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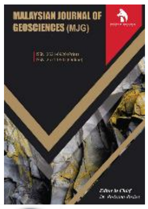

RESEARCH ARTICLE

INVESTIGATION OF THE ZETA FIELD RESERVOIR ROCK AND FLUID TRANSPORT PROPERTIES, NIGER DELTA BASIN

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ABSTRACT

The study on petrophysical properties have been conducted. The wells (X_1, X_2 and X_3) in the Zeta Field may be developed if the result of investigation is appreciable as it is necessary for well development, well bore stability and could be used to characterize oil reservoirs. Microsoft excel was adequate for the data processing and analysis. The petrophysical properties results for well X_1 include average values of water saturation, porosity and permeability as 0.30 (30%), 19% and 10.36 millidarcy. This means that about 70% hydrocarbon saturation could be available with adequate connectivity of pores for accumulation and migration of reservoir fluids. For well X_2, the average is 0.16 (which is 16%), 30%, and 21.54 millidarcy respectively. Therefore, the hydrocarbon saturation is about 84% with a very good class of porous formation and therefore can store and transmit fluid. The average noted from well X_3 for water saturation, porosity and permeability correspond to 0.27 (27%), 24% and 13.42 millidarcy. The average results of the other properties studied include Shear Modulus, Lame`s Constant, and Young`s Modulus as 9.20×10^9 N/m², 5.0×10^{13} N/m² and 2.12×10^{10} N/m² respectively from well X_1. Also, the average obtained from well X_2 are 3.94×10^9 N/m² for Lame`s Constant, $5.82 \times 10^9$ N/m² for Shear Modulus and $1.34 \times 10^{10}$ N/m² for young`s modulus. Well X_3 findings have the average results as Shear Modulus = 7.64×10^9 N/m², Lame`s Constant = $5.18 \times 10^9$ N/m² and young`s modulus = 1.77×10^{10} N/m². These results indicate that the studied reservoir formation is brittle and wells could stand a test of time. This information implies that the hydrocarbon saturation is about 73%, highly porous and has the ability to accumulate and migrate fluids. The results of their dependent parameters are presented in section 4. Properties like acoustic impedance and shear impedance have an average of 7.5×10^6 and 4.6×10^6 for well X_1, 5.7×10^6 and 3.5×10^6 for Well X_2; 6.7×10^6 and 4.1×10^6 for Well X_3 respectively.

KEYWORDS

Petrophysical properties, water saturation, young's modulus, Lame's constant, Porosity, Niger Delta

1. INTRODUCTION

Niger Delta region is known to have deposits of hydrocarbon. Most locations in the Niger Delta Basin have deposits of reasonable Oil and Gas from the subsurface but some may not have in economical amount. The factors affecting the availability of reservoir fluid in some locations include low porosity, low permeability, rock texture, brittleness, hydrocarbon saturation and others. Oil and gas generate revenue and boost the economy of our country, Nigeria. Oil and gas well completion depend heavily on the right porosity, permeability, young's modulus information to ensure oil and gas can be extracted. Incorrect assessment of the rock and fluid transport properties may lead to reduced hydrocarbon recovery and increased operational risks among others (Brown and Kazemi, 2004; Serra et al., 2017).

Rock physics may describe a reservoir rock by physical properties such as porosity, rigidity, compressibility; properties that will affect how seismic waves physically travel through the rocks (Dewar, 2001). Petrophysics studies the chemical and physical properties of the rocks and fluids in it (Thomas, 1992). Both petrophysics and rock physics have different goals which is to transform well log measurements to rock and fluid properties such as: saturation, clay content, porosity among others in order to determine the physical relationship between rock and fluid properties (Ellis and Singer, 2007; Mavko et al., 2007).

Previous researches outcomes on petrophysical properties have been noted. A group researcher conducted research using marginal field data to evaluate the rock and fluid properties (Ugwu et al., 2022). They concluded that the study has shown that the reservoir intervals evaluated in UPX fields have the necessary requirement to be termed good reservoir rocks for production. The reservoir rocks are of good to excellent quality and can be produced with minimum stress because of low shaliness, high net to gross, good to excellent effective porosity and permeability, good hydrocarbon saturation values. Airen and Mujakperuo evaluated the petrophysical properties and used to characterize reservoir (Airen and Mujakperuo, 2023). The study evaluates petrophysical properties of the Sapele shallow field in the Niger Delta Area of Southern Nigeria with the aid of log data. Reservoir "A" was the only delineated reservoir in Sapele shallow that was encountered at a shallow depth of 672.16 m (2218.13) – 2115.06 m (6979.70 ft) across the field. A group researcher determined and evaluated the petrophysical properties of Fenchuganj Gas Field in Sylhet district of Bangladesh (Ahammod et al., 2023). The investigation was done to understand their effects on the reservoir hydrocarbon prospects and gas productivity of the field. The results suggest high hydrocarbon potential.

The aim of this research is to investigate the physical properties of the Zeta Field. Lithologies have to be identified, the shale volume is a requirement for further findings, the ratio of compressional wave and shear wave velocities is one of the needed parameters, poisson's ratio must be

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determined, shear modulus information is required, acoustic impedance will be determined as well as shear impedance. Other parameters whose results will yield the goal of this research are young`s modulus, lame`s constant, porosity, water saturation and permeability. There is no known investigation on petrophysical properties of the Zeta Field of the Niger Delta Basin. This research will be adequate for the accurate information required to develop a well for hydrocarbon exploration.

1.1 Geology and Location

The Niger Delta is a region in the West Africa with an area of about 7 x 10^4 square kilometers; situated in the Southern part of Nigeria. From many studies, it is located within latitudes 3º N and 6º N and longitudes 5º E and 8º E (Atat et al., 2020a; Akpabio et al., 2023a; Umoren et al., 2019; Reijers et al., 1996; Atat et al., 2023b). It is characterized with two distinct seasons: wet and dry (Atat et al., 2020b; George et al., 2017; Ejoh et al., 2023). This region is a major source of hydrocarbon and produces about 90% of oil and gas in Nigeria. In order to find oil and gas in economical quantities, the properties of the rocks of the Niger Delta Basin are important, for accurate decisions and easy extraction of oil and gas. The Niger Delta began after the Eocene tectonic phase, up to 12.0km of silicic high energy deltaic deposits and shallow marine sediments have assembled in the basin. Some researchers have agreed to the entire space occupy by the sediment to be about 50 x 10^4km^3 (Atat et al., 2020b; Umoren et al., 2020; Atat et al., 2020c). The Niger and the Benue Rivers are the core suppliers of sediments. Three lithostratigraphic units are notable in the Tertiary Niger Delta: the basal Akata, the Agbada and the Benin Formations (Atat et al., 2023a; Atat and Umoren, 2016). Benin Formation is the uppermost unit of the Niger Delta Complex that lays on top the Agbada Formation (Atat et al., 2023a).

2. Theoretical Information

Petrophysics is the study of the physical and chemical rock properties and its interactions with fluids used to study reservoirs (Tiab and Donaldson, 2004). It presents how interconnected a subsurface is and availability of hydrocarbon. The characteristics of petrophysics of reservoir rocks include water saturation (S_w), porosity (Ø), formation factor, permeability (K), hydrocarbon saturation, water resistivity. Porosity (Ø), permeability (K) and fluid saturation are the most significant (Harry et al., 2022). Petrophysical properties are proper indicators in identifying oil and gas reservoirs since its pore fluids have an important effect on wave responses (Rupeng et al., 2021). They provide the foundation for making informed decisions in the oil and gas industry and contribute to the efficient and sustainable extraction of natural resources.

