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3D Static Modeling of Geomechanical properties in Aku Field in the Niger Delta, Rivers state, Nigeria

Collins G. A.¹, Prof. Ehirim C. N.², Dr. Dagogo N.³

Student, Department of Physics, Applied Geophysics option, Faculty of Sciences, University of Port Harcourt,
Choba, Rivers state, Nigeria¹

Faculty of Sciences, University of Port Harcourt, Choba, Rivers state, Nigeria^{2,3}

ABSTRACT: The static modeling of the geomechanical properties shows that several subsurface structures and details can be unravelled. The approach inculcates the use of the Schlumberger Petrel interface to estimate the reservoir petrophysical properties, evaluate the geomechanical properties, then we generate the seismic-to-well tie convert the time map to depth, carry out fault mapping, generate the pillar grid, correlation, facie modeling, upscaling and validation of the results. The results gave us a Young's modulus ranging from 1 to 4Mpsi, Shear modulus ranges from 0.3 to 2.3Mpsi, Poisson's ratio ranges from 0.25 to 0.45, Bulk modulus ranges from 1 to 2.5Mpsi, Unconfined Compressive stress (UCS) ranges from 0.1 to 1.75Mpsi, the P-wave-S-wave velocity (V_p/V_s ratio) ranges from 0.25 to 4.5, S-Hmin ranges from 6000 to 7500psi, S-Hmax values ranges from 17000 to 27000psi, overburden stress 2000 to 1500psi. These results imply that higher modulus (closer to 4 Mpsi) indicates stiff rock, suitable for sustaining fractures created during hydraulic fracturing, while lower values suggest more deformable formations. Poisson's ratio gives the rock's tendency to expand laterally when compressed; **Lower Values** (e.g., 0.25): Indicate brittle rocks, which are ideal for fracturing. **Higher Values** (e.g., 0.45): Represent ductile rocks, which may hinder fracture propagation. The wells should be placed in zones with moderate Bulk Modulus (1.5–2.0 Mpsi) and UCS (> 1.0 Mpsi) to ensure good mechanical integrity while maintaining sufficient reservoir deformability for production. During hydraulic fracturing, avoid areas with extremely high Bulk Modulus (> 2.3 Mpsi) as fractures may not propagate effectively. Moderate values are ideal for achieving optimal fracture geometry. Zones with low UCS (< 0.5 Mpsi) are more prone to compaction, which could affect permeability and porosity. Pressure support mechanisms should be implemented to mitigate compaction risks. During drilling the driller should maintain a mud weight that balances the in-situ stress, particularly in zones with low UCS, to avoid collapse or sanding issues. During drilling, use inclined wellbores to access deeper reservoir sections with reduced risk of buckling also. Drilling perpendicular to the maximum stress (S-Hmax) minimizes shear failure.

KEYWORDS: UCS, V_p/V_s , S-HMIN, S-HMAX, QC, SSTVD.

I. INTRODUCTION

There is an on-going quest for exploring hydrocarbon without incurring much cost and most importantly, to get a reservoir that will give good value for the money spent in establishing and exploring the wells. Static modeling is one of the integrated approaches intended to reduce the associated risks and losses during exploration. The need for the best exploration approach and method cannot be over-emphasized, there is need to inculcate an advanced and more reliable way of interpretation such as will reveal a better information on the in-situ stress state of the reservoir and further give clarity on the best decision. Reservoir static modeling is proposed for this study based on its uniqueness, robustness and ability to provide details of subsurface structures. According to Zoback (2010), 3-D geomechanical models provide a more comprehensive understanding of the stress state and mechanical properties by incorporating data from multiple wells and geological layers, unlike 1-D models, which are limited to vertical well paths and singular data points. 3-D models are particularly advantageous for optimizing hydraulic fracturing operations. By simulating stress distributions and fracture propagation in three dimensions, these models can help engineers design effective stimulation treatments that maximize reservoir connectivity while minimizing the risk of unwanted fracture growth into non-target zones (Schlumberger, 2018). 3-D models allow for the integration of seismic data, lithological heterogeneity, and lateral variations in stress fields, enabling a more accurate assessment of fault reactivation risks and wellbore stability in

anisotropic formations. This capability is critical in areas with complex structural features, such as faulted or folded regions, where 1-D models may oversimplify stress variations (Tingay et al., 2013).

