*American Journal of Sciences and Engineering Research*

*E-ISSN– 2348–703X, Volume 8, Issue 6, 2025*

# Assessing Fault Seal Potential in a Niger Delta Fractured Sandstone Reservoirs through 3D Geomechanical Modelling

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***Abstract:*** *The faults in the prolific hydrocarbon province of Niger Delta serve as a conduit or barrier and hence the sealing ability is a very important exploration risk. The classical approaches are incapable of explaining the dynamic current stress field. Therefore, the aim of this study is to assess fault seal potential in a Niger Delta fractured sandstone reservoirs through 3D geomechanical modelling. The objectives are to execute an integrated 3D structural and geomechanical model of Gabo oil field by synthesizing seismic data, well logs and core measurements; execute 3D geomechanical metrics to assess the fault seal potential of Gabo oil field reservoir; and identify the impact of reservoir depletion on fault stability and fracture network conductivity. This study incorporates seismic interpretation, well logs and core data to build a strong 3D geomechanical model, which defines the in-situ stress and rock mechanical properties. The model computes the tendency to slip and potential of fracture in the fault that corresponds to the critically stressed fault that is prone to reactivation and hydraulic failure. The results show a high level of correlation between the modern stress regime and fault seal behaviour that make it possible to classify the fault segments as high risks, and low risks based on their spatial position. This workflow offers a predictive pattern of determining those areas where fault seal integrity is hindered, de-risking the objectives of drilling and optimization of well paths to bypass areas of violated compartments.*

***Keywords:*** *Fault Seal Potential, Fractured Sandstone, Reservoirs, 3D Geomechanical Modelling, Niger Delta*

## I. Introduction

Fault seal potential is an important factor that determines the success of hydrocarbon exploration, production, and evaluation of the possibility of faults serving as conduits or effective traps in fluid migration (Yahaya-Shiru et al., 2022). According to Ogbuagu et al., (2025) the sandstone reservoirs in Gabo oil field are also prone to intricate fracturing in the prolific Niger Delta basin that has vast growth faults and roll-over anticlines. Such fractures may greatly increase the permeability but also create a high risk of compartmentalization and seal breakage, the causes of mechanical failures, compaction of the reservoir, and unsustainable production. The simplistic, traditional fault seal analysis techniques, including calculating a one-dimensional shale gouge ratio (SGR), have failed to describe these complex systems, and there are cases where the result of the analysis causes inaccuracies in the hydrocarbon leakage prediction. It is therefore high time that a stronger and more vigorous strategy is adopted (Ogilvie et al., 2020, Lawson Jack Osaki, 2025).

The 3D geomechanical modelling application is a game changer in assessment of the fault seal integrity under realistic in-situ and production induced conditions. Compared to traditional pyroclastic frameworks that tend to ignore inelastic deformation and complicated fault zone characteristics, advanced 3D coupled hydromechanical models can model irreversible reservoir contraction, stress-dependent rock characteristics and fault zone fluid dynamics (Chen et al., 2025; Lawson-Jack Osaki, 2025). The models are capable of predicting the risk of fault reactivation and the change in stress state during depletion by providing the brittle and strong

 Received-12-11-2025 Accepted- 27-11-2025

properties of the Niger Delta reservoir rocks using the properties of geomechanics such as the Youngs modulus, Poisson ratio as well as Unconfined Compressive Strength (UCS) properties (Eladj et al., 2022).

Therefore, this paper would use a detailed 3D geomechanical model to evaluate the potential of the fault seal in the fractured sandstone reservoirs of Gabo oil field in the Niger Delta. The results would help to de-risk the drilling campaigns, optimise the field development plans and improve the safety and efficiency of the hydrocarbon recovery in this strategically vital basin.

*A. Aim and Objectives*

The aim of this research is to assess fault seal potential in a Niger Delta fractured sandstone reservoirs through 3D geomechanical modelling. The objectives are to;

i. execute an integrated 3D structural and geomechanical model of Gabo oil field by synthesizing seismic data, well logs and core measurements;
ii. execute 3D geomechanical metrics to assess the fault seal potential of Gabo oil field reservoir; and
iii. identify the impact of reservoir depletion on fault stability and fracture network conductivity.

