3D SEISMIC GEOMECHANICAL MODELLING FOR FRASNIAN HOT SHALE BOREHOLE STABILITY ANALYSIS

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Abstract:

Construction a modern well in time without any problems like mud losses, kick, stuck pipe and tight hole represent a technically and economically challenging not only for drillers but for all disciplines. For better understanding the main reasons possible for these borehole stability problems and to predict equivalent mud weight window for next offset future wells of the field, building a mechanical earth model was essential step by representing the state of stress (Min/Max horizontal stress, Overburden), pore pressure and the rock mechanical proprieties (Young's Modulus, Poisons 'Ratio, UCS, internal friction angle, cohesion). In this work a geomechanical model was developed for X field based on wireline logs measurements, formation evaluation, drilling data, which was conducted us to study the behavior of rock failure around the wellbore and to estimate the safe and intact mud weight window using Mohr-coulomb failure criteria.

This study demonstrates also the necessity of the core analyses and field tests such as the triaxial test and the Leak off test to reduce uncertainty of the results and to improve the mechanical earth model especially when studying lithology with high heterogeneity.

Introduction

Wellbore stability can be characterized as preventing mechanical failures and falls due to mechanical stress in the well. To maintain wellbore stability the well must be drilled with the appropriate mud weight to avoid wellbore instability problems such as collapse, kick, and wash-out or tighten which increase drilling costs, stopping production, and eventually well loss. The mechanical properties of the rocks, the vertical and horizontals stress of the region, and the pore pressure computed from acoustic impedances and bulk density estimated from 3D seismic inversion are the most important parameters of the wellbore stability analysis. Core data are used to establish the relationship between dynamic and static mechanical parameter and the well log data are used to build 1D geomechanical model and to estimate safe mud window in the well.

Geological setting

The interest zone appears as a vast anticline dome near the Northeastern end of the intra-carotic basin of Timimoun with regular and continuous sedimentation throughout the Paleozoic from the Cambrian to the Carboniferous. The Meso-Cenozoic caps these Triassic deposits in the Plio-Pleistocene to a much lesser thickness. We note the existence of important dune ridges cover the northern part of the region known as (Grands Ergs Occidental) which partly covers the desolate surface of the Tanezrouft plateau and Erg Iguidi on the borders of Mauritania.

This Middle Cretaceous (Albian–Thoronian) reservoir is one of the carbonate units of the Dezful embayment (Fig. 1) in the Zagros Basin, with an average thickness of 640 m.

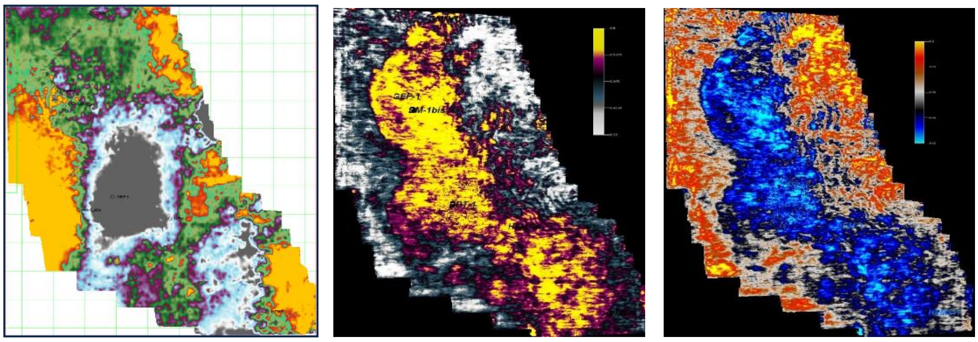

Figure 1. *Thickness map (a), facies (b) and total porosity distribution (c) at Frasnian hot shale Formation.*

Geomechanical Modelling

The purpose of this study is to build a geomechanical model for wellbore stability analysis starting with 1D model using well log data and then extended the study to 3D model using acoustic velocities and bulk density generate by inverting 3D seismic data. We start with calculating vertical stress and pore pressure, than the minimum and maximum horizontal stress which calculated using poroelastic equations.

Figure 2 illustrate 1D Geomechanical model results with Safe mud window for Frasnian hot Shale formation.

