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Prediction Of Wellbore Stability And Geo-Mechanical Modeling In "SOC Field", Niger Delta.

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Abstract

In the field of drilling operations and production of hydrocarbon, sustaining a balanced well-bore is of utmost significance. An in-depth knowledge of the geo-mechanical environment can extenuate the risk or associated drilling hazards. It is important to ensure well-bore competence, cost productivity and operational safety, that is, the walls of the well-bore are stable and do not collapse. Geo-mechanical modeling aid in forecasting and alleviating challenges associated with well-bore instability. In this study, data driven, analytical method was used to predict well bore stability, and also develop extensive geo-mechanical models. Five vertical wells were evaluated through petrophysical analysis in "SOC Field", Offshore Niger Delta. By analyzing the petrophysical properties of the rock formations, such as porosity, permeability, and rock strength (the docile and the unmanageable factors), and by visual inspection of well logs, the stability of the wellbore, geo-mechanical and potential issues were predicted. The results of the analysis revealed the presence of different sand and shale units, wash out and break out zones, and over-pressure and under-pressure zones (abnormal pressure). The values of porosity ranged between 15-19 %, permeability (low to very low) with values ranging from 10^{-6} - 10^{-8} *cm/sec while the formation pressure values ranged from 2.08-19.97 Mpa. This provided deeper understanding into reservoir management thereby enhancing drilling operations and reduce associated risks.*

Keywords: *Geo-mechanical, Over-pressure, Petrophysics, Well Logs, Well-bore Stability.*

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I. Introduction

Well-bore stability means the capability of a borehole to sustain its integrity and structural stability during drilling, completion and production operations. Geo-mechanical factors such as the type of rock formation, drilling fluid and pressure can affect well-bore stability. This leads to significant interruption/ recess thereby increasing the operative costs. By carefully analyzing and managing these factors, stable and efficient drilling operations could be attained in the petroleum industry.

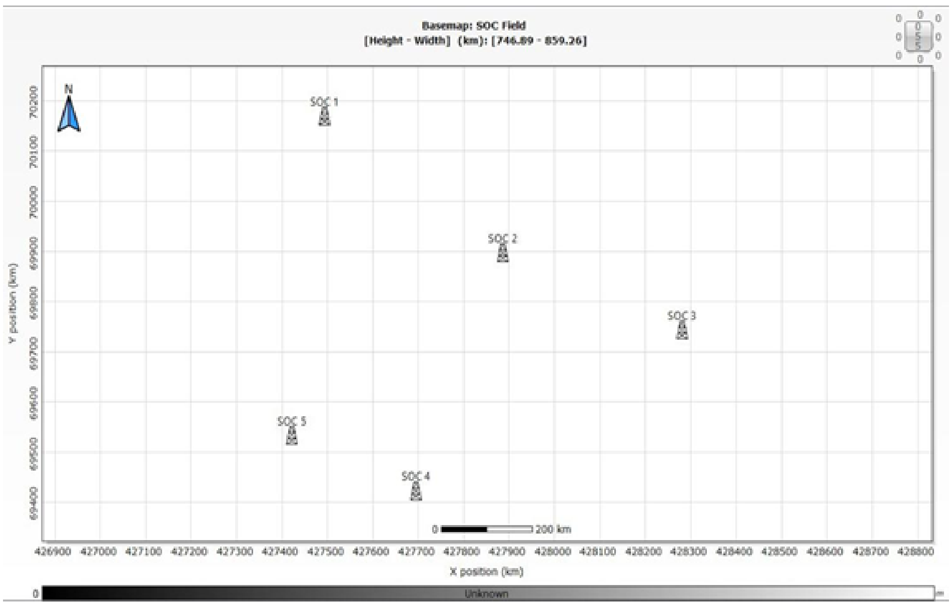


Figure 1: Base-map of the Study Area

The study is crucial because 75% of all formations drilled globally are within shale and 90% of all well-bore instability problems occur within shale formations (Okafor, 2021). The main causes of well bore instability are unconsolidated formation, overburden stress / mobile formations, fractured formation, naturally over pressured shale, induced over pressured shale, reactive shale, tectonic stress. A combination of these parameters is used to replicate real time conditions and predict probable non successive scenarios. This project emphasizes the development of a robust workflow for wellbore stability prediction and the generation of geo-mechanical models

