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RESERVOIR CHARACTERIZATION USING WELL LOGS AND SEISMIC INVERSION: A CASE STUDY OF CANEA FIELD, ONSHORE NIGER DELTA BASIN

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Abstract
Effective reservoir management requires the identification of the reservoir and non-reservoir units so as to be able to enhance productivity and manage the reservoir properly. Identification of these reservoir and non-reservoir units (if any present) can be a great challenge with respect to the right techniques to adopt. The aim is to characterize reservoir using well logs and seismic inversion in order to identify reservoir and non-reservoir units so as to boost existing reserves. The objective involves the use of post-stack seismic data inversion in order to generate petrophysical volumes and well log data - gamma ray, resistivity, neutron and density logs to evaluate the acoustic impedance and petrophysical properties like porosity, water saturation and lithology. Range of values for CANEA_1 and CANEA_2 respectively in the three wells A, B and C were obtained for each start and end value from which the average petrophysical parameters were obtained. Well B was observed to have very high resistivity and low gamma ray value. Also recorded in Well B was very high hydrocarbon saturation (0.94(1-Sw) in CANEA_1 and 0.98(1-Sw) in CANEA_2) and low water saturation. Well C was seen to have not so favourable response of petrophysical properties having the highest water saturation (0.16(Sw) in CANEA_1 and 0.13(Sw) in CANEA_2). The reservoir units were identified, Shale serve as source rocks while the Sandstones in Wells A, B and C house the hydrocarbon reservoir rocks. The results obtained showed that well logs and seismic inversion can be used to identify reservoir and non-reservoir units so as to be able to increase productivity of these mature fields. However, a lot has been done as a result of the difficulty of determining reservoirs from well logs but the identification of reservoirs based on the conventional (oil and gas) and unconventional (shale) hydrocarbon is very important.
Keywords: *Petrophysical Properties, Seismic Inversion, Niger Delta Basin*

Introduction

Reservoirs are obtained using various petrophysical parameters like porosity, water saturation and lithology. Acoustic impedance gotten from seismic inversion can be used to identify the accumulation of hydrocarbons. The use of well data e.g. neutron, density, resistivity, gamma ray and seismic inversion are usually used for good prediction of reservoir. Measurement of certain petrophysical parameters is useful to aid in the management of reservoir. These parameters include lithology, porosity, permeability, fluid saturation, net pay, etc. The productivity of wells in reservoirs depend on these parameters. The acoustic impedance (AI) of a reservoir helps the model, the properties of rocks and fluids using well log data and seismic data. Coker *et. al*. (2021) carried out the Application of Well Log Analysis in Alpha Oilfield, Niger Delta, Nigeria. The determination of four wells was done identifying the gamma ray, sonic, caliper, density, resistivity, and neutron logs. The well logs were used to determine the porosity, permeability, shale volume, water saturation and hydrocarbon saturation. It was shown that the Alpha field reservoir contain hydrocarbons. The reservoir hydrocarbon bearing units were identified as the resistivity logs were determined.Ilevbare and Omorogieva, (2020) carried out Formation Evaluation in E-Field Onshore, Niger Delta, Nigeria using the wells petrophysical properties. The lithological and petrophysical properties of two wells were determined and water saturation of the reservoirs was detected. The reservoirs were detected as wet reservoir which is regarded as non-commercial and some as commercial reservoirs. The resistivity showed low water, medium oil and high gas. Since the E-Field is a gas field, it should be used as a power generator in Nigeria.Mustafa *et. al*. (2019) carried out Petrophysical Characterisation of Mishrif, Tuba oil Field, Southern Iraq. The shale volume, porosity and water saturation of reservoir quality were evaluated. The Density versus Neutron Cross Plot showed that most limestone lines and few dolomite lines were involved. The reservoir and non-reservoir units were identified. The reservoir units had good properties of gamma ray log which was lowand high porosity based on the sonic, density and neutron logs which indicated a good reservoir.Akaerue*et. al.* (2018) carried out Petrophysical Evaluation in Niger Delta, Nigeria of Etu Field Coastal Swamp I Depobelt. Seven well logs were evaluated and the reservoirs and sealing were formed. The reservoirs were moderate, good and excellent. The porosity and permeability were determined and the reservoir identified.Okpogo *et. al*. (2018) carried out Reservoir Characterization and Volumetric Estimation of Oroko Field, Niger Delta. Check shot data and 3D seismic from the field were used, porosity, water saturation and net to gross ratios were identified. Four gas bearing reservoirs with their effective porosities fluid saturation, seismic ties and volumetric estimates were identified. The gamma ray, resistivity, density and neutron logs were used to identify sandstone per reservoir. The reservoir parameters favor hydrocarbon accumulation in Oroko Field and the development of wells in the field for effective optimization is required.Ulasi*et. al*. (2018) carried out Petrophysical Evaluation Using Well Log and Core Data in Uzek Well, Offshore Depobelt, Niger Delta, Nigeria. Porosity, permeability, shale volume, fluid saturation and net pay thickness were determined in this work. The reservoir hydrocarbon-in-place was also determined based on porosity, water saturation and net-to-gross ratios. Neutrons, density, gamma ray, resistivity, and sonic logs were determined and reservoir was identified. Uzek reservoir was seen to have sandstone with low gamma ray, decreased neutron porosity and increased density porosity. The resistivity log was also determined and it was observed that the carbonate rocks are petroleum reservoirs while the shale are not good reservoirs. In Uzek well, different techniques apart from core laboratory was said to be used in hydrocarbon production for reservoir characterization. Imaseun*et. al*. (2011) carried out Reservoir Evaluation of Well A in Field Y, Niger Delta North-East. It is case of a Problematic Sandstone. Wire line logs and cores were used to evaluate the well and parameters obtained from the wire line logs and cores were compared. Two reservoirs were analysed economically and it was seen that there is sand-shale with good porosity and permeability.Specifically, in agreement with Nwankwo *et. al*, (2014) and Azuoko *et. al*, (2021), the high porosity observed within the intervals in the well locations are indicative of high permeability which is required of any productive hydrocarbon reservoir within the Niger Delta.

