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Geomechanical Characterization of Reservoir Rocks in Field 'DL' of the Onshore Northern Depobelt Niger Delta, Nigeria, using Well-Logs Data

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Abstract:
Geomechanics is the study of how soils and rocks deform in response to changes of stress, pressure, temperature, and other related parameters. Central to the understanding of how rocks are removed by drill bits, borehole stability is characterised, the stability of perforation tunnels is predicted, and designing and monitoring of stimulation programs, is the study of geomechnics. Petroleum Engineers and Geoscientists use Geomechanics to model the movement of fluid and predict how fluid removal or injection can bring about variations in permeability, fluid pressure, as well as in situ rock stresses, that could have sufficiently great effects on reservoir performance. Consequently, geomechanics has been employed in the oil and gas industries for the evaluation of reservoirs. In this study an attempt has been made to employ geomechanical variables for the evaluation of the reservoirs in the studied wells in the Niger Delta. The geomechanical characterization was done with the aid of shear modelling calibration to delineate the shale – sand lithologies using Greenberg and Castagna 'Shale – Sand Model'. From the study, it was observed that, V_p/V_s ratios exceeded the threshold of 2.0 for the shaley intervals in the entire study. A decrease in modulus values, including bulk modulus (K), shear modulus (G) and Young's modulus (E), along with a substantial increase in Poisson's ratio (v) from 0.20 to 0.37 were observed. The observed results indicates that the rock was in a state of distress, as a result of the rock reaching its mechanical limits or being subject to excessive stress, which implies potential structural instability in the subsurface especially at the deeper depth in the study area. A decrease in unconfined compressive strength (UCS) was also observed in the shaley interval which may also be associated with this change in mechanical properties of the rocks. Geomechanical characterization of reservoirs in the Northern Depobelt of the onshore Niger Delta is critical in understanding the behaviour of the reservoir rocks in the region, thus it will bring about harnessing hydrocarbon potentials and increasing hydrocarbon production in the region.

Key words: Geomechanics, unconfined compressive strength, Depobelt, Lithology, Modulus

I. Introduction

Rock elastic properties, such as Poisson's ratio, Young's modulus, shear modulus and bulk modulus, plays an important role in various stages of upstream operations, such as wellbore stability, drilling, hydraulic fracturing, production, [1]. These parameters often lead to finding the location and even amounts of hydrocarbon in the reservoir of interest. Mechanical rock properties can be obtained from two ways: one using the core data and the other by means of wireline logs data [2,3]. The reason for using well logs is mainly to obtain

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a continuous profile of mechanical rock properties required for in-situ stress and determining other rock strength properties [4].

Geomechanics is the study of how subsurface rocks deform or fail in response to changes of stress, pressure and temperature in the subsurface [5]. The knowledge of geomechanical properties such as the Poisson's ratio, young's modulus, bulk modulus and shear modulus are fundamental in the evaluation of the life cycle of oil and gas Fields in the Niger Delta [6]. They are equally crucial in geomechanical applications, most essentially where the understanding of sand production, hole stability analysis, hydraulic fracking, geopressure analysis and casing designs are critical. The ability to accurately estimate these elastic properties are somewhat challenging to the Petroleum Geologist and Petroleum Engineers. The elastic properties can be experimentally evaluated (static properties) using the stress-strain response of core samples under uniaxial compression, but this is highly time-consuming and sometimes, could be complicated especially when the core samples are not properly handled. With advances in new technologies, most of the challenges in laboratory determination of rock elastic properties have been overcome via new computing and experimental techniques. The advent of improved technologies and robust interpretation algorithms, geophysical well logs techniques have been employed in estimating inherent rock and fluid properties of the reservoirs. It provides a non-destructive (dynamic properties), cost efficient, real-time and covering most entire length of the especially the reservoir intervals.

Geomechanical properties such as; Poisson Ratio, Young's, Shear and Bulk moduli which are the parameters for characterizing rock mechanical properties, are estimated and used in reservoir characterization to predict the mechanical competency of the formation for hydrocarbon exploration. Well planning demands knowledge of these geomechanical properties which can be used to estimate the pressures required to initiate a fracture into a formation for the safety of the personnel and equipment, in particular minimizing the associated risks and generally to determine if sanding can occur in the reservoir during hydrocarbon production [7].

The importance of geomechanical studies is well known in the life cycle of an oil Fields, from hydrocarbon exploration to the drilling stages, and is considered one of the most important tools for increasing production while decreasing the risks involved in the process. Application of the rock mechanics in different parts of the oil industry in some areas such as sand production, wellbore stability, and optimizing production has played essential role in oil and gas production. Proper geomechanical analysis has a main role in identifying and controlling these problems. Despite the presence of a multitude of problems such as wellbore failures, fault reactivation, sand production, caprock integrity, and gas storage problems, geomechanical studies have not been considered seriously and its implementation has been limited [8]. Poor understanding of a Field's geomechanics including the rock elastic properties, rock strength, in situ stress and wellbore stresses around the wellbore wall is a major contributory factor to poor well design and suboptimal production leading to collateral problems including severe wellbore collapse, lost circulation, blowouts, sidetracking and even well abandonment especially in directional and extended reach wells. This demands wellbore stability analysis during the planning phase of a field. This study is aimed at carrying out geomechanical and wellbore stability analysis of wells in Field 'DL' at the central parts of Northern Depobelt in the Niger Delta to Evaluate the geomechanical properties of the reservoirs.