II. Methodology

A suite of logs (gamma ray, density, neutron, resistivity and sonic) from 5 wells obtained from the field of study was used. Geolog 7 software application was used for the interpretation of the well log data. Availability of data is the major constraint in the characterisation of geo-mechanical properties. In previous researches, geo-mechanics was not seen as a vital part of reservoir characterisation. Hence, limited data was available for analysis in this field. Some of the parameters were derived from measurements from well logs and were calibrated using caliper logs and formation pressure data, others were calculated using standard formulas. The interpretation process and procedure included data importation of the well heads and logs for the five wells SOC 01, SOC 02, SOC 03, SOC 04 and SOC 05. The lithologies penetrated by the wells were delineated from the gamma ray log available. Reservoirs were identified using the signatures of both gamma ray and resistivity logs. Fractures were identified on caliper logs as wash out while in sonic and nuclear logs, it showed as wave attenuation while on resistivity logs, it showed as high resistivity values. Over-pressured zones are characterized by sudden increase in the sonic interval transit time with corresponding decrease in bulk density. Pore pressure is predicted using Eaton's equation obtained from the resistivity and sonic logs. The Eaton's equation is used in predicting abnormal pore pressures, mostly in over-pressured formations. This aids in avoiding blowouts or kicks during drilling operations and also to maintain safe drilling conditions. Hence, pore pressure trend is delineated and the gradient evaluated from the interval between the reservoir rocks and the overburden. The diverging observed values are related to the corresponding normal trend-line values which is adjusted by an exponent, depending on the data being evaluated. The density log was also used to calculate the permeability using the Schlumberger-Doll Research Equation (1965):

$$K = \frac{C\,\emptyset^{m}}{P_b - P_{ma}} \quad 3.1$$

where $\emptyset$ is porosity, ρ_b is bulk density, ρ_{ma} is matrix density, c and m are empirical constants.

The density and sonic logs were used to calculate the pore pressure using the Eaton's (1975) equation:

$$P = 0.67 \text{ X P X } \frac{VP^2}{10^6} \quad 3.2$$

where P is the pressure in Pascals (Pa), ρ is the density of the rock in kilograms per cubic meter (kg/m^3) and V_p is the compressional velocity in meters per second (m/s). The required data for Geo-mechanical modeling are shown in Table 1.

Table 1: Data required for Geo-mechanical modeling

Rock Property Profile	GR Log	Caliper Log	Resistivity Log	Density Log	Neutron Log	Sonic Log
Pore Pressure	✓	✓	✓	___	___	✓
Overburden Stress	___	___	___	✓	✓	___
Mech. Stratigraphy	✓	__	✓	✓	__	✓
Horizontal stress (min)	✓	__	__	__	__	✓
Elastic Parameters	__	__	__	✓	✓	✓

POISSON RATIO:

This is the ratio of the comparative contracting strain, either lateral, radial or transverse strain normal to the discreet load to the correlative axial strain in the direction of the discreet load. It can be expressed as:

μ = - transversal Strain / axial Strain (1)

$$E = -\frac{Et}{Ei}$$

where μ = Poisson's ratio, ε_t = transverse strain (m/m) and ε_l = axial strain (m/m)

Poisson's ratio ranges from -1.0 to *+0.5* though for ordinary materials, it is between 0 to 0.5. The standard Poisson Ratios for usual materials are denoted in Table 2. Poisson ratio and Young modulus can be obtained majorly from core analysis. In the absence of core data, rock properties are also generated from sonic log, both compressional and shear waves and bulk density for incessant details.

