis model are more persuasive.

On the CAST-V data, the alteration of color gives a visual depiction of the waves propagation through the surrounding solid environment, it is used as a database in order to accurately identify borehole collapse. The method of well images transmission works based on the principle of re-transmission the well images (the degree of wellbore integrity or deformation) based on the principle of acoustic waves emission. Acoustic impedance z (MRayls) is visually performed by different colors showing the ability of wave interference or propagation through different solid layers:

- Red: shows solid medium where CAST-V waves pass through with a low acoustic impedance, z reaches 0 - 0.38 Mrayls, this is to indicate the presence of gas when measuring log in barefoot well as well as the presence of fractures and faults.
- Light blue (light): z = 0.38 - 1.15 MRayls indicates the presence of fluid but has a lower acoustic impedance than water (1.50MRayls), which indicate the presence of the mix between gas and liquid (gas - cut liquid).
- Blue: z = 1.15 - 2.30 Mrayls indicates the presence of water or drilling mud in the measured position.
- Yellow: z = 2.30 - 2.70 shows the medium with good permeability and has heavy drilling mud along with filter cake.
- Light yellow color: z = 2.70 - 3.85 MRayls indicates tight solid medium.
- Brown: z = 3.85 - 5.00 MRayls indicates CAST-V waves travel through the cement layer on the borehole wall.
- Based on the colored alteration on the CAST-V data of the wells, there are an ease and visualization for determining the location of a borehole collapse, fracture or longitudinal crack across wells. (Figures 7-8 -9-10-11) They also happen in case of FMI data.

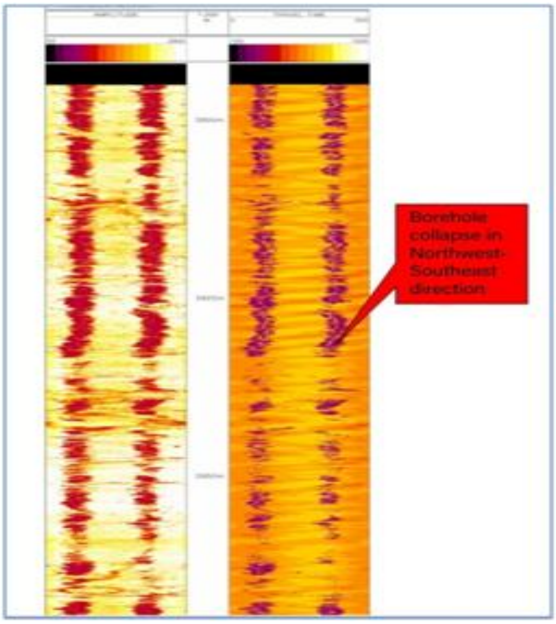

Fig7: Borehole collapse in well X15

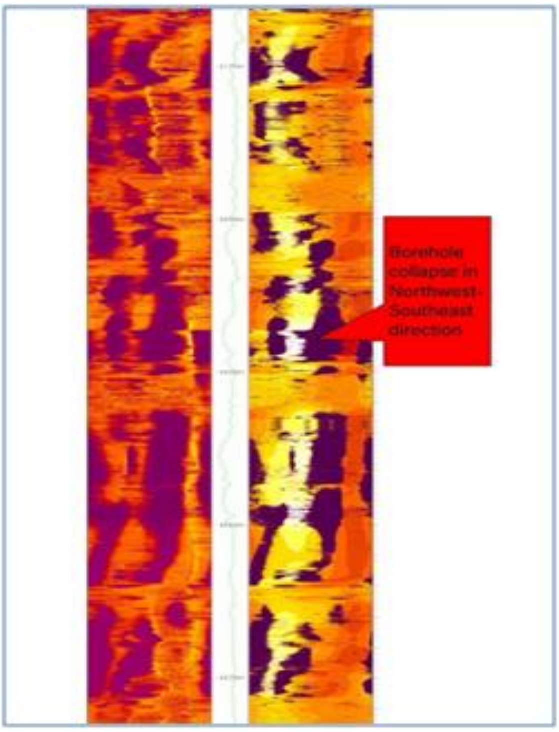

Fig8: Borehole collapse in well X16(4075- 4150m)