2.1 Determination of shale volume (V_{sh})

Shale volume is a physical parameter that represents the fraction of fined grained indurated sedimentary rock formed by the consolidation of clay or silt. Shale reduces the porosity and permeability of a reservoir (Kamel and Mabrouk, 2003). Gamma ray log is preferred (Asquith and Krygowski 2004). The IGR may be computed from the gamma ray log using Equation 1. To determine shale volume, Equation 2 may be used. As more shales are present or build up in the reservoir rock, it will be more difficult to store and produce hydrocarbons. High shale volume lowers the quality of a reservoir and stops the movement of hydrocarbon to a well. All reservoir sand bodies have lower than 25% shale volumes (on average) which suggest that there is a reduced amount of resistance to the flow of fluids within the reservoir rock. This indicates that only a minor quantity of the reservoir sands is dirty, therefore, near 70% of the reservoir sands are clean and can produce hydrocarbon (Ugwu et al., 2022).

$$IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

Where IGR = Gamma Ray Index

GR log = Gamma Ray Log

GR min = Minimum value of Gama Ray (sand)

GR max = Maximum value of Game Ray (shale)

$$Vsh = 0.083\,(23.7\,IGR - 1) \quad (2)$$

Where Vsh = Volume of Shale

2.2 Determination of water saturation (S_w)

Water saturation is the proportion of pore space within a subsurface geological formation that is filled with water may be expressed as a percentage or decimal between 0 and 100%. This parameter is critical for evaluating reservoir quality and estimating the volume of hydrocarbons that can be economically recovered from a subsurface reservoir. This may be obtained using Equation 3.

$$S_w = \sqrt{\frac{R_o}{R_t}} \quad (3)$$

Where S_w = Water Saturation

R_o = Value of rock resistivity

R_t = Value of resistivity

2.3 Determination of porosity (Ø)

The porosity of a rock is the fraction of the volume of space between the solid particles of the rock to the total rock volume where the space includes all pores, cracks, inter- and intra-crystalline spaces (Glover, 2010). It defines the capacity of rock to hold fluid, including reservoirs storage capacity. Density log is may be used as it has the formation bulk density information (Horsfall et al., 2013). According to a study, the formation bulk density is related to the formation matrix density (ρ_{ma}) and formation fluid density (ρ_f) as presented in Equation 4 (Horsfall et al., 2013).

$$\rho_b = (1-Ø)\,\rho_{ma} + Ø\,\rho_f \quad (4)$$

Rearranging the above,

$$Ø = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (5)$$

(Akpabio et al., 2023b)

Where Ø = Porosity

ρ_{ma} = Matrix density = 2.65 g/cm3 for sandstone

ρ_b = Bulk density from the log

ρ_f = Fluid density. 0.85 for oil, 0.2 for gas

2.4 Determination of permeability (K)

Permeability is a measure of the connectivity of pores in the surface. It is measured in millidarcy (md) or Darcy (1000md) of the narrow throats. Common permeability in the range of 100 to 500 md is a reasonable value for a petroleum reservoir rock (Satter and Labal, 2016; Tiab, and Donaldson, 2016). The value of permeability may be appreciable if Equation 6 is considered (Coates and Dumanoir, 1974). Levorsen and Rider classified reservoir quality based on permeability values as follows: less than 10 mD indicates poor to fair, greater than 10 to 50 mD show moderate, greater than 50 mD to about 250 mD is Good, greater than 250 to 1000 mD is very good and more than 1000 mD signifies excellent (Levorsen, 1967; Rider, 1986; Ugwu et al., 2022).

$$K = 100\frac{Ø^2(1-S_{wir})}{S_{wir}} \quad (6)$$

Where K = permeability

S_{wir} = irreplaceable water saturation

Ø = porosity

S_{wir} = 0.3

Rock physics deals with the study of reservoir rocks by physical properties as seismic waves travel through rocks (Dewar, 2001). It links geological and reservoir properties to the elastic and seismic parameters. Reservoir conditions and important reservoir properties such as lithology and fluid saturation could be more understood and predicted more precisely by analyzing well logs and seismic data in a rock physics context (Johari and Niri, 2021).

A group researcher stated that the physical relationship between rocks and fluid properties may be determined (Mavko et al., 2007). Sonic log is needed to obtain compressional wave velocity (V_p) and shear wave velocity (V_s), to achieve parameters such as Young`s Modulus, Poisson`s Ratio, Shear Modulus, AI, SI and Lame`s Constant. Equation 7 is adequate to convert sonic log in µs/ft. to s/ft.

$$Sonic\ (s/ft) = \frac{Sonic\ log}{1000000} \quad (7)$$

The reciprocal of sonic (s/ft) yields Equation 8.

$$Vp\ (ft/s) = \frac{1}{Sonic(s/ft)} \quad (8)$$

The product of the local fit constant (0.305) and Equation 8 leads to Equation 9 (Atat, et al., 2021).

$$Vp\ (m/s) = 0.305\ V_p \quad (9)$$

Equation 9 yields shear wave velocity in m/s (Equation 10).

$$V_s(m/s) = 0.611 V_p(m/s) + 0.2862$$

(Castagna et al., 1985) (10)

Equation 10 is Castagna Equation with local fit constraint from Niger Delta Basin (Atat et al., 2021).

2.5 Determination of shear modulus

Shear modulus is the ratio of shear stress to shear strain, which tells how resistant a material (or rock) is to shearing deformation. Where a higher value of shear modulus indicates a very rigid material usually measured in Pascal (Pa) or N/m^2. Mathematically:

$$\mu = \rho V_s^2 \quad (11)$$

Where ρ = density

Vs = shear wave velocity

2.6 Determination of poisson`s ratio (σ)

Poisson`s ratio is a fundamental elastic parameter used to determine rock properties and is a vital factor of rock physics study as it responds to stress and strain of rocks, under various geological conditions and interpreting seismic data to infer subsurface rock properties. According to some studies, Poisson`s ratio could be expressed as stated in Equation 12 (Atat and Umoren, 2016; Atat et al., 2023b; Atat et al., 2024).

$$\sigma = \frac{(\frac{V_p}{V_s})^2 - 2}{2(\frac{V_p}{V_s})^2 - 1} \quad \text{(Atat and Umoren 2016; Atat et al., 2024)} \quad (12)$$

σ = Poisson`s ratio

V_s = compressional wave velocity

V_p = shear wave velocity

In calculating elastic parameters of a rock, Poisson`s ratio is used in conjunction with two other important parameters: Bulk modulus and Young`s modulus.

2.7 Determination of young`s modulus

Young`s modulus is a property of the material that tells how easily it can stretch and deform and may be defined as the ratio of tensile stress to tensile strain. It is expressed mathematically in Equation 13 (Atat et al., 2020d; Atat et al., 2024).

$$E = 2\mu(1 + \sigma) \quad (13)$$

Where E = young`s modulus

σ = poisson`s ratio

μ = shear modulus

(Atat et al., 2024)

2.8 Determination of acoustic impedance (AI)

According to Chung and Petchsuk, acoustic impedance is a parameter used for evaluating the acoustic energy transfer between two materials (Chung and Petchsuk, 2003). It is the product of the density and seismic velocity of a rock unit. This is expressed in Equation 14.

$$AI = \rho V_p \quad (14)$$

Where ρ = density

V_p = compressional wave velocity

2.9 Determination of shear impedance (SI)

It describes the mechanical properties of geological materials, mostly how they respond to shear waves.

$$SI = \rho V_s \quad (15)$$

Where ρ = density

Vs = shear wave velocity

2.10 Determination of lame`s constant

Lame`s constant is the compression stiffness of the fluid or gas when the sample is compressed on one axis and constrained on the other two (Lowe, 2001). A higher Lame's constant tells resistance to volumetric or shear deformation. Equation 16 is adequate to obtain Lame's constant.

$$\lambda = V_s{}^2 \rho \quad (16)$$

3. Materials And Methods

3.1 Materials

The materials used for this project include: well data from three wells having gamma ray log, resistivity log, Sonic log, depth information, Caliper log among others. Microsoft Excel was adequate for the processing, analyses and computations.