Castagna's correlation method was used to calculate both the young modulus and the Poisson ratio because it provides the most accurate result in sand and shale formation.

$$E = 3.1 \text{ X } 10^6 \text{ X } \left(\frac{1}{\Delta t}\right)^{3.5}$$

$$V = \frac{1.13 \ X \ (\frac{1}{\Delta t})^2 - 1.13}{2 \ (1.13 \ X \ (\frac{1}{\Delta t})^2 - 1}$$

Where E = Young modulus
V= Poisson ratio
Δt= compressional wave velocity from sonic log

Table 2: Material Property data for Usual Materials (CRC, 2024)

Usual Materials	Standard Poisson Ratio	Density (g/cm^3)	Young Modulus (GPa)
Lead	0.431	10.0	14
Sand	0.29	2.65	25
Concrete	0.15	2. 4	24
Granite	0.25	2. 4	85
Clay	0.37	2.3	7
Magnesium	0.35	1. 8	45
Marble	0.25	2.7	65
Sandy Clay	0.37	1.4	17
Sandy Loam	0.31	1.55	59
Zinc	0.331	6.2	70
Alluminium Alloy	0.33	2.65	69

III. Results And Discussion

Delineation of Lithologies and Rock Type

In the well SOC 01, the gamma ray log indicated an interpolation of sand and shale where a deflection to the left indicates sand and deflection to the right indicates shales. This is concluded because of the geology of Niger delta is basically composed of sand and shale. The sand is indicative of the yellow colour while the shale is indicative of the ash colour from the lithology log. The five wells predominantly comprised of sand and shale. The five wells with a suite of logs are illustrated in Figures 2 to 6.

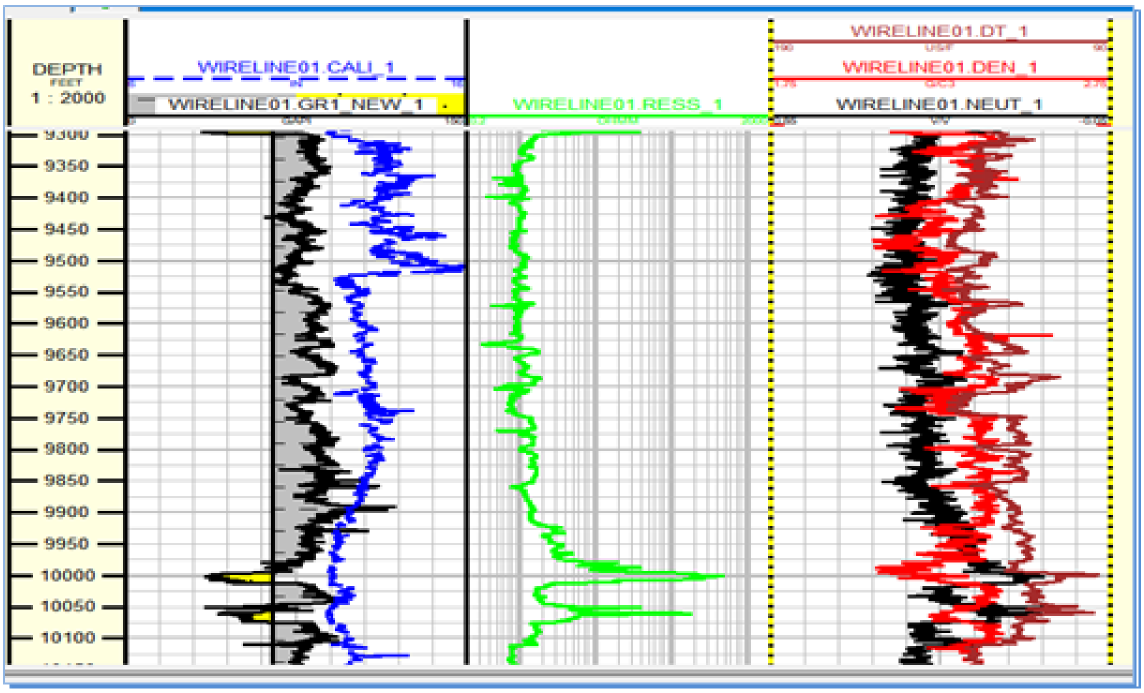


Figure 2: The Lithology (Gamma Ray And Caliper), Resistivity And Porosity (Density, Neutron And Sonic) Logs Of Well SOC 01.

