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Petrophysical Evaluation and Seismic Interpretation of Geowil Hydrocarbon Bearing Reservoir in the Niger Delta Region of Nigeria

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ABSTRACT: The objective of this research was to carry out a petrophysical evaluation and seismic interpretation of Geowil hydrocarbon bearing field in the Niger Delta Region of Nigeria using standard techniques. Three hydrocarbon bearing sands were identified namely reservoir R-1000, R-2000 and R-3000 from the well log data. The result showed that both reservoir R-1000 and R-2000 reveal high resistivity values and low water saturation while reservoir R-3000 indicates that the hydrocarbon contained is oil and gas. Both reservoir R-1000 and R-2000 are observed to be thinning out across the field, reservoir R-3000 is seen to be slightly undulating across the field. The petrophysical computation obtained for the three reservoirs (R-1000, R-2000 and R-3000) revealed that they all have very good average porosity anomalies of 27%, 27% and 25% respectively as well as moderate permeability values (159.974Md, 126.9Md, and 162.02 Md respectively) rating. The hydrocarbon saturation index obtained for all the three reservoir (55%, 54% and 50%) showed that they are all good indicator of prolific hydrocarbon accumulation. The result of the volume of hydrocarbon originally in place and the volume that can be recovered estimated revealed that R-1000 has STOIIP of 262.47MMSTB, R-2000 has 2.66MMSTB and R-3000 has 42.67MMSTB. The ultimate recovery for the three reservoirs is 19.31MMSTB, 1.19MMSTB, and 19.2MMSTB respectively. This implies that the reservoir has great potential for oil resources in considerable size.

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Three generations of reservoir characterization have taken place, starting with petrophysics and moving on to geologic analogs and, more recently, multidisciplinary integration (Fajana *et al.,* 2019). Reservoir characteristics were ascertained using logs, cores, and well testing in the 1950s as part of the petrophysical method. The notion between wells was included in the second generation, which was based mainly on geologic analogs. Interwell prediction was enhanced by the analog technique, although choosing the appropriate analog was frequently challenging, particularly in situations with complicated structural and stratigraphic patterns. The third generation of the multidisciplinary approach seeks to combine all currently available geology, engineering, and geophysical data with contemporary probabilistic and risk analysis methods to create a more accurate reservoir model (Osuagwu *et al.,* 2009; Futalan *et al.,*

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2012). The definition of field development programs for this third generation reservoir makes extensive use of 3D seismic amplitude anomalies and other intricate trace characteristics. This research project used an interdisciplinary approach. The physical and chemical characteristics of rock and how they interact with fluids are the focus of the field of petrophysics (Tiab and Donaldson, 2004). Lithology, porosity, net-to-gross thickness, water saturation, permeability, and shale volume content are a few of these characteristics. These are so important that they are used as reservoir characterisation input data. In the Niger Delta region, the Agbada Formation is home to the subsurface accumulations of hydrocarbons. Schlumberger (1991) demonstrated a number of techniques for evaluating the formation of hydrocarbon reserves in Nigeria, the majority of which are based on wireline formation tests and logs combined with core samples. Studies on the development of the clay distribution trend have been used to shed light on reservoir behavior. Studying the log responses of various clay distribution patterns in reservoirs reveals that detrital clays like structural and laminated clays produce similar log responses on thick shale layers, leading to the development of a shally-sand equation that calls for the use of shale-resistivity values. The main petroleum traps in the Niger Delta, according to Chukwu (1991), are the growth fault and rollover anticline. He said that they had extensional growth faults that had formed on the present shelf and slope and that they were the result of compressional uplift that occurred quite near to the slope. Using data from well records, Mode and Anyiam (2007) described the "Paradise Field" reservoirs. They asserted that the offshore depobelt provides superior prospects for the Paradise field due to favorable structural and stratigraphic traps in the basin ward (Niger Delta). They came to the conclusion that the reservoirs for the identified hydrocarbons are sandstones in the Agbada Formation, while the Akata Formation's turbidite sands may contain undiscovered petroleum below currently producing intervals in the distal parts of the delta system. Ehinlaiye et al, 2022 conducted a similar research on Ataga field, onshore Niger Delta with the intent of deciphering the reservoir quality with the combined use of well log and seismic data. The result revealed that the reservoir is highly faulted (largely antitetic faults) with a very good porosity and permeability in nature which very hydrocarbon promising. In the same vein, Osisanya et al., 2021 carried out a detailed study on the reservoir petrophysical features and structural evaluation to delineate the oil bearing zone in “Oswil” field. It was inferred that the two reservoir unit evaluated in the study area are indicative of highly prospective reservoir zones. Hence, the objective of this work is to conduct a petrophysical evaluation and seismic interpretation of Geowil hydrocarbon bearing field in the Niger Delta Region of Nigeria.