Geology of the Niger Delta

The Niger Delta basin is a very productive petroleum system. It is located in the Gulf of Guinea, Central West Africa at the culmination of the Benue Trough and considered one of the most prolific hydrocarbon provinces in the world [Corredor *et. al.* (2005)]. It covers about three hundred thousand square kilometers total area. The Niger Delta is divided into Akata, Agbada and Benin formations which are the three main units and they decrease in age basin wards, [Etim*et. al*. (2002), Chukwu *et. al.* (2021)]. In the Niger Delta, Akata formation is the main source rock for oil while the Agbada is the major petroleum bearing unit. Agbada formation overlies Akata formation while the Benin formation overlies the Agbada formation.The Akata formation was estimated to be seven thousand metres thick, Agbada formation is three thousand seven hundred metres thick and Benin Formation is about two thousand metres thick, [Chukwu *et. al.* (2021)].

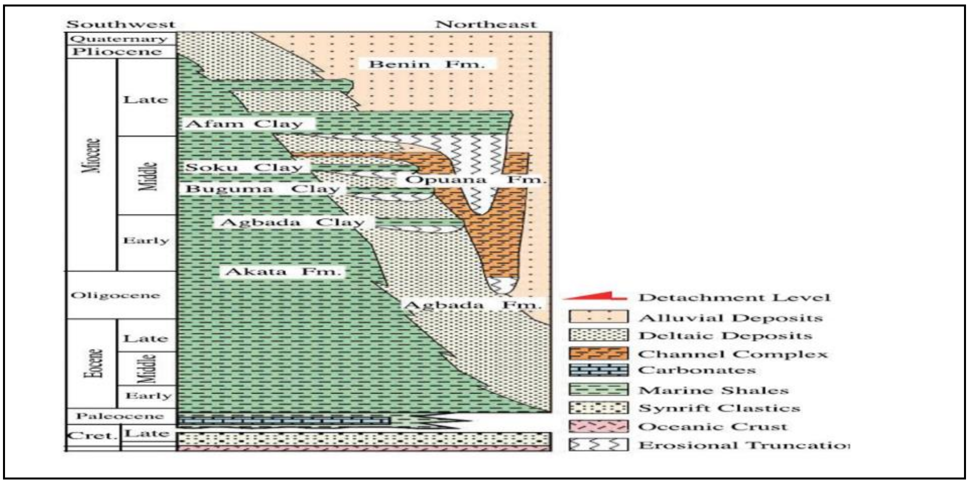

Figure 1.Niger Delta Regional stratigraphy (Lawrence *et. al*. 2002; Corredor*et. al*. 2005)

Figure 2. Geological map of the Niger Delta showing the study location[Lucas and Omodolar, (2018)].
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MATERIALS AND METHODS

Data analysis was carried out using the Hampson Russell software and Interactive Petrophysics (IP) software. The base map shows well A, B and C.