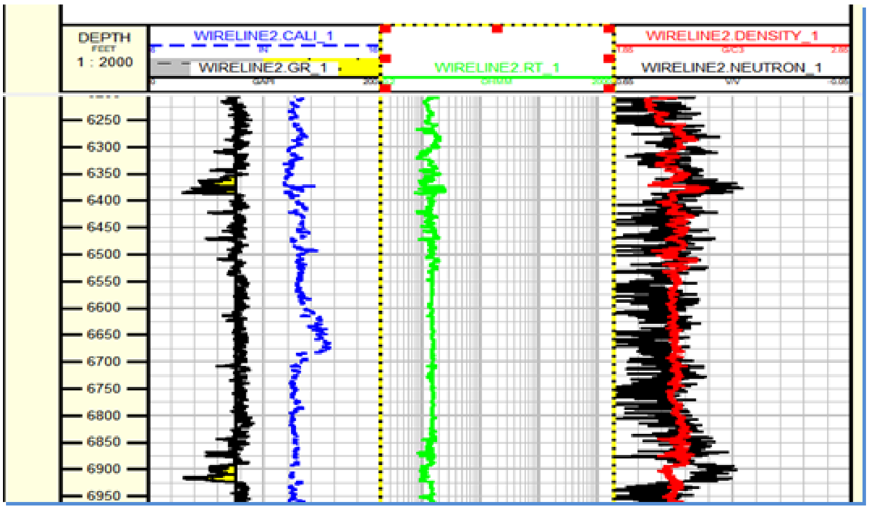


Figure 3: The Lithology (Gamma Ray And Caliper) Log, Resistivity And Porosity (Density, Neutron And Sonic) Logs Of Well SOC 02.

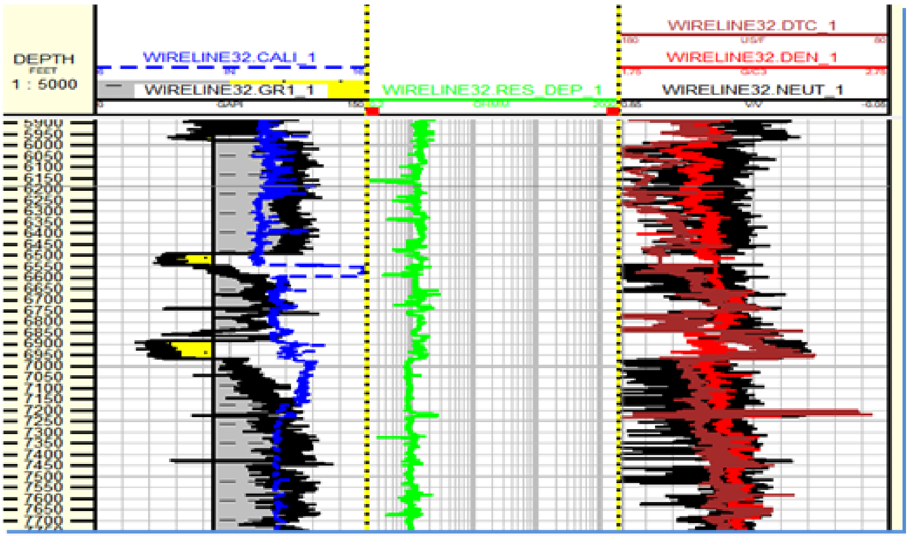


Figure 4: The Lithology (Gamma Ray And Caliper), Resistivity And Porosity (Density, Neutron And Sonic) Logs Of Well SOC 03

