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Estimation of Pore Pressure and In-Situ Stresses for Halfaya Oil Field: A Case Study

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Abstract: Formation pressure is the pressure of fluid in rock pores. As a geologic parameter, formation pressure plays an important role in exploration activity, drilling engineering and oil/gas field development. For drilling engineering, formation pore pressure is an indispensable parameter for rapid, safe, and economic drilling, so it is very important to forecast formation pressure precisely. Stratigraphy is always in a triaxial stress, it can be expressed by the principal stress in three directions. That is the maximum horizontal principal stress, the minimum horizontal principal stress and the vertical stress. In the horizontal direction exists extrusion stress approximately perpendicular to the long axis of the anticline, namely NNE-SSW direction. The three main stresses should be relatively homogeneous, and there is no great difference.

Keywords: Geologic parameter, Pore pressure, Vertical stress, Homogeneous

1. Introduction

When developing a geomechanical model, the primary parameters that are taken into consideration are the in-situ stresses, pore pressure, and mechanical rock characteristics. The pressure of fluid in rock pores is called formation pressure. As a geological parameter, formation pressure is a key part of exploration, drilling engineering, and the development of oil and gas fields, the pressure inside the pores of the formation is one of the most challenging variables that affects the success of drilling operations. For drilling engineering, formation one of the most significant factors is the pore pressure for fast, safe, and cost-effective drilling. Because of this, it is very important to make accurate predictions about formation pressure. Pore pressure is used to estimate the in-situ stress state in integrated wellbore stability investigations. In-situ or far-field stress describes this phenomenon. The weight of formations that lie on top of one another is what causes overburden stress and the fluids they contain. Geological occurrences such as salt domes and magma are examples intrusion can cause vertical tension.

1.2. Area of Study

Halfaya oilfield is located 400 kilometers to the southeast of Iraq's capital city, Baghdad, the location of the study area in Missan governorate. Most areas are deserts and are flat, measuring around 38 kilometers in length and 12 kilometers in width (Figure 1).

1.3. General information

Halfaya field was discovered in 1976. By the end of 2009, eight wells were drilled and seven oil-bearing formations were discovered. The structure was characterized by two-dimensional seismic data acquired between the years 1976 and 1980, Until the end of June 2010, there were a total of eight wells that reached depths of 4,788 meters or more. In the Halfaya oil field, nine (9) formations, Jeribe, Upper Kirkuk, Hartha, Sadi B, Tanuma, Khasib, Mishrif, Nahr Umr B, and Yamama, were discovered as oil reservoirs.

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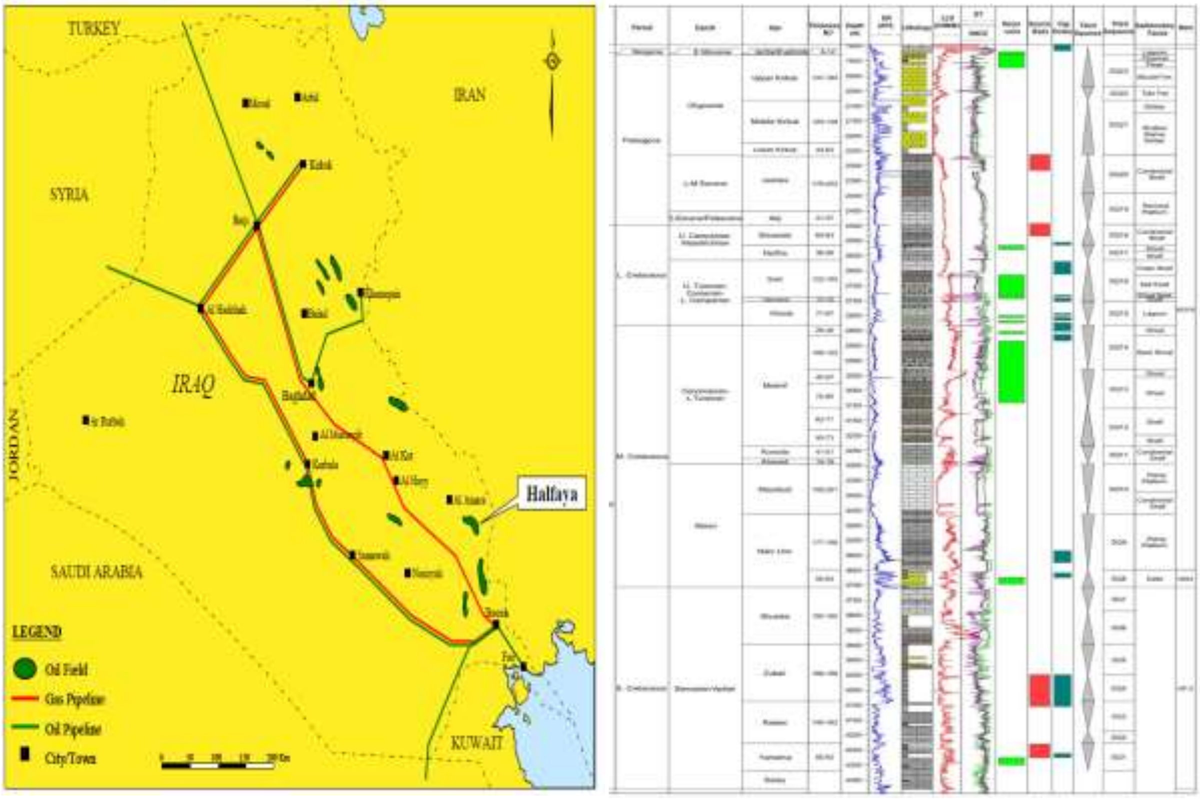