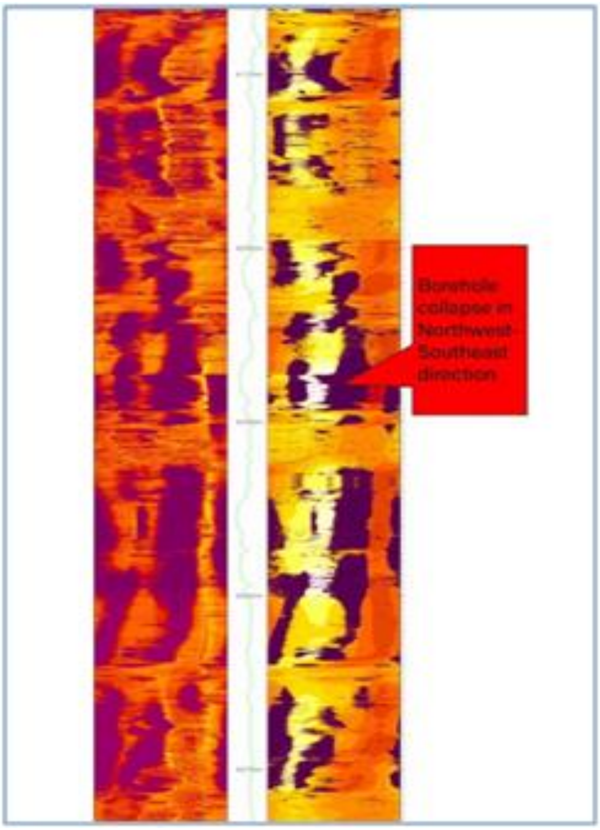

Fig9: Borehole collapse in well X16(4175 – 4275m)

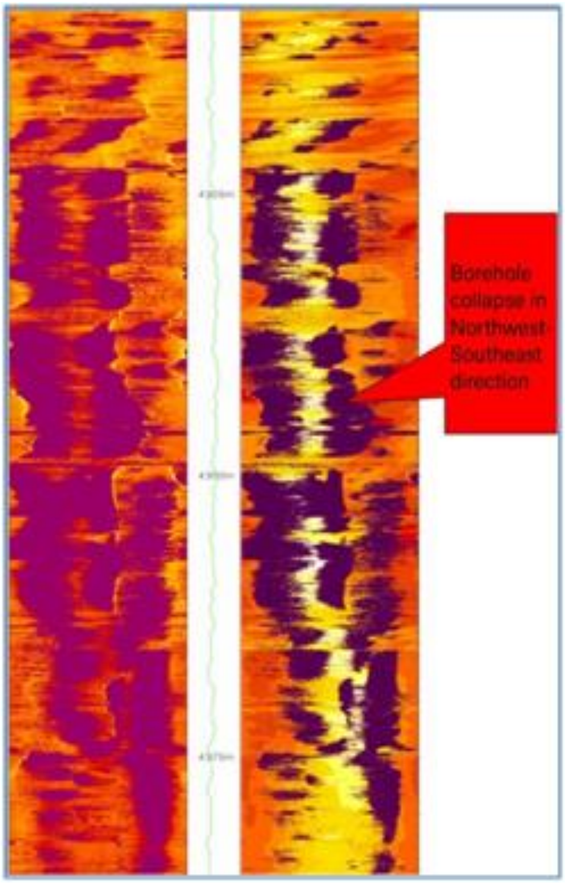

Fig10: Borehole collapse in well X16(4325 – 4375m)

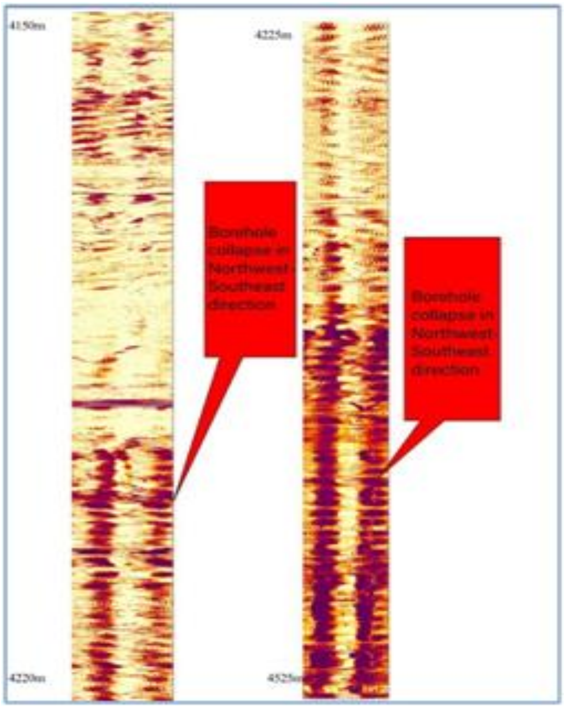

Fig11: Borehole collapse in well X17

At locations where exist the borehole collapse phenomenon, it allows to determine the azimuth of the minimum horizontal stress axes. According to the theory of stress field, there is an obviousness for determine the maximum horizontal stress axis when plotting the azimuth of the minimum horizontal stress axis on the map of the study area – X field (Figure 11).