II. Geology of The Study Area

The study area is the '*DL*' Field, located within the central parts of the Northern Depobelt in the Niger Delta oil and gas province. The area lies within Northern Depobelt region of the Niger Delta, between longitudes 7^o to 8^o E and latitudes 4^o to 4.5^o N (Fig 1). The Niger Delta is situated in the Gulf of Guinea (Fig 1) and extends throughout the Niger Delta Province as defined by [10]. From the Eocene to the present, the delta has prograded south-westward, forming Depobelts that represent the most active portion of the delta at each stage of its development [11] (D. These Depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km^2 [12] a sediment volume of 500,000 km^2 [13], and a sediment thickness of over 10 km in the basin depocenter [14].

The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and south-western Cameroon. The northern boundary is the Benin flank--an east-northeast trending hinge line south of the West Africa basement massif. The north-eastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east- South-East by the Calabar flank - a hinge line bordering the adjacent Precambrian. The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin (the eastern-most West African transform-fault passive margin) to the west, and the two-kilometre sediment thickness contour or the 4000m bathymetric contour in areas where sediment thickness is greater than two kilometres to the south and southwest. The province covers 300,000km^2 and includes the geologic extent of the Tertiary Niger Delta (Akata-Agbada) Petroleum System. The Niger Delta Province contains only one identified petroleum system [12,15]. This system is referred to here as the Tertiary Niger Delta (Akata-Agbada) Petroleum System.

[16,17] in their research stated that Tertiary Niger Delta is divided into three main formations, which represent the prograding depositinal facies of sand and shale. The Akata Formation at the base of the delta is of marine origin and is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt. The second is the Agbada Formation which is the major petroleum-bearing unit. Its formation consists of paralic siliciclastics over 3700 m thick and represents the actual deltaic portion of the sequence. The clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environment. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds. The Agbada Formation is overlain by the third formation, the Benin Formation, a continental latest Eocene to Recent deposit of alluvial and upper coastal plain sands that are up to 2000 m thick.

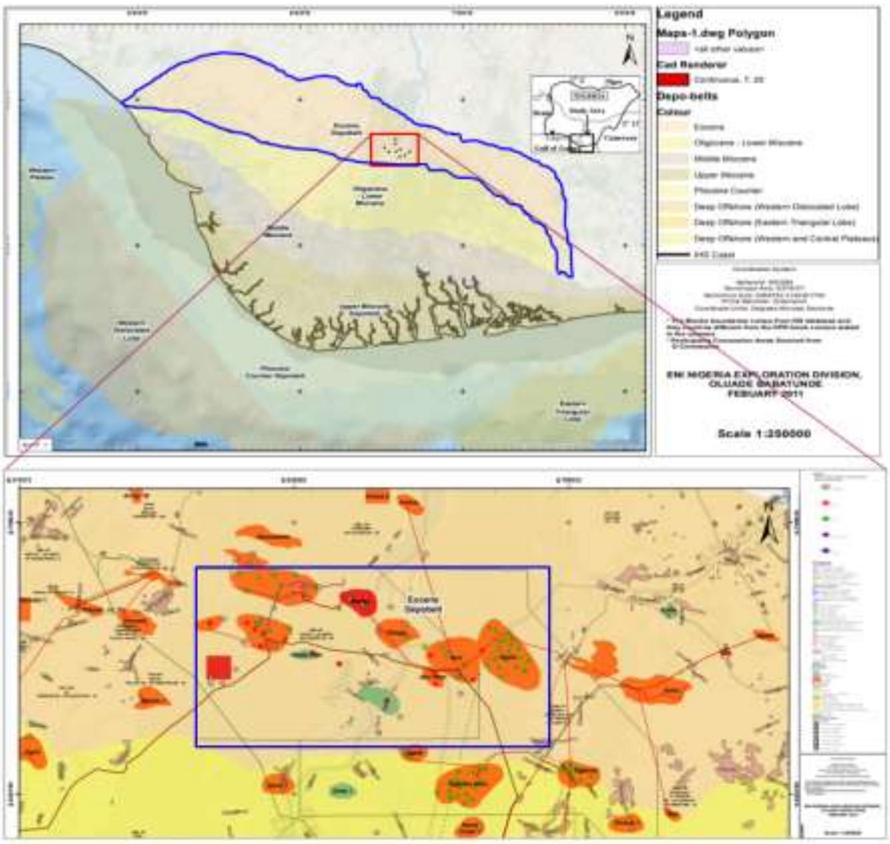

Fig. 1: Map of Niger Delta showing Study Area (GIS ENI Nigeria 2011)

III. Materials and method

In executing the study, five (5) well logs with suits of logs, gamma ray, resistivity, neutron, density and sonic were employed. The software used was the Schlumberger Techlog64, 2015.3. The well logs were carefully conditioned or edited prior to their use in a modelling workflow on Techlog Workstation. The well logs conditioning includes, De-spike and filter to remove or correct anomalous data points, normalization of the logs to determine the appropriate ranges and cut-offs for porosity, clay content, water resistivity and Saturation.

3.1 Shear Velocity Modeling Calibration

In this study, P-wave and S-wave velocities were determined using the equation given by [18]. The P-wave velocity was obtained from Equation 1 which is a standard relationship for compressional velocity transformation from sonic transit time measured in µsec/ft.

For the purpose of modelling and calibrating shear velocity for accurate determination of elastic properties from wireline well logs, the values in Table 1 were used extensively for accurate results. two shear wave Equations were considered according to [18], one in sandstone domain while the other in shale domain as indicated in Fig. 2 and Equations 2 and 3 respectively.

