A methodology to define drilling parameters from well data and seismic data

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Abstract

The process of drilling an oil well is a complex activity that involves high financial risk. Much of this risk is directly related to the definition of drilling parameters. The definition of these parameters is marked by high uncertainty level. This paper presents a methodology to support the definition of drilling variables based on seismic data and correlation well data. The workflow proposed consist of four stages, the first stage is responsible for picking the initial data that will be used. These data are derived from seismic and correlation well records. In the second step the mechanical profiles of the rocks that will be drilled are defined. Based on this compressibility profile, the third step defines the geo-pressure gradients for these rocks in order to know the working window. Finally, in the fourth stage, from data obtained in previous steps, it is possible to build a table for prediction of drilling parameters. With the set of test data, the proposed methodology showed itself as an effective tool for predicting the behavior of drilling operation, helping to define the parameters of perforation.

Introduction

The drilling operation is not only expensive, but also dangerous, that's why many cares are taken in this step. In order to keep a safe and efficient operation, we try to watch continuously the drilling parameters, such as weight on bit, RPM, pumping flow and torque.

The difficulty is that watching these parameters in real time is not always possible, since communication failures can happen sometimes. Besides this, the interpretation of data obtained during the drilling can cause ambiguity. Data interpreted wrongly can lead to an unnecessary round trip, causing a financial loss to the company, or even accidents with the possibility of casualties.

The best way of avoiding or reducing ambiguity is to have greater knowledge about the working environment. Thus, a tool capable of generating a methodology for prediction of drilling parameters from the physical properties of the rocks is of extreme importance for petroleum industry.

With the forecast methodology, drillers and technicians involved can anticipate and assess changes in drilling parameters, reducing uncertainty, accelerating and tuning drilling into a safer and more efficient process.

The proposed methodology for developing the methodology of drilling parameters prediction is based on a knowledge of the physical properties of rocks in subsurface. These physical properties are obtained from a seismic survey and well data correlation.

Method

As illustrated in Fig. 1, the proposed methodology consists of 4 steps. The first step is responsible for the correlation of wells and lithological simulation. In the second step, the mechanical properties of rocks that will be drilled are estimated from the definition of the lithology. Then, in the third step, the window of operational geo-pressures is defined. Finally, in the fourth stage, the framework of prediction for the drilling parameters is built based on the knowledge of the mechanical properties and the window of operational geo-pressures.

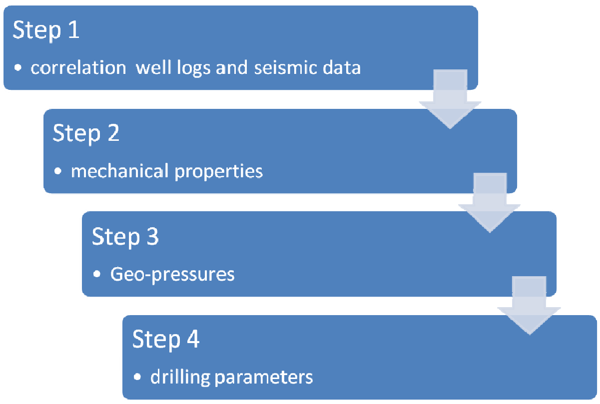

Fig. 1. *Steps of the proposed methodology for the development of a drilling parameters forecast tool.*

The correlation wells selected for the first stage necessarily should have the gamma ray and sonic logs. From the core samples, drill cuttings and geological interpretations, the wells are correlated. This stage is the base for the simulation of the mechanical and geo-mechanical parameters of the new well to be drilled, still allowing to make the project of the well from the definition of its trajectory to the definition of pore pressure, overburden gradient, collapse and fracture.

To simulate the required parameters, the compressional acoustic time (DTC), shear acoustic time (DTS), compressional acoustic time on framework (DTMC), shear acoustic time on framework, clay volume, porosity, resistivity, gamma ray, formation density and grain density are used. In this step, the porosity is estimated using the formulation proposed by Wyllie et al. (1956).