II. RELATED WORK

Osita Okeke, (2021), in their work titled “Integrated 3D geomechanical characterization of a reservoir: case study of ‘Fuja’ field, offshore Niger Delta, Southern Nigeria” aimed at evaluating the mechanical properties of the reservoir with a view of reducing the challenges encountered during hydrocarbon exploration. They integrated bulk density, sonic log and gamma ray log, with 3D seismic log to estimate reservoir elastic and inelastic rock properties, the reservoir pore pressure, total vertical stress, maximum and minimum horizontal stress.

Olotu S. J. et al., (2020), in their work titled Estimating Reservoir Geomechanical Parameters for Enhanced Characterization; aimed at identification of lithology, delineation of hydrocarbon reservoir units which are in the formation, to compute the petrophysical parameters and estimate the geomechanical parameters of the associated reservoirs for an enhanced reservoir characterization and establish the stress regime of the field.

Fidelis A. Abija, (2019), studied geomechanical property evaluation and the mechanics of growth faulting in a Niger Delta field. This research aimed at understanding the behavior of rocks along the vertical and lateral axes, also how the rock formation undergoes compartmentalization as a result of the effects of stress and the communication of the fluids within the formation. The purpose is to aid drilling, completion of production wells, and hydrocarbon production.

Difference O. & Mary O. (2019), worked on “Anisotropic Geomechanical Characterization of Sojuko field in the shallow offshore of the Niger Delta”. In this work they aimed at determining parameters responsible for the stability of a well during drilling and development; the three major parameters that they considered are; the Thompson’s delta anisotropic parameter, which is gotten from analyzing well and seismic interval velocities, followed by the epsilon and gamma anisotropic parameters.

III. MATERIALS AND METHODS

The materials used include the following:

1. The Schlumberger Petrel software; this is used in the entire work in processing the required results of the work. The choice of this software is as a result of it’s ability to combine the various datasets required to carry out Geomechanical characterization of a reservoir.
2. Micro soft Excel; this is used to QC the data for any possible errors, we also arrange the
3. well logs in the expected order using this interface.
4. Datasets; the data used in this work include Gamma ray logs (GR), Density logs, Sonic logs, resistivity logs, Neutron-porosity logs, Self-Potential (SP) logs, core data, and checkshot data.
5. The method adopted for this research involves the following:
6. First loading the data into the software: The identified data were loaded successfully into the software. The sequence of events are shown on the flowchart in Fig. 2.1.

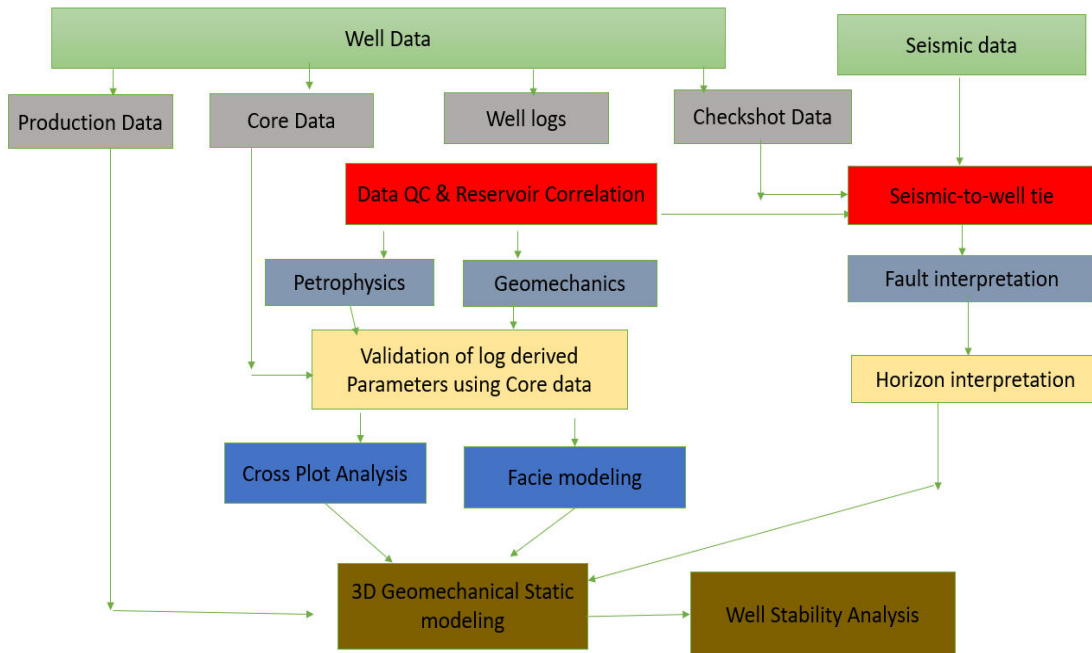


Fig.2.1.

i) QC the data and carry out Reservoir Correlation: Four wells were studied in the course of this work as shown in Fig. 2.2. The data QC was done successfully and correlated as shown in Fig. 2.2.