Table 1: Representative Regression Coefficients for Shear Wave Velocity versus Compressional Wave Velocity in Pure Porous Lithologies [18]

Lithology	a_{i2}(quadratic)	a_{i1}(linear)	a_{i0}(constant)
Sandstone	0	0.80416	-0.85588
Shale	0	0.76969	-0.86735
Limestone	-0.05508	1.01677	-1.03049
Dolomite	0	0.58321	-0.07775

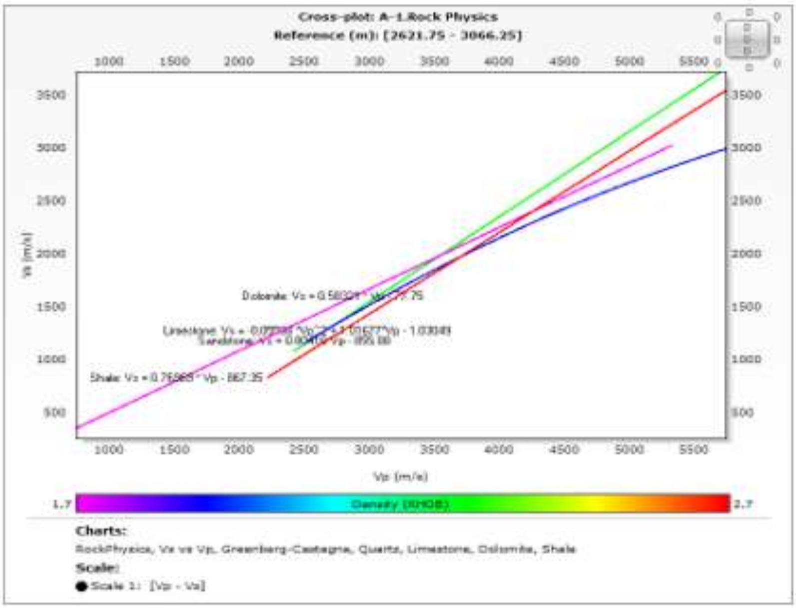

Fig. 2: Shear Velocity Modelling Calibration Standard Cross plot [18]

V_p = 1000000*(0.305/DT) (m/s) (1)

$V_s = 0.80416V_p - 0.85588$ (km/s) sand (2)

$V_s = 0.76969V_p - 0.867355$ (km/s) shale (3)

Where DT is the interval transit time recorded by sonic log in µsec/ft and converted into compressional velocity in meters per second (m/s) as indicated in Equation 1. A model was developed with the IF and ELSE commands in Microsoft Excel as Equation 4 to delineate sand and shale lithologies using the Gamma ray log as lithology log and scaled from 0 to 150 GAPI. Cutoff of 80 GAPI was applied to Gamma ray dataset as a transition zone between the two lithologies. 0 to 79 GAPI was modeled as sand zone while 80 to 150 GAPI was modeled as shale. The essence of the delineation was to achieve the shear velocity modelling calibration in both sand and shale lithologies being the dominate lithologies in Niger Delta for accurate determination of the rocks geomechanical properties.

IF(GR<80,(0.80416*V_p)-0.85588,(0.76969*V_p)-0.86735) (4)

Equation 4 therefore, was integrated into the model for the determination of the elastic properties presented in this study. Shear velocity modelling calibration was significant in study as it ensures that subsurface models accurately reflect the geological reality. This led to improved subsurface imaging, enhanced reservoir characterization, reduced exploration and drilling risks, and more efficient hydrocarbon production, contributing to the overall success of exploration and production activities in the oil and gas industries in the study area.

3.2 Determination of Elastic Properties

Elastic properties, including Poisson ratio (v), Shear Modulus (G), bulk Modulus (K) and Young's Modulus (E), were determined using Ogagure [19] V_p and V_s relationship model for Niger Delta sedimentary region in Equations 5 to 8 respectively.

3.2.1 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 (V_p) in km/s and slowness of the shear wave (V_s) in km/s ratio is used to determine the Poisson ratio [20, 21].

$$v = \frac{Vp^2 - 2Vs^2)}{2(Vp^2 - Vs^2)} \quad (5)$$

3.2.2 Shear Modulus (G)

The shear modulus is the ratio of the shear stress to the shear stress which for a homogeneous and elastic rock is given by eq. 3.17 [20].

$$G = \rho(Vs^2) \quad (6)$$

3.2. Bulk Modulus (K)

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

$$K = \rho(Vp^2 - \tfrac{4}{3}Vs^2) \quad (7)$$

3.2. Young's Modulus (E)

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

$$E = \frac{\rho Vs^2(3Vp^2 - 4Vs^2)}{(Vp^2 - Vs^2)} \quad (8)$$

IV. Results and Discussions

The results of the shear velocity modelling calibration from proper lithologic delineation are presented in Figs 3, 4, ,5 and 6 respectively. The results show perfect match with the results obtained by [18] cross plot for sand and shale delineation, Greenberg-Castagna shear velocity calibration and Greenberg-Castagna shale-sand model calibration respectively. Based on these calibration results of the shear velocity, the geomechanical properties of the rocks were computed. The calculated geomechanical properties are as follows: Compressional

Velocity (V_p), Shear Velocity (V_s), V_p/V_s Ratio, Bulk Modulus (BM), Shear Modulus, Youngs Modulus (YM) and Poisson's ratio (PR).

Table 2, 3, 4 and 5 respectively shows the average geomechanical properties of rock in the four (4) wells used in this study.

Generally, Young's modulus, bulk modulus and shear modulus increases in depth. A decrease in depth can affect the structural integrity of the well or any engineering construction leading to failure. Only Poisson ratio decreases with depth due to rock distress and overburden pressure [22]. Again, [22] stated that low Poisson's ratio (0.1 – 0.25) means that rocks fracture easily whereas high Poisson's ratio (0.35 – 0.45) indicates the rocks are harder to fracture.