MATERIALS AND METHODS

Location and Geological framework: The Niger Delta Basin is situated at the southern end of Nigeria boarding the Atlantic Ocean and extends from about Longitude 300 00′E to 90 00′E and Latitude 40 3′ N to 50 20′ N (Lambert, 1981).

Study Area: The study area is the Geowil field. It is mainly an offshore field within Niger Delta. The field has five wells namely GEOWIL 1, GEOWIL 2, GEOWIL 3, GEOWIL 4 and GEOWIL 5 whose distribution orientation are aligned for geological inference. (Fig. 1). The research region is located throughout the Niger Delta and the Gulf of Guinea on the west coast of Central Africa (Fig. 1). (Stacher 1995). The Tertiary Period is at the mouth of the Niger Delta, the Atlantic Ocean is built up. A watershed area that is a part of the Niger Benue river system encompasses more than one million square kilometers of primarily plains with savannah grasses. About 75,000 km2 and more than 300 km are covered by the sub-aerial portion of the delta. From height to climax. The Niger Delta's tertiary sequence consists of three major stratigraphic units (Fig. 2). Formations of the Akata, Agbada, and Benin are listed in ascending sedimentation order. The totally marine Akata Formation (Marine Shale) deposit is distinguished by homogeneous shale growth with lenses of siltstone and sandstone. Generally under pressure (i.e., under-compacted). Each formation's borders are not usually clearly defined, but progressive transition is typical. This formation has a maximum thickness of over 6100 m in the delta's center and is thought to have been deposited in front of the advancing delta. Thermally matured Akata shale is regarded as the primary source rock for the production of hydrocarbons. The Akata Formation is found above the Agbada Formation, which is found below the Benin Formation. The Agbada Formation is a paralic sequence made up of alternating sands (sandstones) and shale that was produced as a result of local transgression and regression, differential subsidence, fluctuating sediment supply, and shifts in delta depositional axes. The designation of the top and bottom of the Agbada Formation raises significant issues. The base is frequently located at the start of strong over-pressures during drilling, but the top is typically described by local geologists as the base of freshwater incursion. The majority of the hydrocarbon reserves are found in this sequence, which is linked to sedimentary growth faulting (Fig. 3). The Agbada Formation is composed of the following four individuals: 1. D-1: This is primarily maritime sand and shale that is regressive and has a small amount of oil and gas reservoirs. 2. Qua-Iboe: In some areas, this area may have oil and gas reservoirs because of the thick shale piles with thin intercalated sands. 3. Truncated beds of rubble are located just beneath the Qua-Iboe. 4. Member of Biafra: It is primarily made of sand and shale and contains the main oil and gas resource. There are three sections: upper, middle, and bottom.