3.2 Method

The simple illustration of the step-by-step approach is presented in Figure 1.

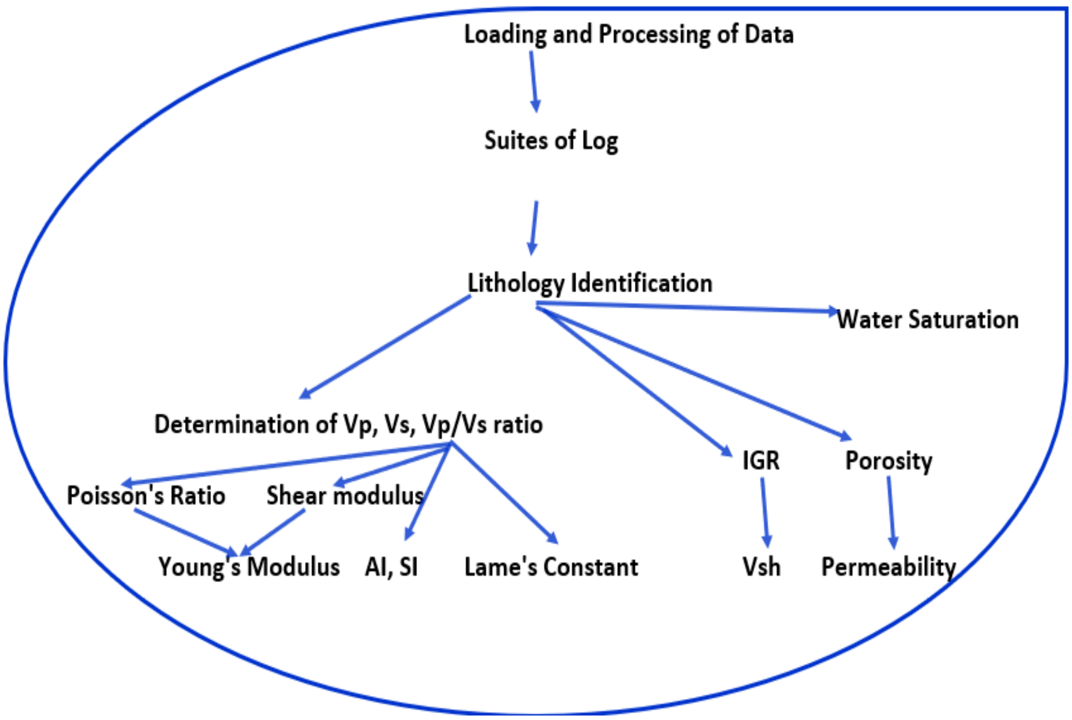

Figure 1: The workflow of the study

4. RESULTS AND DISCUSSION

4.1 Results

The oil field of investigation is Zeta. The wells are X_1, X_2, and X_3. Suites of log were generated from the data obtained from onshore oil field. Lithology (sand and shale) baseline was identified such that gamma ray index greater than 65 API was marked for shale and gamma ray less than 65 API was marked for sand. The colour for each parameter include red for gamma ray, green for sonic, black for porosity (%), purple is acoustic impedance, yellow for shear impedance, brown for young's modulus, ash for shear modulus, sky blue for permeability, turquoise for water saturation and dark blue for resistivity. The results obtained are presented in Figures 2 to 10.

Tables 1, 2 and 3 present some parts of the results of the petrophysics and rock physics properties. These initial results aid the accurate steps to achieving the desired goal.

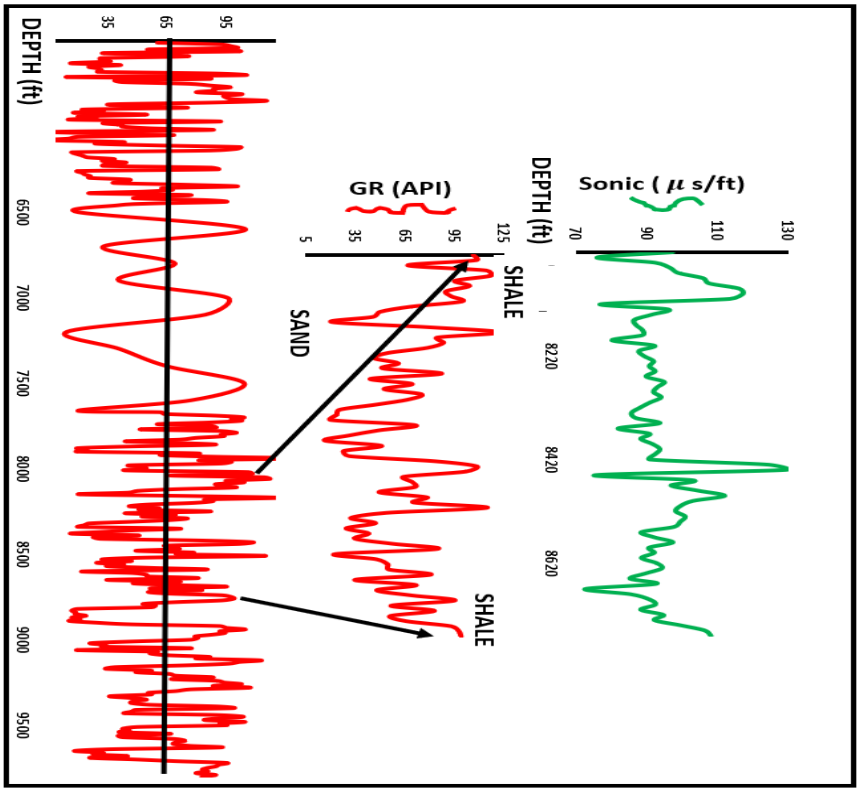

Figure 2: The generated suites of log with Depth for gamma (red) and sonic (green) indicating sand and shale baseline for Well X_1.

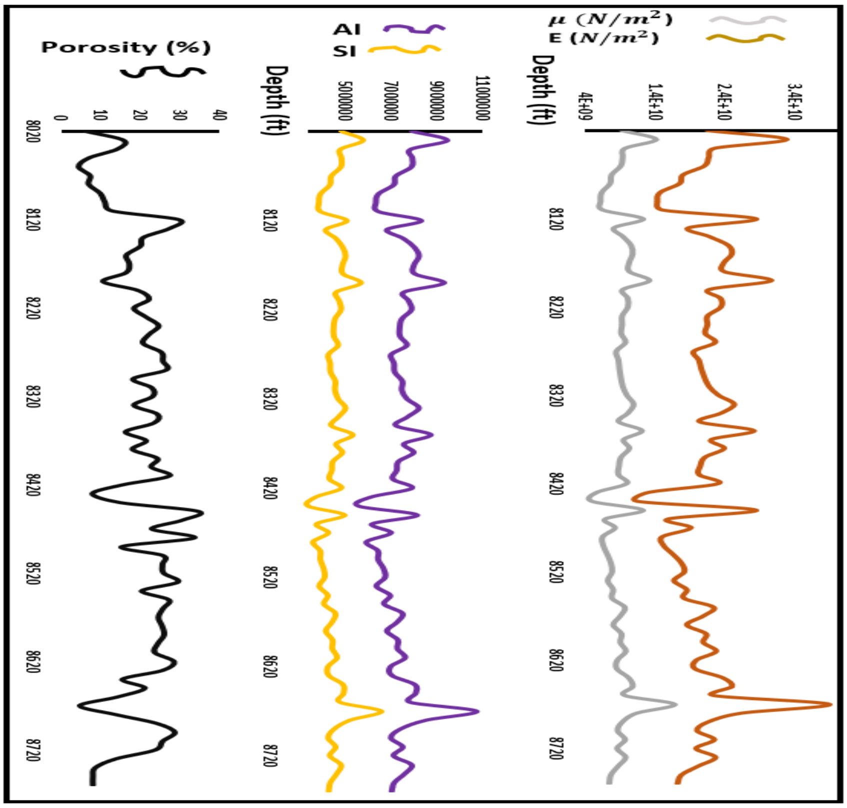

Figure 3: The curves of parameters of petrophysics (porosity in black, AI in purple, SI in yellow) and rock physics (young`s modulus in brown, shear modulus in ash) for Well X_1.