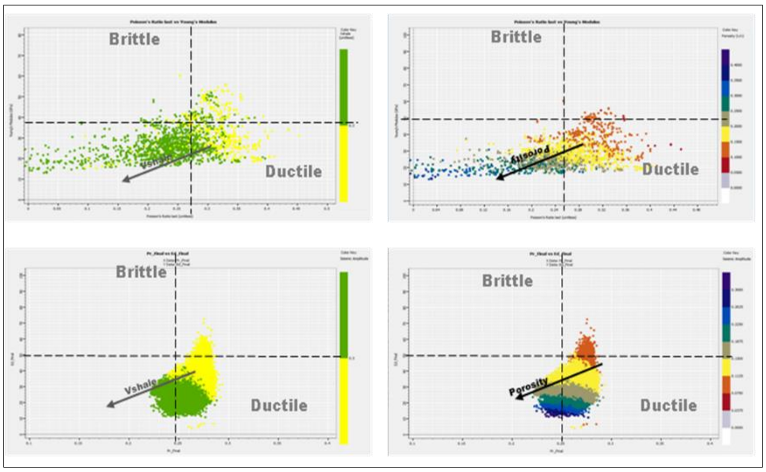

Figure2: *Thickness map-total porosity (a)*

- **Mechanical properties of the rock**

Rock mechanical parameters can be divided into two categories: elastic and strength parameters. Elastic parameters such as Young's modulus, Bulk modulus, Shear modulus, and Poisson's ratio which express the behavior and sensitivity of rock to variability or failure under stress. They can be calculated both statically and dynamically using laboratory tests on drilling core in plug scale (uniaxial or triaxial).

$$E_{dyn} = \rho V_s^2 \frac{3V_p^2 - 4V_s^2}{V_p^2 - V_s^2} \quad \text{...(1)} \qquad \upsilon_{dyn} = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)} \quad \text{...(2)}$$

Where E_{dyn} is dynamic Young's modulus, ν_{dyn} is Dynamic Poisson's ratios, ρ is density, V_p and V_s are compressional and shear velocity, respectively.

$$K = \frac{E}{3(1-2\upsilon)} \quad \text{...(3)} \qquad G = \frac{E}{2(1+\upsilon)} \quad \text{...(4)}$$

The rock strength parameters are the Uniaxial Compressive Strength (UCS) and Tensile Strength. In this study, (UCS) was estimated using Horsrud model in shally formation based on P wave velocity. UCS in Hot shale Frasnian formation mechanical tests and FMI were used for calibration.