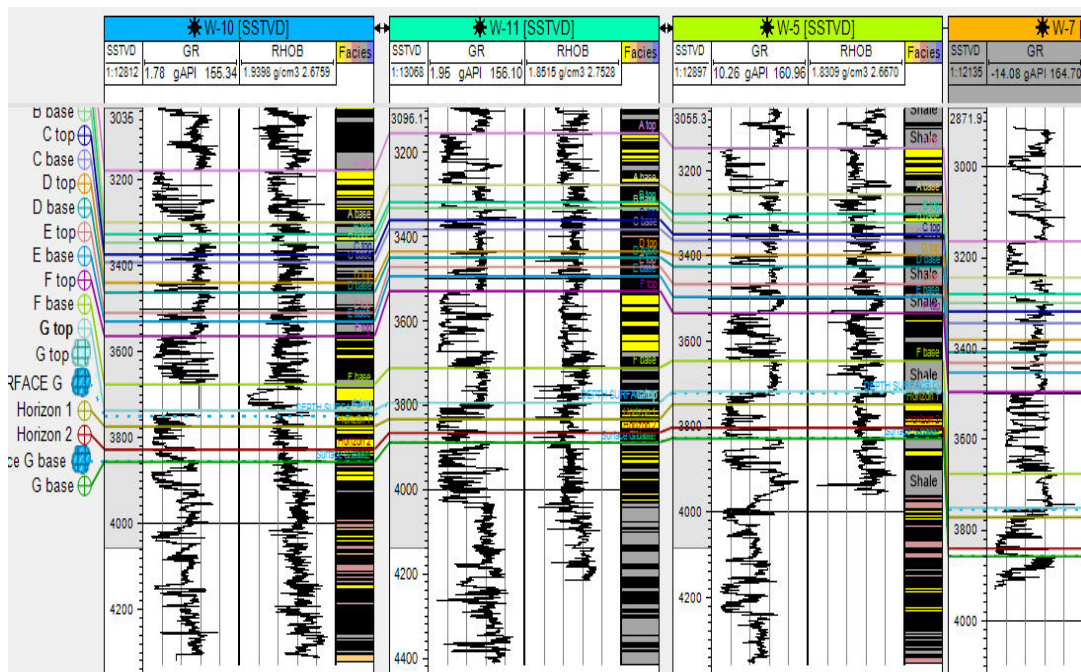


Fig 2.2.

ii) Perform petrophysical evaluation: Petrophysical evaluation was carried out by means of the required equations as they were loaded into the software, Fig 2.3-2.6:

Total porosity is given by:

$$\phi_t = \phi_{ef} + V_{sh} * \phi_{sf} \quad (1)$$

Where;

ϕ_t = total porosity of clean sand,

ϕ_{ef} = effective porosity,

V_{sh} = volume of shale in the formation and

ϕ_{sf} = total porosity of shale formation

Water saturation is given by:

$$S_w = \frac{V_p}{V_w} \quad (2)$$

Where;

V_w = Volume of water

V_p = Total pore volume

Also,

$$S_w = \left(\frac{R_w}{R_t} \cdot \frac{1}{\phi^m} \cdot \frac{1}{a} \right)^{\frac{1}{n}} \quad (3)$$

Where:

ϕ is porosity,

m is the cementation exponent,

a is the tortuosity factor, and

n is the saturation exponent (Archie, 1942).

