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In-situ Stress Determination for Well Planning in the Niger Delta

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ABSTRACT

During drilling, production and injection activities, great disturbances occur in the rock formation which causes change in the initial equilibrium of rock formation, altering the mechanical conditions and also virgin in-situ stresses. These disturbances which occur in the rock formation lead to redistribution of stresses around the wellbore, which may negatively affect the drilling, completion operations and also production efficiency leading to increased cost and delays in operations. Wellbore failure accounts for more than 10% of non productive time in drilling and other related issues in Niger Delta. This research work evaluates some rock mechanical properties critical to wellbore stability, both during drilling and production, using caliper, gamma ray, density, sonic and true resistivity logs from a well in the Niger Delta. These logs were run into software and the investigated stratigraphic units are the typical interlayered, shales and sandstones of the Agbada formation. The lithology was found to consist of 20 sand sections and 20 shale sections. It was also found that wellbore breakouts were predominant in shales and weak shaly sandstones across the lithologic units. Mud weight window varies between 0-8.7ppg with depth due to heterogeneity and anisotropy in the formation. The friction angle at depth 8461ft is 14.9^0 and generally in the NE direction. The vertical stress ranges from 0 to 5260.917 psi/ft, the minimum horizontal stress range from 963.8206 psi at 6142.317ft to 5059.214 psi at 11615.95ft. The maximum horizontal stress varied from 6142.317ft to 7111.654ft and remained constant from there onto 11615.95ft with a value of -0.2138psi. The hydrostatic pressure was found to increase with depth due to increase weight of overburden pressure. Tensile strain was also seen to be higher in shales than sand as a result of their unstable nature. Significant variations in properties between the cap rocks and the reservoir sand units in the well were also observed with the cap rock having an average of 0.2 Poisson ration and bulk moduli of 466.1 MPa. These data will be useful in well planning for other wells around the case study area as well as the field at large.

Key words: Stratigraphy, Vertical stress, Friction angle, Maximum Horizontal Stress, Minimum Horizontal Stress.

INTRODUCTION

In-situ stresses are existing stress conditions in a formation when in equilibrium. They are also known as far field stresses described as undisturbed or existing ground stresses that are compressive in nature prior to drilling activities. In-situ stresses are the most important factor which affect underground rock stability (Barton et al., 1988; Bell, 2003; Dart., 1990; Haftan et al., 2008; Haimson & Fairhurst, 1970; Han et al., 2014). There are two types of stress namely normal stress σ normal to the plane and shear stress τ which acts along the stress plane. Normal stress leads to a tensile or compressive failure while shear stress leads to shearing or slippage along a plane. In terms or solid rocks analysis, compressive stresses are classified as positive while tensile stresses are classified as negative.

Far field stresses are a function of depth and strength of sources. Rocks are subjected to various stresses at different points below the ground surface which can be very high at great depth. The earth is a free surface on which there are no shear stresses, thus it is a principal plane. The principal plane is normal to the vertical direction and thus the vertical direction is assumed to be a principal stress direction. Thus, the stress state at any point in a rock formation is presented in terms of the principal stresses. Underground formation when confined and under stress experience three principal stress states which includes: vertical stress (σ_1), minimum horizontal stress (σ_2) and maximum horizontal stress (σ_3).

The weight of overlying formations is the main cause of vertical stresses, their contained fluids (overburden stress) and also geologic conditions like magma or salt domes. The weight of overburden stress spreads in different directions, causing the overlying rocks to spread in horizontal lateral directions. This can be attributed to the effect of Poisson's ratio defined as the ratio of lateral expansion to longitudinal contraction for a rock under a uniaxial stress condition. Also, the movement or spread in horizontal lateral directions is restricted or impaired by adjacent materials which exist in the formation. This restriction results in lateral stresses like minimum horizontal stresses (HS_{min}) and maximum horizontal stresses (HS_{max}). Knowing the magnitude and direction of principal stresses is of great importance as it helps to determine the direction of rock failure, stresses that are capable of crushing or disrupting propants during production, pressure required for creating and propagating a fracture (fracture pressure) and the vertical extent and shape of fracture.

METHOD

Wireline logs from one well code named well "X" for proprietary reasons was utilized for this research. The studied rock interval ranges in depth from 0ft to 12025ft in the subsurface. It falls within the Agbada formation whose stratigraphic success consist of imbedded sandstones and shales. These logs were available in well log American Standard Code for information Interchange (ASCII) standard files format. These logs were also subjected to quality checks and converted to true vertical depth and thereafter loaded into the Techlog 2011 software for analysis. Rock mechanical properties were determinded which included elastic and inelastic properties. These well logs include sonic, density, gamma ray and resistivity logs.