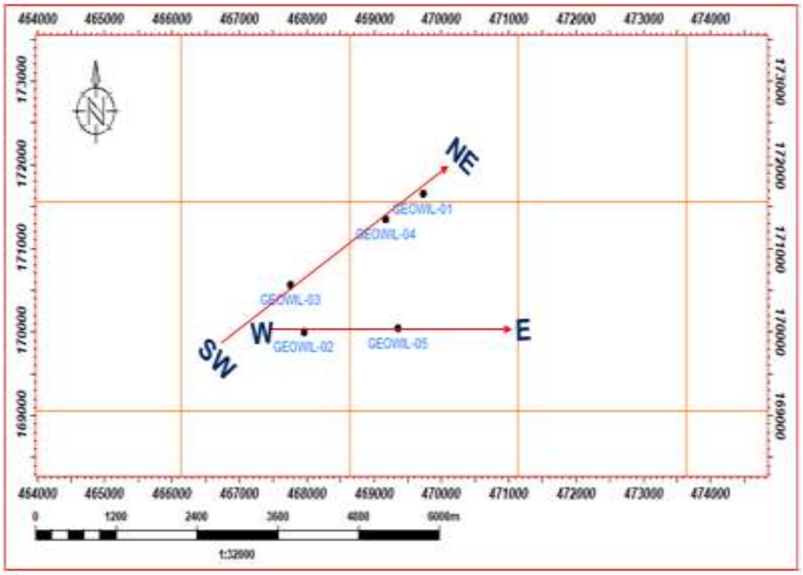

Fig 1: Basemap of the study area

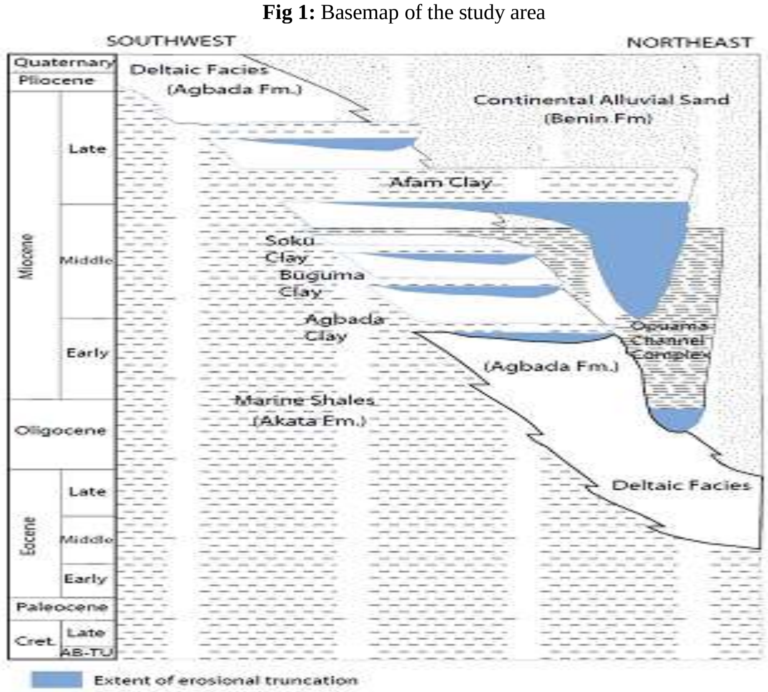

Fig. 2 Stratigraphic column displaying the three Niger Delta formations Shannon, Naylor, Doust, and Omatsola (1990).

The Niger Delta's topmost and shallowest stratigraphic unit is this one. It is made up of irregularly sorted, medium to fine-grained, fresh water-bearing sands and conglomerates, together with a sparse amount of sparsely distributed intercalations of shale. This formation has a thickness of around 2100 m, holds non-commercial amounts of hydrocarbon, and has a sand content of more than 80%. This formation is oligocene in age (Short and Stauble 1967). The "Geowil" field is located southwest of the Niger Delta offshore and is faulted intricately. The field has a good representation of the uppermost Benin Sands, middle parallic Agbada Formation, and marine Akata Formation shales. Only normal faults, which signify an extensional deformational phase during subsidence and uplift associated with instability of the overpressured shale in the Late Cretaceous, characterize the field.