Well DL1 Results of Shale Geomechanical Properties

In Well DL1, Table 2; V_p/V_s ratios for the shaley intervals are 2.01, 2.02, 2.02 and 2.03 for shale 1, 2, 3 and 4 respectively. According to [23], clay or shales have V_p/V_s ratio > 2.0. The results obtained for the shaley intervals in Table 2 have V_p/V_s ratios exceeding 2.0. This result shows that V_p/V_s ratio can be used as a complimentary tool for lithology identification and delineation in the study area. Bulk modulus (K) ranges from 13.29 to 22.35 GPa, shear modulus (G) ranges from 6.79 to 11.01 GPa, Young's modulus (E) ranges from 17.38 to 28.33 GPa and Poisson's ratio (v) ranges from 0.28 to 0.30. Poisson ratio recorded indicates that shale beds are harder to fracture. Unconfined Compressive Strength ranges from 48.00 to 57.30 GPa. These results suggest that any applied uniaxial stress during drilling that exceeds 57.30 GPa will fracture the shale formations.

Decrease in modulus values, including bulk modulus (K), shear modulus (G) and Young's modulus (E), along with decrease in Poisson's ratio (v) to 0.28 were observed in shale 3. Significant increase in modulus values and Poisson's ratio (v) observed in the underlying shale 4 in Table 2 indicating the variations in rock behaviour due to stress and rock strength failure [22].

Well DL2 Results of Shale Geomechanical Properties

In Well DL2, V_p/V_s ratios for the shaley intervals are 2.02, 2.05, 2.01, 2.02, 2.02 for shale 1, 2, 3, 4 and 5 respectively. The results obtained for the shaley intervals in Table 3 have V_p/V_s ratio that exceeds [23] threshold as discussed above. Bulk modulus (K) ranges from 11.85 to 19.19 GPa, shear modulus (G) ranges from 6.20 to 9.27 GPa, Young's modulus (E) ranges from 15.78 to23.57 GPa and Poisson's ratio (v) ranges from 0.27 to 0.31. Poisson ratio recorded indicates that shale beds are harder to fracture. Unconfined Compressive Strength ranges from 31.10 48.49 MPa. These results suggest that any applied uniaxial stress during drilling that exceeds 48.49 MPa will fracture the shale formations. Decrease in modulus values, including bulk modulus (K), shear modulus (G) and Young's modulus (E), along with increase in Poisson's ratio (v) to 0.30 were observed in shale 3 and shale 5 suggesting same conditions stress and rock strength failure [22].

Well DL3 Results of Shale Geomechanical Properties

In Well DL3, V_p/V_s ratios for the shaley intervals are 2.00, 2.01, and 2.02, for shale 1, 2, and 3 respectively. The results obtained for the shaley intervals in Table 4 have V_p/V_s ratio that exceeds [23] threshold as discussed above. Bulk modulus (K) ranges from 18.81 to 20.32 GPa, shear modulus (G) ranges from 8.40 to 10.64 GPa, Young's modulus (E) ranges from 21.88 to 27.08 GPa and Poisson's ratio (v) ranges from 0.28 to 0.31 Poisson ratio recorded indicates that shale beds are harder to fracture. Unconfined Compressive Strength ranges from 44.61 to 55.01 MPa. These results suggest that any applied uniaxial stress during drilling that exceeds 55.01 MPa will fracture the shale formations.

Decrease in modulus values, including bulk modulus (K), shear modulus (G) and Young's modulus (E), along with increase in Poisson's ratio (v) to 0.30 were observed in shale 3 and suggesting same conditions in [23].

Well DL4 Results of Shale Geomechanical Properties

In Well D-5, V_p/V_s ratios for the shaley intervals are 2.04, 2.02, 2.01, for shale 1, 2, and
3 respectively. The results obtained for the shaley intervals in Table 5 have V_p/V_s ratio that exceeds [23] threshold as discussed above. Bulk modulus (K) ranges from 18.49 to 18.95 GPa, shear modulus (G) ranges from 7.63 to 8.70 GPa, Young's modulus (E) ranges from 20.09 to 22.75 GPa and Poisson's ratio (v) ranges from 0.31 to 0.32 Poisson ratio recorded indicates that shale beds are harder to fracture. Unconfined Compressive Strength ranges

from 39.99 to 45.02 MPa. These results suggest that any applied uniaxial stress during drilling that exceeds 45.02 MPa will fracture the shale formations.