Table 1: The results of some Petro-physics and rock physics properties from Well X_1

DEPTH (ft)	$D(\frac{g}{cm^3})$	IGR	V_{sh}	$V_p(\frac{m}{s})$	$V_s(\frac{m}{s})$	λ
8020	2.5382	0.84591	0.643541	3134.28	1915.3	4.8E+13
8040	2.3936	0.4725	0.195836	3302.52	2018.1	5.3E+13
8060	2.57	0.94844	0.862074	3082.84	1883.9	4.6E+13
8080	2.5242	0.82485	0.605337	2835.62	1732.8	3.5E+13
8100	2.451	0.71943	0.442277	2603.71	1591.2	2.6E+13
8120	2.1134	0.49329	0.211109	3951.35	2414.6	8E+13
8140	2.2759	0.27233	0.083879	3328.04	2033.7	5.1E+13
8160	2.3534	0.591	0.294869	3506.9	2143	6.2E+13
8180	2.3554	0.64	0.345462	3434.2	2098.6	5.8E+13
8200	2.3003	0.58374	0.2879	3310.7	2023.1	5.1E+13
8220	2.319	0.27681	0.085808	3419.83	2089.8	5.7E+13
8240	2.2072	0.33044	0.110696	3359.4	2052.9	5.1E+13
8260	2.2773	0.25859	0.078102	3392.09	2072.9	5.4E+13
8280	2.1876	0.33671	0.11384	3277.39	2002.8	4.7E+13
8300	2.3234	0.47753	0.19946	3242.84	1981.7	4.8E+13
8320	2.2343	0.08231	0.019509	3461.8	2115.4	5.7E+13
8340	2.2127	0.03243	0.007199	3506.9	2143	5.8E+13
8360	2.3576	0.30596	0.09891	3718.88	2272.5	7.4E+13
8380	2.3257	-2E-05	-4.2E-06	3450.98	2108.8	5.8E+13
8400	2.2402	0.10523	0.025713	3253.91	1988.4	4.7E+13
8420	2.3708	0.62929	0.333861	3353.96	2049.6	5.5E+13
8440	2.3836	0.80294	0.567732	2361.05	1442.9	1.9E+13
8460	2.0997	0.4962	0.213311	2961.84	1810	3.3E+13
8480	2.0452	0.30836	0.100036	2921.65	1785.4	3.1E+13
8500	2.1874	0.50719	0.221788	2962.06	1810.1	3.5E+13
8520	2.184	0.3498	0.12056	3105.84	1898	4E+13
8540	2.2833	0.28651	0.090062	3066.54	1873.9	4E+13
8560	2.1874	0.2493	0.074307	3443.72	2104.4	5.5E+13
8580	2.191	0.38487	0.139718	3132.66	1914.3	4.1E+13
8600	2.2115	0.05669	0.012988	3310.42	2023	4.9E+13
8620	2.1372	0.35823	0.125008	3284.73	2007.3	4.6E+13
8640	2.371	0.60246	0.306141	3403.67	2079.9	5.7E+13
8660	2.3937	0.51879	0.230984	3291.18	2011.2	5.2E+13
8680	2.4015	0.49049	0.209008	3567.49	2180	6.7E+13
8700	2.1338	0.37673	0.135113	3298.02	2015.4	4.7E+13
8720	2.2227	0.37191	0.132436	3218.45	1966.8	4.5E+13
8740	2.494	0.72136	0.444879	3062.83	1871.7	4.4E+13
8760	2.5054	0.77565	0.52374	2821.52	1724.2	3.4E+13

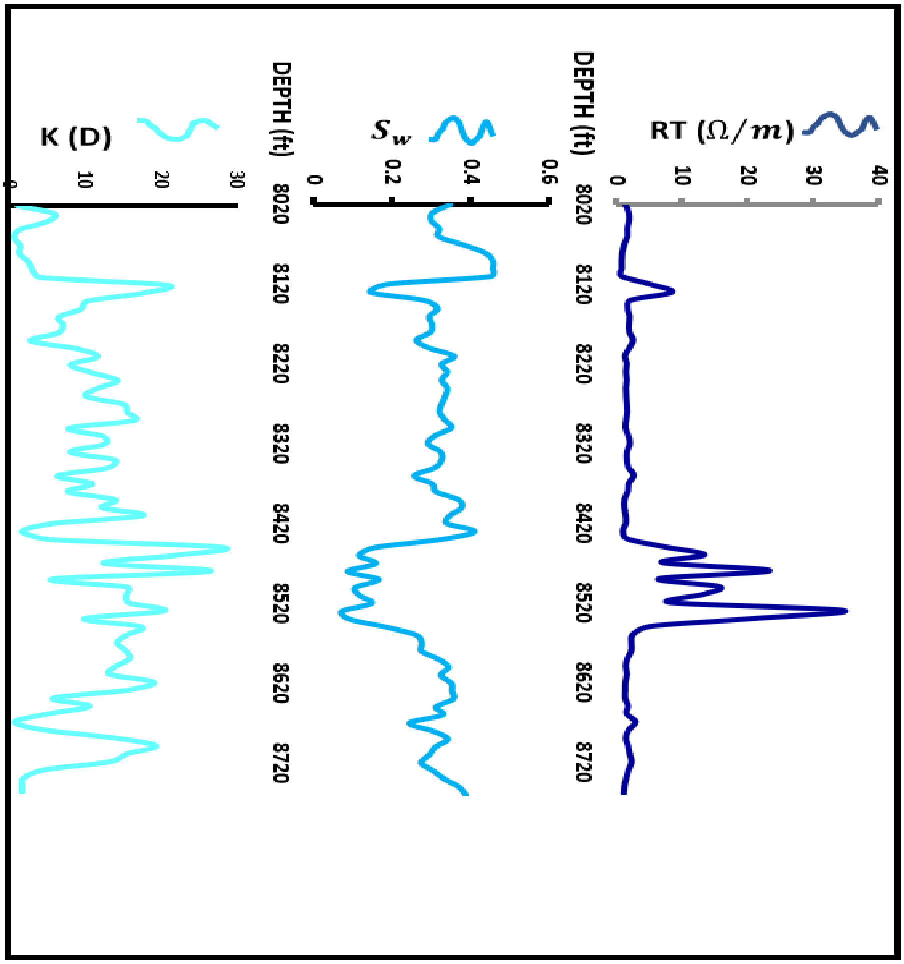

Figure 4: The curves of permeability (sky blue), water saturation (turquoise) and resistivity (dark blue) for Well X_1.