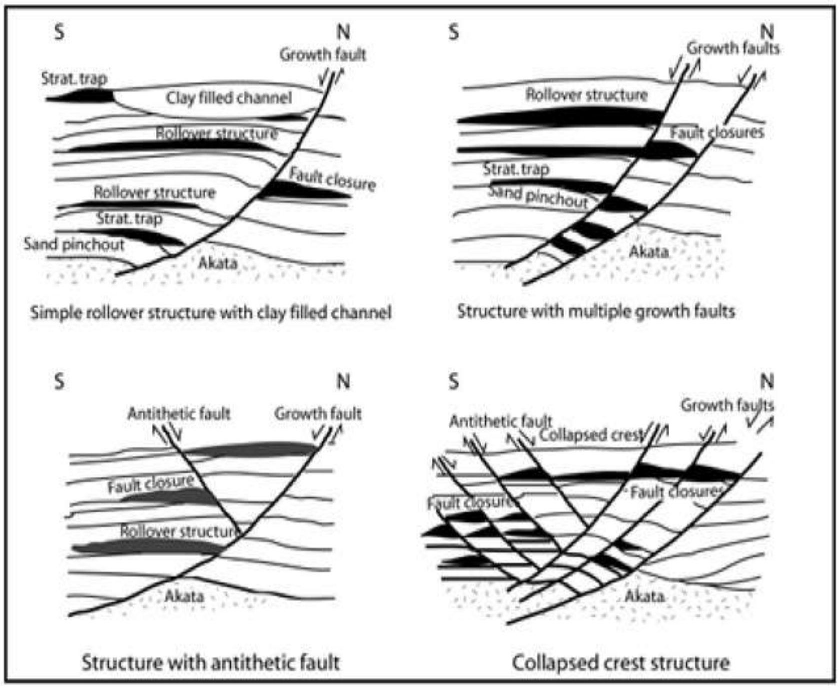

Fig. 3 The Niger Delta's main types of oilfield structures, together with schematic representations of typical trapping arrangements (after Tuttle et al. 1999)

Methodology: The data set used for the study (table 1) are set of well data namely well heads, well deviation, well logs and checkshot data with 3D seismic data using interactive petrel software and Microsoft office. The signatures from the gamma ray log indicate the type of lithology.

Lithology identification is done using the gamma ray log. Thus, the sand units were identified following deflection of the gamma ray signature to the left whereas its deflection to the right indicates shale lithology. The range of the gamma ray log was set at 1 – 150API and cut-off set at 75API.

The lithologic units identified from the well logs using gamma ray and deep resistivity logs are sand and shale units. Sand (curved filled with yellow colour) is a potential reservoir rock while shale (curve filled with grey colour) is a potential cap or seal rock (Fig. 4). The available checkshot data alongside with the suitable logs were used in the production of time structural map which was later converted to depth structural map to show the equivalent depth and the real position of the geological structure within the subsurface. (Fig. 10 and 11).

Petrophysical analysis: Petrophysical computations were carried out for the five wells that penetrated the three reservoirs in the area of study. From the wireline logs, the petrophysical empirical formulae were used to determine Net-to Gross (NTG), volume of shale (V_{sh}), porosity (Φ), Effective porosity, permeability (K), water saturation (S_w), bulk volume water and residual oil saturation were estimated. The estimated parameters were plotted cross-wise (Table 3, 4, 5 and 6).

Table 1: Available well log data

Available logs	GEOWIL 01	GEOWIL 02	GEOWIL 03	GEOWIL 04	GEOWIL 05
Caliper					
Gamma ray					
Spontaneous potential					
Deep resistivity					
Density					
Neutron					
Sonic (compressional)					

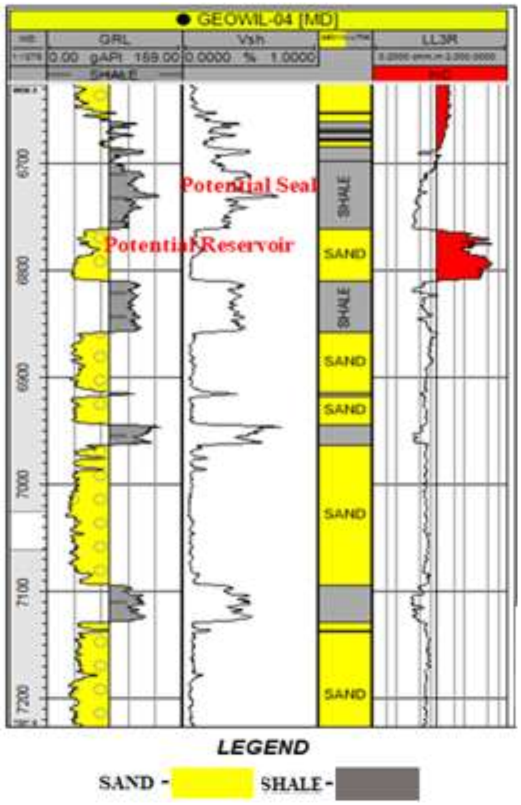

Fig 4: Lithologic interpretation of Geowil 01 well.