Well A,B and C

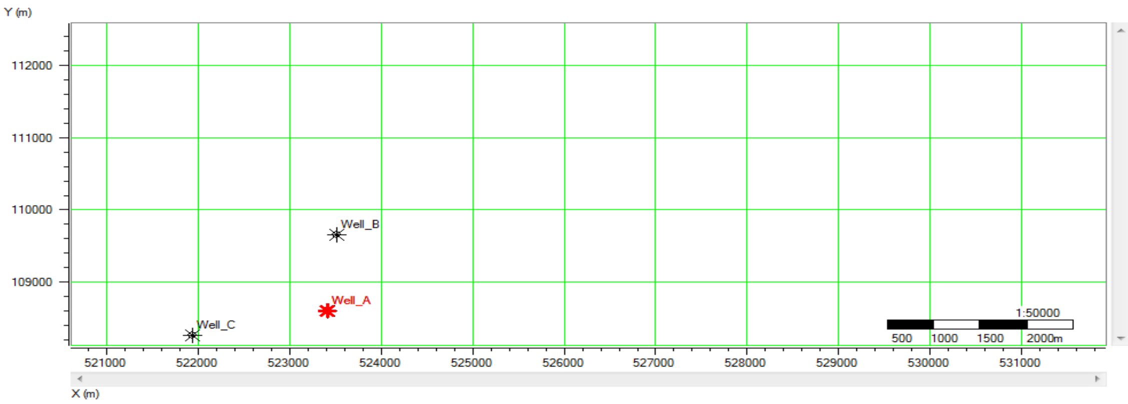

Figure 3.Base map showing Well A,B and C

Petrophysical parameters (e.g. Porosity, water saturation, Shale volumes, etc) were determined from well logs (gamma ray, resistivity, density and neutron logs) and compared with rock physical parameters derived from post stack seismic volumes in order to determine other prospects away from well control.

Estimation of shale volume

The Gamma ray log is used to determine the clay volume using the formula below:

IGR = (GRlog – GRmin) / (GRmax – GRmin) (1)

IGR = gamma ray index, GRlog = gamma ray of formation, GRmin = minimum gamma ray, GRmax = maximum gamma ray

Estimation of water saturation (S_w)

This is the fraction of a pore volume containing water.

$Sw = [(a/\phi^{m}) \times (Rw/Rt)]^{2}$ (2)

Tortousity factor = a, Cementation exponent = m, Resistivity formation water = R_w

True resistivity = R_t, Porosity = ϕ

Estimation of density (ℓ)

This measures the total porosity in the pore spaces of the formation.

$\ell = \ell_{ma} (1 - \phi) + \phi \, \ell_f$ (3)

Fluid density = ℓ_f

Matrix density = ℓ_{ma}

Log porosity = ϕ

Estimation of impedance = velocity * density (4)

It is the product of velocity and density.

Velocity = m/s, density = g/cc

Results

These results show the petrophysical parameters and the reservoir evaluation of the different wells used in this work. The wells used were Well A, B and C. Each of the well has two reservoir named CANEA_1 and CANEA_2 respectively. The data for the three Wells – Well A, B, and C are shown in the figures below.