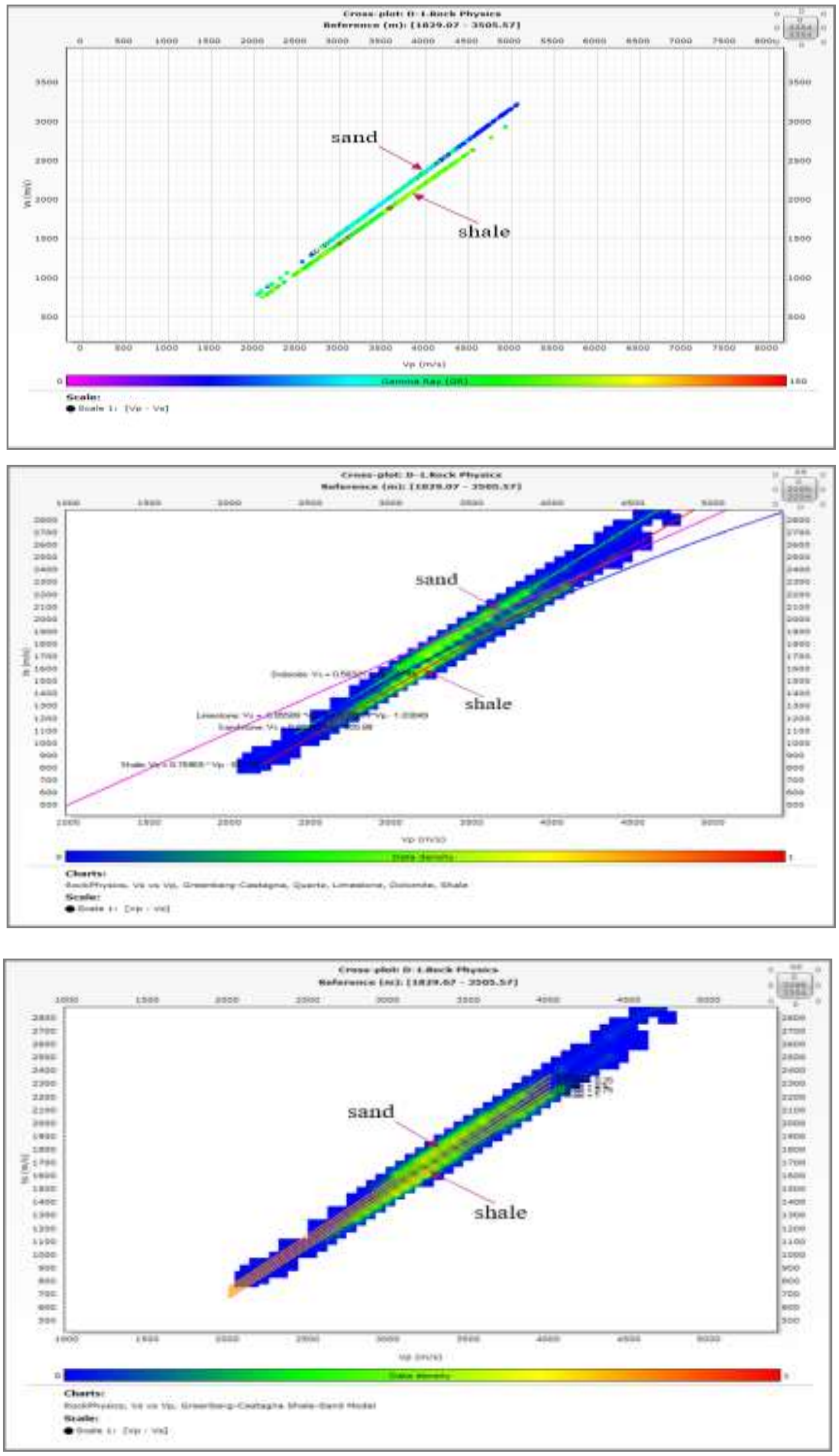

Fig. 3: Reservoirs Shear Velocity Modelling Calibration for Well DL1 (a) Sand and Shale Delineation, (b) Greenberg-Castagna Shear Velocity Calibration, (c) Greenberg and Castagna Shale-Sand Model