Net to Gross, NTG: Net-to gross was calculated as a percentage using the expression (Sanuade et al. 2018; Ibe and Oyewole 2018):

$$NTG = \left(\frac{h}{H}\right) * 100\% \qquad (1)$$

Where; NTG= Net to Gross, h = Net reservoir thickness and H= Gross reservoir thickness.

Porosity: Porosity is described as the percentage of pore spaces to total bulk volume of the rock. Porosity is taken as the measure of the void space relative to the entire reservoir volume and shows the storage strength of the given reservoir to pore fluids (Osisanya *et al.*, 2021)

$$\emptyset = (\sqrt{\emptyset^2 Density + \emptyset^2 Neutron}))/2 \qquad (2)$$

Where $\phi_{Neutron}$ is neutron porosity and $\phi_{density}$ is density porosity

Effective porosity: When the pore spaces are relatively connected then it is described as an effective porosity which accounts for the free flowing fluid.

$$\Phi eff) = (1 - Vsh) * \Phi Total \qquad (3)$$

Where; Φ_{eff} = effective porosity V_{sh} = volume of shale Φ_{Total} = total porosity

Permeability (K): Permeability is simply the degree or a measure of the ease of flow through a medium via its interconnected pores, capillaries or fractures. In order to determine the permeability of the given formation, several factors must be known. The Tixier model, 1949 is given as:

$$K = \sqrt{(250 * \emptyset eff^3)//Swirr} \qquad (4)$$

Where; K = permeability, Φ_{eff}^3 = effective porosity, S_{wirr} = irreducible water saturation

Volume of shale, V_{sh}: Volume of Shale (V_{sh}) was derived from the three reservior R-1000, R-2000 and R-3000 within the five wells using Larionov tertiary rock method (Larionov 1969; Sanuade et al. 2018) given as:

$$V_{sh} = 0.083(2^{3.7*IGR} - 1 \qquad (5)$$

Formation factor (F) estimation: This essentially expresses the relationship between a formation's resistivity and the resistivity of the water it is saturated with. The formation factor F in borehole geophysics is given by equation

$$F = \frac{a}{m} \qquad (6)$$

Where a = Tortuosity factor, m Cementation factor, Ø Porosity; where *a* = 1 and *m* = 1.8.

Water saturation estimation (Sw): The Archie (1942) formula was used to determine the water saturation in each reservoir formation. The following equation 5 yields it:

$$S_w = \left(F \times\times \frac{R_W}{R_t}\right) \qquad (7)$$

Where F= Formation factor, Rw=Formation water resistivity at formation temperature, Rt=True formation resistivity.

$$Sh = (1 - Sw) \qquad (8)$$

Where Sh =hydrocarbon saturation

$$Swirr = (F/2000)\,\square(1/2) \qquad (9)$$

S_{wirr} = irreducible water saturation

Bulk volume of water (BVW): The bulk volume of water (BVW) in a reservoir is simply the product of the water saturation (S_w) times the porosity (ϕ)

$$BVW = S_w * \emptyset \quad (10)$$

As used by Ibe and Oyewole (2018)

Volumetric Estimation: A map-based volumetric calculation approach was used to estimate the volume of hydrocarbon in place and the ultimate recovery within the three delineated reservoirs. The contacts identified were useful in the calculation of areas. Gross thickness, net-to-gross, porosity, and water saturation were used in the estimation. Original Oil and gas initially in place and ultimate recovery of the volumes was estimated. A recovery factor of 0.45 was used for the calculation. The computation was done using the equation below:

$$STOIIP = \frac{A*h*NTG*\Phi eff*(1-SW)}{BO} \quad (11)$$

$$UR = STOIIP * R_f \quad (12)$$

Where, A is the area, h is gross thickness, NTG is Net-to-gross, ϕ_{eff} is effective porosity, S_w is water saturation, Boi is the formation volume factor for oil (taken to be 1.25) and R_f is the recovery factor, STOIIP is stock tank oil initially in place and UR is ultimate recovery.