Well A

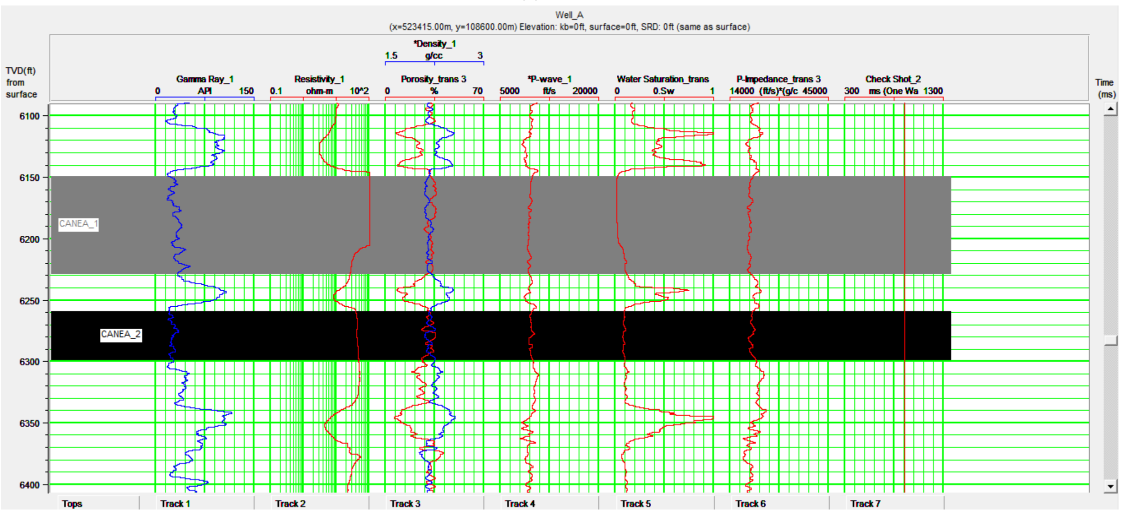

Figure 4.Well A showing CANEA_1 and CANEA_2

Well B

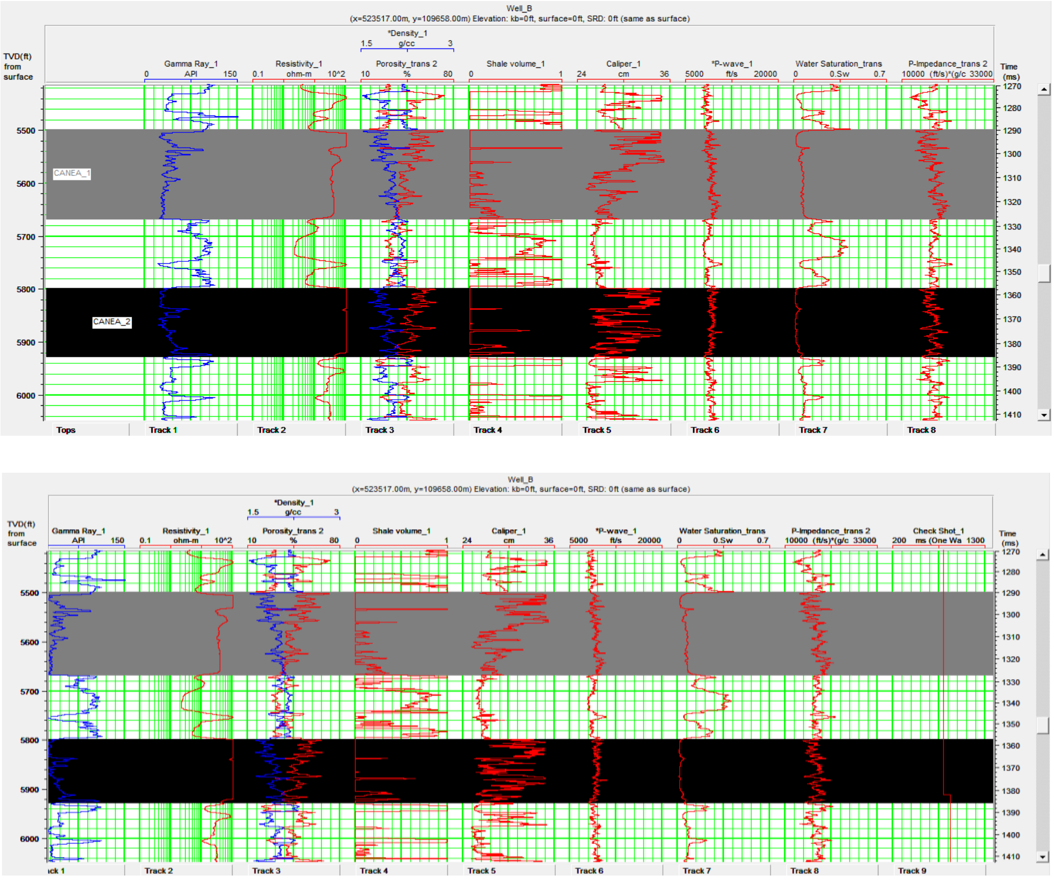

Figure 5. Well B showing CANEA_1 and CANEA_2

Well C

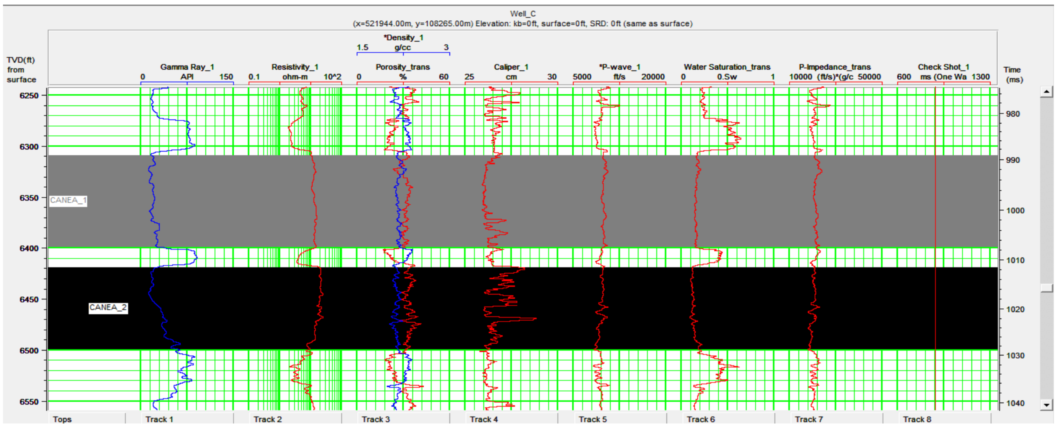

Figure 6.Well C showing CANEA_1 and CANEA_2

The average petrophysical properties for the three wells A, B and C with CANEA_1 and CANEA_2 respectively are shown in Table 1.

Table 1.Average Petrophysical parameters

WELL	Reservoir	Depth Range (ft)	Gamma Ray (API)	Resistivity (Ohm.m)	Density (g/cc)	Porosity (%)	Water Saturation (S_w)	Hydrocarbon Saturation ($1-S_w$)
A	CANEA_1	6150 – 6230	30.49	1017.36	2.14	32.61	0.05	0.95
A	CANEA_2	6260 – 6300	24.70	42. 83	2.17	31.00	0.10	0.90
B	CANEA_1	5500 – 5670	39.04	72.59	1.95	45.23	0.06	0.94
B	CANEA_2	5800 – 5930	38.76	452.99	1.90	48.21	0.02	0.98
C	CANEA_1	6310 – 6400	19.64	12.67	2.17	30.82	0.16	0.84
C	CANEA_2	6420 – 6500	29.22	17.02	2.13	33.37	0.13	0.87

From the displayed results, in Well A and B, it was shown that the hydrocarbon saturation was very high with low water saturation while Well C has a lower hydrocarbon saturation and higher water saturation. The three wells all have gamma ray response indicative of sandstone, though Well B indicated higher gamma ray than Well A and C. In Well A and B, CANEA_1 and CANEA_2 respectively have higher resistivity values than Well C. The porosity of Well B was seen to be high with lower density than that of Well A and C. In Well A, CANEA_1 consists of hydrocarbon and brine in some sections, while CANEA_2 is completely brine dominated. In Well B, CANEA_1 comprises of Gas, Oil and brine, while CANEA_2 is comprises only of Gas. In Well C, CANEA_1 is comprises of brine and hydrocarbon, while CANEA_2 comprises of Gas. These observations are seen in the log panels, capturing the over lay of porosity and density

.

Generation of Petrophysical Attribute Slices

Using amplitude plotting, petrophysical attribute slices were generated. Attribute slices from selected horizons corresponding to the top of either CANEA_1 (horizon 1) or top of CANEA_2 (horizon 2) are shown in Figures 7 to 12.