Incoming information are usually obtained from different depth ranges logs of one or more correlation wells. In cases of exploratory wells, seismic data are used to determine the elastic properties and geo-pressures.

The mechanical properties are directly related to drilling activity. In the second stage of the proposed methodology, mechanical properties of rocks are estimated based on the sonic log.

For rocks of shale's family the friction angle is calculated from the model of Lal (1999). For other rocks we use the model of Plumb (1994).

The ratio used in the methodology for the definition of the values of cohesion is represented by the Eq. 1. given by:

$$C = 5 \cdot \frac{(V_p - 1)}{\sqrt{V_p}} \cdot 145{,}0377 \qquad (1)$$

where C is the cohesion and V_p is the compressional wave velocity.

Typically, the compressive strength is calculated from the cohesion and friction angle, however, according to Militzer & Stroll (1973), one can calculate the compressive strength directly from the compressional time. Thus, for shales and sandstones of Gulf of Mexico, the compressive strength is given by Eq. 2 and for limestones and dolomites it is given by Eq 3. The equations are defined respectively as:

$$UCS = \frac{2{,}05 \times 10^9}{(dtc)^3}; \qquad (2)$$

$$UCS = \left(\frac{7682{,}0}{dtc} \right)^{1{,}82} \qquad (3)$$

where *UCS* is the compressional strength and *dtc* is the d compressional time.

The mud window is the interval between the maximum and minimum values for the weight of the drilling fluid. The purpose of the third stage is to estimate this interval.

According to Bellotti & Giacca (1978), for formations cemented and compacted, the formation density can be calculated by Eq. 4, assuming the compressional acoustic time on framework of the shale as 47µseg/ft. For weakly cemented formations, the formation density is defined by Eq. 5.

$$\rho b = 3{,}28 - \left(\frac{dtc}{89{,}0} \right); \qquad (4)$$

$$\rho b = 2{,}75 - 2{,}11 \cdot \frac{(dtc - dtmc)}{(dtc + 200)} \qquad (5)$$

where ρb is the formation density, *dtc* is the compressional time, *dtmc* is the compressional acoustic time on framework.

The calculus of overburden gradient starts with obtaining the vertical stress at the first point, represented in Eq. 6.

$$\sigma_v^1 = P_{atm} + 1{,}422334 \rho_w Z_w + 1{,}422334 \rho_b^1 (Z_1 - Z_0) \qquad (6)$$

where Z_0, in a sea wells, is the sum of the heights of water surface and rotary table, Z_1 is the vertical depth of the first point, measured from the rotary table, ρ_b^1 is the formation density at the first point, ρ_w is the density of sea water, Z_w is the height of sea surface, P_{atm} is the atmospheric pressure and σ_v^1 is the vertical stress at the first point.

So, the overburden gradient for the first point is given by Eq. 7 and for the other points it is given by Eq 8.

$$G_s^1 = \frac{\sigma_v^1}{Z_1} \cdot 5{,}8674; \qquad (7)$$

$$\sigma_v^i = 1{,}422334 \cdot \Delta Z_i \cdot \rho_b^i + \sigma_v^{i-1}; \qquad (8)$$

$$\Delta Z_i = Z_i - Z_{i-1} \qquad (9)$$

where σ_v^1 is the vertical stress for the first point; G_s^1 is overburden gradient for the first point; Z_1 is the vertical depth of the first point; σ_v^i is the vertical stress for a point at depth Z_i; G_s^i is the overburden gradient; ρ_b^i is the formation density; Z_i is the vertical depth, measured from the rotary table.

The pore pressure gradient is calculated using the method of Eaton (1975), supported by several authors as Yoshida et al. (1996), Sayers et al. (2000) and Bridges (2003), which indicate this method as one of the most used in the petroleum industry to estimate the pore pressure gradient.

