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3D Geomechanical reservoir model for Appraisal and Development of Emi-003 field In Niger Delta, Nigeria

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ABSTRACT

In this paper, geomechanical parameters were effectively integrated in 3-D geostatic model of Emi-003 reservoir in the Niger Delta basin, Nigeria for deformability and rock strength appraisal using well logs and 3D seismic volume. Unconsolidated sandstone and compacted shale were delineated and evaluated by determined elastic moduli (Poisson ratio, Young modulus, Bulk modulus, Shear modulus and Compressibility) and the Unconfined compressive strength (UCS) using sonic logs and petrophysical analysis, correlations and cross plots for comparison of the evaluated reservoir strength, physical properties (such as modulus, porosity, velocity) of the five mapped zones from five vertical wells in the studied reservoir for validation were done. Finally, incorporation of elastic properties, unconfined compressive strength in 3D static model of the studied reservoir was carried out to capture strong lateral variance of rock elastic moduli and strength into areas where well control may not exist. especially off the well points. The results show average parameters of the weakly cemented sand to have lower Poisson ratio, Young, Bulk, Shear modulus and Unconfined compressive strength (0.27, 2.3GPa, 10.8GPa, 6.91GPa, 14.21MPa respectively,) high compressibility and porosity (0.13 GPa-1, 0.26) conversely the compacted shale have higher Poisson ratio, Young, Bulk, Shear modulus and rock strength as (0.36, 8.91GPa, 18.05GPa, 21.09GPa, 56.44MPa respectively) lower compressibility and porosity (0.05 GPa-1, 0.05 respectively). There is a marked increase of rock strength and elastic moduli with relative decrease in porosity. The mechanical failure in the NNW direction of the reservoir will be relatively lower than other areas as analyse using the 3D earth model. The information gathered will help manage reservoir stress and strain induced during development and maximize reservoir performance, while mitigating risk.

Keywords: 3-D Geomechanical model, Elastic moduli, Petro physical properties, Niger Delta.

1. INTRODUCTION

Recently, exploration and exploitation of unconventional reservoirs is on the increase and crucial in the portfolio of oil and gas industries in Niger Delta, these reservoirs are expected to secure the energy demand in the next decades. Operational challenges arising from drilling, coupled with the high demand to decrease developmental and operational costs have made reservoir mechanic found a whole lot of applications especially in addressing problems that have to do with prediction of pore pressure, hydrocarbon column heights and fault/seal integrity during field assessment and development phase, well stability with the ideal mud weight, prediction of permeability heterogeneity within fractured reservoirs, optimal completion methodologies, prediction of changes like sand production in reservoir performance during production phase , water flooding, steam injection during the secondary and tertiary recovery phase.

As the geomechanical complications are of dormant concern in the oil and gas exploration, it is very vital to link scientific findings of both geomechanical and geological evaluation to help assess the risk created by reservoir stimulation and reservoir performance optimization. Substantial depletion is likely to cause changes in situ stress field leading to reservoir compaction, induced seismicity, cap rock integrity, fault reactivation, reduction in permeability which are some of geomechanical complication that can only be evaluated adequately with the peculiar benefits of the 3D numerical earth model that honours structural and stratigraphic constraints. A 3D earth model also provides the benefit of flexibility to update the model when data from additional offset wells are available and accessibility across discipline in the asset team.

Seismic velocities are affected by several factors such as lithology, interstitial fluid, porosity, clay content, depth, density, temperature and so on. Lithology is an obvious factor affecting velocity (P-wave and S-wave). Pores are one of the weakest and the most deformable elements in rocks; hence Porosity affects the velocity of the acoustic waves penetrating the rocks (Horsrud, 2001; Jizba, 1991). Wyllie et al., (1950), developed equations showing the relationship between velocity and porosity.

$$\Delta t = \phi \Delta t_f + (1 - \emptyset)\Delta t_{ma} \qquad (1)$$

Where Δt,Δt_f, Δt_m=Specific transit time (slowness), pore fluid, rock matrix respectively.

$\emptyset$ =Porosity

In terms of velocity, equation (1) can be re-written as,

$$\frac{1}{v} = \frac{\emptyset}{v_f} + \frac{(1-\emptyset)}{v_{ma}} \qquad (2)$$

Where,v =Bulk density v_f=Velocity of the fluid v_ma=Velocity of rock matrix. Equations (1) and (2) are statistical and empirical. According to Han (1986) and Hosrud (2001) petrophysical properties of a reservoir have a strong empirical relationship with the elastic moduli and rock strength of a reservoir hence in the absence of core data, geophysical measurement is used in establishing deformability and strength information of reservoir rock due to the close link geomechanical parameters have with compressional velocity (Vp), transit time (μs/ft) and porosity ($\emptyset$).

In spite of all the information on regional stress field made handy by the world stress map project (Zoback, 1992; Sperner et al., 2003), the local stress field of reservoirs is often not homogeneous due to mineralogical changes, structural geometry and pressure gradient, a precise tectonic stress field prediction from Geomechanical description is necessary in the Niger Delta which can be used for appraisal and developmental purpose during drilling, production and injection phases.

Secondly a similar work on Geomechanical Characterization was done in Wabamun Lake and Nisku formation Canada by Haug et al., (2008) and Nygaad (2008) using core samples and 2D approach with limitation of over simplification of geological structures but available in 3D geostatistics techniques. In this work geomechanical propropeties of a reservoir is adequately analysis and incorporated into 3D earth model using well logs and seismic section to map and interpolate variations in rock deformability and strength. Cross plots and correlation of rock mechanical properties and petrophysical parameters were carried out for validation of relationship, reserve estimation and producibility of the reservoir are out of the scope of this work. The synergy of 3D geological model with mechanical parameters and Rock strength will uncover the benefits for more accurate well and field development planning in structural complex reservoir like the Niger Delta basin.

1.1. Study Area and Geology

The Emi-003 reservoir is located within the offshore depo belt of Niger delta basin, Nigeria (Figure 1). Niger Delta is situated within the Gulf of Guinea with extension throughout the Niger Delta Province. It is located in the southern part of Nigeria between the longitude 40 –90 east and latitude 40-60 north. It is situated on the West African continental margin at the apex of the Gulf of Guinea, which formed the site of a triple junction during continental break-up in the Cretaceous [7]. Niger Delta Province contains only one identified petroleum system referred to as the Tertiary Niger Delta (Akata –Agbada) Petroleum System [24]. The area is geologically a sedimentary basin, and consists of three basic Formations: Akata, Agbada and the Benin Formations. The Akata is made up of thick shale sequences and it serves as the potential source rock. It is assumed to have been formed as a result of the transportation of terrestrial organic matter and clays to deep waters at the beginning of Paleocene. According to [7], the thickness of this formation is estimated to about 7,000 meters thick, and it lies under the entire delta with high overpressure. Agbada Formation is the major oil and gas reservoir of the delta, It is the transition zone and consist of intercalation of sand and shale (paralic siliciclastics) with over 3700 meter thick and represent the deltaic portion of the Niger Delta sequence. Agbada Formation is overlain by the top Formation, which is Benin. Benin Formation is made of sands of about 2000m thick [24].