## II. Geographical Location of the Study Area

Gabo oil field is located at latitudes 4° 19′ 00″ N to 5° 50′ 00″ N and longitudes 5° 30′ 30″ E to 6° 10′ 00″ E in Niger Delta, Nigeria. Fig. 1 depicts the Map showing the location of Gabo Oil Field in Niger Delta (Iheaturu et al., 2024). An excellent location for evaluating fault seal potential using 3D geomechanical modelling is the Gabo Oil Field. The field's structure is defined by rollover anticlines growth faults that were formed within the Agbada Formation, which is dominated by interbedded sandstones and shales Amupitan et al., 2022). While the adjacent shales serve as possible fault seals, these sandstones create abundant reservoirs that are frequently naturally fractured. The importance of fault architecture, shale gouge development, and stress reactivation in regulating hydrocarbon trapping and leakage has been emphasized by earlier research conducted in Gabo (Agoha et al., 2021). Its suitability for sophisticated geomechanical analysis is increased by the availability of high-quality 3D seismic, well logs, and rock property data. Through the integration of stress modelling, fault potential, and shale gouge ratio techniques, the Gabo Field offers an excellent case study to evaluate seal integrity, predict leakage risk, and improve hydrocarbon prospect assessment in fractured sandstone reservoirs (Horsfall et al., 2024).


Fig. 1. Geographical Location of Gabo Field (Marked with Hatched Square) in the Niger Delta Map Showing where Fault Seal Potential in the Fractured Sandstone Reservoirs Are Being Assessed (Sourced from Agbasi, et al., 2021).

## III. Literature Review

The 3D geomechanical modelling is a critical and contemporary approach for assessing fault seal potential in the complex reservoirs of the Niger Delta (Agoha et al., 2021; Osaki et al., 2019). Recent research such as Ogbuagu et al., (2025) emphasizes the need to switch from static fault seal analysis to dynamic, model-based evaluations. Major risks include fault reactivation and seal integrity in the Niger Delta, which is marked by substantial tectonic activity and shale. According to Kruszewski et al., (2022) 3D geomechanical models are the main tool used in current research to comprehend the in-situ stress conditions that govern fault stability. Despite the fact that these studies effectively describe the geomechanics of reservoirs, there is a glaring research gap in the explicit integration of fault seal analysis in fractured sandstone reservoirs with these detailed property models.

This study addresses the gaps by combining 3D geomechanical modelling with a specific focus on fault seal potential, offering a significant advancement for de-risking hydrocarbon exploration in the Niger Delta.

## IV. Methodology

### *B. Geological Settings*

Niger Delta Basin is the large geological province with big reservoirs of petroleum on the passive continental margin of the Gulf of Guinea, which is found in southern Nigeria (Shi et al., 2025). This basin also has a typical triple layer stratigraphy, with the Benin Formation (continental sands) and the Agbada Formation (paralic sequence and primary hydrocarbon reservoir) as its top and bottom respectively and the Akata Formation (marine shales serving as the source rock and detachment layer) separating them (Horsfall et al., 2024). The structure of the basin is defined by the gravitational nature of deformation whereby an extensive coupled system of growth faults and thrust folds in the deep-water offshore area exists, which contain large oil and gas fields. Gabo oil field is located in this very rich deep-water fold and thrust belt of the offshore Niger Delta Basin (Nduaguibe et al., 2019).

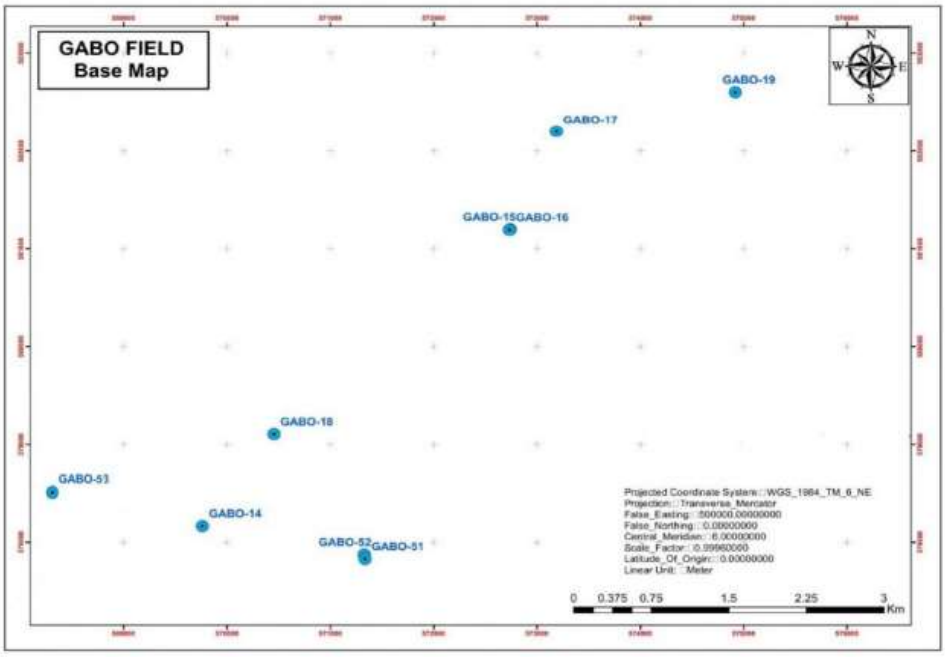


Fig. 2. Base Map showing the Seven Reservoir Locations of Gabo Field, Niger Delta. GABO-03, GABO -14, GABO-18, GABO-51, GABO-16, GABO-17 and GABO-19 (Sourced from Amupitan et al., 2022)