The collapse and fracture gradients are respectively the upper and lower limits of security operational window, which defines the weight of the drilling fluid to be used in the project.

The collapse of wells has different consequences depending on the type of rock. Permanent deformation, in case of ductile rocks, reduces the well diameter, causing operational difficulties such as torque increase, with possible imprisonment of the column. For fragile rocks, there is collapse, increasing the diameter, enhancing the formation of pack-offs, reducing the rate of penetration and turning the cleaning of the well into a hard task.

The upper limit of the fracture gradient defines the boundary where the material breaks down due to tangential stresses, since the lower limit of fracture gradient is the limit below which the material breaks due to radial stresses.

Finally, with this information, in the fourth stage of the process, the data obtained are analyzed and a table of forecasts for drilling parameters can be built. This framework can be used by the driller to know in advance critical areas and the actions to be taken to optimize the drilling process.

Examples

To exemplify the suggested methodology, a geological scenario was built where the drill of a directional hole in a water depth of 1280 m with the rotary table height of 12 m is proposed.

The Fig. 2 illustrates the three phases stages planned for the well.

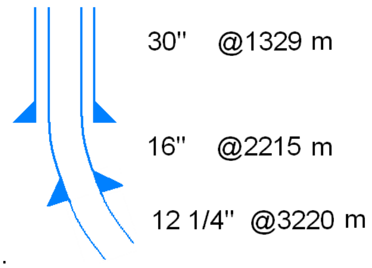

Fig. 2. *Schematic design of the directional well proposed.*

Fig. 3 shows the gamma-ray and delta time for the correlation well used in the reservoir region, the planned trajectory of the well to be drilled, a previewed lithology table set for the new well and an adapted lithology table set to serve as base for the mathematical simulations.

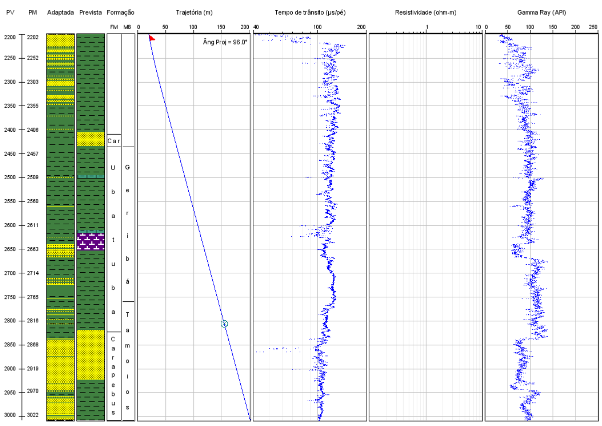

Fig. 3. *Correlation logs used as base for well project.*

Fig. 4 shows the mechanical gradients calculated for the rocks in the reservoir region to the designed well.

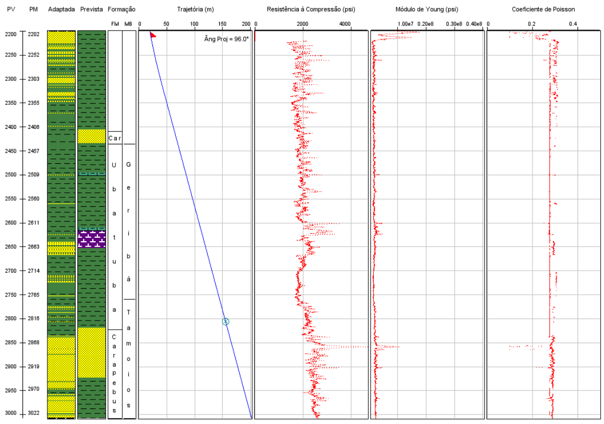

Fig. 4. *Mechanical gradients calculated for the rocks in the reservoir region.*

Fig. 5 shows the geo-pressures window estimated for the test well, including pore pressure, upper and lower collapse gradient, fluid weight, fracture gradient and overburden gradient.