Figure 1 Location and Stratigraphy column of Halfaya oilfield (PetroChina 2018)

2. Pore Pressure Estimation

Eaton's technique is a trusted indirect pressure calculating method. Equation 1 As mentioned in chapter three using a resistivity log to predict the pore pressure gradient in shales (Eaton 1975). Compared with the Eaton technique, projected pore pressure to field measurements showed excellent agreement. Figure 2 show Pore Pressure for well N002H according to Eaton's Method and Slowness logs.

$$Pp = \frac{\sigma_T - \sigma_e}{\alpha} \quad (1)$$

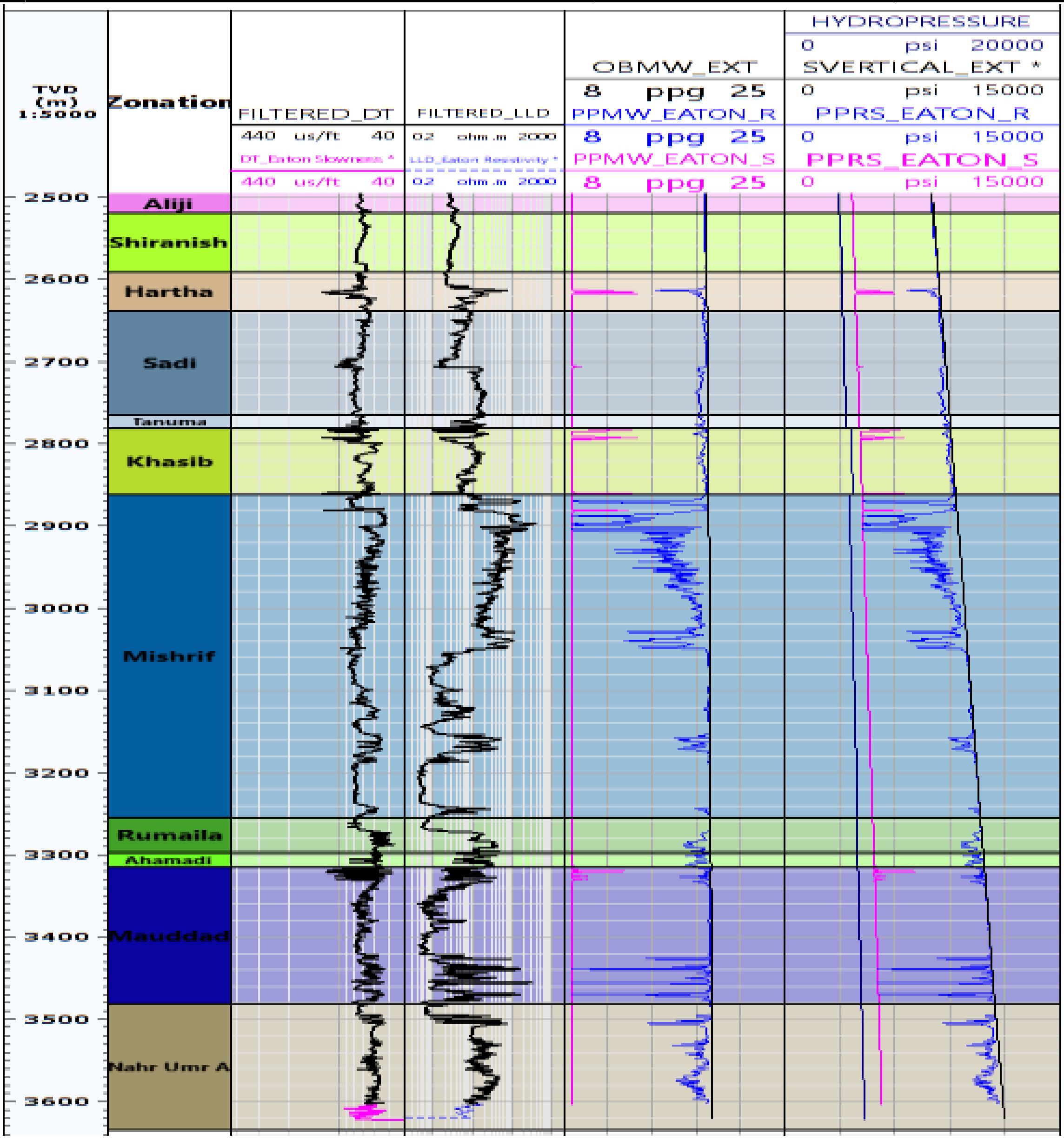

Figure 2 Pore Pressure by according to Eaton's Method (Techlog 2018).

3. Stress Magnitude at Depth

For applying the stress notion in the subsurface, it helps to simplify the stress tensor into three major stresses, which have no shear stress. Tensor becomes:

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} = \begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix} \quad (2)$$