From the analyzed CAST-V data, the statistics are as follows:

• The axes of longitudinal fracture across the borehole have the azimuth of Northwest, Northwest - Southeast in term of the maximum horizontal stress axis.

• The axes of the borehole collapse have the azimuth of Northeast - Southwest direction in term of minimum horizontal stress axis.

The above analysis results show the model of the minimum horizontal stress axis with the azimuth of Northeast - Southwest and the maximum horizontal stress axis with the azimuth of North Northwest - South Southeast, which coincides with the analysis results from the FMI data. Therefore the azimuth of the maximum horizontal stress of the BH field is the North Northwest – South Southeast.

Comparing with the current stress field of the Cuu Long basin: the maximum horizontal stress of the Cuu Long basin is North Northwest – South Southeast, therefore the stress model of the BH field is considered to be reasonable and governed by larger stress scale of the Cuu Long basin.

3.3. Maximum Horizontal Stress Model Recommended from FMI and CAST-V Data Analysis

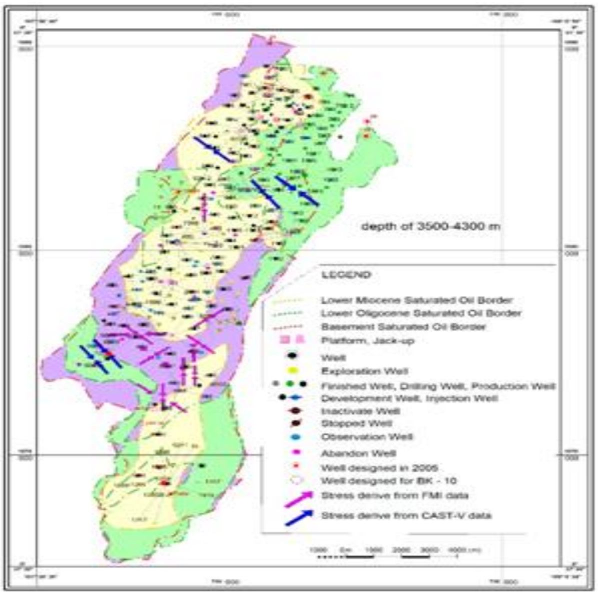

Fig12: The model of maximum horizontal stress (pressing) of the X field has the direction of North-West - South-East

3.4. Determine the Intensity of Vertical Stress

Because it is governed by the current stress field of the Cuu Long basin, the field has the same current stress axis as the Cuu Long basin ones, so it is possible to apply the empirical equation to calculate the vertical stress of the Cuu Long basin to approximate the intensity of vertical stress of X field.

Determination of the intensity at 3500m in term of depth within a homogeneous granite basement is obtained for two reasons: almost relevant data to determine the maximum and minimum stress intensity are collected clearly and completely in the basement rock; besides, the basement rock has a stabilization in terms of structure as well as the texture and petrographical composition of the rock, and the stress field affecting on the rock is the same follow the increase of the depth.

Apply the formula (Đỗ Quang Khánh, 2018):

$$\sigma v = 0.0093 * (z) 1.1066 \quad (MPa) \quad (1)$$

Table1: Table of vertical stress values at different depths below sea level

Well / Depth	X1	X2	X3	X4	X8	X7	X9	X10	X11
3650	81.379	81.379		81.379			81.379		81.379
3700		82.614	82.614			82.614			82.614
3750			83.850		83.850		83.850	83.850	
3800	85.088			85.088		85.088			
3850		86.328		86.328	86.328				86.328
3900	87.569					87.569		87.569	
3950			88.813			88.813	88.813		
4000	90.058				90.058			90.058	
4050		91.304		91.304			91.304		91.304
Average Value	86.024	85.406	85.092	86.025	86.745	86.021	86.337	87.159	83.440

Conclusion: The value of vertical stress from 3650m to 4050m in term of reaches the average value 85 - 86 (MPa).