### *C. Geomechanical Models*

1. 3D Seismetic Data

The 3D seismic reflection data (961 inline and 444 crossline) with an estimated study area of 76km$^2$ was used to check shot survey data and a base map of the study area. The files are all standard digital. The data of the check shot were obtained through seismic shooting on the surface where geophones are placed anywhere, at intervals, in the borehole to give the correlation between time and depth. The check shot data allows the seismic interpretation to be correlated with the well logs of Gabo field to be analyzed (Amupitan et al., 2022).

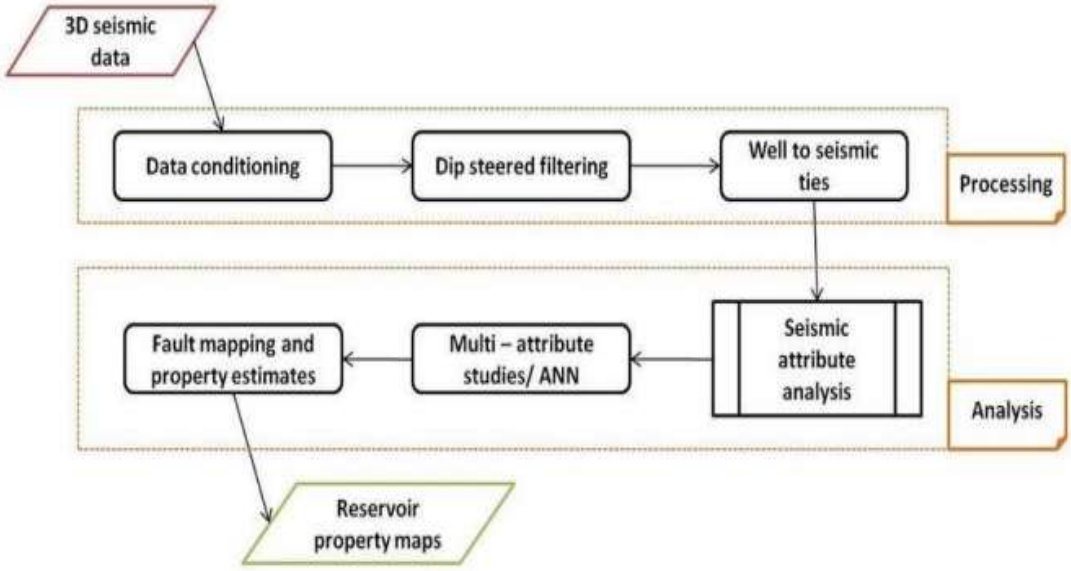


Fig. 3. 3D Seismic Structure of Gabo Oil Field Workflow Across the Seven Reservoirs Showing the Data Collection, Processing and Analysis (Sourced from Amupitan et al., 2022).

2. Well Log and Core Data

This project had access to five wells in Gabo field (GABO 4, GABO 12, GABO 13, GABO 20 and GABO 51). One of the wells (GABO20) at the bottom provided a total cored section of 69.3 m (206.7 ft) with three core samples. A complete suite of conventional logs was also available on each well, such as Gamma Ray (API), Caliper (In), Density (g/cm3), Neutrons (m3/m3), Sonic (us/f) and resistivity (ohm-m). Three cores were taken out: between 2597.00 and 2624.00 m/RT (driller depth) of the core 1, between 2686.50 and 2713.50 m/RT (driller depth) of the core 2, and between 2886.50 and 2904.50 m/RT (driller depth) of the core 3 (Horsfall et al., 2024). Table 1 provides a summary of the well log and core data available in each well.