σ_1, σ_2, and σ_3 are referred to by the following terms: maximum, intermediate, and minimum stresses, respectively. in earth's subsurface S_V, S_{Hmax}, and S_{hmin} refer to vertical, maximum, and minimum horizontal stresses. The overburden of sediments above affects vertical tension, whereas horizontal stress is caused by tectonic and geological processes. Anderson defines stress regimes by horizontal-to-vertical stress ratio. Table 1 describes Anderson categorization.

Table 1. *Relative stress and faulting.*

Regime	Stress		
	S_1	S_2	S_3
Normal	S_V	S_{Hmax}	S_{hmin}
Strike - Slip	S_{Hmax}	S_V	S_{hmin}
Reverse	S_{Hmax}	S_{hmin}	S_V

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Anderson's categorized system has meaning: Horizontal primary stresses may be lower or greater than vertical stresses depending on tectonic activity and geology, the depth crustal layers of the earth's surface limit the three insitu primary stresses and active tectonic fault regime in a location associated with far-field main stresses.

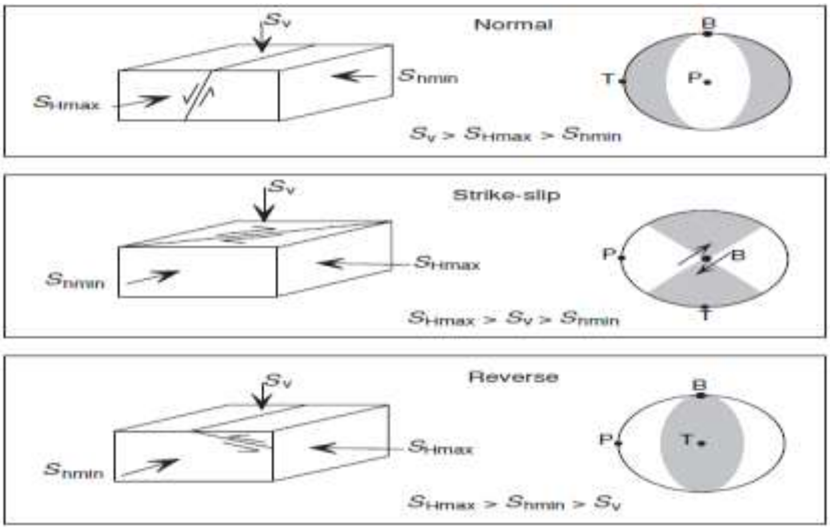

Figure 2 Faulting regions (Anderson 1951).