Stress induced wellbore failure zones known as breakouts were isolated from non-stress induced wellbore enlargements such as keyseats and washouts with the use of 4-arm caliper and gamma ray log. Rock mechanical properties which include elastic and inelastic properties were carried out using density, compressional sonic (ΔT_C) log and shear sonic (ΔT_s) log. The elastic properties included Poisson ratio (V), elastic modulus (E), Biot's coefficient (α). The inelastic properties determined were fracture gradient and rock strength which include uniaxial compressive strength (UCS) / tensile and cohesive strengths and frictional angle. Poisson's ratio and Young's modulus were determined from P- and S- wave velocity. The Techlog 2011, a Schlumberger tool is the software used for this research and Microsoft Excel used for data presentation. The well header information which carries the well location of the well in time and space was loaded and also the well deviation which carries the original trajectory pathway of the well. The logs were then loaded into the software.

MATERIALS USED FOR RESEARCH

The following materials were used for the research;

Sonic log, density log, gamma ray log, resistivity log and Schlumberger 2011 Techlog software.

RESULTS AND DISCUSION

Results of lithology, failure image, friction angle, maximum and minimum horizontal stress

The lithology was seen to consist of 20 sand and 20 shale sections. Figure 1.0 shows a cut section of the true vertical depth (TVD), lithology, maximum and minimum horizontal stresses, failure image and friction angle logs. In the figure, the first column shows the depth of the well as it increases down below the surface (TVD). The second column shows the different lithologies where we have shale, sandstones and mixture of shale and sandstones. The region which deflects to the right shows presence of shale while the region which deflects to the left shows the presence of sandstone. This information is of great importance as it helps to detect regions where we have oil and thus perforation can be appropriately done during completion process.

The third column shows the maximum and minimum horizontal stresses as they vary with depth. The red zigzag line shown on the column indicates the maximum horizontal stresses which vary with depth of burial due to the variations in the bulk densities of the subcrustal rocks. The green zigzag line shows how the minimum horizontal stress also varies in depth which is important to note during drilling as having knowledge of the minimum and maximum horizontal stresses helps in designing the drilling mud which is needed at different depth to prevent fluid in the formation from flowing into the well and also weight of mud that will be used at different depth without fracturing the formation.

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Fourth column show the failure image showing the strength on the different rocks. It is observed that shale is weaker than sandstones. The low rock strength accounts for the occurrence of wellbore failure in shales and weak shaly sandstones as seen in the failure image. This shows these areas should receive adequate attention while drilling for well collapse and high pore pressure. Also, pay zones in these intervals should be properly examined so as to determine appropriate completions in order to avoid sand production. The last column shows the friction angle which is the angle at which a formation is likely to break when subjected to pressure. The friction angle at depth 8461ft is 14.9^0 in the NE direction.

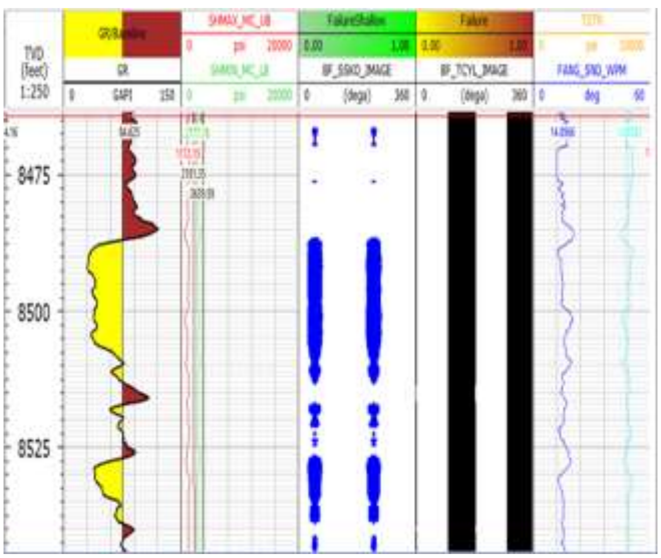

Figure 1: A cut section of the TVD, lithology, maximum and minimum horizontal stress, failure image and friction angle logs.

Results of TVD, density, vertical stress, tensile stress, hydrostatic pressure, static and dynamic Poisson ratio logs.