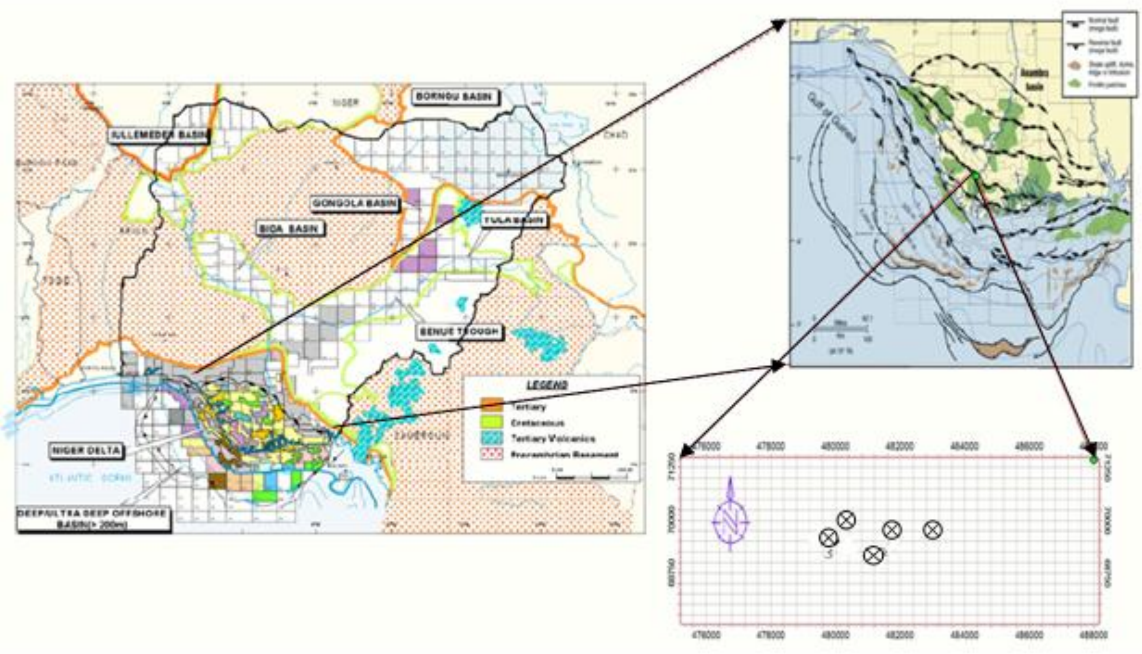

Figure 1: Map of the Niger Delta Basin in Nigeria Showing Study Area and Base Map (Source: Onuorah et al., 2014).

2. MATERIAL AND METHOD

The material used for this work comprises of suites of composite logs (GR, Sonic, Resistivity, Compensated Density and Neutron Porosity Logs), 3D seismic section, Microsoft excel and petrel to simulation soft wares. In this project, core samples of the overburden formation of the reservoir are not available for Geomechanical laboratory testing hence the evaluation of the 3D earth mechanical property model is based on data obtained from well logs and 3D seismic volume.

The methodology utilized is broken into four basic phases; practically at the first stage is correlation of the five wells to identify the reservoir of interest using the lithological logs. The dataset was imported into the excel software and saved in text delimited format, compressional and Shear velocity which is key for the generation of mechanical properties were generated from acoustic sonic. The data was then quality checked and grouped together. Petro physical relationships were calculated from the logs which were then used to derive the Geomechanical parameters and the rock strength. Cross plots of rock unconfined compressive strength were also carried out against petro physical parameters (porosity and acoustic travel time), this is to validate their relationship and for better understanding of the area of interest

A 3D geocellular model consisting of skeletal and structural framework was generated, where both the discreet and continuous properties including mechanical properties were distributed into geologic cells by pillar gridding, up scaling and the use of geostatistical principles. This was done after the seismic interpretation and petrophysical analysis of the reservoir.

Finally the mechanical parameters, rock strength and structural features were analyze on depth structure maps, seismic sections and 3D geomechanical model of the Emi003 reservoir showing the lateral extent of deformability, rock strength and structural contraints of the reservoir around the well environment.

2.1. Determination of Rock Mechanical Properties.

Mechanical properties of the field were determined using wireline logs. These were Elastic properties which include poisson ratio (v), elastic modulus (E) Shear/rigidity modulus (G), Bulk and matrix/grain moduli (Kb and Km) Bulk and grain compressibilitie (Cb and Cr) Biots coefficient and inelastic prosperity, unconfined compressive strength (UCS) .

2.2. Determination of Elastic Properties

2.2.1. Poisson Ratio (v)

The log derived Poisson ratio was computed from acoustic measurements such as sonic log usually displayed in terms of slowness, the reciprocal of velocity called interval transit times, (ΔT) in units of microseconds per foot. The Slowness of compressional wave (ΔVp) and slowness of the Shear wave (Vs) ratio is used to determine the Poisson ratio [16].

$$V = 0.5\frac{\left[\left(\frac{V_P}{V_S}\right)^2 - 1\right]}{\left[\left(\frac{V_P}{V_S}\right)^2 - 1\right]} \qquad (3)$$

The theoretical maximum value of v is 0.5.

2.2.2. Shear Modulus (G)

The Shear modulus is the ratio of the Shear stress to the Shear strain which for a homogeneous and elastic rock is given by equation (13) [Schlumberger, 1989].

$$G = \frac{a\rho_b}{v(\Delta Ts)} \qquad (13)$$

Where coefficient coefficient a = 13464, ρ_b = Bulk density in g/cni3, Δ Ts = Shear sonic transit time in us/ft. v = Poisson ratio. The unit of G is 10^6 MPa.

Bulk Modulus (K_b) is a static modulus but an equivalent dynamic modulus can be computed from the sonic and density logs. The relationship is given in below:

$$K_b = a\rho_b\left(\frac{1}{\Delta Tc^2} - \frac{4}{3Ts^2}\right) \qquad (14)$$

where a =13464, ρ_b =Bulk density in g/cm^3, ΔTc and ΔTs = change in compression and shear wave respectively in us/ft The unit of K_b is 10^6 MPa

Matrix/Grain Bulk Modulus

$$K_m = \frac{K_s\rho_{ma}}{\left(\frac{1}{\Delta Tc_{ma}^{\ 2}} - \frac{4}{3Ts_{ma}^{\ 2}}\right)} \qquad (15)$$

where KS is constant and equals to1000m , ΔTcma and ΔTsma = change in compression and shear wave respectively of the rock matix in us/ft and = Matrix density in g/c

2.2.3. Young Modulus (E)

Young modulus or modulus of elasticity was determined from the relationship between Young modulus, Shear modulus and Poisson ratio.

E = 2G (1+v) (16)

Where G = Shear modulus and v =Poisson ratio. E is in psi or MPa.

Bulk Compressibility (Cb,) with Porosity

$$C_b = \frac{1}{k_b} \qquad (17)$$

Where Kb = Bulk modulus

2.2.4. Rock Compressibility (Cr) Zero Porosity

$$C_r = \frac{1}{a\rho_{\log}\left(\frac{1}{1/\Delta Tc_{ma}{}^2} - \frac{4}{3\Delta Ts_{ma}{}^2}\right)} \qquad (18)$$

Where coefficient a =13464, ρ = density in g/cm^3, ΔTc_{ma} and ΔTs_{ma} = change in compression and shear wave respectively of the rock matix in us/ft

Biot Constant was determined using the expressions in equations (14) and (15).

$$a = 1 - \left(\frac{K_b}{K_m}\right) \qquad (19)$$

in term of bulk and grain modulus where Kb and Km are skeleton bulk and solid grain moduli respectively (Crain 2000) in terms of compressibility it is expressed as

$$a = 1 - \left(\frac{C_r}{C_b}\right) \qquad (20)$$

Where

Cr/Cb is grain and bulk compressibility respectively.