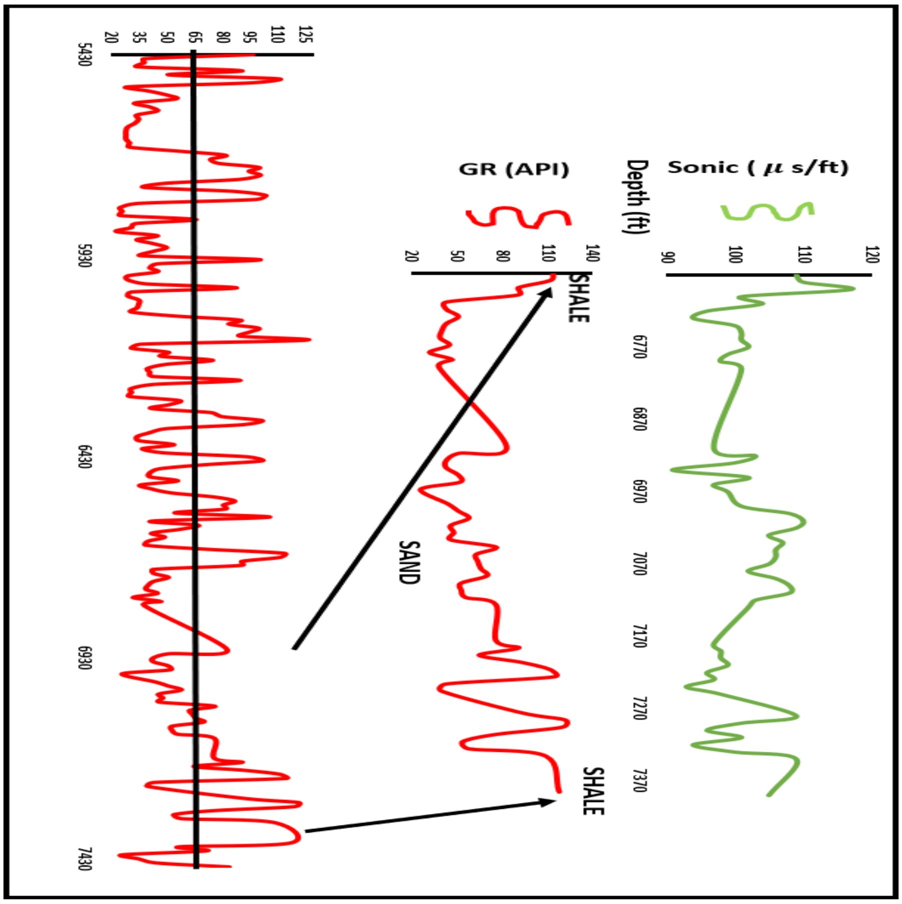

Figure 5: The generated suites of log with depth for gamma (red) and sonic (green) indicating sand and shale baseline for Well X_2.

Table 2: The results of some petrophysics and rock physics properties from Well X_2

DEPTH (ft)	V_{sh}	$V_p(\frac{m}{s})$	$V_s(\frac{m}{s})$	λ	$D(\frac{g}{cm^3})$	IGR
6670	0.788107	2699.115	1649.445	4.18E+09	2.2653	0.916667
6680	0.742785	2420.635	1479.294	3.14E+09	2.1183	0.895833
6690	0.388217	2500	1527.786	3.38E+09	2.1369	0.677083
6700	0.388217	2459.677	1503.149	3.25E+09	2.121	0.677083
6710	0.047712	2293.233	1401.452	2.68E+09	2.0126	0.177083
6720	0.047712	2563.025	1566.295	3.45E+09	2.0722	0.177083
6730	0.078858	2541.667	1553.245	3.34E+09	2.0412	0.260417
6740	0.047712	2541.667	1553.245	3.36E+09	2.0562	0.177083
6750	0.037645	2824.074	1725.795	4.21E+09	2.0854	0.145833
6760	0.034465	2699.115	1649.445	3.83E+09	2.0765	0.135417
6770	0.054886	3210.526	1961.918	5.57E+09	2.1352	0.197917
6780	0.01443	2364.341	1444.899	3.04E+09	2.1462	0.0625
6790	0.062454	2652.174	1620.764	3.64E+09	2.0452	0.21875
6800	0.031368	2541.667	1553.245	3.45E+09	2.1104	0.125
6910	0.297543	2772.727	1694.423	4.07E+09	2.092	0.59375
6920	0.078858	3080.808	1882.66	4.95E+09	2.0584	0.260417
6930	0.047712	2723.214	1664.17	3.88E+09	2.0682	0.177083
6940	0.047712	2904.762	1775.096	4.53E+09	2.1225	0.177083
6950	0.078858	2850.467	1741.922	4.41E+09	2.1461	0.260417
6960	0.08324	2961.165	1809.558	4.66E+09	2.1014	0.270833
6970	0	2699.115	1649.445	3.92E+09	2.1242	0
6990	0.051251	2990.196	1827.296	4.75E+09	2.0981	0.1875
7000	0.078858	2961.165	1809.558	4.66E+09	2.0978	0.260417
7010	0.112141	2904.762	1775.096	4.46E+09	2.0862	0.333333
7020	0.058619	2629.31	1606.795	3.61E+09	2.0615	0.208333
7030	0.066392	2850.467	1741.922	4.28E+09	2.0832	0.229167
7040	0.058619	2699.115	1649.445	4.05E+09	2.1977	0.208333
7050	0.232637	2772.727	1694.423	4.13E+09	2.1228	0.520833
7060	0.140028	2479.675	1515.368	3.18E+09	2.0417	0.385417
7070	0.146067	2401.575	1467.648	3.05E+09	2.0912	0.395833
7080	0.158638	2420.635	1479.294	3.05E+09	2.0535	0.416667
7090	0.18589	2420.635	1479.294	3E+09	2.0234	0.458333
7100	0.087741	2747.748	1679.16	3.85E+09	2.0157	0.28125
7110	0.087741	2699.115	1649.445	3.7E+09	2.0072	0.28125
7120	0.101988	2584.746	1579.566	3.62E+09	2.1411	0.3125
7130	0.232637	2606.838	1593.064	3.54E+09	2.058	0.520833
7180	0.232637	2479.675	1515.368	3.25E+09	2.0899	0.520833
7190	0.388217	2772.727	1694.423	4E+09	2.0544	0.677083
7200	0.152269	2904.762	1775.096	4.5E+09	2.1081	0.40625
7210	0.414079	2932.692	1792.161	4.72E+09	2.1679	0.697917
7220	0.742785	2850.467	1741.922	4.56E+09	2.2178	0.895833
7230	0.811692	2961.165	1809.558	4.91E+09	2.2137	0.927083
7240	0.047712	2932.692	1792.161	4.63E+09	2.1268	0.177083
7250	0.037645	2904.762	1775.096	4.62E+09	2.1642	0.145833
7280	0.414079	2877.358	1758.352	4.03E+09	1.9218	0.697917
7290	0.995671	2824.074	1725.795	4.48E+09	2.2178	1
7300	0.93955	2675.439	1634.979	4.01E+09	2.2153	0.979167
7310	0.232637	2723.214	1664.17	4.17E+09	2.2235	0.520833
7320	0.092364	2850.467	1741.922	4.43E+09	2.1536	0.291667
7330	0.112141	2652.174	1620.764	3.78E+09	2.123	0.333333
7340	0.679185	2479.675	1515.368	3.58E+09	2.2978	0.864583
7390	0.886349	2606.838	1593.064	3.43E+09	1.9931	0.958333