The density of the formation was seen to vary due to difference in lithology between sand and shale where the density of sand is seen to be lower than that of shale in the second column of figure 2. The third column on figure 2 shows the vertical stress which increases with depth due to the weight of the overburden. At depth 8486.11ft, the vertical stress was 2185.21psi. the fourth column shows the tensile strain and it is noticed to be higher for shales than for sand and this is due to their unstable nature. The fifth column shows the hydrostatic pressure which increases with depth primarily because of the increasing weight of the overburden which causes pore fluids to be expelled more readily.

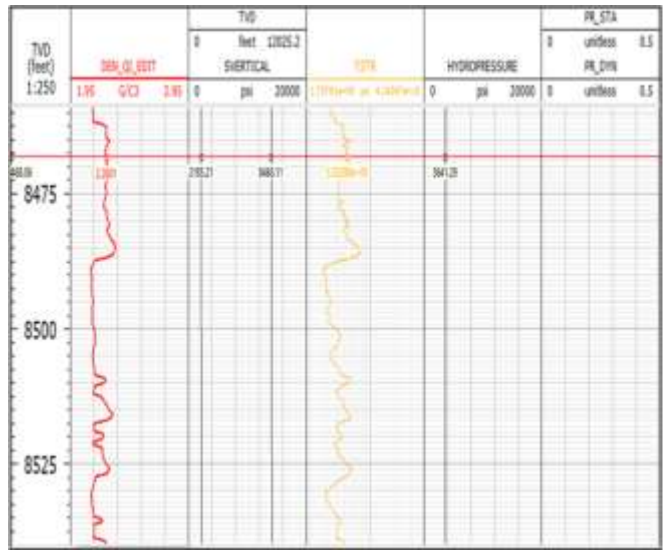

Figure 2: A cut section of the TVD, density, vertical stress, tensile stress, hydrostatic pressure, static and dynamic Poisson ratio logs.

Lower bulk compressibility and rock strength makes the shale more ductile, stiffer, less compressible and more prone to compressive shear failure, but better fracture stimulators and barriers. Conversely, sandstones, the main reservoir rocks, have relatively lower Poisson ratio, elastic, bulk and rigidity moduli but higher compressibility and rock strength, making them more brittle with higher potential for tensile failure. Thus, sandstones will fracture before shales under the same fracture gradient while shales will form the barrier to fracture growth. Low rock strength accounts for the occurrence of wellbore failures in shales and weak shaly sandstones. The increase in rock compressibility with effective vertical stress and effective porosity, decrease compressibility with depth and decrease in effective porosity with bulk compressibility supports equilibrium compaction. Increase in effective overburden stress due to sediment loading and expulsion of fluids, causes grains to slide in shear as well as compactional deformation, coupled with reduction in the bulk and grain compressibility, as depth increases.

There are significant variations in properties between the cap rocks and the reservoir sand units in the well. The cap rock which is shale has an average Poisson ratio, elastic, bulk moduli of 0.2, 23, 466.1 MPa. However, lower bulk compressibility and rock strength makes the shale more ductile, stiffer, and prone to compressive shear failure, but better barriers for fracture stimulation.

There is a general decreasing trend in the modulus of rigidity, bulk and matrix moduli and an increase in elastic modulus of the rocks with depth. This mechanism is responsible for generation of over pressures since impermeable sediments such as shales saturated with an incompressible fluid will not deform. Sedimentary rocks deform primarily by compaction resulting in progressive loss of porosity with increasing depth of burial.

CONCLUSION

In-situ stress can be due to the weight of an overburden stress of a formation. Consequently, the lower the pore pressure of a formation, the higher the effective stress. Most fields in the Niger Delta are characteristic of inconsistent pressures in relation to overburden stress and these uncertainties can lead to challenges in well planning. Rock instability occurs when rock stress is greater than rock strength, thus a failure criterion must be chosen with defined boundary conditions.

In this study, the vertical stress increases vertically through the well due to variation in density of subcrustal materials. There is also an increase in the elastic modulus of the rocks with depth due to an increase in confining stress. Mud weight window varies between with depth due to heterogeneity and anisotropy in the formation. The friction angle at depth 8461 is 14.9^{θ} and overall in the NE direction. The vertical stress ranges from 963.8206 psi at 6142.317ft to 5059.214 psi at 11615.95ft. The maximum horizontal stress varied from 6142.317ft to 7111.654ft and remained constant from there onto 11615.95ft.

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