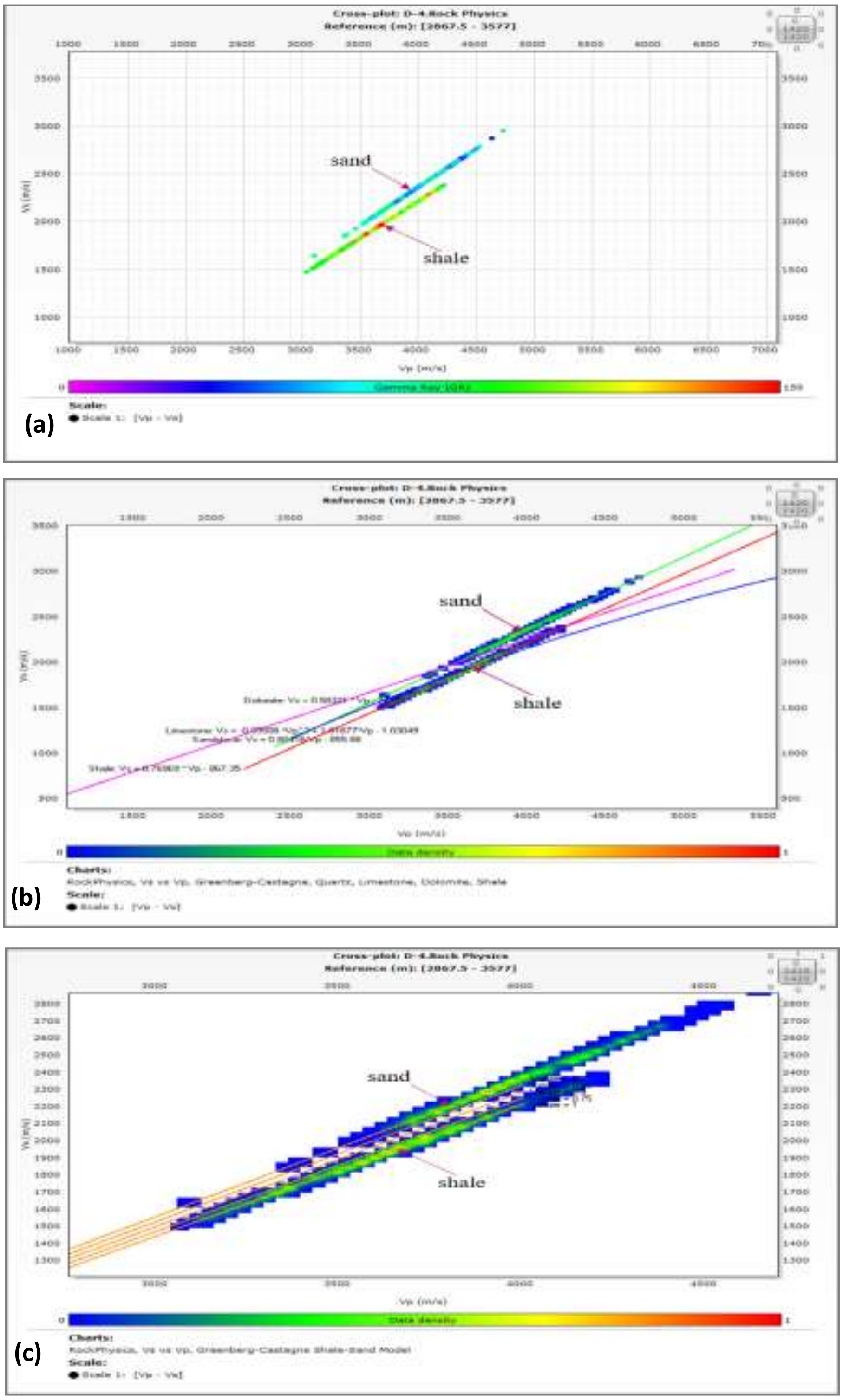

Fig. 4: Reservoirs Shear Velocity Modelling Calibration for Well DL2 (a) Sand and Shale Delineation, (b) Greenberg-Castagna Shear Velocity Calibration, (c) Greenberg and Castagna Shale-Sand Model

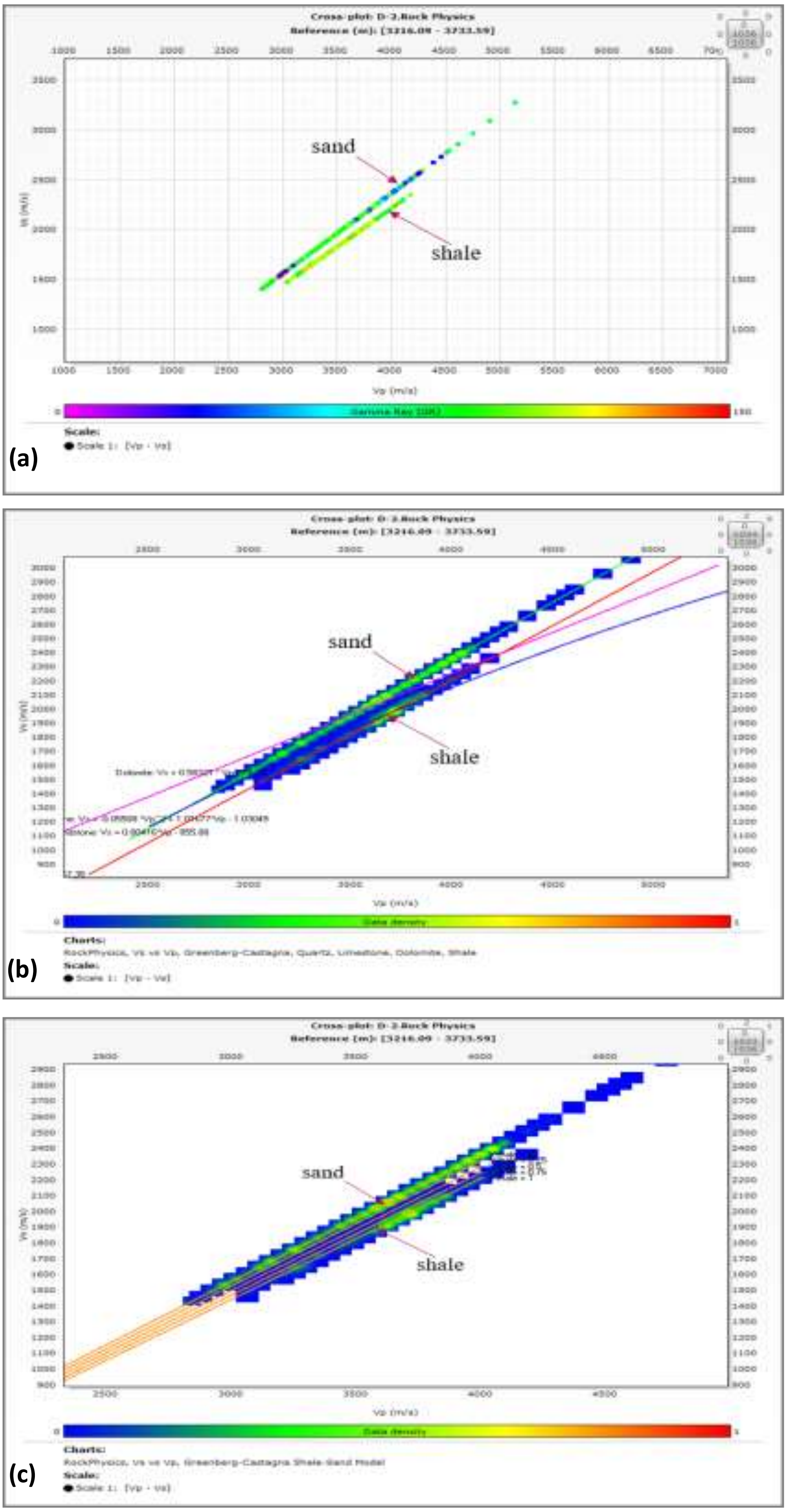

Fig. 5: Reservoirs Shear Velocity Modelling Calibration for Well DL3 (a) Sand and Shale Delineation, (b) Greenberg-Castagna Shear Velocity Calibration, (c) Greenberg and Castagna Shale-Sand Model