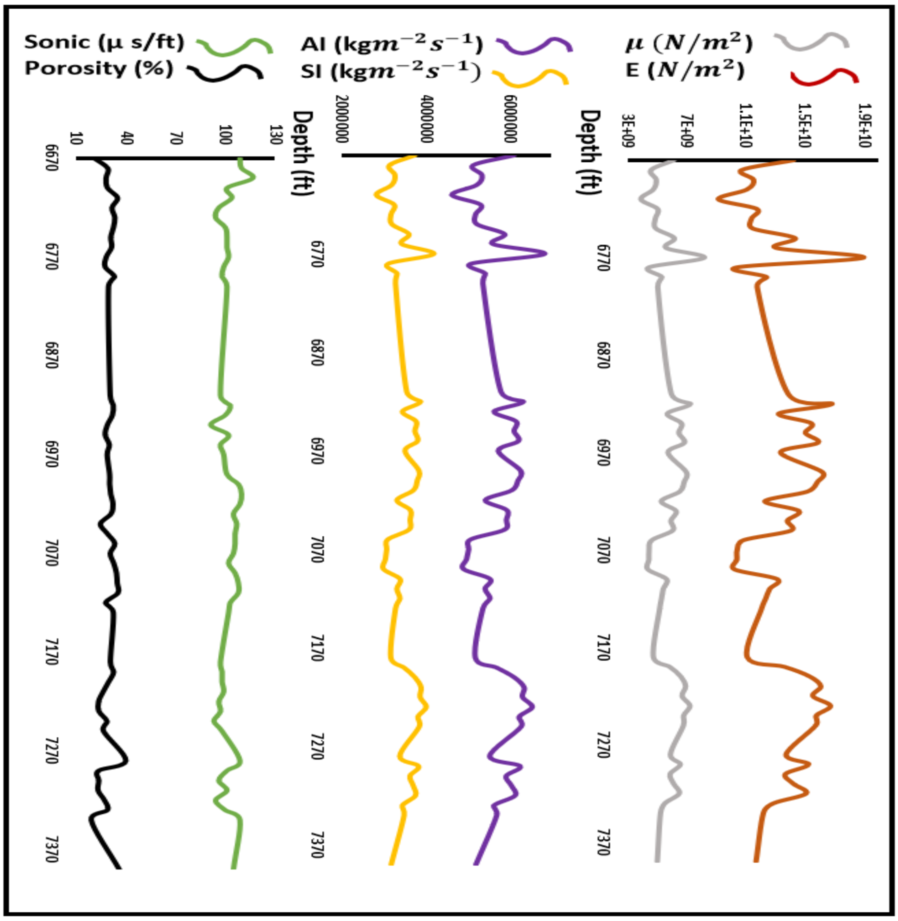

Figure 6: The curves of parameters of petrophysics (porosity in black, AI in purple, SI in yellow) and rock physics (young`s modulus in brown, shear modulus in ash) for Well X_2

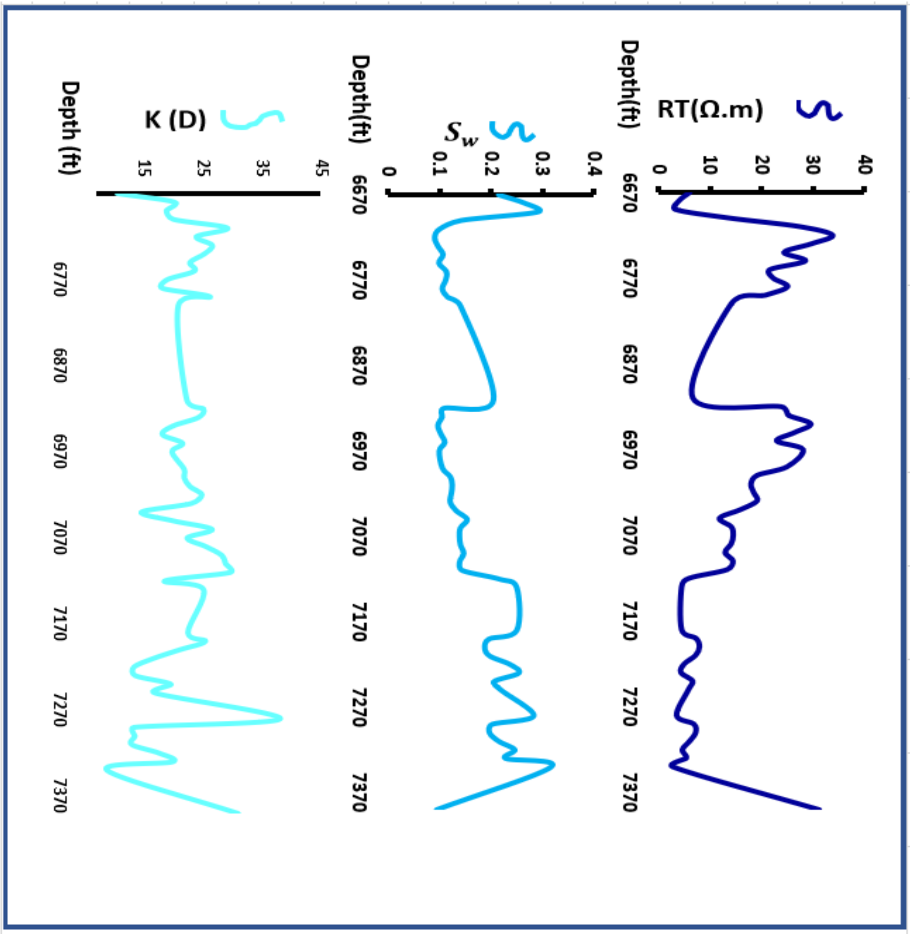

Figure 7: The curves of permeability (sky blue), water saturation (turquoise) and resistivity (dark blue) for Well X_2.

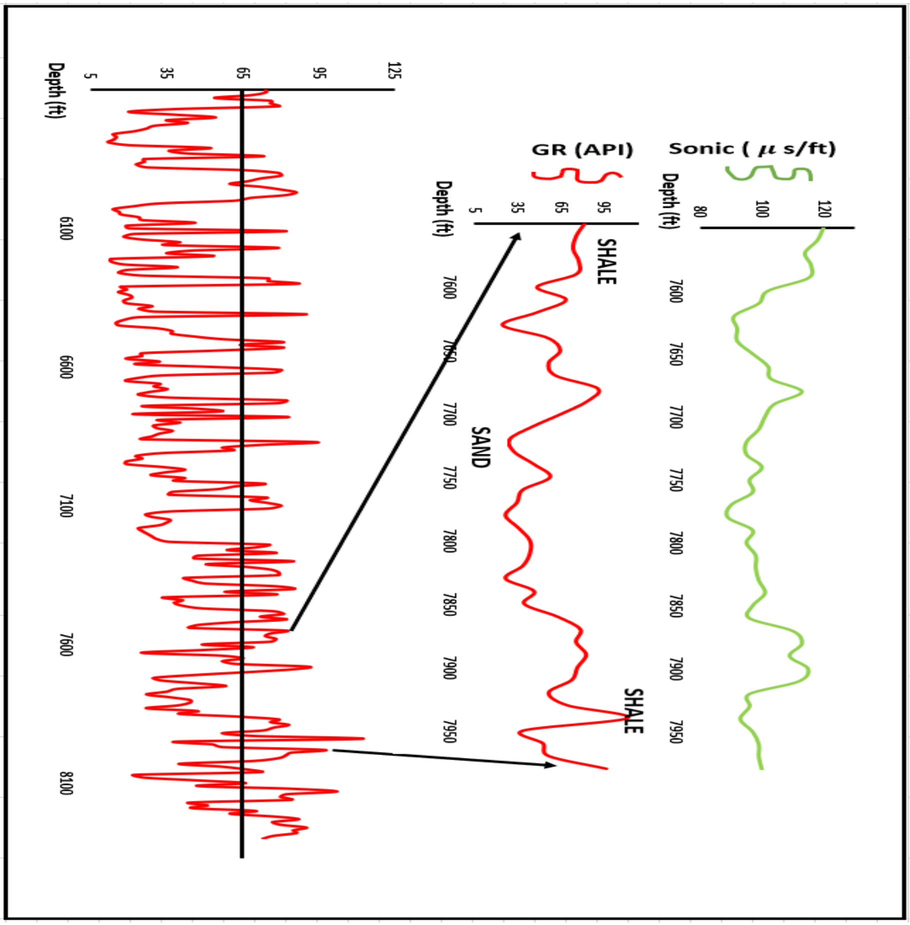

Figure 8: The generated suites of log with depth for gamma (red) and sonic (green) indicating sand and shale baseline for Well X_3.