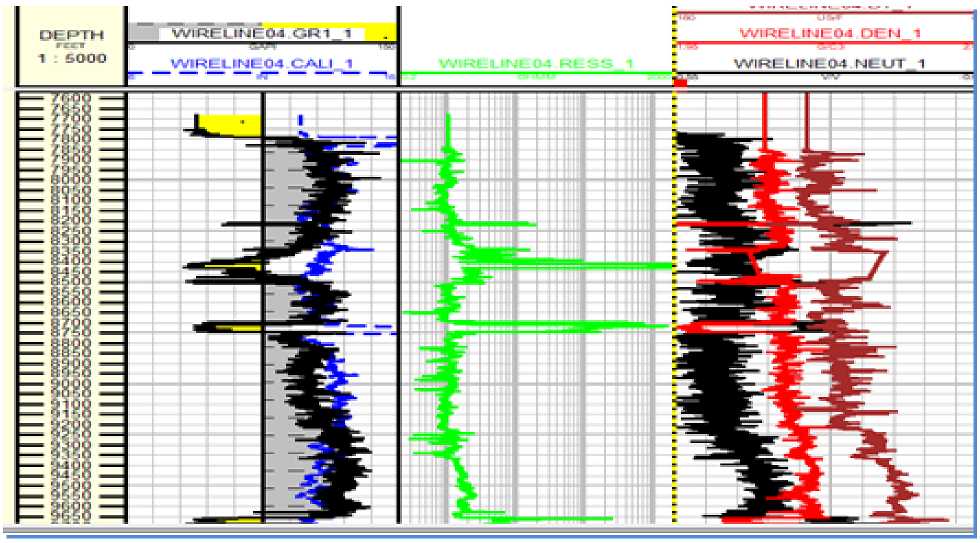


Figure 5: The Lithology (Gamma Ray And Caliper), Resistivity And Porosity (Density, Neutron And Sonic) Logs Of Well SOC 04.

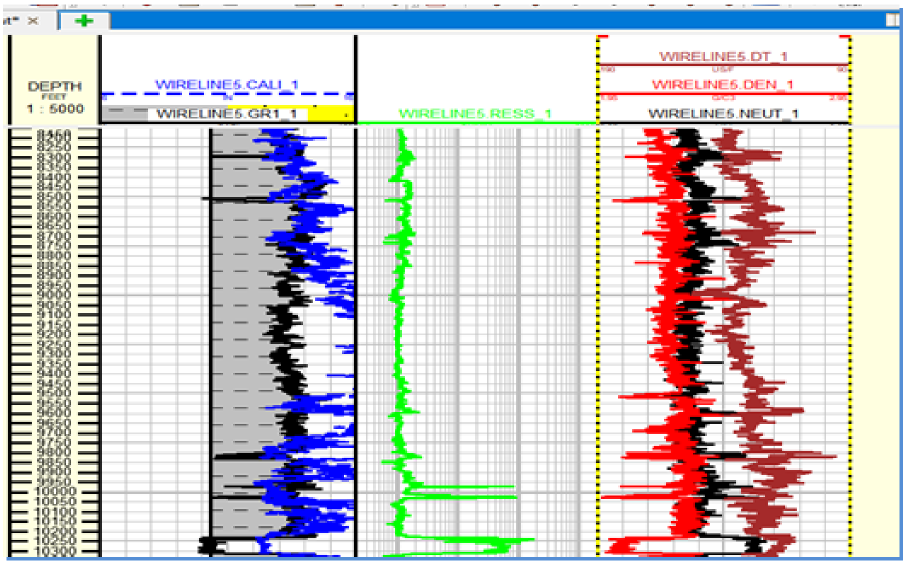


Figure 6: The Lithology (Gamma Ray And Caliper), Resistivity And Porosity (Density, Neutron And Sonic) Logs Of Well SOC 05.

Delineation of Fracture Zones

Fractures can be characterized using typical suites of logs. Places where the caliper logs showed anomalies are associated with fractures while the natural gamma log indicated a major change in lithology. Electrical resistivity anomalies are associated with both borehole enlargement and alteration with neutron log anomalies. Fractures are usually associated with large spike like anomalies on caliper logs. These spikes represent the effects of mechanical enlargement of fracture mouths during drilling. The caliper log is indicated with a blue dash line.

In Well SOC 01, 6390 - 6402 ft there is a spike in the caliper log with an increase in both resistivity and sonic values. There are spikes between 8850-8865 ft and 11255 ft in Well SOC 02; in Well SOC 03 within 9266 - 9288 ft; in Well SOC 04, there are spikes at 7618 - 7622, 9985 -9958 ft. Also, in Well SOC 05, there are spikes at 10652 - 10658 ft. These spikes might be indicative of fractured zones.

The caliper log in Well SOC 01, the bit size is 12inch in diameter. The formation between 5500-6500 ft is a well consolidated, non- permeable massive sand while the shale formation beneath between 6500 - 6570 ft is a bad hole or tight spot as a possible result swelling shale. The top of the sand formation from 6570 - 6650 ft is a weak formation of unconsolidated sand while the remaining part is consolidated. The shale beneath between7050 - 7194 ft is indicative of brittle shale and then downward up to 7984 ft is an impermeable shale formation. Also, within the depth 8250 - 8440 ft, a weak formation of brittle shale is present.