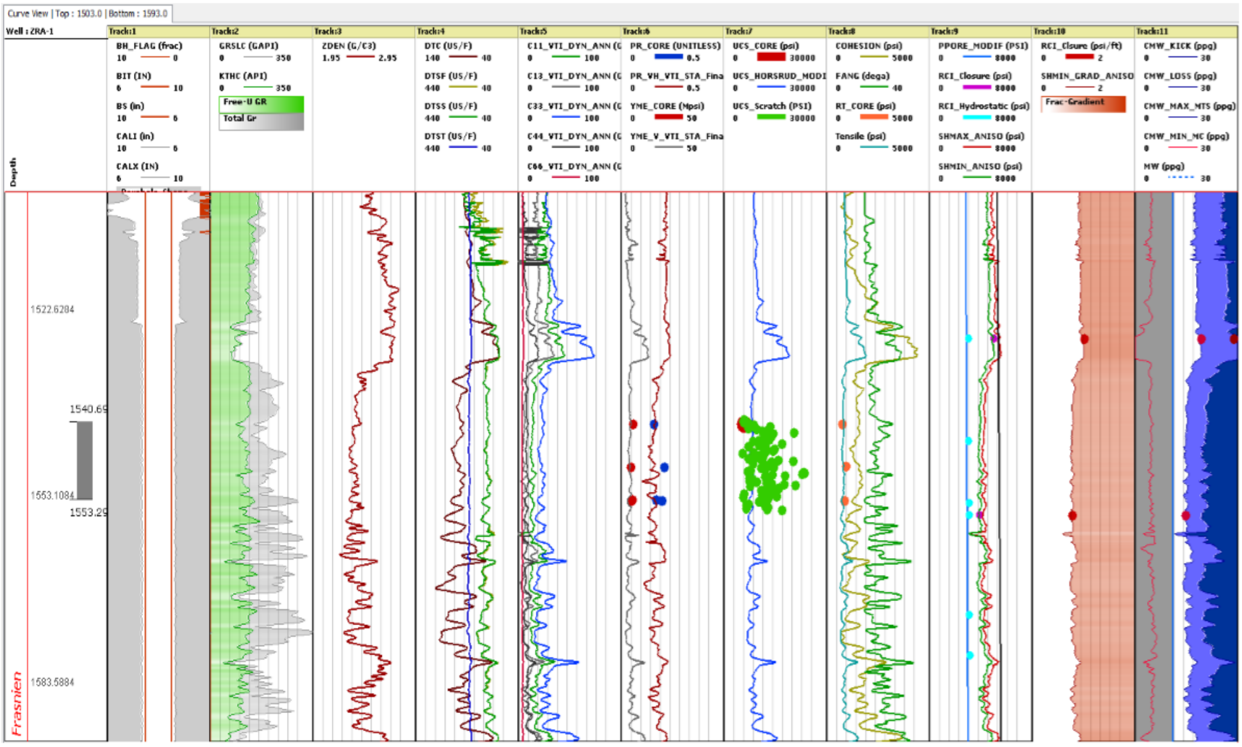

***Figure 3**. 1D geomechanical model computed for wellbore stability analysis. Last column shows: Shear failure pressure (CMW_MIN_MC), kick pressure (CMW_KICK), mud loss (CMW_LOSS), break down pressure (CMW_MAX_MTS and MW (MW) in ppg*

Tensile strength (T0) is typically measured from 1/8 to 1/12 of the uniaxial compressive strength (Zoback 2010). In this study, Tensile strength is known to be 1/10 of UCS.

$$UCS = 111.65 \left(\frac{304.8}{DTCO}\right)^{2.93} \quad .....(5) \qquad T_0 = 0.1\, x UCS \quad .....(6)$$

- **Vertical stress and pore pressure**

Overburden pressure at each point in the subsurface is due to the weight of upper layers and the role of different factors, such as rock type, porosity type, rock density, and the density of fluid filling the pores, digenetic impact tectonic factors…etc. The vertical stress (S_V) at a specific depth (Z) is determined from Eq. 7 as following:

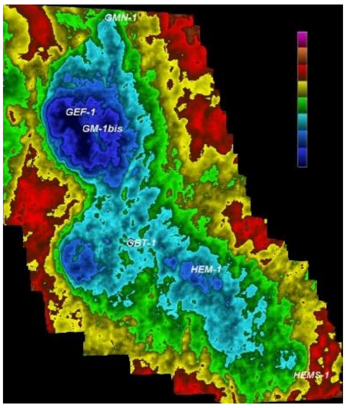

***Figure 4.** Overburden from density*

$$S_V = \int_0^z \rho g dz \quad ....(7)$$

Where S_V is the vertical stress (Mpa), g is the gravity constant (9.8 g/s^2), ρb is the bulk density (gm/cm3).

Figure 4 illustrate the distribution of lithostatic pressure at Frasnian hot shale formation computed using bulk density computed by prestack seismic inversion and extrapolated to surface ground using the following equation:

$$\rho_{ext} = 1.8 + 0.145Z^{0.2083} \qquad .....(8)$$

- **Minimum and Maximum Horizontal stress**

The minimum horizontal stress (Shmin) and maximum horizontal stress (Shmax) are required for geomechanical study in particular, wellbore stability analysis and hydraulic fracture. Before well drilling, the stresses applied to the rocks are almost identical in different directions in isotropic medium. However, after drilling the stresses change significantly because of active tectonic and induce a mechanical failures in the wellbore.