4. In-Situ Stress

Rocks are stressed. Depending on their direction and source, these stresses may be quite strong in the deep earth. Before any artificial activity like drilling, an undisturbed formation will be exposed to compressive forces, The overburden stress's lateral movement is constrained by surrounding materials, causing horizontal stress max/min (S_{H} and S_{h}). Temperature changes affect all stresses, whereas earthquakes only affect horizontal stresses (Aadnoy and Looyeh 2019).

4.1. Vertical stress

Overburden stress is created by overlaying formations. If the underlying formations have a density of ρ, compute overburden stress (S_{v}) by:

$$\sigma_v = \int_0^z \rho(z) g \mathrm{d}z \approx \bar{\rho} g z \qquad (3)$$

where g is the acceleration that results from the force of gravity; z :depth (Zhang 2019).

Another equation to measure vertical stress when density changes with depth is:

$$S_v = \int_0^D \rho D g d_D \qquad (4)$$

Employing may be extrapolated. Density to surface gaps from Eq. 5 (Rana and Chandrashekhar 2015).

$$\rho_{\text{extapolated}} = \rho_{\text{mudline}} + A_o \times (TVD - \text{ Air Gap })^{\alpha} \qquad (5)$$

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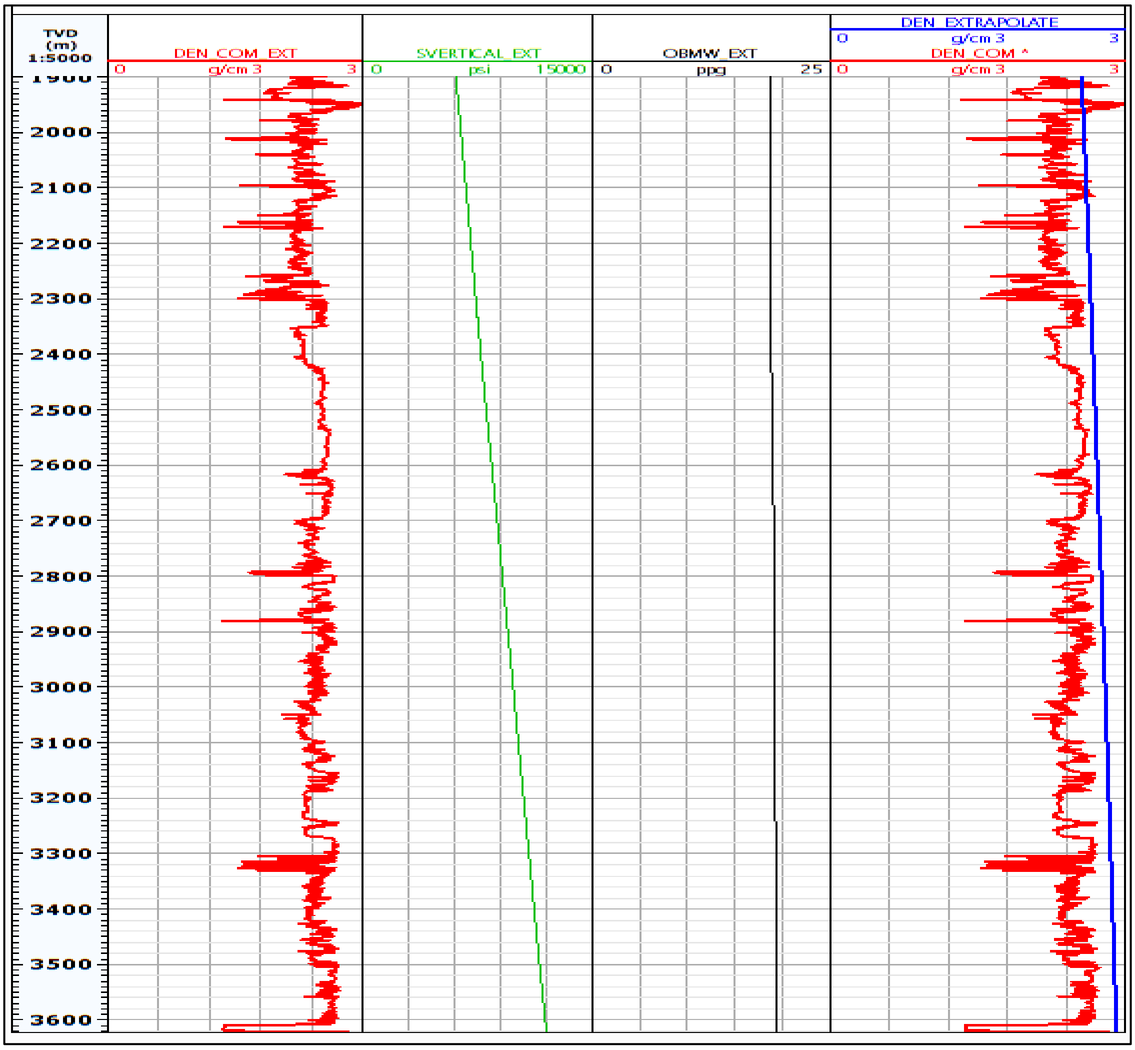