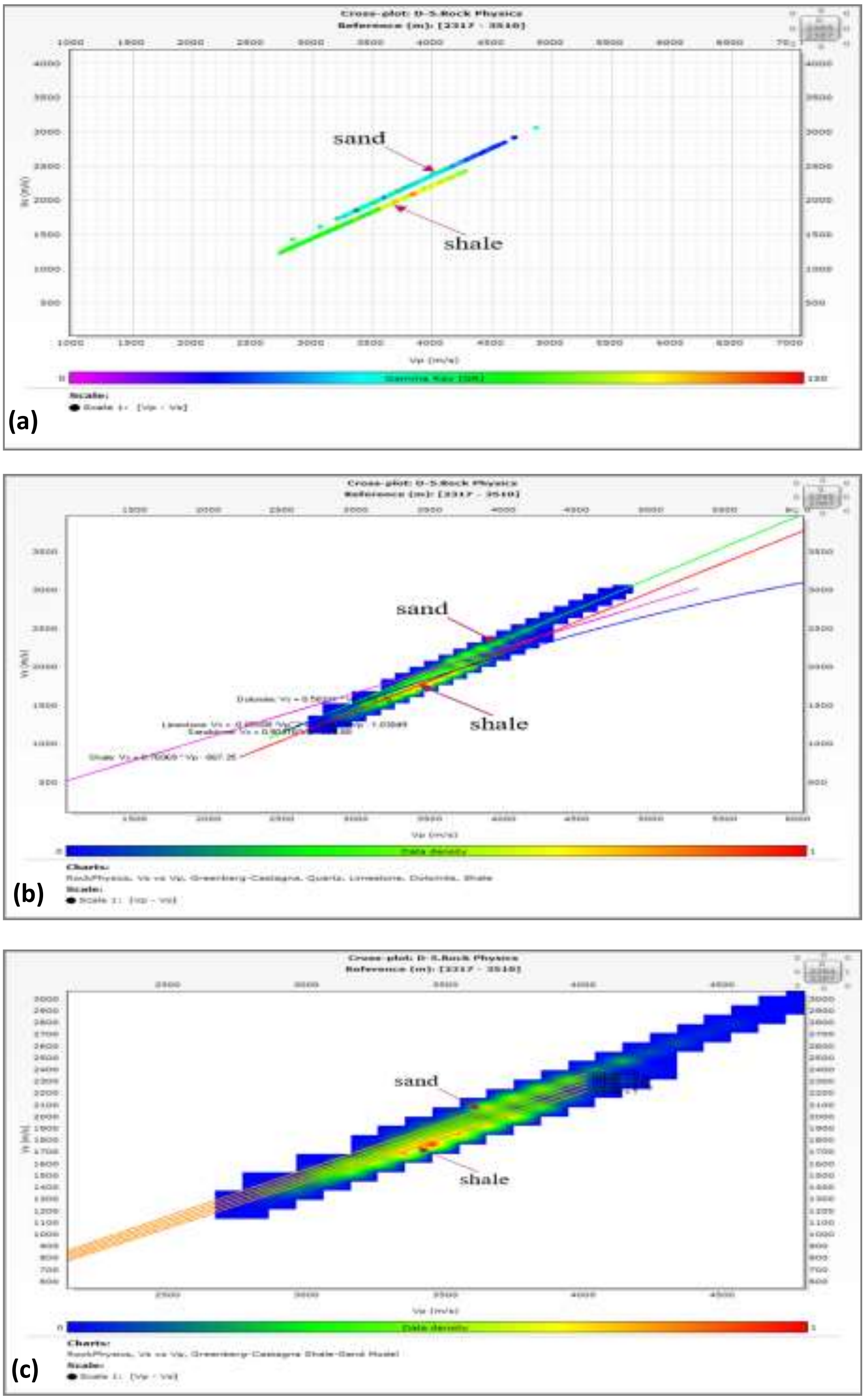

Fig. 6: Reservoirs Shear Velocity Modelling Calibration for Well DL4 (a) Sand and Shale Delineation, (b) Greenberg-Castagna Shear Velocity Calibration, (c) Greenberg and Castagna Shale-Sand Model

Table 2: Average geomechanical properties of rocks in Well DL-1

Zones	Top	Bottom	Gross	Vp	Vs	Vp/Vs	K (BM)	G (SM)	E (YM)	V (PR)	UCS
	m	m	m	Km/s	Km/s	unitless	GPa	GPa	GPa	Unitless	MPa
Sand 1	2877.12	2909.01	31.89	3.78	2.12	1.78	18.13	9.87	25.01	0.27	55.18
Shale 1	2909.01	2940.90	31.89	3.60	1.79	2.01	18.15	8.68	22.40	0.30	48.36
Sand 2	2940.90	2969.74	28.84	4.03	2.35	1.72	19.13	12.00	29.67	0.24	65.66
Shale 2	2969.74	3085.43	115.69	3.60	1.78	2.02	18.24	8.59	22.24	0.30	48.08
Sand 3	3085.43	3094.93	9.50	3.87	2.17	1.79	19.00	10.23	25.97	0.27	58.62
Shale 3	3094.93	3360.91	265.98	3.59	1.77	2.02	13.29	6.79	17.38	0.28	48.00
Sand 4	3360.91	3427.07	66.16	4.57	2.80	1.64	25.42	19.23	45.96	0.20	89.67
Shale 4	3427.07	3481.69	54.62	3.83	1.89	2.03	22.35	11.01	28.33	0.29	57.30