3.5. Minimum Horizontal Stress Intensity

According to the formula σh = Pc (2) the minimum horizontal stress is equal to the closure pressure in the hydraulic fracturing or cracking experiments. From the pressure values measured in the wells when conducting the pilot test, determine the average value of the minimum horizontal stress. Values are determined from the graph shown in Figure 13. and figure 14-15 and 16 with corresponding wells.

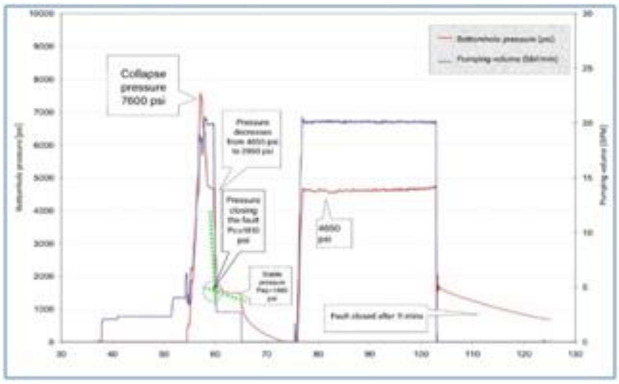

Fig13: Determine pressure for closing the fault by data of pressure drops in well X6

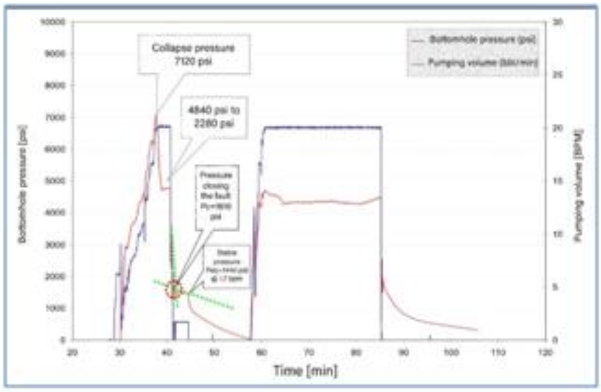

Fig14: Determine pressure for closing the fault by data of pressure drops in well X8

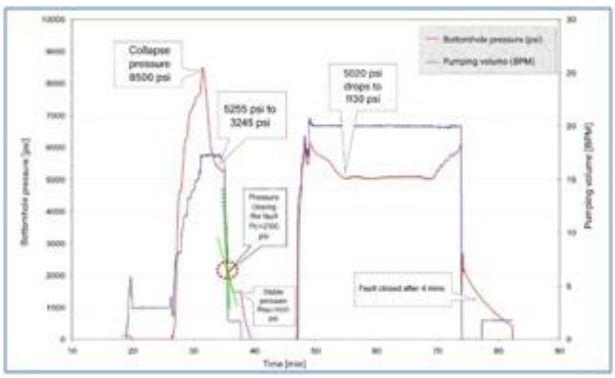

Fig15: Determine pressure for closing the fault by data of pressure drops in well X15

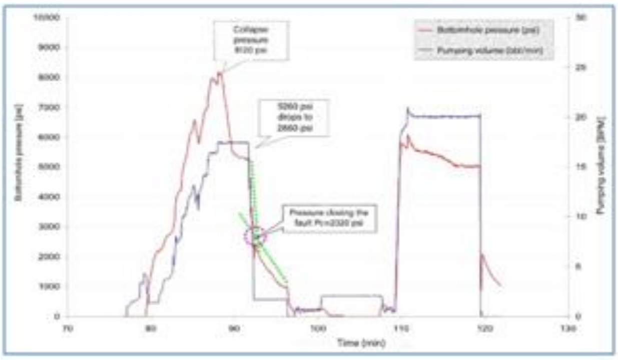

Fig16: Determine pressure for closing the fault by data of pressure drops in well X17

Table2: Closure pressures at certain wells

X6	X8	X15	X17
P_C=18 10 psi	P_C=1610 psi =11.101MPa	P_C=2100 psi =14.479MPa	P_C=2320 psi =15.996MPa
Mean closure pressure value: P_c = 13.514 MPa			

The minimum horizontal stress intensity directly base on the hydraulic fracturing pilot test analysis at certain wells and closure pressure from experiment (which equal to minimum horizontal stress). Data uses to illustrate closure pressure values at certain wells in order to determine minimum horizontal stress at research area: Lower Oligocene has average value of (1610; 2320) psi or (11.101; 15.996) MPa.