Figure 3 Vertical stress (Techlog 2018).

4.2. Horizontal Stresses

Poisson's ratio determines horizontal stress. Rocks with a higher Poisson's ratio exhibits a greater amount of horizontal tension. The Poisson ratio, the Biot constant, the vertical stress, and the horizontal component of pore pressure are the variables that are being discussed here. (Avasthi, Goodman et al. 2000) the empirical equation that will be used is as follows was given as a means of estimating the horizontal in situ stress:

$$\sigma_h = \frac{v}{1-v}(\sigma_v - \beta P_o) + \beta P_o \qquad (6)$$

Poisson's ratio is represented by v, and is represented by β.
Horizontal stress is equal. (i.e., $\sigma_H = \sigma_h$), when they are only due to overburden stress.
In general, there are two ways to measure stresses in place: directly and indirectly.
As suggested by, the direct method includes four main ways to test.

- Hydraulic Fracture Evaluation.
- The flatjack method of evaluation
- USBM's overcoring gauge test.
- CSIRO's overcoring test.

4.2.1. Minimum Horizontal Stresses (S_{hmin})

Many geomechanics issues may be handled by understanding horizontal stress orientation and magnitude. S_{hmin} is estimated using LOT, mini-frac, and extended leak-off tests (direct method). Hydraulic fracture testing is the best method to determine of S_{hmin} is in a wellbore (Zhang 2019). The poroelastic model calculates minimal horizontal stress (Thiercelin and Plumb 1994). Equation 7 uses elastic parameters, pore pressure, and vertical stress.

$$S_h = \frac{v}{1-v}\sigma_v + \frac{1-2v}{1-v}\alpha P_p + \frac{E}{1-v^2}\varepsilon_x + \frac{vE}{1-v^2}\varepsilon_y \qquad (7)$$

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4.2.2. Maximum Horizontal Stresses (S_{Hmax})

Maximum horizontal stress is a difficult metric to forecast directly. Numerous technological techniques have been devised to anticipate the maximum horizontal stress. Using the Mohr-Coulomb criteria and elasticity theory, Equation 8 calculates maximum horizontal stress using the poroelastic model.

$$S_H = \frac{v}{1-v}\sigma_v + \frac{1-2v}{1-v}\alpha P_p + \frac{E}{1-v^2}\varepsilon_y + \frac{vE}{1-v^2}\varepsilon_x \quad (8)$$

ε_x and ε_y : tectonic strains the horizontal stress that is the highest and the least according to the orientation of the horizontal plane, respectively.ε_x and ε_y utilizing Equations 9 and 10, an estimate based on the overburden stress can be obtained.