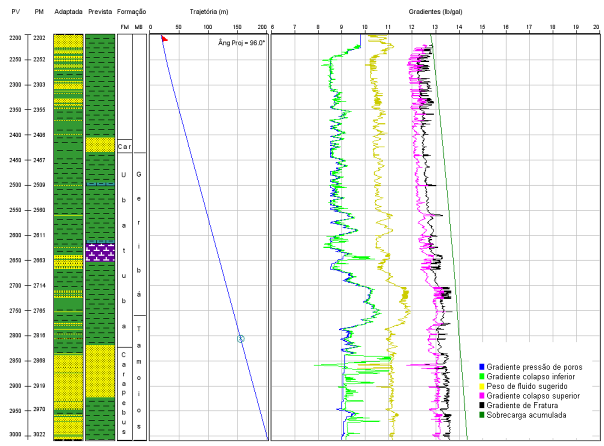

Fig. 5. *Geo-pressures window estimated for the test well.*

The mechanical properties of rocks in the desired range are estimated from the transit time. Based on the analysis of the compressive strength, one can predict the points where there will be changes in drilling rate. In Fig. 6, the blue lines represent the point where a negative anomaly in drilling rate is expected and the green lines represent the points where a positive anomaly is expected.

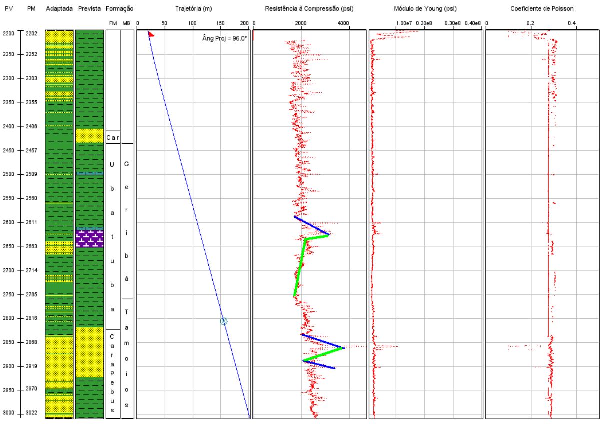

Fig. 6. *Expected areas where there will changes in penetration rate.*

Results

Having regard that the well has had its drilling started with a weight of 15klb over the drill, flow rate of 800gpm and torque between 4 and 6klb.ft and analyzing the graphic shown in Fig. 6, an adjustment to drilling parameters was proposed, before we got losses in penetration rate.

In the interval between the measured depth of 2600 m and 2640 m, the compressive strength increased from 1800 psi to 3000 psi, with a tendency to increase as the torque grows. In this situation the driller can keep the flow constant , increase the weight over the drill to 20 klb, increasing the rotation to 70 rpm.

Between 2641m and 2650 m, the compressive strength drops to 2200 psi. In this situation we can keep the current parameters to maintain the penetration rate or return to the initial parameters to preserve the conditions of the drill.

For the interval between 2840 m and 2880 m, the compressive strength increases from 2000 psi to 3800 psi, thus, in order to keep the penetration rate, we should maintain the flow at 750 gpm and the torque at 50 rpm.

From 2900 m to 2940 m, the compressive strength goes from 2100 psi to 3200 psi, therefore it's necessary to increase the weight over the bit to 10 klb and keep the rotation at 70 rpm and the flow rate constant at 750 gpm in order to maintain the penetration rate.

Conclusions

The process of drilling a well is an extremely complex activity, involving large financial risks. In this scenario, where the uncertainty involved is high, the proposed methodology was able to extract enough data to assist decisions and reduce uncertainty related to the anomalies which may occur during the drilling. Besides saving on drilling rig time, the proposed method is useful in allowing and optimization of the drill and can even extend its lifetime and increase the reliability of the process.

Acknowledgments

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