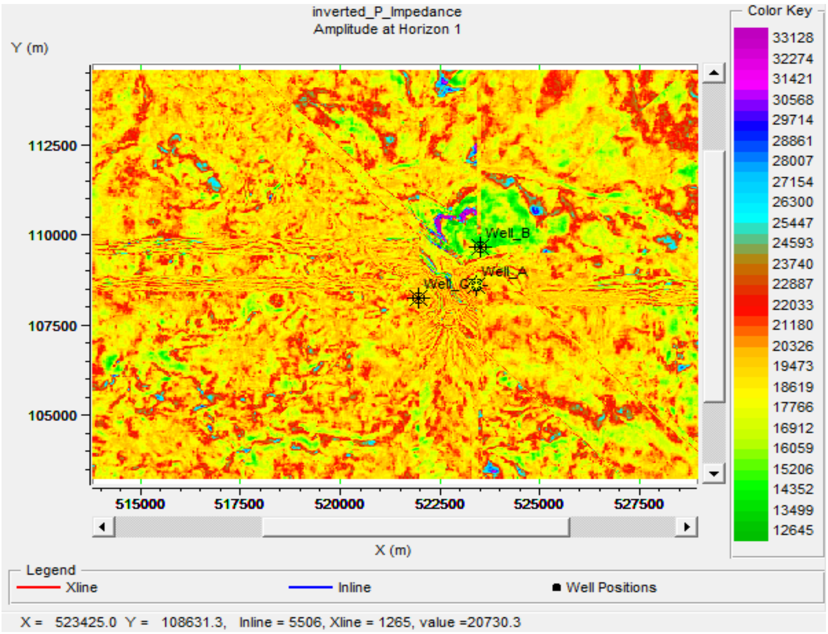

Figure 7.P-Impedance slice at CANEA_1

In Figures 7 and 8, low to intermediate values and intermediate to high values of acoustic impedance are respectively identified at the well locations. Higher values of acoustic impedance are observed in well A, with Well C having the highest Zp value in both CANEA_1 (Figure 7) and CANEA_2 (Figure 8). These higher acoustic impedance values are also observed around the CANEA field.

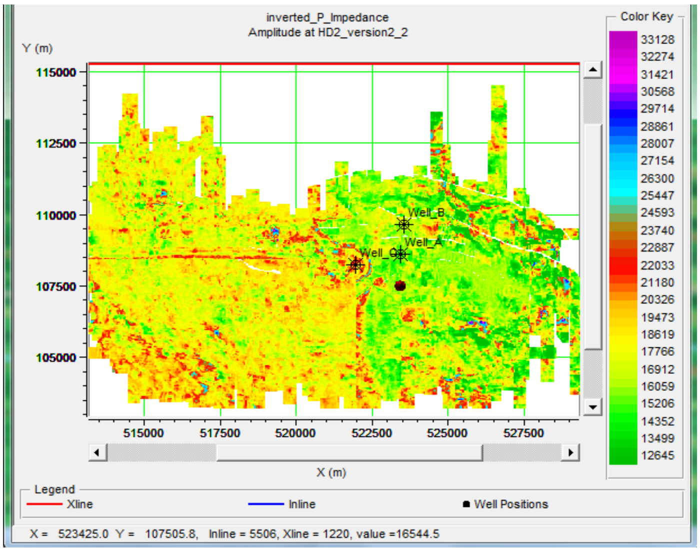

Figure 8.P-Impedance slice at CANEA_2

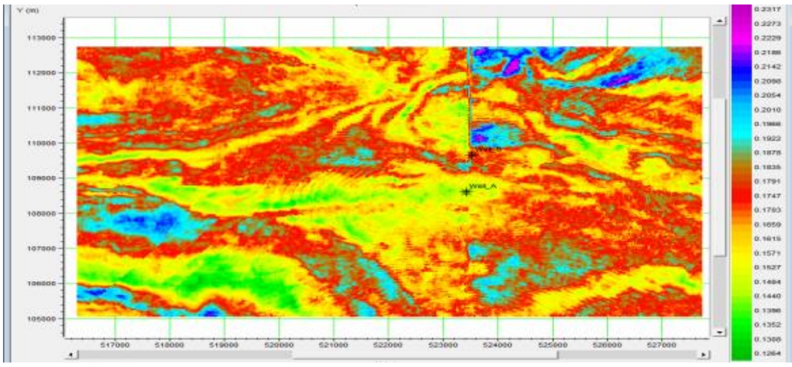

Figure 9.Water saturation slice at CANEA_1

Very low (green coloration), through intermediate (red coloration) water saturation value to low (yellow coloration) dominates the Well A location. Well B location experiences an interplay of low to very high water saturation values.