3.6. Maximum Horizontal Stress Intensity

In addition to the equations of the pressure analysis methods from the hydraulic fracturing or pilot tests, the stress value can be determined according to the experimental equation [15]:

$$\sigma_h = 0.0135 * z + \alpha \frac{1-2\nu}{1-\nu} * (P_p - P_h) \tag{1}$$

$$\sigma_H = 0.0155 * z + \alpha \frac{1-2\nu}{1-\nu} * (P_p - P_h) \tag{2}$$

With:

By the experimental equation (2) we can determine the maximum horizontal stress with the corresponding values for the depths below sea level ZB = 50m as follows:

Table3: Table of values of maximum horizontal stress intensity at the X field

Well / Depth	X1	X2	X3	X4	X8	X7	X9	X10	X11
3650	56.575	56.575							56.575
3700			57.350		57.350	57.350			
3750	58.125			58.125			58.125		
3800			58.901			58.901		58.901	
3850				59.675			59.675		
3900	60.451		60.451			60.451			60.451
3950		61.225			61.225		61.225	61.225	61.225
4000	62.000		61.225		61.225			61.225	
4050		62.775		62.775			62.775		62.775
Average	**59.288**	**60.192**	**59.48**	**60.192**	**59.933**	**52.234**	**60.450**	**60.450**	**60.257**

The maximum horizontal stress intensity of the BH field ranges from 59 MPa to 60,450 MPa. Therefore within this area, the intensity of the minimum horizontal stress is much lower than the value of the maximum horizontal stress.

Combining the pressure drop data and the elastic porosity coefficients, calculate the value h and at the respective pressure conditions.

Table4: The calculated results for the minimum horizontal stress under formation pressure is equal to hydrostatic pressure.

Well	ν	α	$\alpha\frac{1-2\nu}{1-\nu}$	P(MPa)	S_h at place have pressure drop (MPa)	S_h at place where pressure is equal to Hydrostatic pressure (MPa)	S_H at place have pressure drop (MPa)	S_H at place where pressure is equal to Hydrostatic pressure (MPa)
A	0.08	0.785	0.72	-3.61	44.83	47.42	53.6	56.22
B	0.126	0.7	0.6	-4.4	50.12	52.76	56.19	58.82

From the table above it can be observed that the minimum horizontal stress increases with depth under hydrostatic pressure condition. The mean value of the mean minimum horizontal stress of the X field Sh = 36.19 Mpa, the maximum horizontal stress Sh = 57.52 MPa at the place where the pressure is equal to the hydrostatic pressure.

Compare with the average value of the current stress intensity calculated from the experimental equations when the wall pressure is not equal to the hydrostatic wall pressure:

P_p = Ph	$P_p \neq$ Ph
σ_H = 57.52 MPa	σ_H = (59 ÷ 60.45) MPa
σ_h = 36.19 Mpa	σ_h = (11.101 ÷ 15.996) MPa

Comment: the value of maximum horizontal stress in two above cases has not large difference. In contrast, there is a significant difference between the minimum horizontal stress values: when the formation pressure is equal to the hydrostatic pressure, the hh is relatively large and twice more than the value in the case of formation pressure before pump pressure differs from hydrostatic pressure.

However, the vertical stress axis is always 1, the maximum horizontal stress (pressing axis) reaches the intermediate value 2 and the minimum horizontal stress acts as 3.

In summary, the main stresses of the X field include vertical stresses, maximum and minimum horizontal stresses: $S_v \geq S_H \geq S_h$. This is the stress mechanism of the normal fault, consistent with the stress value of the Cuu Long basin. (Fig.4.16.)

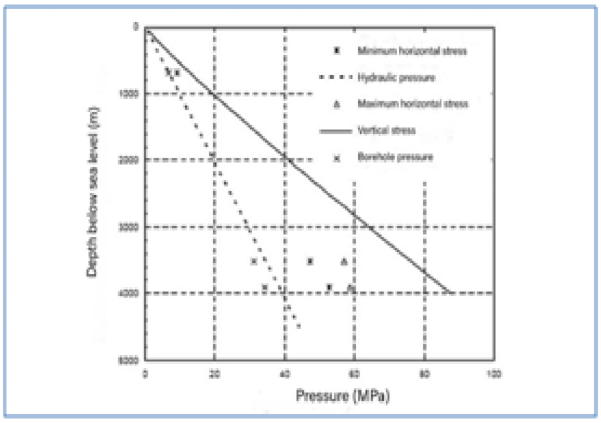

Fig17: The strength of the three basic stresses of the Cuu Long basin

From the qualitative results of the maximum and minimum horizontal stress models as well as the quantitative results of the maximum and minimum horizontal stress values, it can be confirm that the stress model of the X field is affected by the current stress field impacting on Cuu Long basin. The proposed X field stress model is a part of the overall stresses in Cuu Long basin, research on stress fields of the X field is the study of stress fields of Cuu Long basin at local scale and typical case. In contrast, the study of stress on the Cuu Long basin can interpolate the local stress field in the X field. The stress field of the X field locates in the impact range of the stress caused by the Cuu Long basin.