In Well SOC 02, there is a wash out zone within the depths 7714 - 7770 ft, 8140 - 8170 ft, 8730 -8758 ft and 9894 - 11850 ft. In Well SOC 03, at depths 5540 - 6592 ft, 6900 - 6962 ft, 8624 - 8600 ft and 9210 - 9308 ft, there is presence of enlarged caliper value on the log. In Well SOC 04, a break out occurred between 7790 - 7832 ft, 8720 - 8752 ft on the caliper log. There is a porous and permeable sand at 9782 - 9790 ft. Between 10350-10400 ft, there a slight increase indicating probably a brittle-plastic shale. In Well SOC 05, there is a wash out between 6420 - 6700 ft, 6780 - 6884 ft and 6960 -7017 ft either occurring as a result of brittle shale or permeable sand.

Identification of Reservoirs

In Well SOC 01, there is presence of hydrocarbon bearing reservoirs between the depths of 8080-8158 ft, 9250- 9296 ft and 9980-10074 ft. In Well SOC 02, hydrocarbon reservoirs occurred within 7576c -7590 ft, 8900 - 8918 ft, and 9120 - 9146 ft. In Well SOC 03, the hydrocarbon bearing zone is between 9346 - 9380 ft and 9550-9568 ft, 10750 - 10762 ft. In Well SOC 04, the hydrocarbon bearing zones occurred within the depths 8390 - 8432 ft, 8698 - 8746 ft, 10750 - 10762 ft. In Well SOC 05, the hydrocarbon bearing zone occurred at 6892 - 6898 ft, 9970 - 10032 ft and 10232 - 10312 ft, although some zones are relatively thin for exploration.

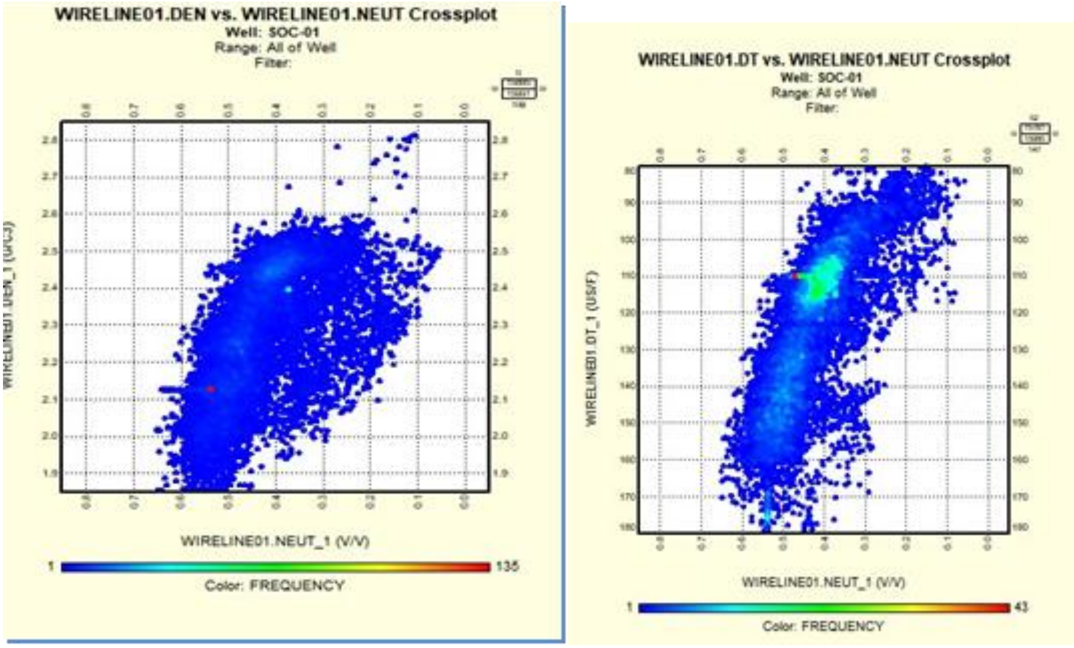
Delineation of Over Pressured Zones

While some zones appear to be under-pressured, others are over-pressured. In Well SOC 01, over-pressured zones are observed in between 5764 - 5798 ft, 6000 - 6038 ft, 6510 - 6600 ft, 6490 - 6660 ft, 5994 - 6100 ft and 7094 - 7194 ft. Also, in the Well SOC 02, over-pressured zones appeared at 11450 - 11486 ft and 10494 - 10520 ft.