**Table 1:** The Well Log and Core Data for Five Wells In Gabo Oil Field, Niger Delta, Showing the Presence or Absence of the Core Data for Each Well

| *Well* | *Gamma Ray (API)* | *Caliper (In)* | *Density (g/cm$^3$)* | *Neutron (m$^3$/m$^3$)* | *Sonic (US/F)* | *Resistivity (ohm-m)* | *Core* |
|---|---|---|---|---|---|---|---|
| *GABO4* | Yes | No | Yes | Yes | No | Yes | No |
| *GABO12* | Yes | No | Yes | Yes | Yes | Yes | No |
| *GABO13* | Yes | No | Yes | Yes | No | Yes | No |
| *GABO20* | Yes | No | Yes | Yes | No | Yes | Yes |
| *GABO51* | Yes | Yes | Yes | Yes | Yes | Yes | No |

**Source:** (Horsfall et al., 2024).

3. Well Correlation

Well correlation entailed the determination of the related lithological boundaries based on gamma ray and resistivity logs, which were colour coded to make the distinction easier. Examples of petrophysical properties assessed were volume of shale. The top and base of reservoirs were determined on sand packages that were

expressed on log signatures, particularly gamma ray logs, resistivity logs, porosity and water saturation. Each well was determined in sand baseline and the shale baseline and the shale cutoff was positioned at the halfway point of these two baselines. The values of the gamma rays which struck on the left of the cut off denoted clean sand, but those which struck on the right indicated shales.

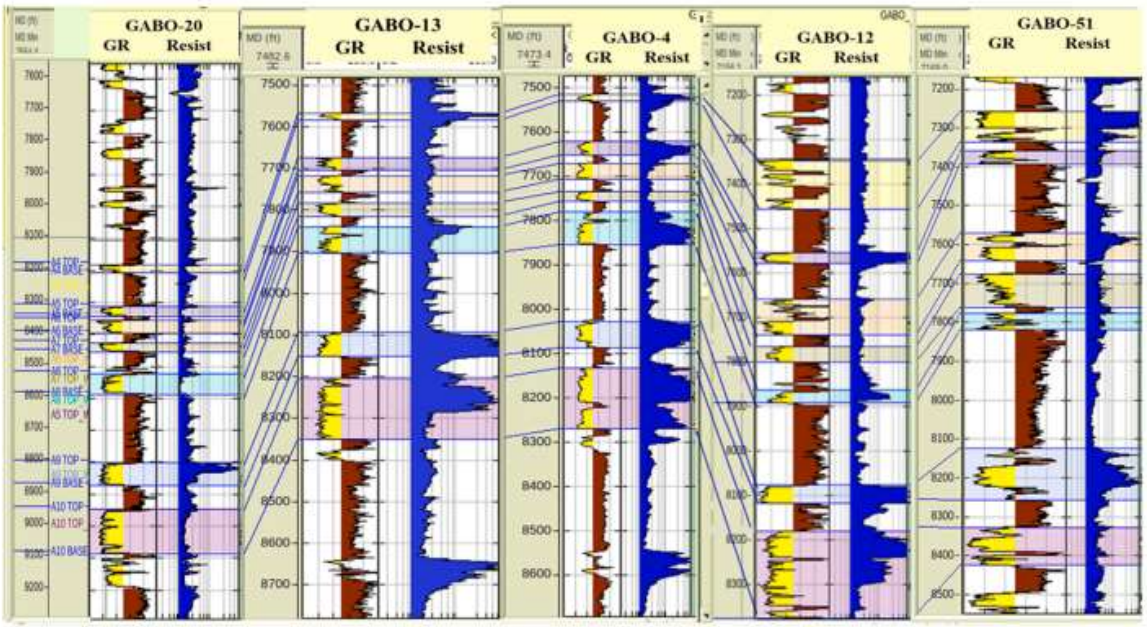


Fig. 4. Well to Well Correlation Across GABO 20, GABO 13, GABO 4, GABO 12 and GABO 51 Wells Showing Various Reservoir Zones (Horsfall et al., 2024).

*D. Geomechanical Metrics*

Geomechanical metrics are measurable parameters that are applicable to assess the mechanical conditions, stability and deformation characteristics of rocks and faults in subsurface stress conditions. They contrast with geomechanical models (that model the behavior of rock) since metrics are the quantifiable measures derived out of data or models (Zhou et al., 2022).

**1. Shale Gouge Ratio (SGR) Analysis**

The Shale Gouge Ratio is among the fundamental geomechanical metrics for fault potential in Gabo oil field. This method approximates clay or shale that is likely to be smeared on a fault zone as it goes along the fault. Faults that have large SGR values (shale-rich gouge) are probable to be sealed and those that have small SGR values (sand-rich gouge) are probable to be leaky (Olaojo et al., 2024).

**2. Fracture Prediction Modeling**

Fracture prediction modelling is applied using geomechanical model (stress field, properties of materials of rocks) to approximate the location of natural fractures and their behavior. Procedures like calculating a strain energy density, (U-value) are employed to identify where energy had been sunken down by tectonic forces into rocks hence making them crack and create their cracks. It applies this to estimate fracture networks capable of bridging or going through fault seals (Feng et al., 2018).