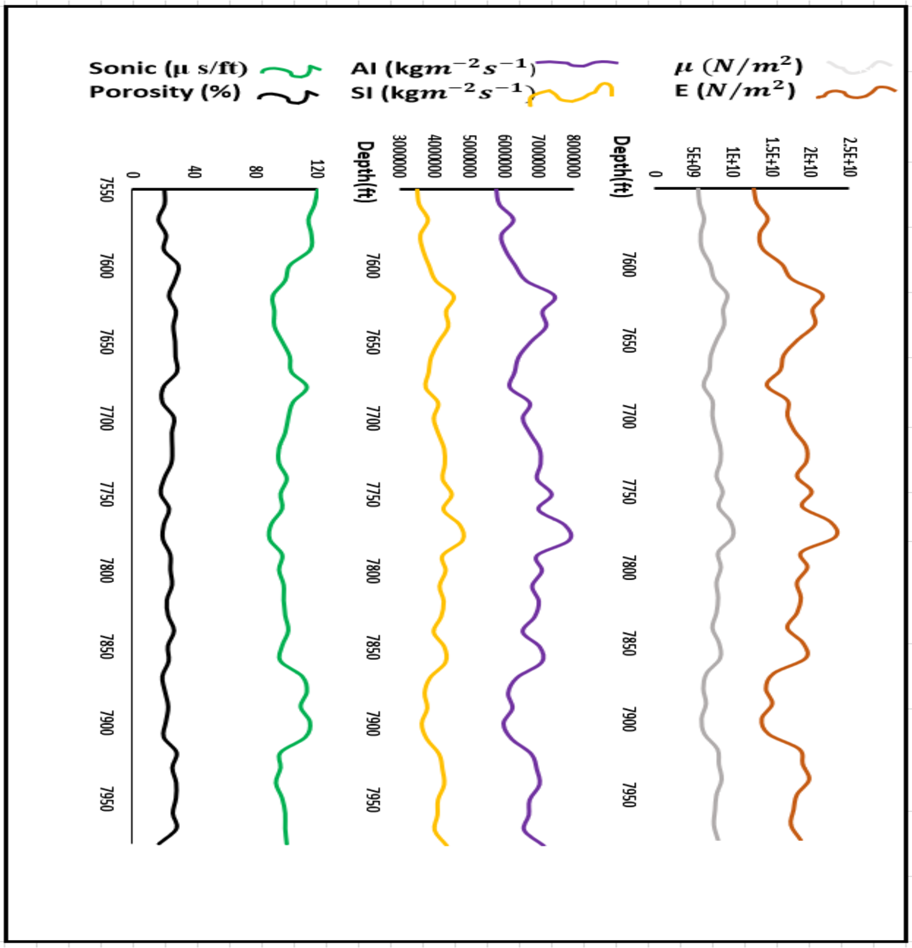

Figure 9: The curves of parameters of petrophysics (porosity in black, AI in purple, SI in yellow) and rock physics (young`s modulus in brown, shear modulus in ash) for Well X_3.

Table 3: The results of some petrophysics and rock physics properties from Well X_3

Depth (ft)	$D(\frac{g}{cm^3})$	IGR	V_{sh}	$V_p(\frac{m}{s})$	$V_s(\frac{m}{s})$	λ
7550	2.2786	0.655172	0.362468	2541.667	1553.245	3.73E+09
7560	2.2758	0.586207	0.290252	2584.746	1579.566	3.85E+09
7570	2.3477	0.563218	0.268882	2675.439	1634.979	4.25E+09
7580	2.2586	0.609195	0.312919	2629.31	1606.795	3.95E+09
7590	2.2834	0.586207	0.290252	2652.174	1620.764	4.07E+09
7600	2.1175	0.275862	0.085398	2990.196	1827.296	4.79E+09
7610	2.1566	0.505747	0.220658	3080.808	1882.66	5.18E+09
7620	2.2251	0.275862	0.085398	3351.648	2048.143	6.33E+09
7630	2.1447	0	0	3315.217	2025.884	5.97E+09
7640	2.1746	0.356322	0.123992	3315.217	2025.884	6.05E+09
7650	2.1547	0.45977	0.186883	3144.33	1921.472	5.39E+09
7660	2.1502	0.367816	0.130185	2990.196	1827.296	4.87E+09
7670	2.1331	0.425287	0.16404	2961.165	1809.558	4.73E+09
7680	2.2906	0.758621	0.497815	2699.115	1649.445	4.22E+09
7690	2.301	0.678161	0.389521	2932.692	1792.161	5.01E+09
7700	2.1684	0.471264	0.194957	3019.802	1845.385	5.01E+09
7710	2.1927	0.241379	0.071145	3080.808	1882.66	5.27E+09
7720	2.1878	0.057471	0.013181	3210.526	1961.918	5.71E+09
7740	2.281	0.252874	0.075756	3050	1863.836	5.37E+09
7750	2.3201	0.37931	0.136562	3177.083	1941.484	5.93E+09
7760	2.2247	0.16092	0.042404	3144.33	1921.472	5.57E+09
7770	2.2848	0.114943	0.028456	3388.889	2070.897	6.64E+09
7780	2.2958	0.022989	0.005041	3426.966	2094.163	6.83E+09
7790	2.2106	0.126437	0.03179	3144.33	1921.472	5.53E+09
7800	2.2089	0.218391	0.06232	3210.526	1961.918	5.76E+09
7820	2.2502	0.16092	0.042404	3112.245	1901.868	5.52E+09
7840	2.1674	0.252874	0.075756	3019.802	1845.385	5E+09
7850	2.238	0.172414	0.046156	3144.33	1921.472	5.6E+09
7860	2.2292	0.436782	0.171431	3177.083	1941.484	5.7E+09
7880	2.2717	0.586207	0.290252	2699.115	1649.445	4.19E+09
7890	2.2344	0.666667	0.375795	2798.165	1709.965	4.43E+09
7900	2.262	0.597701	0.301418	2652.174	1620.764	4.03E+09
7910	2.2857	0.551724	0.25866	2723.214	1664.17	4.29E+09
7920	2.1376	0.367816	0.130185	3177.083	1941.484	5.46E+09
7930	2.1865	0.517241	0.229743	3177.083	1941.484	5.59E+09
7940	2.1418	1	0.995671	3279.57	2004.103	5.83E+09
7950	2.1447	0.16092	0.042404	3144.33	1921.472	5.37E+09
7960	2.1812	0.321839	0.106472	3080.808	1882.66	5.24E+09
7970	2.1389	0.367816	0.130185	3080.808	1882.66	5.14E+09
7980	2.3419	0.827586	0.610191	3050	1863.836	5.51E+09