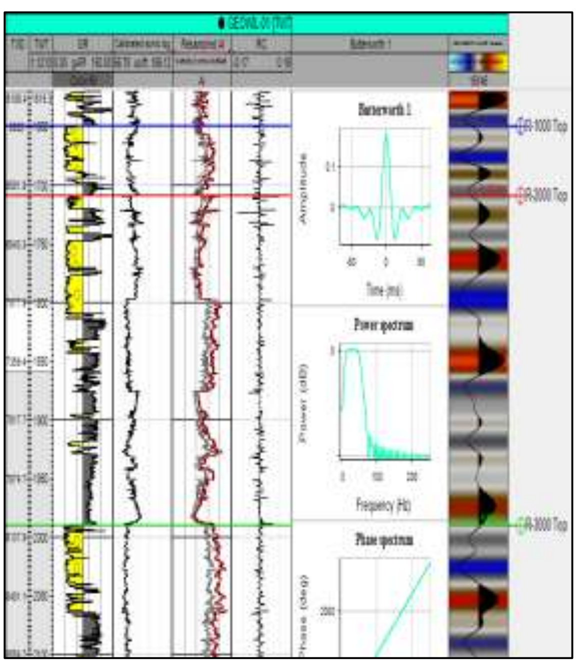

Fig. 5: Seismic-to-well Tie of GEOWIL-01

Qualitative interpretation: The qualitative interpretation of the well log was conducted using the petrophysical analysis of the reservoir units calculated parameters determined from the well logs include gross thickness of the reservoir, net to gross (NTG), effective porosity (Eff-p), reservoir formation (F), irreducible water saturation (Swirr), permeability of gas (k gas), oil permeability (K oil), hydrocarbon saturation and BVW (table 3 to 6). Relevant equations were used in obtaining all the calculated paramenters for the reservoir for each of the wells as presented in (Table 3 to 6). In order to determine the lithology within the five wells, a variety of logs including resistivity (ILD), gamma ray, neutron, and density logs were used. The following generalized formula was then used to estimate various petrophysical parameters including water saturation, hydrocarbon saturation, porosity, and permeability (equation 7, 8, 2 and 4). Seismic to well tie conducted on GEOWIL 01 is showed in fig. 5 below at it was discovered that they aligned. The horizon map (Fig 6) of the reservoir tops on the inline and crosslines at an interval spacing is shown in figure the horizon was picked at inline 15176 and the process of horizon interpretation generates a grid from which a time surface was generated.

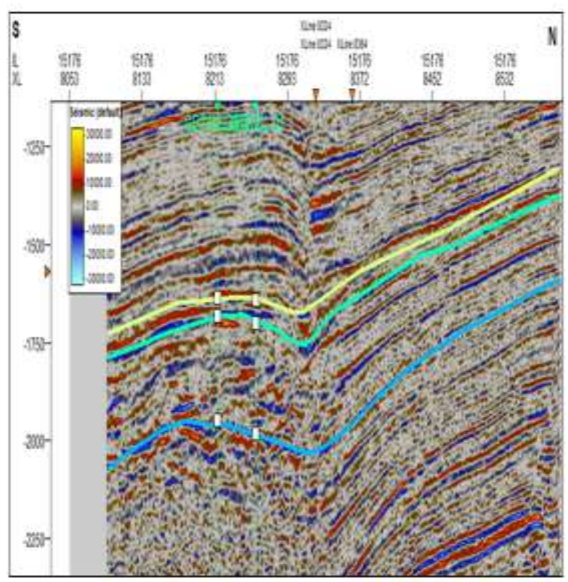

Fig. 6: Horizon Picking on Inline 15176

Table 2: Qualitative Interpretation of Porosity and Permeability Respectively (Rider, 1996, Osisanya et al., 2021)

Porosity Percentage (%)	**Qualitative Interpretation**	**Permeability Values (mD)**	**Qualitative Interpretation**
0 – 5	Negligible	< 10-5	Poor to Fair
5 – 10	Poor	15-50	Moderate
15 – 20	Good	50-250	Good
20 – 25	Very good	250-1000	Very good
Over 30	Excellent	>1000	Excellent

RESULT AND DISCUSSION

*Reservoir delineations***:** The field comprises of two major lithologies which are sand (yellow filled curve) and shale (gray field curve) units (Fig 7).