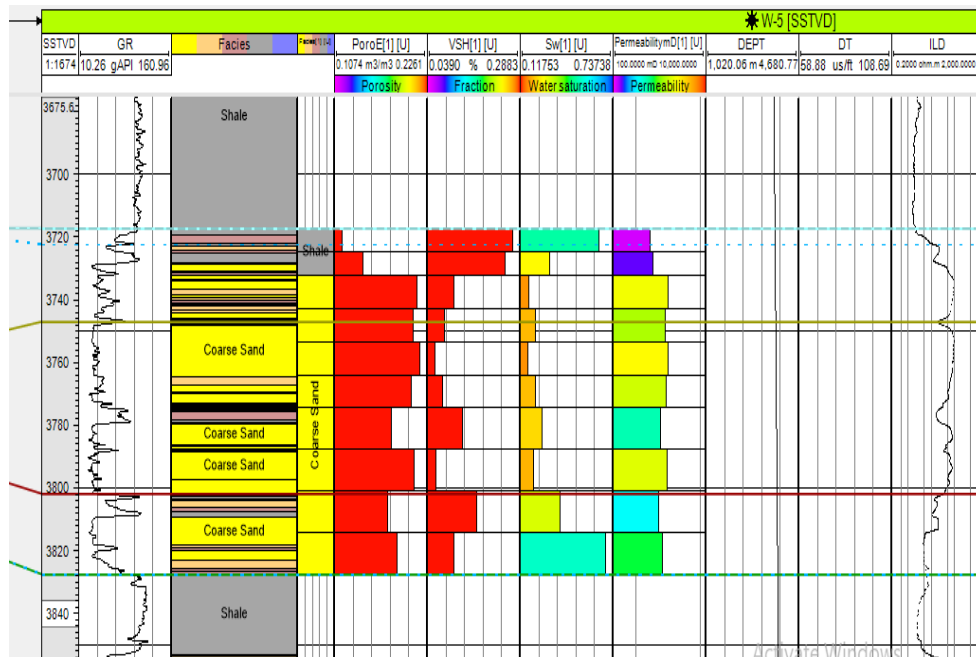


FIG 2.3

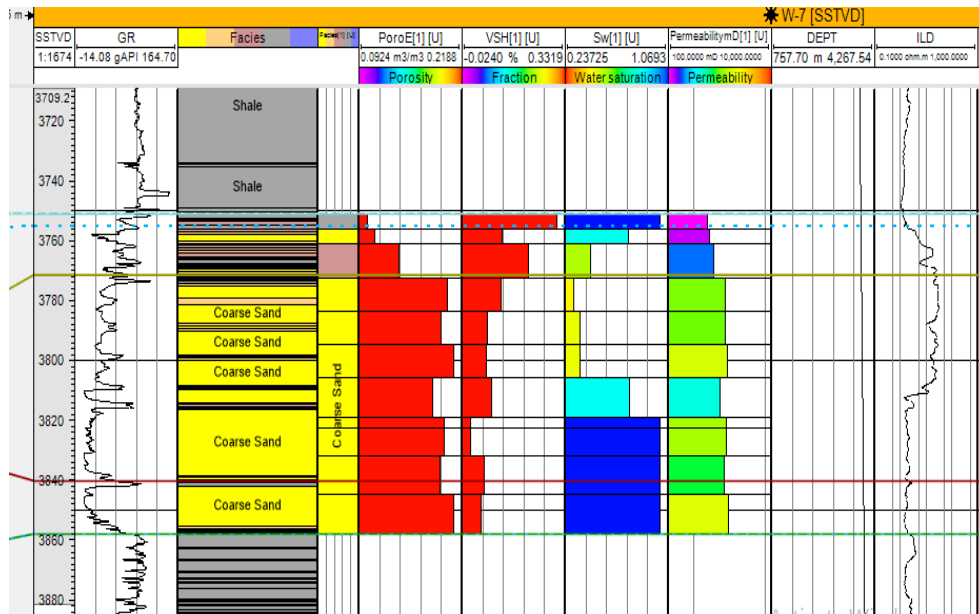


FIG.2.4

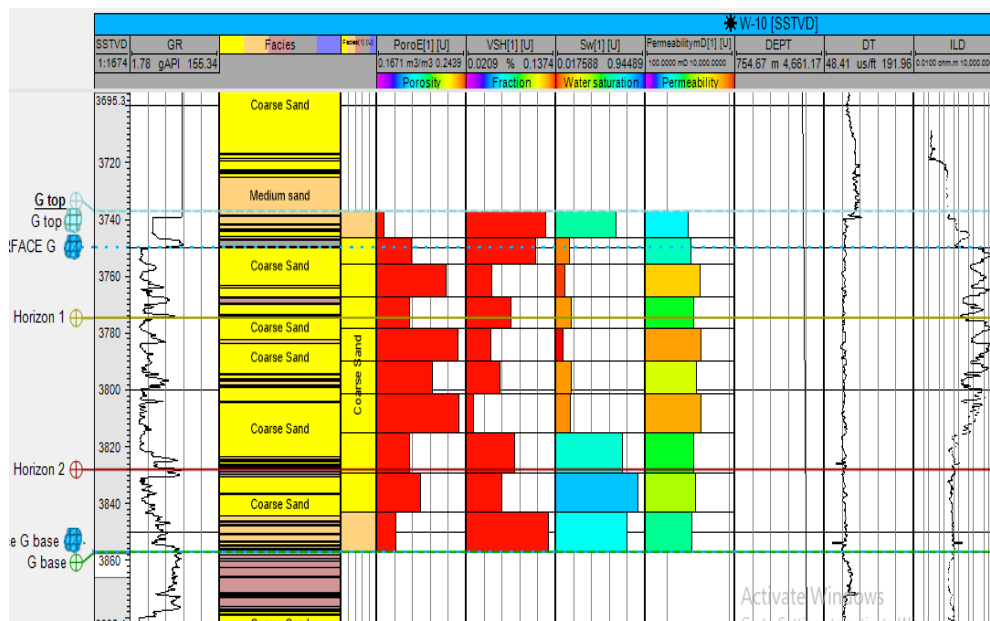


FIG 2.5.

i) Seismic-to-well tie: This involves the following steps:

1. Import the well data; well tops, sonic logs, density log and seismic data into petrel; verify data quality.
2. Generate synthetic seismogram; using sonic and density logs to compute the acoustic impedance and reflection coefficient.
3. Extract a wavelet from the seismic volume near the well location.
4. Convolve the reflection coefficient with a seismic wavelet.
5. Calibrate the wavelet to the seismic data and ascertain accuracy.