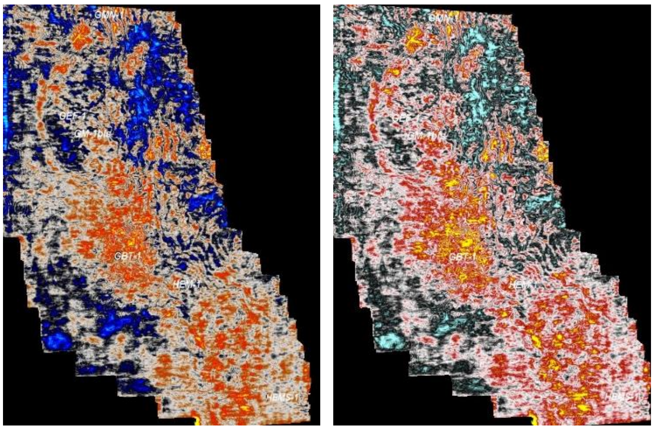

Figure 5. *Minimum stress (a) and maximum stress (b) at Frasnian hot shale calculated by poroelastic equation using seismic data*

These mechanical failures can be in the maximum horizontal stress direction in the form of tensile failures or breakdown, and shear failures or breakouts are in the minimum horizontal stress direction which both are produced roughly parallel to the wellbore axial.

The minimum horizontal stress (Shmin) can be determined directly from well data such as the minifrac test, hydraulic fracture, or LOT/XLOT.

The horizontal stresses can be calculated using poroelastic equations which explains how a porous rock deforms when the pore space is filled with fluid and pressurized:

$$Sh_{min} = \frac{\upsilon}{1-\upsilon}S_V - \frac{\upsilon}{1-\upsilon}\alpha P_p + \alpha P_p + \frac{E}{1-\upsilon^2}\varepsilon_x + \frac{\upsilon E}{1-\upsilon^2}\varepsilon_y \qquad .... (9)$$

$$Sh_{max} = \frac{\upsilon}{1-\upsilon}S_V - \frac{\upsilon}{1-\upsilon}\alpha P_p + \alpha P_p + \frac{\upsilon E}{1-\upsilon^2}\varepsilon_x + \frac{E}{1-\upsilon^2}\varepsilon_y \qquad .... (10)$$

Where P_p is the reservoir pressure, ε_x ($3.\ 10^{-4}$) and ε_y ($5.\ 10^{-4}$) are the tectonic strains, ν is the Poisson's ratio, E is the static Young's modulus and α is Biot coefficient.

Figure 5 illustrate the distribution of horizontal stresses at Frasnian hot shale formation computed using pore pressure, elastic parameters and vertical stress calculated using Prestack seismic inversion.

- **Safe mud window**

The wellbore stability and safe mud window were analyzed after determining the various stresses in the wellbore. The 1D mechanical model for vertical well results are illustrated are in Figure 3 with Shear failure pressure (CMW_MIN_MC), kick pressure (CMW_KICK), mud loss (CMW_LOSS), break down pressure (CMW_MAX_MTS and mud weight MW (MW) in ppg.

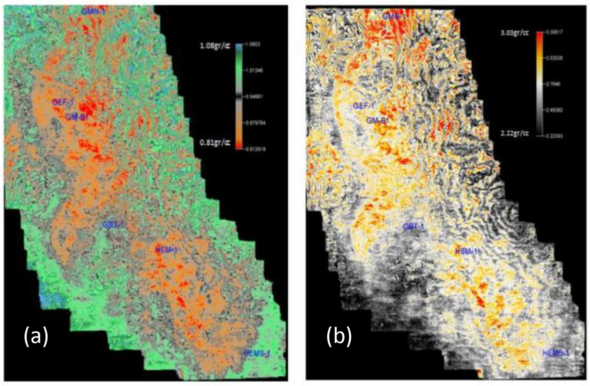

Figure 6. *Minimum and Maximum Mud weight for vertical well*

The safe mud weight (shear failure & break down) is calculated from Mohr-Coulomb failure criteria using the following equations for vertical well (Munoz et Al 1996):

$$P_w^{BO} = \frac{(3Sh_{max} - Sh_{min} - UCS)}{1 + tan^2\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)} \quad ...(11)$$

$$P_w^{BD} = 3Sh_{min} - Sh_{max} - P_p + T_0 \quad ...(12)$$

Figure 6 illustrate the mud weight for vertical well at Frasnian hot shale with a minimum safe window (a) from 0.81 gr/cc to 1.08 gr/cc and the maximum safe window (b) from 2.22 gr/cc to 3.03 gr/cc