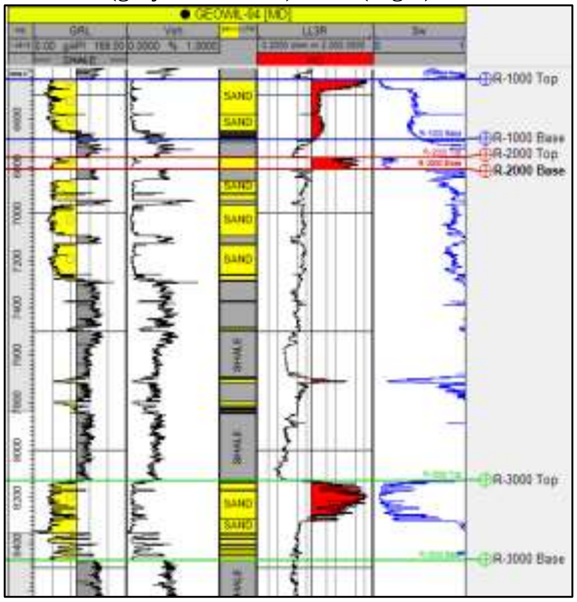

Fig. 7a: Reservoir Delineation of Geowil 04 well

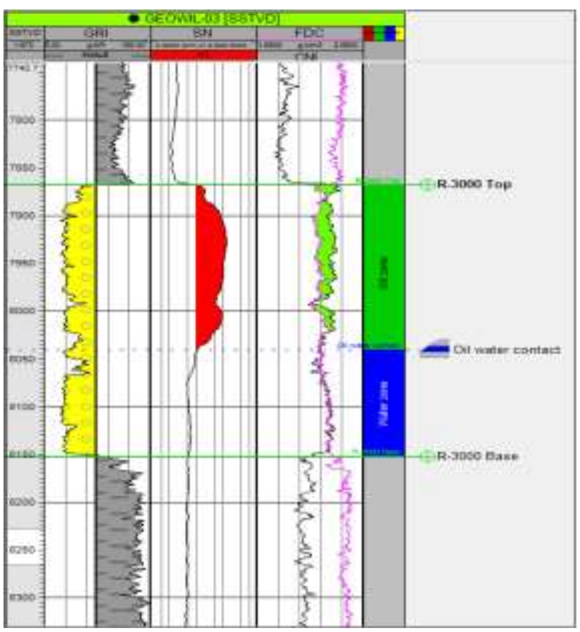

Fig. 7b: Reservoir Delineation of Geowil 03 well showing oil /water contact.

The sand formation is a potential reservoir rock while the shale formation is a potential cap or seal rock. These correspond with the conventional lithological units of the Agbada and Akata formation of the Niger delta region (fig. 2). Three hydrocarbon bearing sand units (labeled R-1000, R-2000 and R-3000) were delineated based on the response of the gamma ray and deep resistivity log which were identified and analyzed as potential hydrocarbon reservoir due to high resistivity values. The reservoirs were also analyzed by taking into cognizance the resistivity log juxtaposed with the water saturation log (Sw) to identify the hydrocarbon fluid types present. Fig. 7a and fig. 7b revealed the reservoir sand contained both hydrocarbon fluid types. On the contrary, Ighodaro et al., (2019) discovered the existence of only hydrocarbon oil across ten reservoirs of a chosen well in offshore Niger Delta when it was evaluated. The correlation panels (Fig. 8 and 9) show the lithostratigraphic correlation conducted within the GEOWIL field.

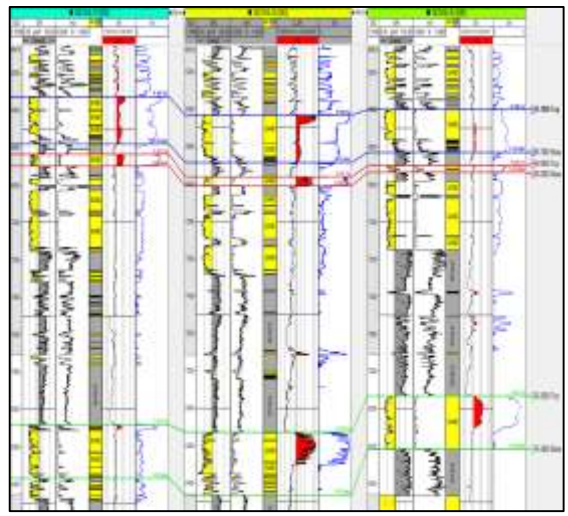

Fig. 8: Lithostratigraphic correlation of GEOWIL-01, GEOWIL-04 and GEOWIL-03 Wells showing the three continuous reservoirs in SW-NE Direction.