## V. Results and Discussion

*F. Well Correlation Result*

The well correlation results of the Gabo oil field reservoir indicated that the vertical stratigraphy of the wells consist of cyclic sands and interbedded shales at shallow levels as the shale thickness was growing in intermediate sections. Deposits like pinch outs and erosive events were identified on the well correlation.

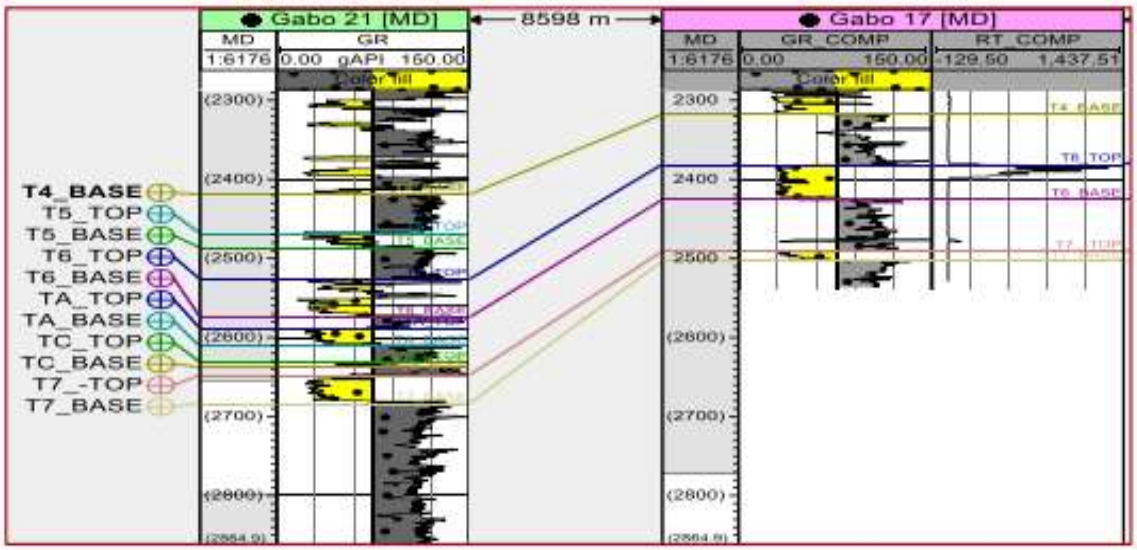


Fig. 5. Well correlation showing the vertical profile of the wells, with an offset distance of 8598m in Gabo Oil Field

Facies descriptions/analysis was employed to develop an insight into the sediment response properties (texture, grain size) and facies associations that could be of environmental interest. Moreover, the nature of the sediments reflects the processes that dominated during its transit, deposition and the period within which these conditions dominated. The facies associations were detected as fluvial distributary channel, tide dominated fluvial channels, abandoned channel or switching and flood plain deposits. This shows that the fluvial bed load (sand, silt and clay) was deposited in an alternating high and low energy regime and transport was mainly traction (bouncing and rolling) and suspension respectively. The depositional environments are deemed to be the upper delta plain, lower delta plain and delta front.

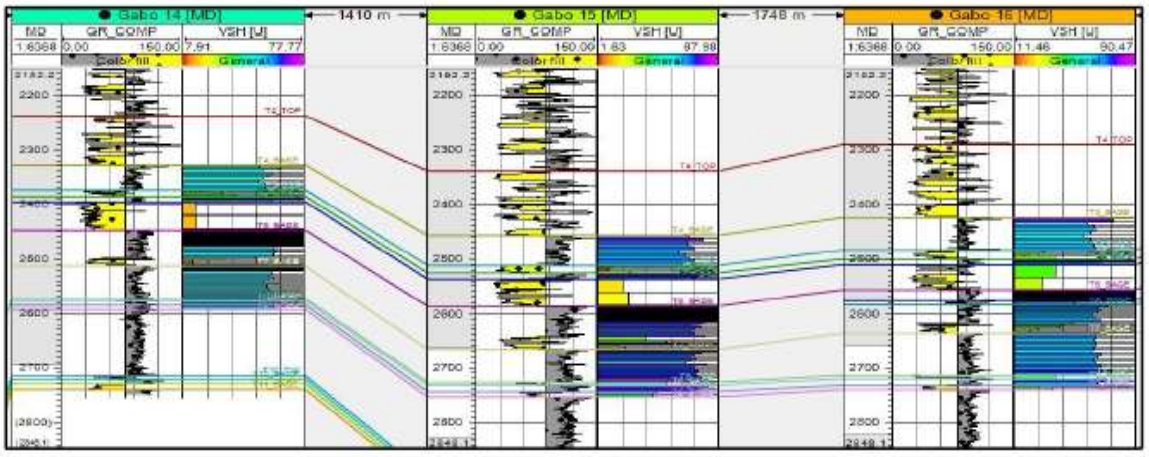


Fig. 6: Result of Well Correlation Showing A Cyclic Succession of Sand and Shale Sequence of Gabo Oil Field with a distance of 1410m between Gabo 14 and Gabo 15, and a distance of 1748m between Gabo 15 and Gabo 16.