2.3. Determination of Inelastic Property

2.3.1. Unconfined compressive Strength (UCS)

Among the several empirical relationships proposed for application in sandstone, shale and Carbonate rocks, the McNally (1987) equation (21) for fine grained both consolidated and unconsolidated sandstones with all porosity ranges Is most suited for the Niger Delta basin while Lal (l999) equation (22) for shales was used for comparison.

$$UCS = 1200\exp^{(-0.036\Delta Tc)} \qquad (21)$$

$$UCS = 10\left(\frac{304.8}{\Delta Tc - 1}\right) \qquad (22)$$

Where UCS = unconfined compressive strength. ΔTc =change in compressional wave transit time matix in us/ft

2.4. Determination of Petrophysical Parameters

2.4.1. Volume of Shale

The volume of shale is the Bulk volume of the reservoir composed of clay minerals and clay hound water. Vshale was determined using Larinov (1962) equation (23)

$$V_{shale} = 0.083(2^{3.71_{gr}} - 1)[\text{Larinov}, 1962] \qquad (23)$$

Where is the shale index (gamma ray index) which is defined in (24)

$$1_{gr} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}} \qquad (24)$$

Where, GRlog= measured gamma ray log reading at depth (z), GRmin minimum gamma ray log in clean sand, GRmin= maximum gamma log reading (in clean shale) Vshale volume of shale in the formation at depth z.

2.4.2. Porosity

Porosity is the total volume of a rock occupied by pores both connected and unconnected. It is the ratio of the pore volume to the Bulk volume expressed as fraction %. Porosity is determined from density, sonic, neutron logs.

The total porosity was determined from density log data which are weighted average densities of the rock and pore fluid using equation

$$\theta_D = \frac{(\rho_{ma} - \rho_b)}{(\rho_{ma} - \rho_{fl})} \qquad (25)$$

Where □D = total density porosity, density of rock matrix, measure density and density of fluid.

3. Effective Porosity

Effective porosity was calculated by application of volume of shale equation

$$\theta_{eff} = \frac{(\rho_{ma} - \rho_b)}{(\rho_{ma} - \rho_{fl})} - \frac{V_{sh}(\rho_{ma} - \rho_{sh})}{(\rho_{ma} - \rho_{fl})} \qquad (26)$$

Where θ_{eff} shale corrected density porosity, V_{sh} is volume of shale and ρ_{sh} is density of shale, ρ_{ma} is density of rock matrix and ρ_{fl} is density of fluid.

3.1. Determination of 3D geomechanical earth model and cross plots

A 3D static reservoir model consisting of structural, stratigraphic, lithological and petrophysical model was generated, mechanical properties were integrated and distributed into geologic cells by pillar gridding, up scaling and the use of geostatistical principles extrapolation of properties around the well environment. This was done prior to the seismic interpretation and petrophysical analysis of the reservoir. The mechanical behavior both vertically and horizontally of the reservoir was appreciated with the generation of the 3D geomechanical earth model

Graphical analysis of the relationship between the evaluated elastic moduli, unconfined compressive strength and petrophysical properties was carried out using cross plots. According to [8, 25], there is a clear relationship between mechanical properties and petrophysical properties as regard rock strength (UCS) of a formation.

Graphic report or cross plot in this work is a justification of the proposed relation of unconfined compressive strength of the reservoir rock and the Geomechanical analysis that was evaluated from the lithological units in the studied formation. The visual examination of these cross plots would give basis for compromise or quality check where necessary especially where statistical results might be misleading.

4. Result Presentation

Detailed results obtained from the study are presented in this section and as follows: Reservoir mapping, Petrophysical evaluation, Geomechanical analysis, Graphical (cross plots) evaluation of rock strength against rock mechanical and petrophysical parameters, 3D Geomechanical model analysis.

5. Reservoir Mapping

The reservoir mapping was carried out first, by the delineation of five wells; Law 1A, Law 001, Law 2, Law 003 and Law 004 in a well correlation panel at depth 8800m-9900m.

The petro physical properties and logs were evaluated to understand the physical properties and reservoir quality with respect to the reservoir elastic properties and rock strength. After close geologic scrutiny of the five wells and correlation of the reservoir sand and shale sequence, the lithological and stratigraphy study of the reservoir using GR log shows that the geological units are predominantly sand and shale with increasing trend of high sand/shale ratio, confirming the area of interest to be within Agbada formation of the Niger delta [7] as shown in Fig. 2.

The correlation revealed five stacks of sand units in the reservoir namely; horizon A,B,C,D,E,F across the five wells with thickness of approximately 84m,100m,102m,96m,133m respectively, the lateral variation in reservoir thickness which tends to be thickest at Law 004 is strongly controlled by differential subsidence variation from compaction of sediments and the presence of growth faults as indicated in Niger delta [24].

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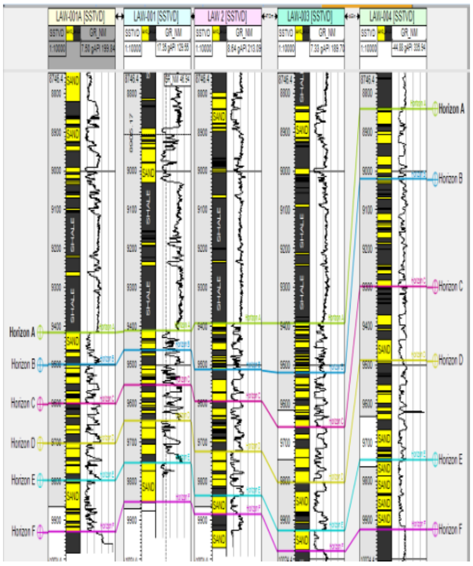


Fig. 2: Well logs from law 1A, 001, 2, 003, 004 showing delineated horizon of the studied reservoir using GR log

6. Determination of Petrophysical Properties:

Hydrocarbon reservoir is a subsurface rock that has effective porosity and permeability which usually contains commercially exploitable quantity of hydrocarbon, these properties have a relational features with the mechanical and rock strength parameters. The formation analysis is the process of using geophysical logs to evaluate the characteristics of the reservoir. The clay content, porosity, water saturation, compressional and Shear velocity affects elastic moduli and rock strength of a reservoir. The porosity of this study was calculated from the density data, the volume of shale was deduce from the GR data while the compressional and Shear velocity were calculated using the acoustic sonic data as shown in Fig. 3. Petrophysical evaluation of the studied reservoir was necessary as it validates rock strength and sand production prediction analysis.

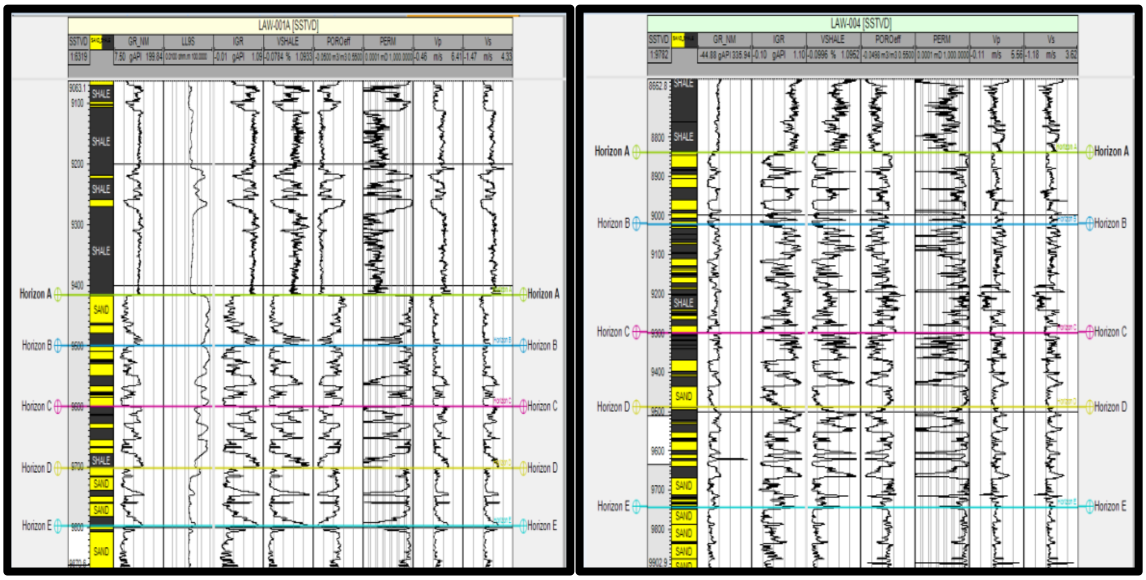


Fig. 3: Petrophysical logs of Law 1A and Law 004 showing the physical properties of the reservoir rock as delineated with Gamma ray (GR), Resistivity (lls) volume of shale (Vsh), compressional (Vp) and Shear velocity (Vs), Effective porosity and permeability.