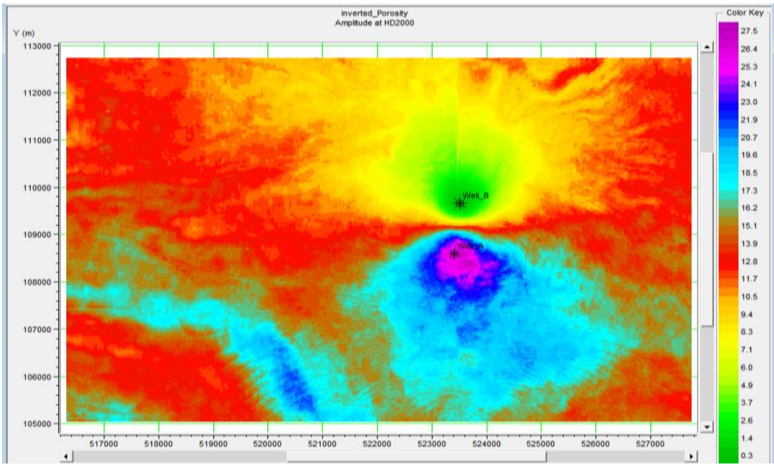

Figure 10.Porosity slice at CANEA_1

Porosity values at well A location decreases from very high (purple coloration) through high (dark blue coloration) and to moderately high (sky blue coloration) values. The point of contact of the very high and high porosity regions is verifiably indicative of the Gas-Oil-Contact, while the contact between the high and moderately high porosity values is probably the Oil-Water-Contact (OWC). At well B location, the Porosity of surrounding formations increase from very low (green coloration), through intermediate porosity (orange to red coloration) to low (yellow coloration).

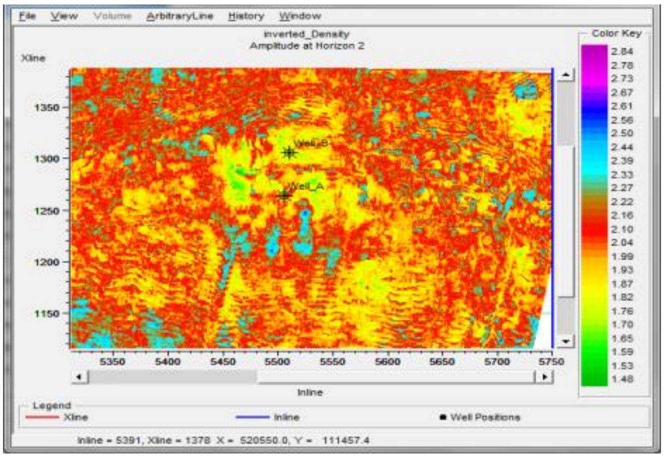

Figure 11.Density slice at CANEA_1

Picked at constant times corresponding to the tops of CANEA_1 and CANEA_2 respectively, the inverted density responses in Figures 11 and 12 reveal very low to intermediate values of density. These observations in the well locations correspond with the average values of density in Table 1.

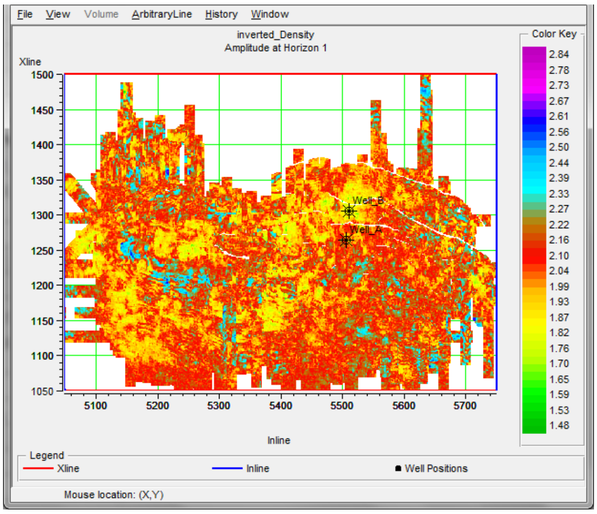

Figure 12.Density slice at CANEA_2

Discussion

Within Wells A, B and C, known reservoirs CANEA_1 and CANEA_2 were delineated in sandstone dominated intervals. Shaly intercalations were also found in the reservoirs at some intervals. Well B has a very high resistivity response and low gamma ray value in the intervals of interest. Also recorded in Well B is very high hydrocarbon saturation (0.94(1-Sw) in CANEA_1 and 0.98(1-Sw) in CANEA_2) and low Water Saturation. Well C was seen to have the lowest yield in the intervals of interest based on the observations of the logs and the subsequent interpretation of generated 3D seismic attribute slices, having the highest water saturation (0.16(Sw) in CANEA_1 and 0.13(Sw) in CANEA_2). Shale serve as source rocks while the Sandstones in Wells A, B and C house the hydrocarbon reserves. Shale-based seals keep the hydrocarbons in place preventing the hydrocarbons from escaping uncontrollably.