4. APPLICATION

4.1. In Oil and Gas Exploration

For the area of X field, in particular fractured Basement Reservoir, the in-situ stress field has been studied: the maximum horizontal stress axis is northwest-northwest-southeast-southeast (Figure 18). Therefore, the exploration deep wells should be designed along the northeast-southwest direction ie in the direction of the minimum horizontal stress axis because then the information from the wells includes many fault systems and fracture caused by the in-situ stress field, allows the property of the present stress field to be determined clearly and continuously, providing more detailed data for a more complete current stress field.

At the same time, information about the maximum horizontal stress is data for the design of subsequent wells using anti-tubing techniques or proper cement filling to drill wells in the direction of the Northeast-West minimum horizontal stress. The southwest can minimize or limit the landslide because in this direction, the soil and rock are easily eroded, making the wells not meet technical requirements and the measurement results in this direction are not qualified for the purpose of the studyas a measure to reduce the appearance of fractures along the well wall in the North-West-South-Southeast direction.

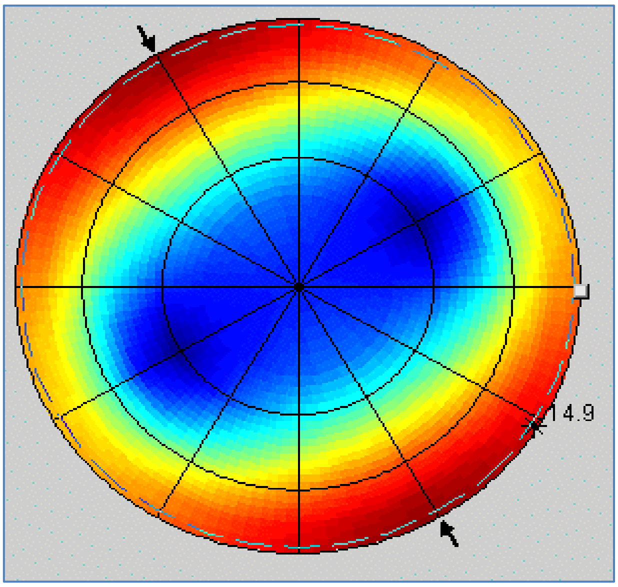

Fig18: Model of maximum horizontal stress of X field

4.2. In Oil and Gas Production

In the oil and gas production in general and the clean-up in particular, the study of the in-situ stresses is meaningful as a data to help the production engineers carry out the perforation, hydraulic fracturing as well as clean-up to achieve higher efficiency, more efficient: the direction of perforation or hydraulic fracturing should coincide with the direction of the maximum horizontal stress axis.

5. CONCLUSION

The study results of the in-situ stress field impacting on X field show that reservois in X field is subjected to maximum horizontal stress in the Northwest - South Southeast direction, the minimum horizontal stress in the East East direction. North - West South West with the intensity value at the corresponding depth about 3500m - 4500m of the main stress axes as follows: $\sigma_v >$ $\sigma_H > \sigma_h$which:

σ_{v} = 85 – 86 Mpa.

σ_H =59 MPa – 60.450 Mpa.

σ_{h} = 11.101 MPa–15 .996 Mpa.

In oil and gas exploration, especially well drilling, it is necessary to pay attention to drilling techniques to ensure the wells limit or minimize the collapse of the wells in the direction of the Northeast - West. South (minimum horizontal stress axis), the well-wall crack phenomenon in the direction of North-West North-South-Southeast direction. It is recommended to design the orbit of the wells in the direction of the Northeast - West Southwest so that the well can cut through many fractures and faults caused by the in-situ stress, then the measurement results include many passing parameters fractures and faults will support more specific and detailed research.

In oil and gas production, for X field, hydraulic fracturing model and clean-up are proposed to be carried out in the direction of maximum horizontal stress: North-West - South-Southeast.

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