7. Determination of Geomechanical Parameters

Poisson ratio, Shear modulus, Bulk modulus, Young modulus, Bulk compressibility and unconfined compression strength of the five sand units intercalated with shale of the studied reservoir were calculated at each well to evaluate variation in sand and shale across the reservoir and the relationship between the elastic moduli and reservoir rock strength of the studied formation. The Geomechanical parameters were derived using related empirical formulas in Microsoft excel programme and then imported into the Schlumberger petrel software 2013 version to generate and evaluate mechanical property and unconfined compressive strength logs as shown in Fig. 4 and Table 1.

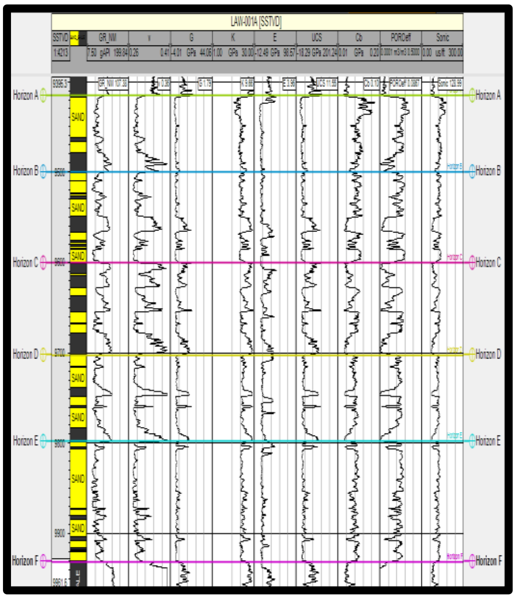


Fig. 4: lithological delineation with Poisson's ratio (v), Bulk modulus (K), Shear modulus (G), Young modulus (E), the unconfined compression strength (UCS), Bulk compressibility (Cb), effective porosity, compression velocity (Vp) of the Law 001A.

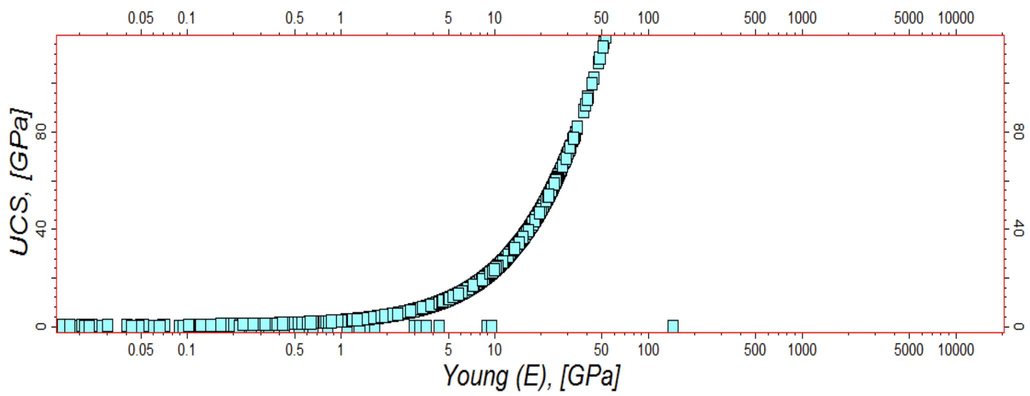
Table 1: Showing Average of Elastic Parameters, Porosity and Unconfined Compressive Strength for Sand and Shale Units of the Five Well of the Studied Reservoir.

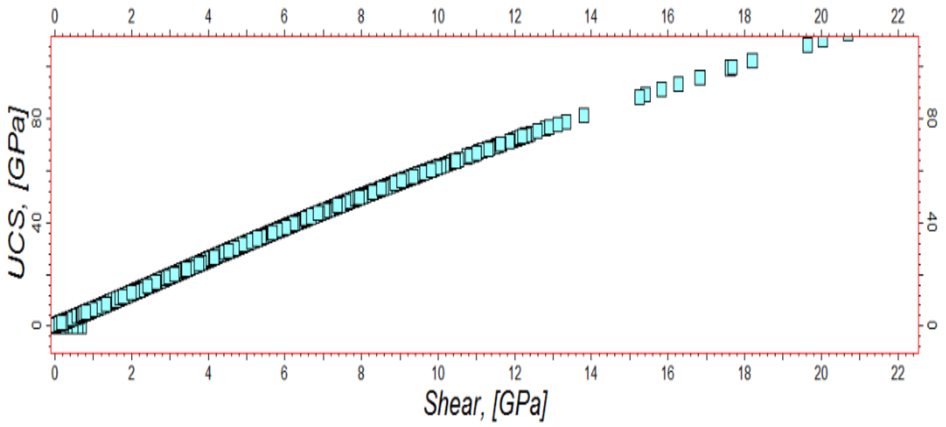
WELL	LITHOLOGY	GR API	Poro Eff	V	G Mpa	K_b Mpa	E Mpa	C_b Mpa^{-1}	UCS Mpa
LAW	SAND	45.57	0.25	0.28	2.24	10.24	6.84	0.10	9.45
001A	SHALE	105.29	0.07	0.36	10.42	19.14	17.32	0.06	47.30
LAW 001	SAND	40.76	0.24	0.27	1.65	9.27	4.64	0.109	10.71
	SHALE	96.76	0.06	0.33	7.7	17.07	20.02	0.062	47.743
LAW 2	SAND	41.46	0.23	0.28	1.53	9.01	4.29	0.11	11.87
	SHALE	97.30	0.06	0.34	8.35	17.62	21.48	0.06	52.12
LAW 003	SAND	37.07	0.23	0.27	1.79	9.52	9.52	0.1	14.57
	SHALE	91.71	0.05	0.33	9.61	18.52	24.28	0.05	61.87
LAW 004	SAND	36.05	0.21	0.28	4.58	12.24	8.87	0.09	25.62

SHALE	109.06	0.04	0.37	8.58	18.05	21.95	0.06	69.34
RESERVOIR SAND AVERAGE	40.18	0.26	0.27	2.3	10.05	6.91	0.13	14.21
RESERVOIR SHALE AVERAGE	100.02	0.05	0.36	8.91	18.05	21.09	0.05	56.44

Cross Plots of Geomechanical Parameters, Rock Strength, Petrophysical properties and Depth

According to [8, 25], there is a clear relationship between Poisson ratios, Young modulus, and Bulk modulus; Shear modulus against unconfined compression strength (rock strength) of a formation. Graphic report or cross plot in this work is a justification for the proposed relation of unconfined compressive strength of the reservoir rock and the Geomechanical parameters, The visual examination of these cross plots also give a basis for compromise where necessary; especially where statistical results might be misleading; in cases where statistical results in correlation rank high while the cross plot clearly predicted low values. As shown in Fig. 5, the formation declared marked increase in unconfined compressive strength with Young modulus, Bulk modulus, Shear modulus and a decrease in unconfined compressive strength with lower Poisson ratio. Cross plots of unconfined compression strength was also carried out against petro physical parameters (porosity and acoustic travel time), this is to confirm the relationship according to [8, 9] and as shown in Figs.6 where increase in unconfined strength is a function of decrease in porosity and acoustic travel time. Fig 7 shows the relationship of the parameters with depth, where parameters increases with depth.