Specifically, in agreement with Nwankwo *et. al.* (2014) and Azuoko *et. al.* (2021), the high porosity observed within the intervals in the well locations are indicative of high permeability which is required of any productive hydrocarbon reservoir within the Niger Delta.

Ilevbare and Omorogieva, (2020) carried out Formation Evaluation in E-Field Onshore, Niger Delta, Nigeria using the wells petrophysical properties. The lithological and petrophysical properties of two wells were determined and water saturation of the reservoirs was detected. The reservoirs were detected as wet reservoir which is regarded as non-commercial and some as commercial reservoirs. The resistivity showed low water, medium oil and high gas. Since the E-Field is a gas field, it should be used as a power generator in Nigeria.

Coker *et. al.* (2021) carried out the Application of Well Log Analysis in Alpha Oilfield, Niger Delta, Nigeria. The determination of four wells was done identifying the gamma ray, sonic, caliper, density, resistivity, and neutron logs. The well logs were used to determine the porosity, permeability, shale volume, water saturation and hydrocarbon saturation. It was shown that the Alpha field reservoir contain hydrocarbons. The reservoir hydrocarbon bearing units were identified as the resistivity logs were determined.

The reservoir delineation approach utilized in this work revealed pockets of prolific reservoirs, having high hydrocarbon saturation (Sh), as high as 0.98 (98%) in the reservoir CANEA_2 across Well B. Log responses within the selected intervals CANEA_1 and CANEA_2, having gamma ray values below the mid-line and tending more towards the sand line, corresponded to standard responses for hydrocarbon bearing reservoirs with focus on porosity, resistivity, water saturation and density.

So far, we have considered Reservoir Characterization Using Well Logs and Seismic Inversion: A Case Study of Canea Field, Onshore Niger Delta Basin. An introduction detailed the need to re-characterize previously producing reservoirs, as resources continue to dwindle, and as cost of production continues to increase.

The study background described the concept of reservoir characterization, which of course had to be understood before we talk about re-characterization. The application of well log data and seismic data in reservoir characterization was also explained, with references made to works carried out in the study area. The geology of the study area – the Niger Delta was also discussed, capturing the – the Akata, Agbada and Benin stratigraphic successions.

The aim and objectives were next presented, with the aim centering on the title of the work, with technical objectives commencing from using gamma ray, resistivity, density and neutron logs to obtain relevant petrophysical parameters that will serve as inputs for building seismic models. The scope, significance of study and limitations in the study were also highlighted.

The particular study Reservoir Characterization Using Well Logs and Seismic Inversion: A Case Study of Canea Field, Onshore Niger Delta Basin. From this we can detect reservoir and non-reservoir units. However, a lot has been done as a result of the difficulty of determining reservoirs from well logs but the identification of reservoirs based on the conventional (oil and gas) and unconventional (shale) hydrocarbon is very important.

Theoretical background detailed aspects of the elements of a hydrocarbon prospect, 3-D seismic data and the processes they undergo before data analysis and interpretation. The data set comprising of well logs and 3-D seismic data were utilized in a methodology starting from well data conditioning, log-based formation evaluation, well log analysis, well to seismic tie, acoustic impedance inversion, generation of petrophysical attribute slices further helped in the characterization of the reservoir.

Conclusion
The results obtained shows that well logs and seismic inversion can be used to identify reservoir and non-reservoir units so as to be able to increase productivity of these mature fields. The Seismic Inversion technique and well logs like Gamma Ray, Resistivity, Neutron and Density logs can always be used to evaluate the acoustic impedance and petrophysical properties like porosity, water saturation and lithology in the reservoir. Identification of these units will help to characterize a maturing field in order to boost existing reserves and maximize production.

Recommendation
From the literature reviews, we can detect reservoir and non-reservoir units. However, a lot has been done as a result of the difficulty of determining reservoirs from well logs but the identification of reservoirs based on the conventional (oil and gas) and unconventional (shale) hydrocarbon is very important. The use of Artificial intelligence if adequately adopted, will greatly improve reservoir characterization and ultimately enhance the recovery of hydrocarbon from reserves across the inland basins in Nigeria.

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