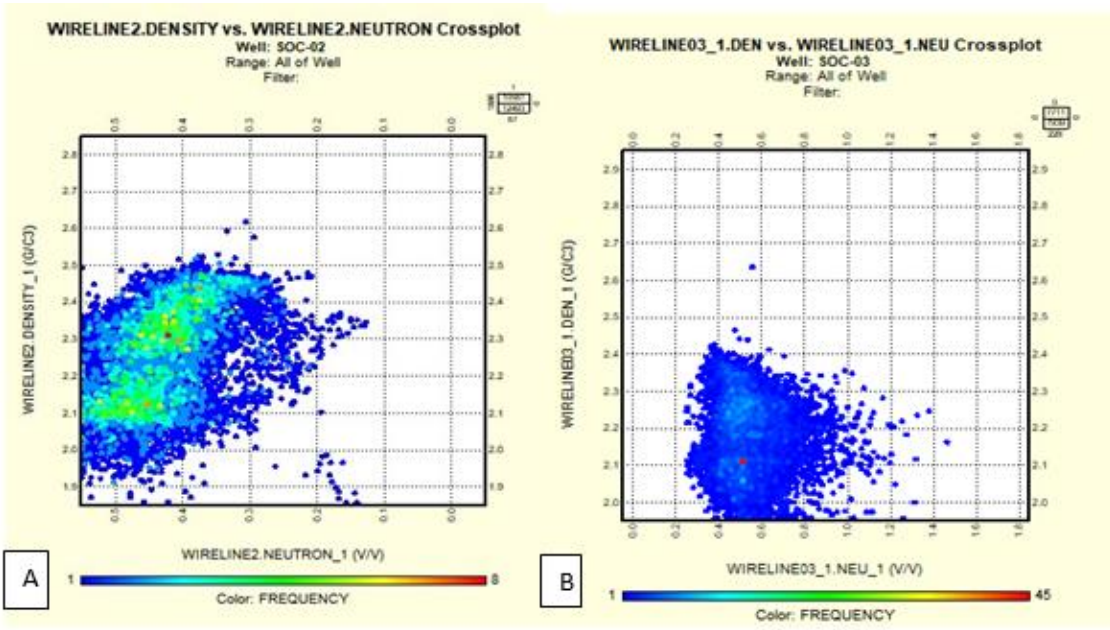
In Well SOC 03, the over-pressured zone occurred between 6010 - 6044 ft and 6540 - 6592 ft while the under-pressured zone appeared within 7210 - 7230 ft. In Well Soc 04, over pressured zone appeared majorly at 8212 - 8200 ft. In Well SOC 05, over-pressured zone was observed within 6594-7000 ft, under-pressured zone also appeared at 7254-7270 ft. These zones should be drilled in smaller hole sizes if possible.

Pore Pressure Analysis

The cross-plots showed compaction and burial of sediments in figures 7-9 below. Decrease in porosity is as a result of higher compaction and burial of sediments, and vice versa. The rate of shale compaction or porosity reduction decreased with increase in burial or compaction. This might be due to decreasing shale permeability and increasing water viscosity, thus decreasing rate of fluid expulsion with increasing compaction. Areas which are over-pressured in the shale sections or with change in lithology, and also areas with low permeability are the major conflicts of interest.



Figures 7(a): Neutron-Density Porosity Cross-Plots of Well SOC 01. (b): Sonic-Neutron Porosity Cross-Plots of Well SOC 01.



Figures 8 (a): Density-Neutron Porosity Cross-Plot of Well SOC 02. (b): Neutron-Density Porosity Cross-Plot of Well SOC 03.