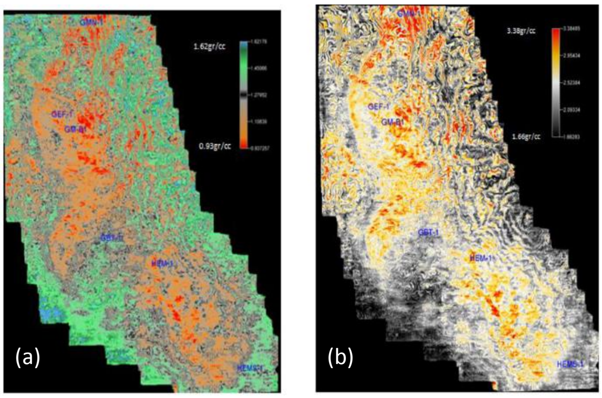

Figure 7. *Minimum and Maximum Mud weight for horizontal well in Shmax direction in Frasnian hot shale*

The shear failure and the break down for horizontal well are calculated using the following equations:

- ***Shmax Direction***

$$P_w^{BO} = \frac{(3S_V - Sh_{min} - UCS)}{1 + tan^2\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)} \quad ...(13)$$

$$P_w^{BD} = 3Sh_{min} - S_V - P_p + T_0 \quad ...(14)$$

Figure 7 illustrate the mud weight for horizontal well in Shmax direction at Frasnian hot shale with a minimum safe window (a) from 0.93 gr/cc to 1.62 gr/cc and the maximum safe window (b) from 1.66 gr/cc to 3.38 gr/cc

- ***Shmin Direction***

$$P_w^{BO} = \frac{(3S_V - Sh_{max} - UCS)}{1 + tan^2\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)} \quad \text{...(15)}$$

$$P_w^{BD} = 3Sh_{max} - S_V - P_p + T_0 \quad \text{...(16)}$$

Figure 8 illustrate the mud weight for horizontal well in Shmin direction at Frasnian hot shale with a minimum safe window (a) from 0.92 gr/cc to 1.67 gr/cc and the maximum safe window (b) from 2.02 gr/cc to 4.1 gr/cc

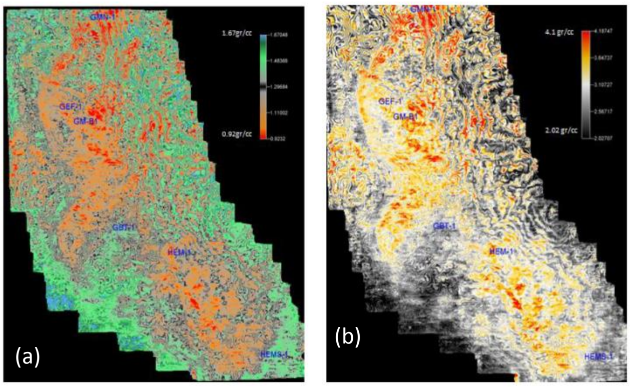

Figure 8. *Minimum and Maximum Mud weight for horizontal well in Shmin direction*

Conclusions

A Frasnian Hot shale source rock was investigated in the present paper. Mechanical parameters were calculated and calibrated with core data tests performed in the offset well. Minimum stress was calculated and using poroelastic model and calibrated with minifrac measurement. Wellbore stability analysis was performed using the failure criterion of Mohr–Coulomb. The low clay content and according to mineralogical analysis which show the dominance of illite in clay composition, the Frasnian hot shale is very favorable to the development of unconventional resources and poses less problem of hole integrity. The results showed that the applied mud weight in this hole was in the safe mud weight window. As a result, the minimum mud weight window is between 0.81 gr/cc and 1.08 gr/cc for vertical well, from 0.93 gr/cc to 1.62 gr/cc for horizontal well in Shmax direction and 0.92 gr/cc to 1.67 gr/cc for horizontal well in Shmin direction. The maximum mud weight window is between 2.22 gr/cc and 3.03 gr/cc for vertical well, from 1.66 gr/cc to 3.38 gr/cc for horizontal well in Shmax direction and 1.67 gr/cc to 2.02 gr/cc for horizontal well in Shmin direction.

References:

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