6. Perform time-to-depth conversion; using checkshot or sonic log.

7. Verify the time-depth conversion with VSP or Checkshot data.
8. Correlation of synthetic seismogram with seismic trace at wells.
9. Validate seismic to well ties by applying it to other wells

ii) Fault interpretation and horizon generation; here we mark out the fault lines in the seismic data using the Petrel interface Fig. 2.6.

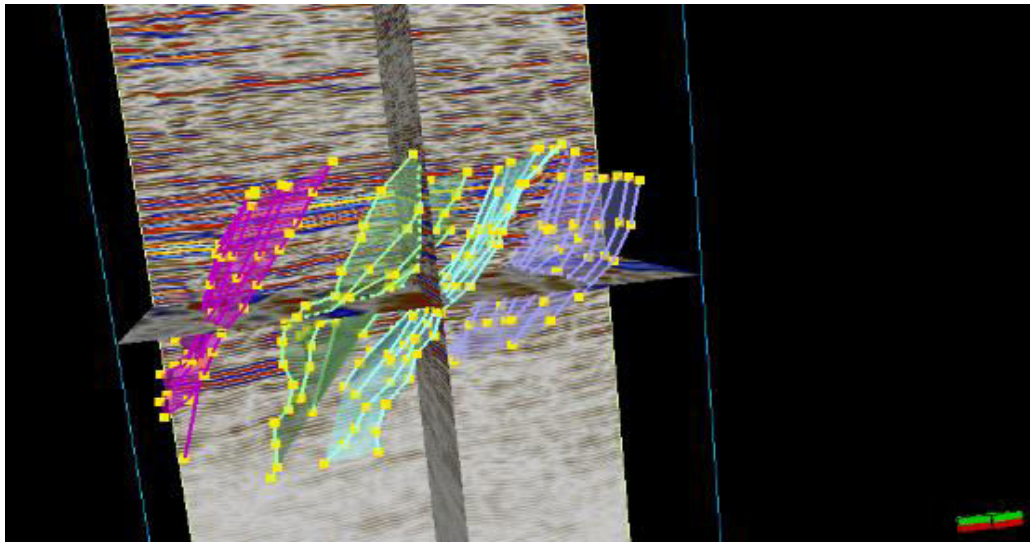


Fig. 2.6

Estimate the geomechanical properties: The geomechanical parameters are also estimated by means of the software: The following formula help in generating the properties:

Young's modulus: This gives the reservoir's ability to withstand stress denoted as E, describes the relationship between stress (σ) and strain (ϵ) in a linear elastic material, according to Hooke's Law, hence:

$$E = \frac{\sigma}{\epsilon} \quad (4)$$

Bulk modulus: It is a measure of a material's resistance to uniform compression, measured in units Pascal (Pa) or gigapascals (GPa): Mathematically, it is expressed as:

$$K = \frac{-VdV}{dP} \quad (5)$$

where:

K = Bulk modulus

V = Initial volume

dP = Change in pressure

dV = Change in volume

V_p/V_s ratio: This is the ratio of the P-waves velocity to that of the S-wave velocity it is dimensionless. P-wave velocity (V_p) is directly related to the bulk modulus (K) and the density (ρ) of the material:

$$V_p = \sqrt{\frac{K + \frac{4}{3}G}{\rho}} \quad (6)$$

where G is the shear modulus. Understanding P-wave velocities helps geophysicists interpret subsurface structures and identify hydrocarbon reservoirs (Mavko, Mukerji, & Dvorkin, 2009).

The shear modulus influences the velocity of shear (S) waves traveling through the Earth. S-wave velocity (V_s) is directly related to the shear modulus (G) and the density (ρ) of the material:

$$V_s = \sqrt{\frac{G}{\rho}} \quad (7)$$

Shear modulus: The shear modulus (G) is defined as the ratio of shear stress (τ) to the shear strain (γ) it produces, hence:

$$G = \frac{\tau}{\gamma} \quad (8)$$

where:

G is the shear modulus,

τ is the shear stress,

γ is the shear strain.

The shear modulus is measured in units of Pascals (Pa) or gigapascals (GPa). It shows how easily or not a material can deform under stress (Schön, 2015).

Unconfined Compressive Strength (UCS): This is defined as the maximum stress a material can endure under uniaxial compression before failing. It is expressed in units of force per unit area, typically megapascals (MPa) or pounds per square inch (psi) (Jaeger, Cook, & Zimmerman, 2007). It can be mathematically represented as:

$$UCS = \frac{F_{max}}{A} \quad (9)$$

Poisson's ratio (ν): This is a fundamental mechanical property that characterizes the elastic behavior of materials, including rocks and soils, under stress.

Poisson's ratio (ν) is mathematically expressed as:

$$\nu = \frac{\epsilon_{lateral}}{\epsilon_{axial}} \quad (10)$$

where:

$\epsilon_{lateral}$ is the lateral strain (perpendicular to the applied stress),

ϵ_{axial} is the axial strain (parallel to the applied stress).

Poisson's ratio typically ranges from 0 to 0.5 for most materials. For geological materials, it generally falls between 0.1 and 0.4, depending on the type of rock or soil and its condition (Jaeger, Cook, & Zimmerman, 2007).

- (i) Cross plot analysis and facie modeling: Here we analyze the properties in line with established theories.
- (ii) Facie modeling: This is where we establish the lithological characteristics of the reservoir.
- (iii) Wellbore stability analysis: Here we interpret the results of the static model generated in terms of the well bore stability, reservoir trajectory, stress analysis and fault regime.

IV. EXPERIMENTAL RESULTS

The reservoir is made up of four (4) wells marked wells 5, 7, 10 & 11. These wells were correlated, and the reservoir selected is marked reservoir-G, having G-top and G-base. A seismic-to-well tie was carried out and the result is shown in Fig.3.1.