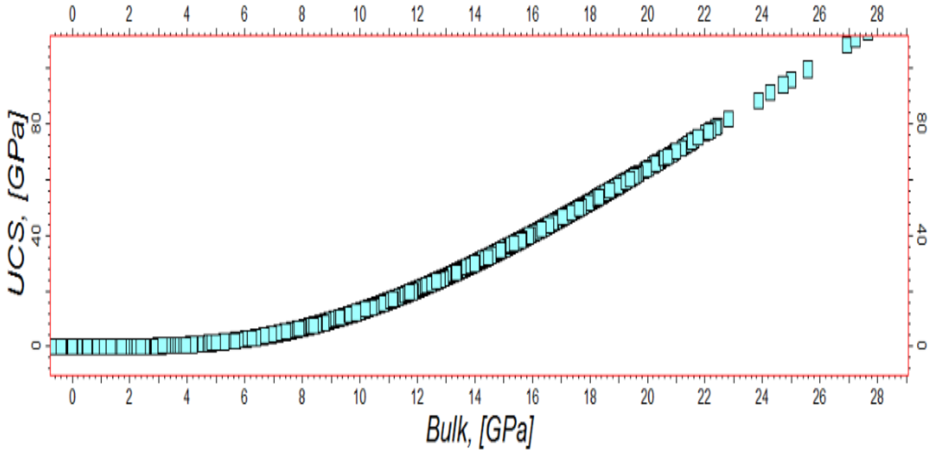


Fig. 5: Cross Plot of Law 001 Showing the Relationship between Unconfined Compressive Strength (UCS) of the Reservoir Sand Units (A) Shear Modulus G (B) Young Modulus E (C) Bulk Modulus Kb

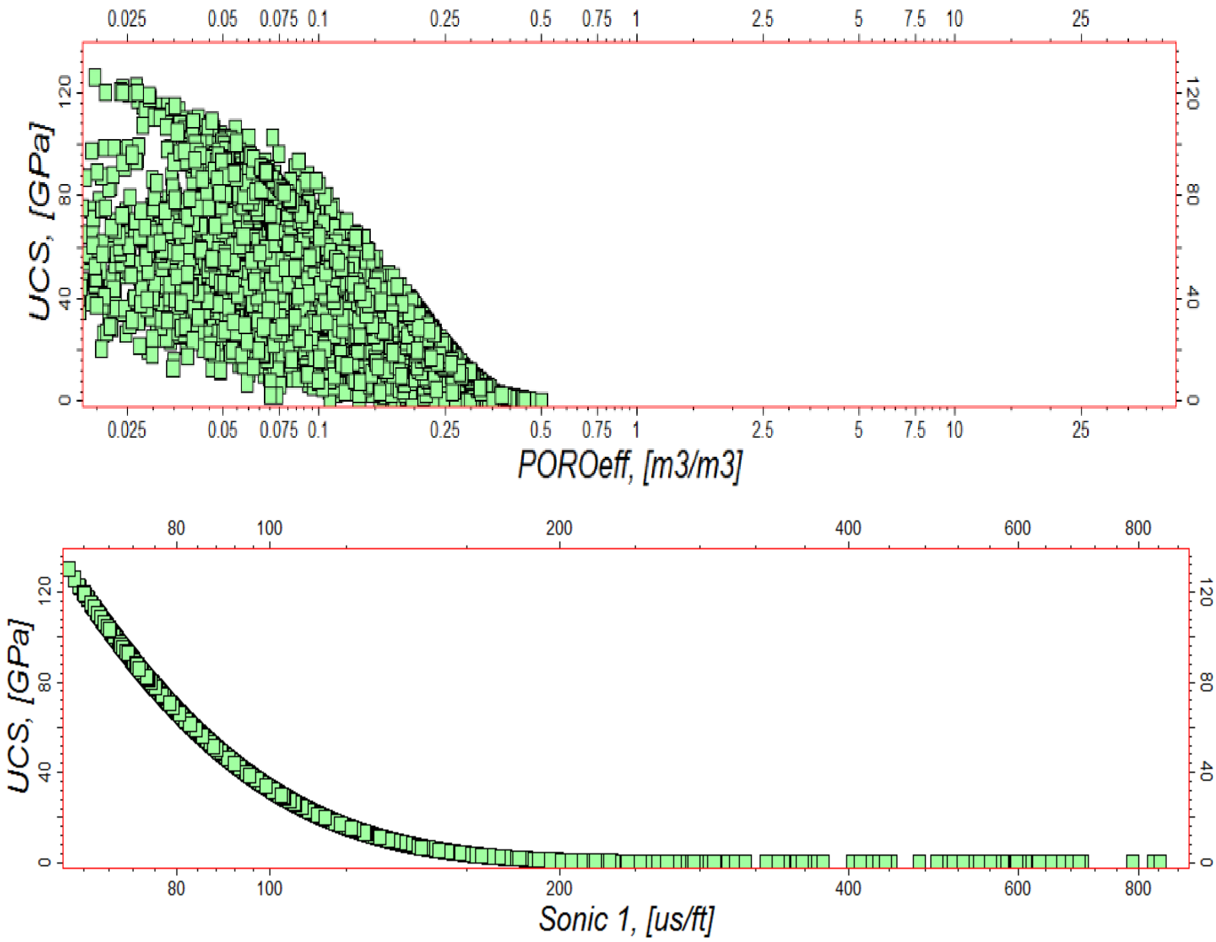


Fig. 6: Cross Plot of Petrophysical Parameters (porosity and acoustic sonic) Against Unconfined Compressive Strength (UCS) of Law 4; (A) Porosity and (B) Acoustic Sonic

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8. Depth structure map and 3D Geomechanical Model of Emi-003 Reservoir:

A south-west dipping (basinward) anticlinal structure of the study reservoir was generated on a depth structure map with major faults (F1 & F2) and the various fault blocks as shown in Fig.7, the northern and middle fault blocks represents the foot wall while the southern fault block depict the hanging wall. A 3D mechanical earth model representing the lateral distribution of the rock mechanical properties and rock strength (UCS) of the studied reservoir was generated. The Poisson ratio, Young modulus, Shear modulus, Bulk modulus and the unconfined compressive strength (UCS) were simulated in to a 3D static model of the Emi-003 reservoir for deformability and rock strength spatial variance as shown in Figs.