*G. Shale Gouge Ratio (SGR) Result*

This results to folds and smearing depending on the prevailing confining pressures. The X-ray diffraction analysis (XRD) of the shales shows that the predominant minerals include kaolinite, rutile, gypsum, albite, microcline and quartz. These minerals may act as matrix (pore plugs and bridging materials) and or cement, which is in line with the discovery of (Iheaturu et al., 2024). They are assumed to constitute the fault rock materials either as phyllosilicates, catalases or clay smears. The mineral grains were probably transported and deposited as

suspended load. Clay minerals in rocks are modified from early to late diagenesis and a fundamental post-depositional process affecting them is compaction. The result of compaction is the inefficient expulsion of water, change in pore morphology, and change in diagenetic facies and reduction in thickness. These diagenetic modifications may result to improved shale and seal quality. The interbedded shales are very fine, fissile and dark brown in colour.

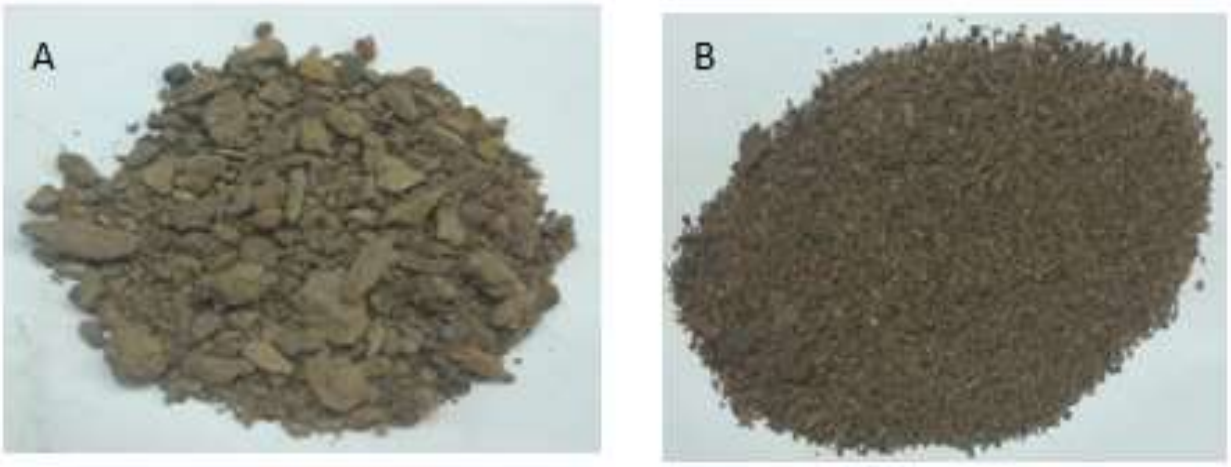


Figure 7: Ditch Cutting Examination Result with figure A showing Shale particles and figure B showing Clay that had Infiltrated the Sand Grains as Pore Filling and Cement

*H. Fault Stability*

Three faults were discovered and they are F1, F2 and F3. Comparing the results of the order of magnitude of the in-situ stresses, the order of magnitude of in-situ stresses are SHmax > sv > Shmin. The intermediate principal stress (sv = s2) is the vertical stress and this association would suggest normal fault. These are in line with the outcome of Agbasi et al., (2021) who reported that, the field is situated in an extensional context. The field structure was studied with reference to their deformational, depositional and post-depositional importance. The relationship between the juxtaposed strata was following the cross section of A-A' and B-B' and this illustrated the structural framework of the field. As observed in cross section A-A', the depositional and post depositional structures are pinchouts (channel abandonment or switching) and shale smears respectively. The cross-section B-B' indicated that the deformational structures are faults F1 and F2 - which are asymmetrical crest-faults and F3 - syn-depositional growth fault where the thick sedimentation occurs on the downthrown block.