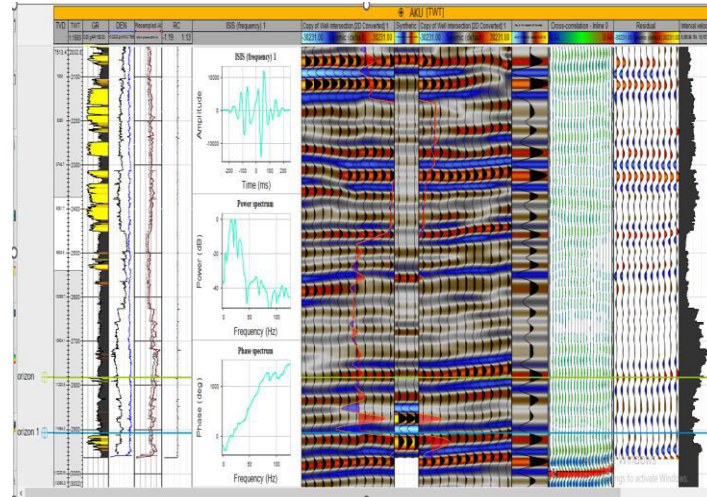


Fig 2.7

The results gave us a Young's modulus ranging from 1 to 4Mpsi, Shear modulus ranges from 0.3 to 2.3Mpsi, Poisson's ratio ranges from 0.25 to 0.45, Bulk modulus ranges from 1 to 2.5Mpsi, Unconfined Compressive stress (UCS) ranges from 0.1 to 1.75Mpsi, the P-wave-S-wave velocity (V_p/V_s ratio) ranges from 0.25 to 4.5, S-Hmin ranges from 6000 to 7500psi, S-Hmax values ranges from 17000 to 27000psi, overburden stress 2000 to 1500psi. These results imply that higher modulus (closer to 4 Mpsi) indicates stiff rock, suitable for sustaining fractures created during hydraulic fracturing, while lower values suggest more deformable formations.

Poisson's ratio gives the rock's tendency to expand laterally when compressed; **Lower Values** (e.g., 0.25): Indicate brittle rocks, which are ideal for fracturing. **Higher Values** (e.g., 0.45): Represent ductile rocks, which may hinder fracture propagation. Low compressibility (high bulk modulus: 2.5Mpsi) indicates strong rocks that resist pore pressure changes during production. Higher UCS values (closer to 1.75 Mpsi) suggest the reservoir is less prone to wellbore instability during drilling. Considering the linear increase in UCS with increasing Bulk Modulus, suggesting that rocks with higher compressibility (lower Bulk Modulus) are more prone to deformation. The wells should be placed in zones with moderate Bulk Modulus (1.5–2.0 Mpsi) and UCS (> 1.0 Mpsi) to ensure good mechanical integrity while maintaining sufficient reservoir deformability for production. During hydraulic fracturing, avoid areas with extremely high Bulk Modulus (> 2.3 Mpsi) as fractures may not propagate effectively. Moderate values are ideal for achieving optimal fracture geometry. Zones with low UCS (< 0.5 Mpsi) are more prone to compaction, which could affect permeability and porosity. Pressure support mechanisms should be implemented to mitigate compaction risks. During drilling the driller should maintain a mud weight that balances the in-situ stress, particularly in zones with low UCS, to avoid collapse or sanding issues. During drilling, use inclined wellbores to access deeper reservoir sections with reduced risk of buckling also. Drilling perpendicular to the maximum stress (S-Hmax) minimizes shear failure.

V. DISCUSSION OF RESULTS

Well Placement: Preferred Orientation: Align wells parallel to the minimum horizontal stress direction (S-Hmin) to minimize stress-induced failures. For this stress regime, a near-vertical borehole is optimal to reduce the risk of collapse or shear failure.

Lithology Targeting: Focus on zones with higher Young's Modulus and lower Poisson's Ratio for stability. Avoid zones with high V_p/V_s ratios as they may indicate fluid saturation or ductility.

Mud Weight Design: Use a mud weight range between hydrostatic pressure (5044.57 psi) and fracture pressure (6832.96 psi). This ensures that the wellbore is stable without inducing fractures. Adjust mud weight dynamically in response to pore pressure changes to prevent wellbore instability.

Fracture Management: Avoid exceeding the fracture pressure of 6930.91 psi during drilling or completion activities. Monitor microseismic data for early signs of fracturing.

Real-Time Monitoring: Incorporate real-time geomechanical modeling to detect variations in stress and pressure. Monitor borehole breakouts and other deformation indicators using logging tools.

Completion Strategy: Given the stress anisotropy, use hydraulic fracturing along the direction of S-Hmax to maximize fracture propagation. Select fracturing fluids based on compatibility with the rock's mechanical properties (Economides & Nolte, 2000).

VI. CONCLUSION

It is advisable to use a mud weight range between hydrostatic pressure (5044.57 psi) and fracture pressure (6832.96 psi), the fracture pressure of 6930.91 psi during drilling or completion activities. Monitor microseismic data for early signs of fracturing. Incorporate real-time geomechanical modeling to detect variations in stress and pressure. Monitor borehole breakouts and other deformation indicators using logging tools. Based on the stress pattern of the reservoir which shows anisotropy, adopt the use hydraulic fracturing along the direction of S-Hmax to maximize fracture propagation.

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