Table 3: Average Geomechanical Properties of Rocks in Well DL-2

Zones	Top	Bottom	Gross	Vp	Vs	Vp/Vs	K (BM)	G (SM)	E (YM)	V (PR)	UCS
	m	m	m	Km/s	Km/s	unitless	GPa	GPa	GPa	Unitless	MPa
Sand 1	3226.56	3250.32	23.76	3.79	2.09	1.81	19.77	10.21	26.08	0.28	55.31
Shale 1	3250.32	3302.62	52.3	3.48	1.72	2.02	18.76	8.04	21.07	0.31	43.48
Sand 2	3302.62	3328.37	25.75	3.99	2.33	1.72	19.82	12.42	30.75	0.24	63.85
Shale 2	3328.37	3338.67	10.30	3.59	1.75	2.05	19.19	8.70	22.63	0.30	47.75
Sand 3	3338.67	3391.77	53.10	3.89	2.23	1.74	19.58	11.60	28.99	0.25	59.75
Shale 3	3391.77	3549.61	157.84	3.61	1.79	2.01	11.85	6.20	15.78	0.28	48.49
Sand 4	3549.61	3561.00	11.39	3.91	2.28	1.71	19.31	12.16	30.13	0.24	60.31
Shale 4	3561.00	3628.37	67.37	3.49	1.73	2.02	17.26	9.27	23.57	0.27	43.64
Sand 5	3628.37	3644.61	16.24	3.61	2.05	1.76	17.71	10.01	25.26	0.26	48.56
Shale 5	3644.61	3668.39	23.78	3.31	1.64	2.02	14.70	6.74	17.49	0.30	31.10
Sand 6	3668.39	3683.85	15.46	3.91	2.29	1.72	20.05	13.01	31.94	0.24	61.58

Table 4: Average Geomechanical Properties of Rocks in Well DL-3

Zones	Top	Bottom	Gross	Vp	Vs	Vp/Vs	K (BM)	G (SM)	E (YM)	V (PR)	UCS
	m	m	m	Km/s	Km/s	unitless	GPa	GPa	GPa	Unitless	MPa
Sand 1	3134.97	3172.69	37.72	3.81	2.15	1.78	19.47	10.79	27.23	0.27	56.29
Shale 1	3172.69	3231.44	58.75	3.51	1.75	2.00	18.81	8.40	21.88	0.31	44.61
Sand 2	3231.44	3318.47	87.03	3.97	2.30	1.73	20.24	12.41	30.81	0.25	63.31
Shale 2	3318.47	3326.45	7.98	3.79	1.82	2.01	20.32	10.64	27.08	0.28	55.01
Sand 3	3326.45	3372.50	46.05	3.99	2.31	1.73	20.69	12.54	31.2	0.25	64.26
Shale 3	3372.5	3473.63	101.13	3.60	1.78	2.02	19.91	9.09	23.62	0.30	48.17
Sand 4	3473.63	3553.73	80.12	4.17	2.47	1.68	21.96	14.62	35.81	0.23	71.14

Table 5: Average Geomechanical Properties of Rocks in Well DL-4

Zones	Top	Bottom	Gross	Vp	Vs	Vp/Vs	K (BM)	G (SM)	E (YM)	V (PR)	UCS
	m	m	m	Km/s	Km/s	unitless	GPa	GPa	GPa	Unitless	MPa
Sand 1	3019.40	3048.36	28.96	3.79	2.14	1.78	19.37	10.75	27.15	0.27	55.24
Shale 1	3046.36	3125.12	78.76	3.44	1.68	2.04	18.95	8.01	21.03	0.32	41.94
Sand 2	3125.12	3139.60	14.48	3.81	2.15	1.78	19.92	10.97	27.74	0.27	56.18
Shale 2	3139.60	3208.96	69.36	3.39	1.68	2.02	18.49	7.63	20.09	0.32	39.99
Sand 3	3208.96	3273.09	64.13	3.87	2.20	1.76	20.22	11.57	29.06	0.26	58.83
Shale 3	3273.09	3392.63	119.54	3.52	1.75	2.01	19.89	8.70	22.75	0.31	45.02
Sand 4	3392.63	3462.56	69.93	4.20	2.49	1.69	22.51	15.04	36.80	0.23	72.87

V. Conclusion

Shear velocity modelling calibration was performed with using [18] correlation to delineate sand from shale. Shear velocity modelling calibration was significant in reservoir characterization as it ensures that subsurface models accurately reflect the geological reality.

This leads to improved reservoir characterization which in turn will reduce exploration and drilling risks and more efficient hydrocarbon production.

The results of rock elastic properties, bulk modulus shear modulus, young's modulus, Poisson ratio and unconfined compressive strength, in Tables 2, 3, 4, and 5 have all revealed that shales in the study area are stiff, compact and harder to fracture. Based on these properties, the shales are good cap rocks as they are hard to fracture. Again, the results also show a decrease in modulus values and an increase in Poisson's ratio in depth indicating changes in material behaviour, often associated with failure or weakening of rock or rock state of distress as a result of rock reaching its mechanical limits or are subject to excessive stress. it also suggests a potential structural instability in the subsurface, developments of fractures, faulting or other structural discontinuities in rock, stress within a material is being redistributed, which may have implications for wellbore stability, subsidence, or surface deformations, changes in reservoir pressure, fluid movement, or compaction, processes such as tectonic movements, faulting or volcanic activity.

VI. References

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