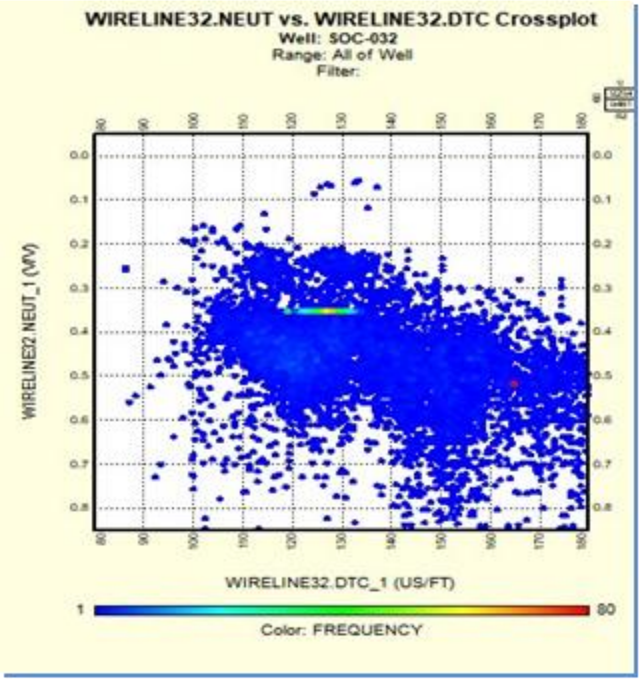


Figure 9: Sonic-Neutron Porosity Cross-Plots of Well SOC 03.

The over pressured sand lithologies will be ignored because it could be a gas formation. The properties of the shale are summarized below.

Table 3: Rock Properties of shale zones in Well SOC 01 - 05

Well Name	Depth	Poisson Ratio (V)	Young Modulus (E) [pa]	Permeability Md_	Status
Soc 01					
	9350	0.157	0.1312	Very Low	Unstable
	10100	0.342	0.3082	low	Unstable
	10550	0.321	0.6974	low	Stable
	11650	0.240	0.4246	low	Stable
	13400	0.331	0.3084	Very low	Unstable
Soc 02					
	7550	0.1228	0.3162	Very low	Unstable
	8450	0.1325	0.6714	low	Stable
	9500	0.3589	0.4392	Very low	Unstable
	10700	0.3712	0.2882	Very low	Unstable
Soc 03					
	8250	0.4585	0.3564	Very low	Unstable
	8900	0.2452	0.3467	Very low	Unstable
	9354	0.2829	0.4235	Low	Stable
	9750	0.1454	0.3567	Low	Stable
	10150	0.1789	0.3578	Low	Stable
Soc 04					
	9525	0.2678	0.4564	Very low	Stable
	9538	0.3467	0.4168	Very low	Unstable
	10750	0.2167	0.4267	Low	Stable

	11793	0.2871	0.3638	Low	Stable
	12650	0.4481	0.5894	Very Low	Stable
Soc 05					
	9600	0.2567	0.4392	Low	Stable
	9947	0.2362	0.2407	low	Unstable
	10750	0.3268	0.5627	Very low	Unstable
	10900	0.4626	0.4674	Very low	Unstable
	12748	0.2927	0.5272	Low	Stable

High Poisson ratio (PR) indicates horizontal stress which can lead to instability while high Young Modulus (YM) indicates a stiff rock and maintain wellbore stability. Typically,
Low PR and Low YM= instability
Low PR and high YM= stability
High PR and high YM= instability
High PR and Low YM= instability

IV. Conclusion

The use of petrophysical analysis in determining well-bore stability has proven to be incredibly valuable. By analyzing rock properties like porosity, permeability, and rock strength, great insights are gained into well-bore stability. In 'Soc field', the shale porosity across the five wells was in the range of 15-19%. Clay has low permeability, therefore permeability ranged from low to very low, and since porosity and permeability are inversely related, area of relatively higher porosity has lower percentage of permeability. The histogram bare of gamma ray was used to check for zones of clean sandstone and shale. The minimum values ranged between 220-110API and the maximum values ranges between 70-125API.

V. Recommendation

Although the wells are stable to an extent, oil-based mud should be used for exploitation because it enhances shale stability and has faster penetration rate. Core analysis can be used to give a more accurate result, as ditch cutting using the sphericity and roundness of cuttings can identify caving types and subsequently determine the dominant failure type. Core analysis provides matrix permeability, bulk mineral density, friction angle, kerogen, grain density, total porosity and gas filled porosity (both free and absorbed gas), as well as many other parameters needed to define drilling locations, well-bore placement and orientation. This was not available fir this study. Also, seismic analysis will be able to identify faults and fractures. Through the incorporation of these other two analysis, the result can be correlated for precision.

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