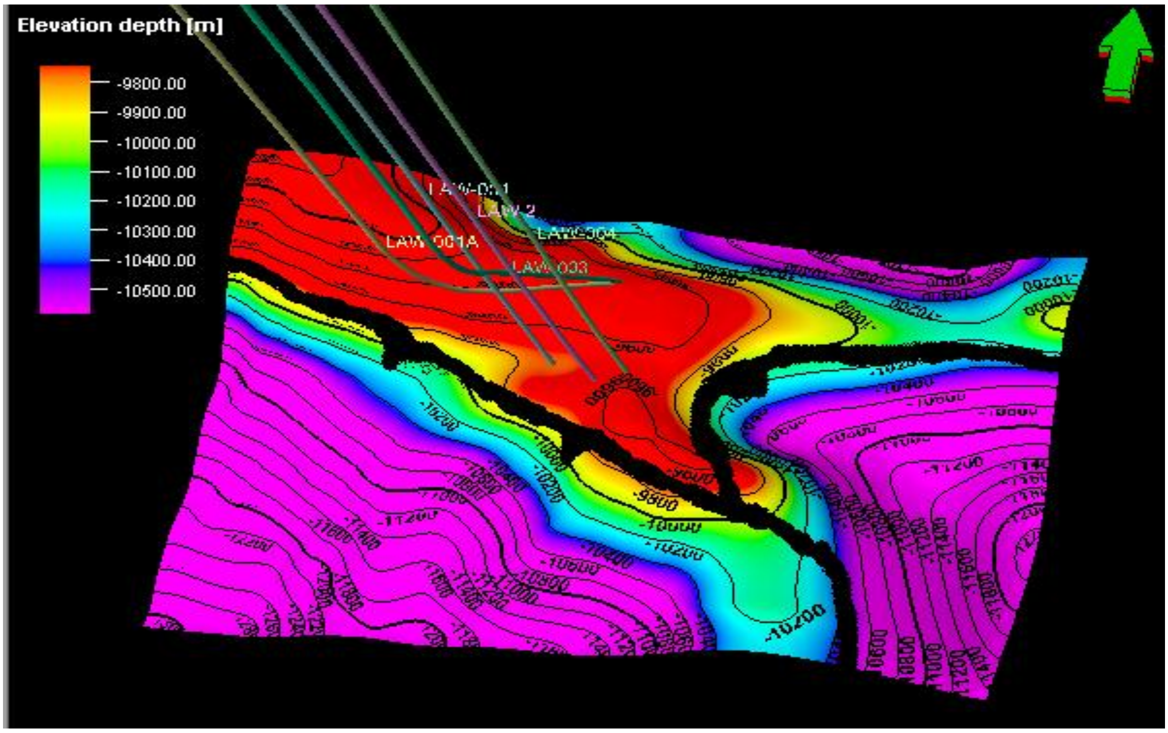

Fig.7: showing south-west dipping anticlinal structure with major faults and blocks of the horizon B in Emi-003 Reservoir

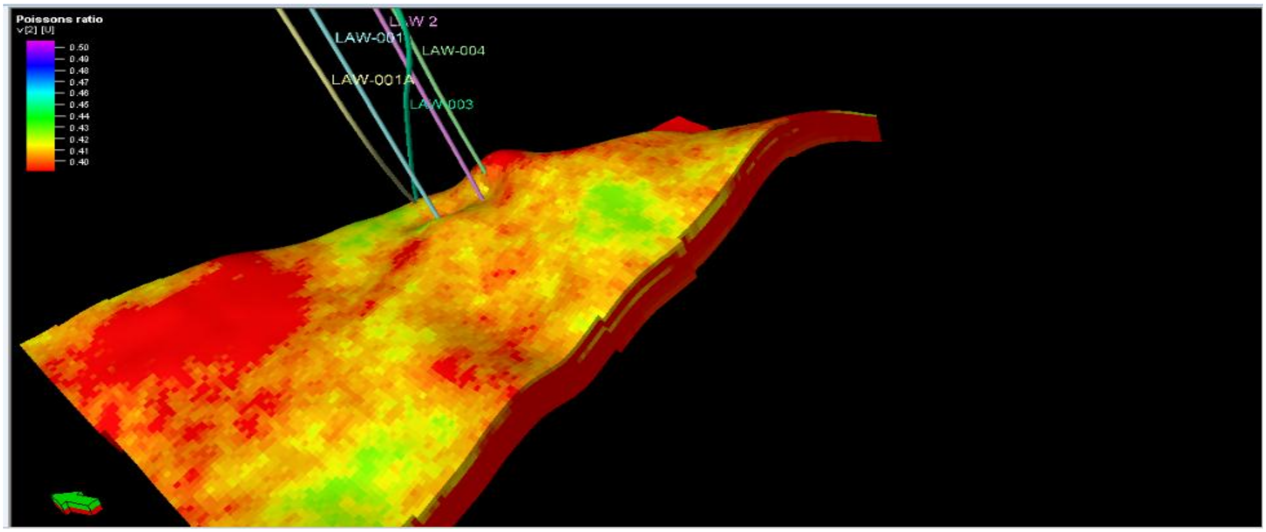

Fig. 8: 3D Geologic model, inserted map and penetrated wells of Emi-003 reservoir showing spatial distribution of Poisson ratio with highest Poisson ratio zone on the reservoir top identified with a white circle in the NNW direction.

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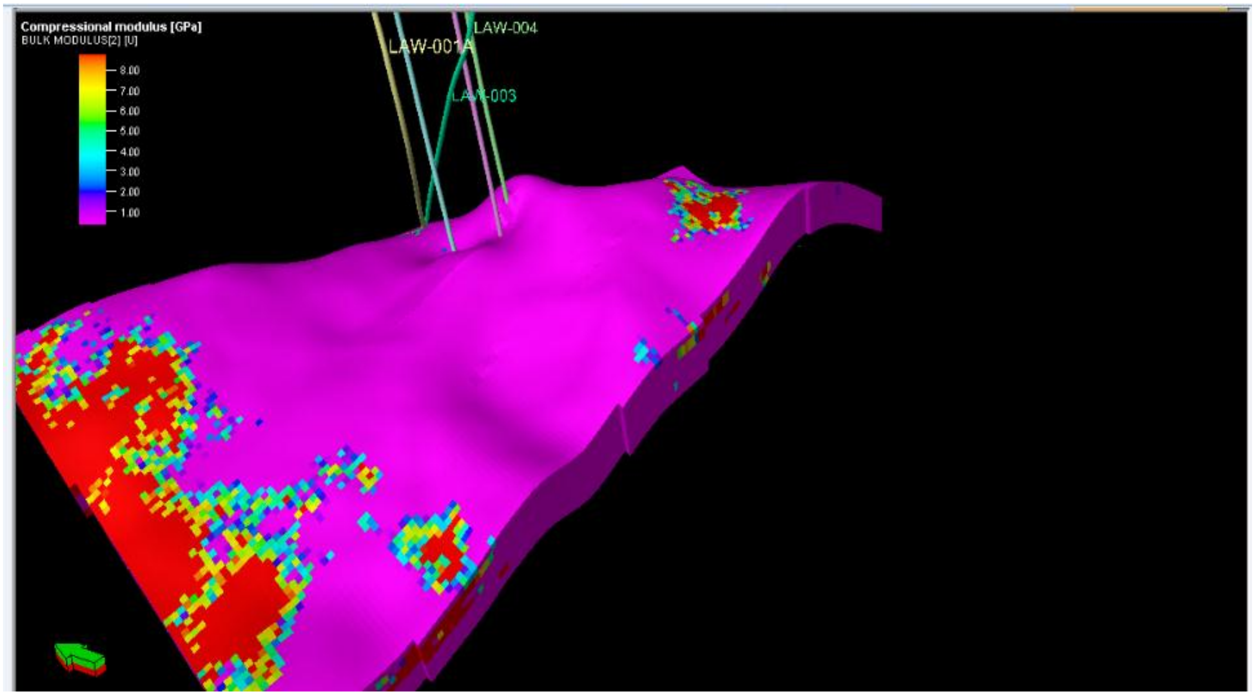

Fig. 9: 3D Geologic model, inserted map and penetrated well of Emi-003 reservoir showing spatial distribution of Young modulus with highest Young modulus zone on the reservoir top identified with a white circle in the NNW direction.