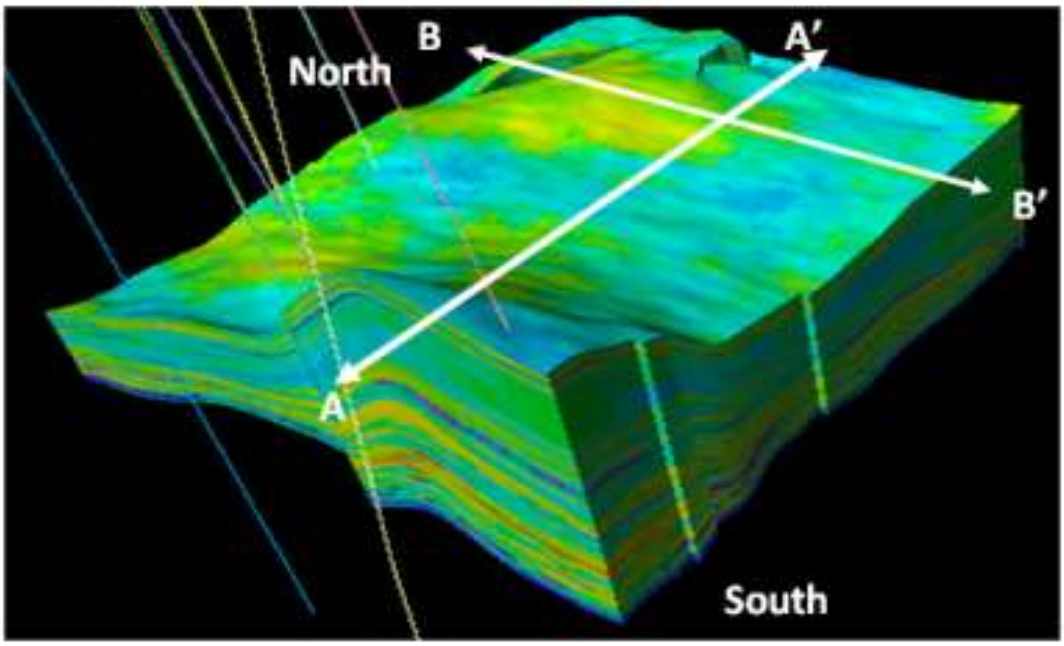


Figure 8: 3D Intersection slices of A-A' and B-B' showing the cross section of Faults in the reservoirs of Gabo Field

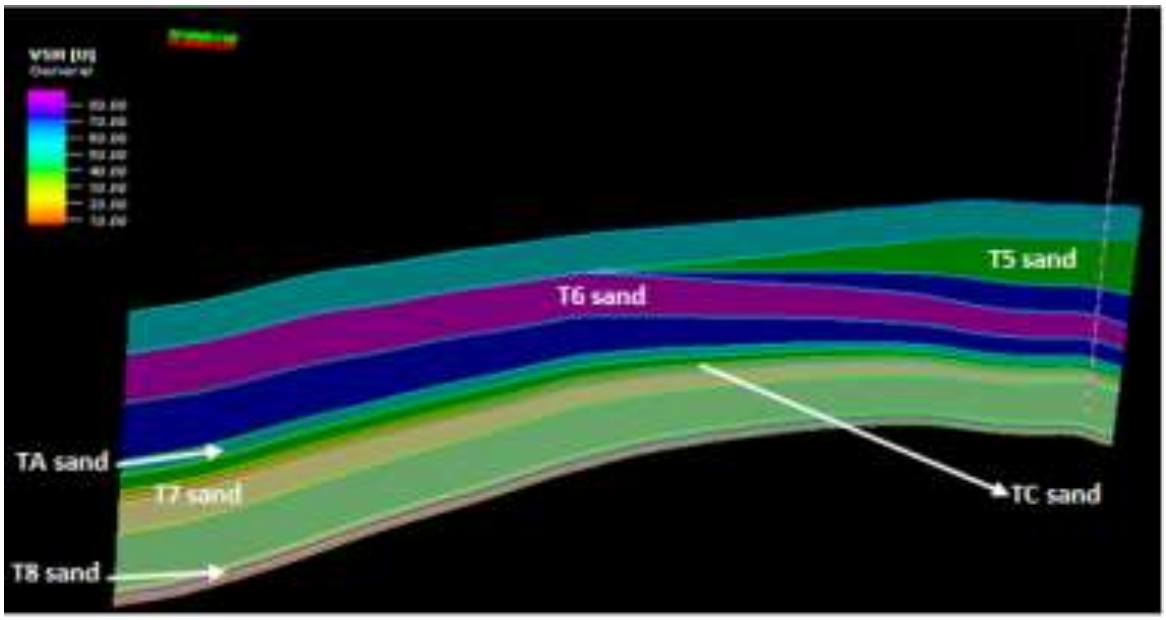


Fig 9: Intersection slice A-A' Section showing the Faults across the east - west length of the Reservoirs in Gabo Field. T5 sand means Prograding sand complexes, T6 presents the sand, T17 means hanging wall block