$$\varepsilon_x = \frac{v\sigma_v}{E}\left(1 - \frac{v^2}{1-v}\right) \quad (9)$$

$$\varepsilon_y = \frac{v\sigma_v}{E}\left(\frac{1}{1-v} - 1\right) \quad (10)$$

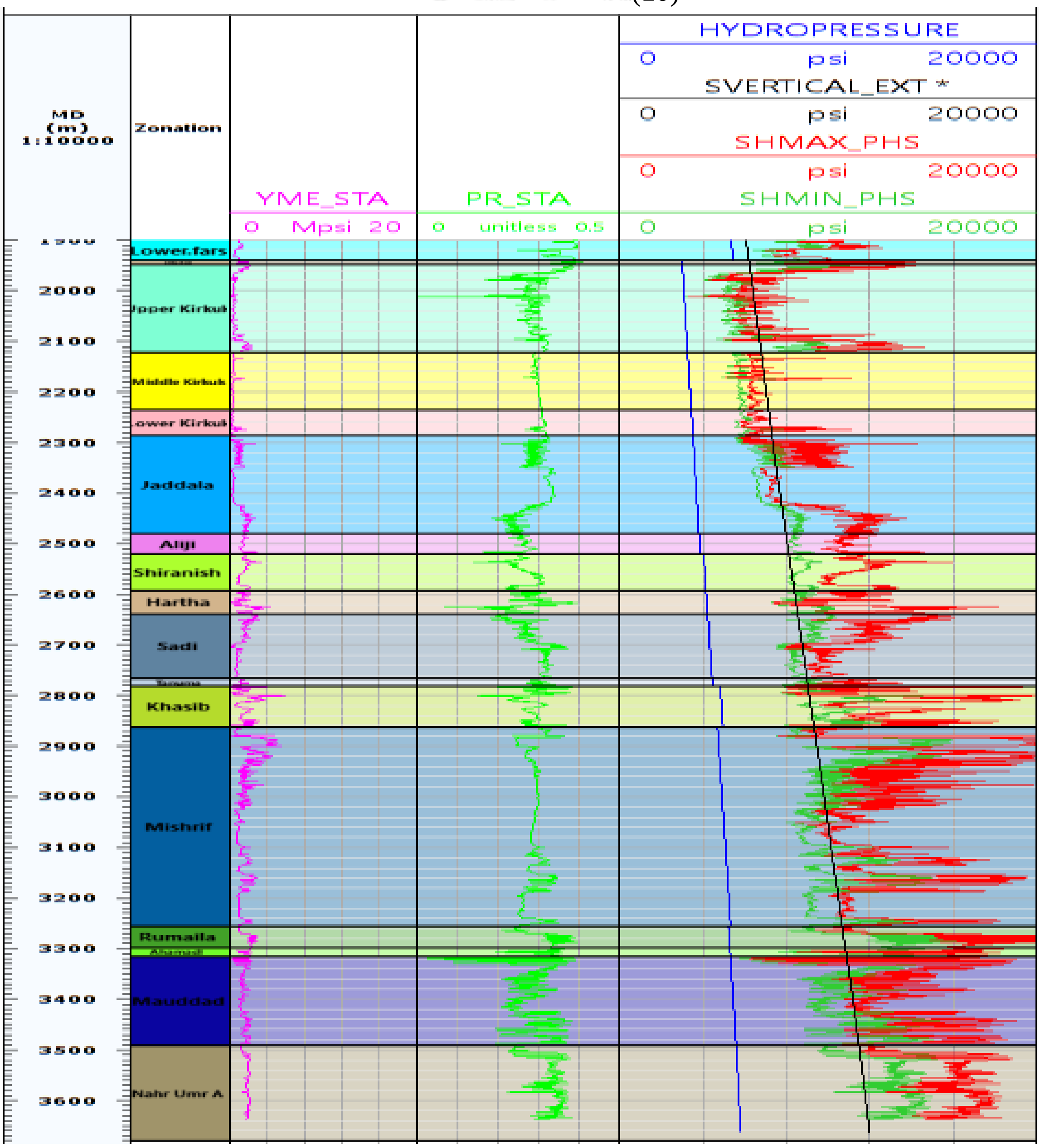

Figure 4 Min. and Max. Horizontal stresses (Techlog 2018).

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5. Conclusion

1. The directions of horizontal stresses were specified by the Formation Micro Imager (FMI).
2. The maximum horizontal stress azimuth in Halfaya oilfield is about N20-35 E.
3. The results showed that the Nahr Umr formation is a reverse faulting regime (S_{Hmax}>S_{hmin}> S_V).
4. Formation lithology affects the horizontal stress in the Halfaya oilfield.
5. The Poro-Elastic Horizontal Strain Model is the more accurate technique that was used in this study.

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