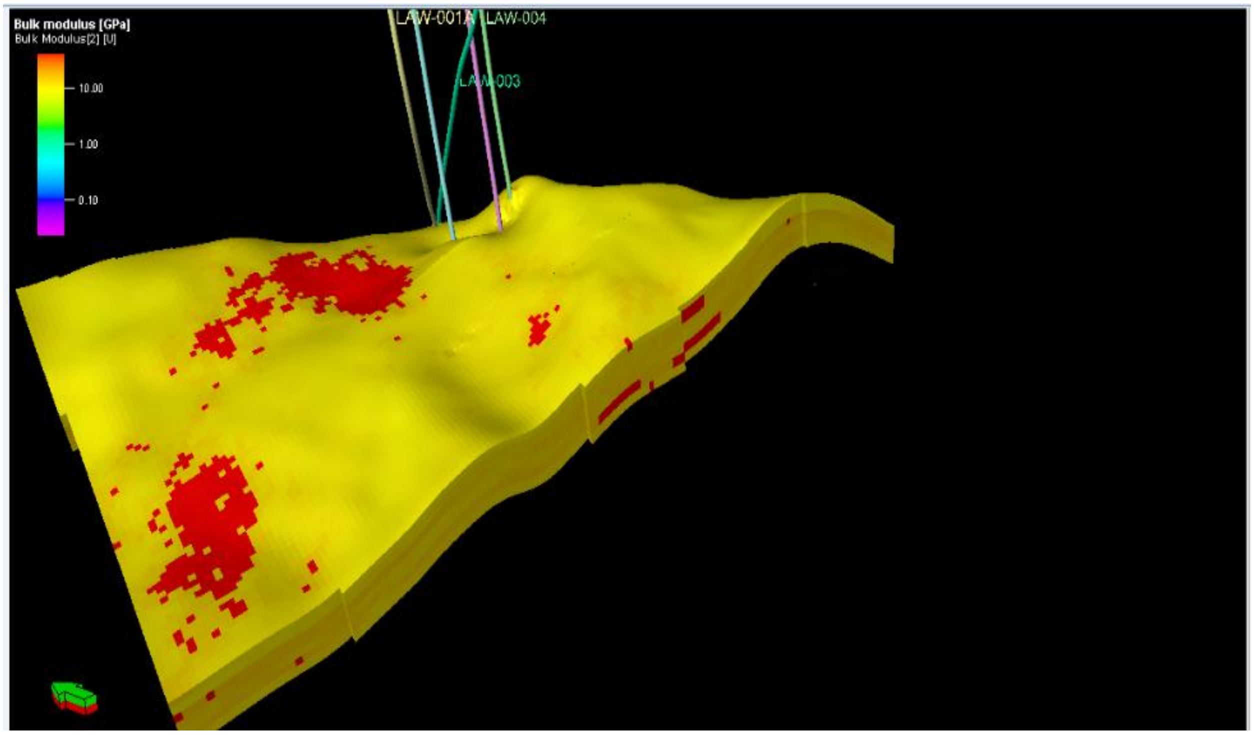

Fig. 10: 3D Geologic model, inserted map and penetrated wells of Emi-003 reservoir showing spatial distribution of Bulk modulus with highest Bulk modulus zone on the reservoir top identified with a white circle in the NNW direction

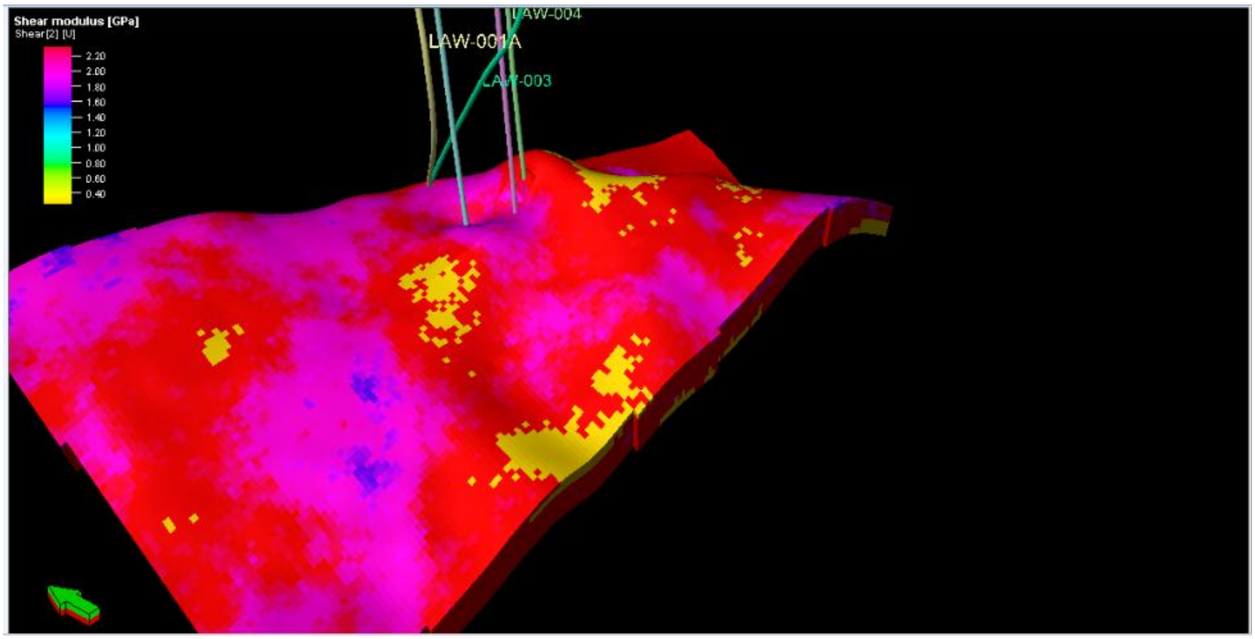

Fig. 11: 3D Geologic model, inserted map and penetrated wells of Emi-003 reservoir showing spatial distribution of Shear modulus with highest Shear modulus zone on the reservoir top identified with a white circle in the NNW direction.

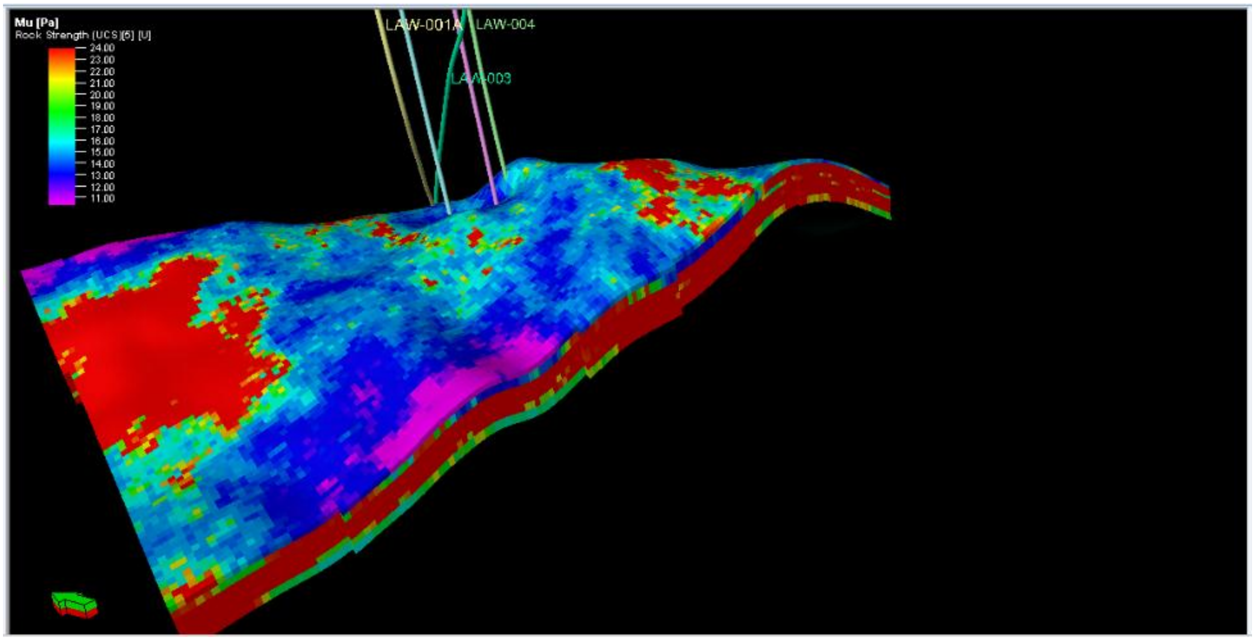

Fig. 12: 3D Geologic model, inserted map and penetrated wells of Emi-003 reservoir showing spatial distribution of Unconfined compressive rock strength (UCS) with highest UCS zone on the reservoir top identified with a white circle in the NNW direction.