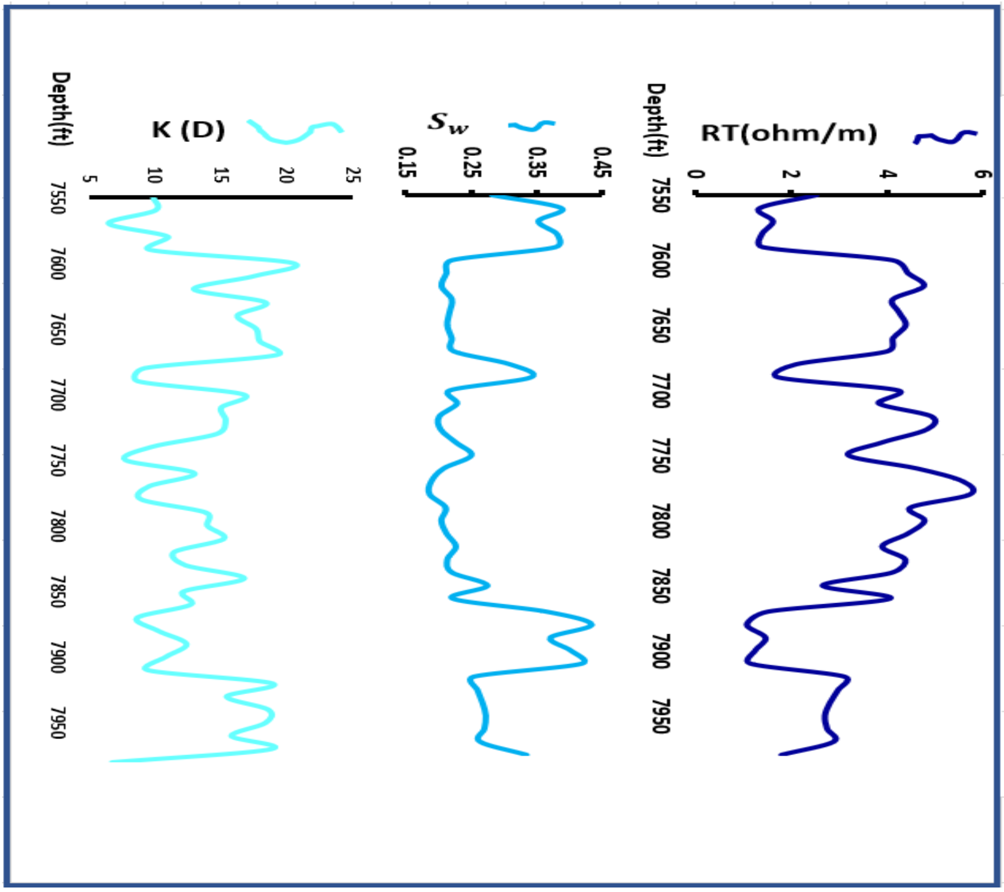

Figure 10: The curves of permeability (sky blue), water saturation (turquoise) and resistivity (dark blue) for Well X_3.

4.2 Discussion

Compressional wave velocity was obtained from the sonic information; shear wave velocity was calculated from Castagna Equation; Vp/Vs ratio has been computed from the ratio of the compressional wave velocity and shear wave velocity which leads to the determination of Poisson's ratio using Equation 12. Shear modulus was determined using Equation 11. This result yields Lame's constant (Equation 16 was adequate). Young's modulus depends on Poisson's ratio and shear modulus and was determined with Equation 13.

After the lithology identification, porosity result was computed using Equation 5. Index of gamma ray was obtained with Equation 1 after the deduction of minimum and maximum values of gamma ray have been noted for each well; permeability depends on the irreducible water saturation and was determined using Equation 6. Other parameters determined includes volume of shale using Equation 2, acoustic impedance (Equation 14 was adequate), shear impedance (Equation 15 was used) and water saturation using Equation 3.

Information on the detection and characterization of hydrocarbon reservoirs is vital to state how the presence of oil affect the elastic properties of rock, identifying potential drilling locations, characterizing the properties such as porosity, permeability, and fluid saturation for reservoir modeling and management; interpretation of well logs like sonic, density and resistivity logs to estimate rock properties and fluid content at various depths.

4.2.1 Well X_1

The thickness examined from sand/shale lithology ranges from 8020 ft. to 8760 ft. which is 740ft (226.672 m). The average of lame's constant, shear modulus and young's modulus are 5.0 x10^{13} N/m^2, 9.20 x 10^9 N/m^2 and 2.12 x 10^{10} N/m^2 respectively. The equivalent of the lowest value of this dynamic young's modulus of 1.15 x 10^{10} N/m^2 in terms of the static young's modulus value is 2.61 x 10^{24} N/m^2. From Britt and Schoeffler, static Young's Modulus greater than 3.5 x 10^6 psi (about 20.684 GPa) will be brittle (Britt and Schoeffler, 2009). Therefore, the lowest value of Young's modulus obtained for this well shows its ability to stand the test of time without deformation and could be developed for hydrocarbon exploration.

Other vital parameters determined, are also stated. The water saturation value computed is displayed in Figure 4 with the lowest and the highest as 0.07 and 0.46 which is 70% and 46% respectively. This finding defines the reservoir to have about 99.3% and 54% hydrocarbon saturation respectively. The average porosity obtained is 0.19 (19%). This reservoir is classified as having good pore spaces (Atat, et al., 2022). Permeability average is 10.36 mDarcy. This indicates that the pores within the reservoir is adequate though moderate for the migration and accumulation of hydrocarbon since this result is within the reasonable value for a petroleum reservoir rock

4.2.2 Well X_2

The thickness examined form sand/shale lithology ranges from 6670 ft to 7390 ft which is 720ft (220.992 m). The average values of lame's constant, shear modulus and young's modulus are 3.94 x10^9 N/m^2, 5.82 x 10^9 N/m^2 and 1.34 x 10^{10} N/m^2 respectively. The equivalent of the lowest value of this dynamic young's modulus of 9.14 x 10^9 N/m^2 in terms of the static young's modulus value is 1.41 x 10^{24} N/m^2. From Britt and Schoeffler, static young's modulus greater than 3.5 x 10^6 psi (about 20.684 GPa) will be brittle. Therefore, the value of the lowest value of young's modulus obtained for this well shows its ability to stand the test of time without deformation and it should be developed for hydrocarbon exploration.

Petrophysical parameters like water saturation are present in Figure 7 with the lowest and the highest as 0.09 and 0.32 which is 9% and 32% respectively. This defines the reservoir to have about 91% and 68% hydrocarbon saturation respectively. The average porosity obtained is 0.30 which is 30%. According to a study, this reservoir is classified as very good pore spaces. Permeability average is 21.54 darcy (Atat, et al., 2022). This indicates the permeability of the formation.

4.2.3 Well X_3

The thickness examined from sand/shale lithology ranges from 7550 ft to 7980 ft which is 430ft (131.072 m). The mean values of lame's constant, shear modulus and young's modulus are 5.18 x 10^9 N/m^2, 7.64 x 10^9 N/m^2 and 1.77 x 10^{10} N/m^2 respectively. The equivalent of the lowest value of this dynamic young's modulus of 1.27 x 10^{10} N/m^2 in terms of the static young's modulus value is 3.44 x 10^{24} N/m^2. From Britt and Schoeffler, static young's modulus above 3.5 x 10^6 psi (about 20.684 GPa) will be brittle (Britt and Schoeffler, 2009). Therefore, the value of the lowest value of young's modulus obtained for this well shows its ability to stand the test of time without deformation and it should be developed for hydrocarbon exploration. Figure 10 shows the water saturation results with the lowest and the highest as 0.19 (19%) and 0.43 (43%). This defines the reservoir to have about 81% and 57% hydrocarbon saturation respectively. The average porosity obtained is 0.24 which is 24%. This reservoir is classified as one with good pore spaces (Atat et al., 2022). Permeability average is 13.42 mD.The average values of the petrophysics analysis and the rock physics analysis of well X_1, X_2 and X_3 are shown in Table 5.

Table 5: A concise outcomes of shear modulus, lame`s constant, young`s modulus, water saturation, and permeability.

Parameters	Well X_1	Well X_2	Well X_3
μ (N/m^2)	9.20×10^9	5.82×10^9	7.64×10^9
λ (N/m^2)	5.0×10^{13}	3.94×10^9	5.18×10^9
E (N/m^2)	2.12×10^{10}	1.34×10^{10}	1.77×10^{10}
S_w (%)	30	16	27
Ø (%)	19	30	24
K (mD)	10.36	21.54	13.42

5. Conclusion

The petrophysical properties and other related rock parameters of Zeta Field have been determined for three wells in the Niger Delta Basin. The outcomes indicate that there is abundance of hydrocarbon in the study area. The reservoirs are highly porous and classified as good. The permeability together with porosity information have shown that the wells have the ability to accumulate and transmit fluids. The young`s modulus and findings revealed the brittleness of the reservoir materials, hence can stand a test of time [without collapsing].

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