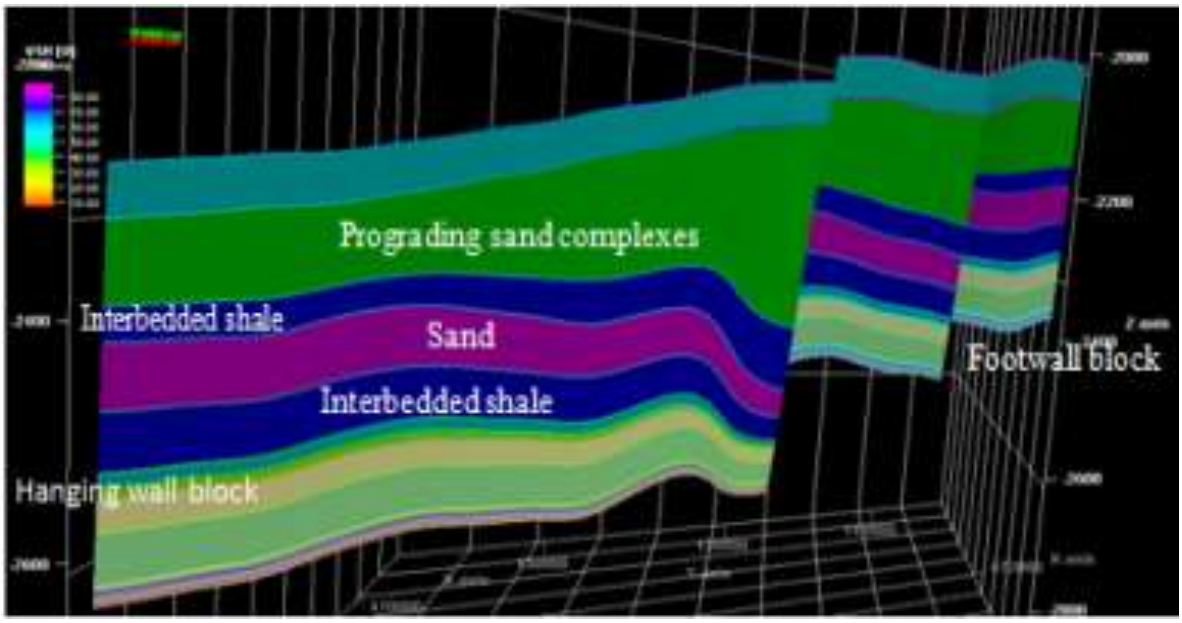


Fig 10: Intersection slice B-B' of expanded section of the field showing the conventional delta play configuration with closely spaced faults across the reservoirs of Gabo field

## VI. Conclusion and Recommendation

This study has established the paramount importance of 3D geomechanical modelling models in determining the capability of fault seals in the fractured sandstone of the Gabo oilfield. The model is beyond the traditional analysis, but a fixed fault seal analysis which portrays a dynamic and optimized analysis since it integrates seismic, well log, and core data. The results revealed that the current in-situ stress field and the resulting slipping tendency of faults are the first and foremost controls of seal integrity in Gabo oil field.

The regions exhibiting heavy shear stress and light effective normal stress are known as especially prone and fault reactivation threatens the top seal and deterioration of the hydrocarbon deposit. As a result, the fault compartments may be categorically defined as high and low-risk according to the geomechanical stability. It is a strong predictive tool used in the de-risking of exploration targets and well placement optimization by bypassing critically-stressed faults sections. This study demonstrates that 3D geomechanical modelling has become an essential element in the comprehension of fault-controlled fluid behaviour and an improved success in exploration in this multifaceted, structurally complicated petroleum province.

The following recommendations are hereby made;

**Dynamic Calibration:** Predicted fracture zones and fault seal integrity should be validated through the use of mud loss occurrences, production history and well tests. This will fill the gap between theoretical modelling and observed reservoir behavior, making the model more predictive in drilling and development.

**Practical Risk Maps:** The complex 3D model results should be turned into feasible and practical risk maps to the asset teams. There should be a generation of racture Susceptibility and Seal Failure Probability maps directly to inform the well guidance and completion design, and infill driller placement.

**High-Resolution Fault Attributes:** There should be an enhancement of the model by integrating detailed fault zone attributes. Including fault rock composition (e.g., shale gouge ratio) and architecture from seismic attributes. This refines the analysis beyond just stress state, providing a more holistic assessment of the fault's true sealing potential.

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