9. Discussion and Interpretation of Result

9.1. Reservoir Mapping

The reservoir of study range in interval from 8800m to 9900m, revealed the structural geometry as south-west basin ward anticlinal structure with major faults (F1 &F2) delineating the field into Northern, middle and southern fault blocks. The Northern and middle fault blocks represent the footwall (upthrown) while the Southern fault block represents the hanging wall (downthrown) as shown in Fig.7, depletion is likely to cause changes in situ stress field leading to reservoir compaction and fault reactivation, F1 has high tendency to slip or dilate downward with respect to the footwall due to the instability of the hanging wall as proposed by E. M. Anderson. The lithologic units are consistent across the five wells (Law1A, Law 001, Law 2 Law 003, Law 004), and the units predominantly shows parallic sequence of interbedded sandstone and shale (Fig.2). The depth of interest describes a formation with sandstone and shale beds deposited in almost equal proportion and much of the sandstone are nearly unconsolidated. Comparisons drawn between the correlation derived and other existing correlations in the industry fits the lower part of the Agbada formation in the Niger Delta region [7, 10, 17]

9.2. Geomechanical, Petrophysical Properties and Rock Strength Evaluation

Table 1 and Fig 3, show the elastic properties, petrophysical parameters, rock strength (UCS), as well as logs of Law 001A derived using empirical relation to characterise the sands and the shale of the various units of the studied reservoir. Results in all wells show significant variation in properties between the shale and the sand. In Table 1, average sand parameters show lower poisson ratio (0.27), Young, Bulk, Shear modulus and unconfined compressive strength (2.3GPa, 10.8GPa, 6.91GPa, 14.21MPa respectively), higher compressibility and porosity (0.13 GPa-1, 0.26) making it more brittle with high potential to tensile failure. On the other hand the shale have higher poisson ratio ,Young, Bulk, Shear modulus and rock strength (0.36, 8.91GPa, 18.05GPa, 21.09GPa, 56.44MPa respectively) lower compressibility and porosity(0.06 GPa-1, 0.06) making it more ductile as a result of its clay content, stiffer (high moduli), less compressible than the unconsolidated sand. Rock strength (UCS) is a function of elastic modulus, hence the higher the elastic modulus of a material the higher the Rock strength (Chang et al., 2006). The shale has maximum average rock strength value of 56.44MPa, which is the force that can be applied to the shale unit without breaking or causing the rock to fail completely under compression.It means larger vertical stress or pressure is needed to achieve deformation in the shale than the sand (14.21MPa). These properties also make the shale fracture stimulation barriers, thus the sandstone of the studied reservoir will fracture before the shale in a hydraulic fracture process under the same fracture gradient while the shale will form a seal to the fracture growth. This is one of the primary causes of separate reservoir compartmentalization, where series of permeable sands are separated by impermeable shales [19]. The result also shows porosity to be high in sand and very low in shale making shale denser and stiffer. Pores are one of the weakest and the most deformable elements in rocks, thus increase in porosity resulted to decrease Rock strength and elastic moduli of the units.

9.3. Graphical (Cross Plots) Evaluation of Rock Strength against reservoir Parameters.

The properties of the studied reservoir and their relationship with the rock strength (UCS) were further justified using graphic report (cross plot) for the five wells (Fig. 5 and 6). According to [8, 25], there are clear relationship between poisson ratios, Young modulus, and Bulk modulus; Shear modulus as against unconfined compression strength (rock strength) of a formation. Despite the considerable scatter in data for each elastic modulus in the formation as a result of anisotropic effect, there is marked increase of unconfined compressive strength with elastic properties. The cross plots shows that higher values of elastic moduli are a function of a more consolidate or compacted unit, which denotes the shale units in the studied formation. Cross plots of unconfined compression strength were also carried out against petro physical parameters (porosity and acoustic travel time), Pores are one of the weakest and the most deformable elements in rocks, hence increase in porosity resulted to decrease Rock strength and elastic moduli. According to [8, 9], increase in unconfined strength is a function of decrease in porosity and acoustic travel time. There is also an appreciable increase in elastic and inelastic properties with depth as shown in Fig 7, this is as a result of Compaction due to overburden loading under effective stress conditions resulting in fluids expulsion, increase in grain contacts, density, Biot's coefficient.

9.4. 3D Gemechanical model of Emi-003 reservoir

The Geomechanical Characterization of the units in the studied reservoir were further validated by the generation of a 3D mechanical earth model representing the lateral distribution of the rock mechanical properties and strength of the studied reservoir as shown in Fig.8-12 for horizon B. Variation in rock strength and in elastic parameters was identify and compared among parameters across the reservoir top. A visual examination depict that the elastic moduli and unconfined compressive strength (UCS) have higher magnitude at the NNW direction of the reservoir, thus mechanical failure or behaviour in the NNW direction of the studied reservoir (horizon B) will be relatively lower than other areas resulting from fracturing or permanent deformation during drilling operations and production phase caused by compression (stress). This integration can help define a drilling program that focuses on the best targets in the field and optimizes the recovery. Potential well bore trajectories can be defined and refined with brittleness, rock stress and lateral information.

10. CONCLUSION AND RECOMMENDATION

This software based analysis establishes a proper multivariate statistical relationship between Geomechanical and petrophysical properties of interest using well logs and high resolution 3D seismic data. This geophysical measurement, an alternative and reliable approach in the absence of core data was used to successfully achieve the ultimate deliverables of this paper. This paper is aimed at evaluating the deformability and rock strength (Poisson ratio, Young modulus, Bulk modulus, Shear modulus, compressibility and unconfined compressive strength) at the well point and around its environment with the involvement of a 3D Geomechanical model of Emi-003 field in the Niger Delta, correlate the determined parameters to petro physical properties of interest for validation and analyze the lateral variation of these elastic moduli and rock strength across the reservoir using 3D static model approach.

The evaluated reservoir is predominantly unconsolidated sandstone which is more brittle and compacted shale that is fracture stimulation barriers, thus the sandstone of the studied reservoir will fracture before the shale in a hydraulic fracture process under the same fracture gradient while the shale will form a seal to the fracture growth. It also causes reservoir compartmentalization, where series of permeable sands are separated by impermeable shales [19]. The compacted shale units in this study, therefore have higher rock strength than the highly porosity unconsolidated sandstone units. The 3D geomechanical model also validates the relationship among the physical rock properties and the lateral variance of these properties in the Emi-003 reservoir

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In this research paper, Geomechanical property correlation at well level and spatial variation at inter-well and undrilled parts of the reservoir was effectively analyzed using petro physical evaluation and 3D numerical modeling approach. Due to spatial heterogeneity caused by time dependent and non-time dependent anisotropies in rock strength, elastic properties and in situ stresses [5], it is concluded that a seismic-driven 3D Geomechanical model can adequately analyze multiple well trajectories for optimal well placement and other reservoir applications during appraisal and development field study. However as relevant as the geophysical measurement method, it must be calibrated with core measured (Geomechanical laboratory testing) data to properly validate in situ conditions so as to optimize producibility of the studied reservoir. Calibration is extremely important before any utilization

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