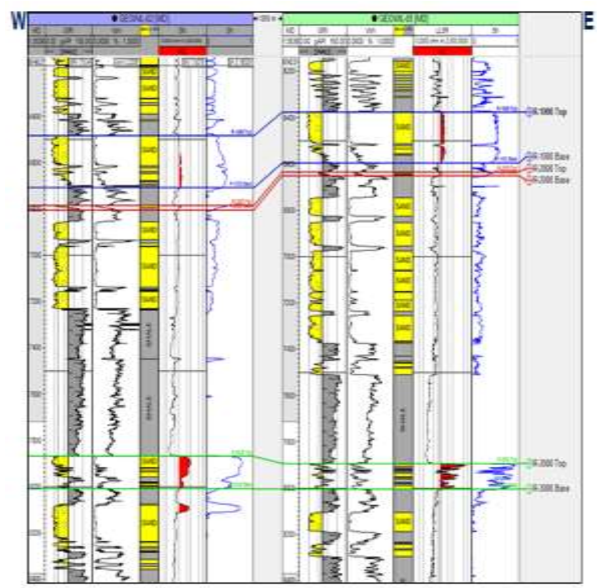

Fig. 9: Lithostratigraphic correlation of GEOWIL-01, GEOWIL-04 and GEOWIL-03 Wells showing the three continuous reservoirs in E-W Direction.

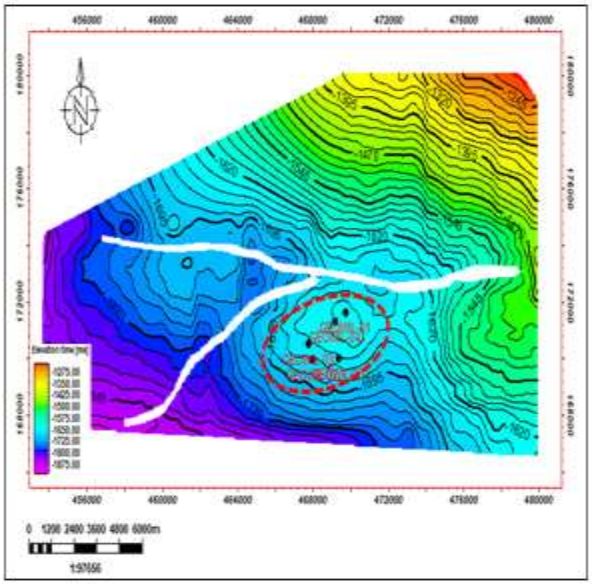

Fig 10: Time Structure Map of R-1000 Top

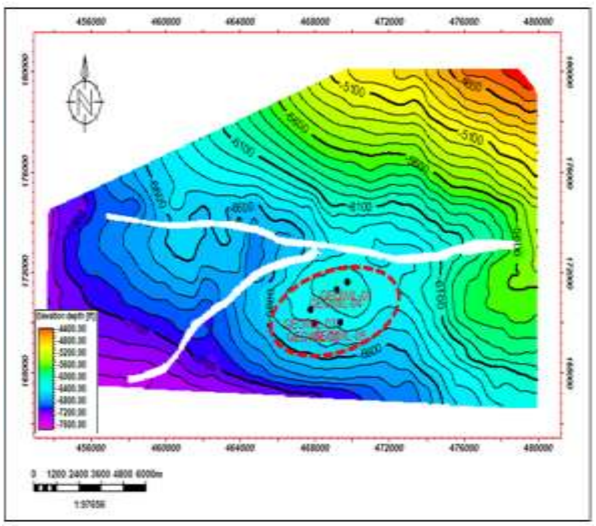

Fig 11: Depth structure map of R-1000 top

Petrophysical Analysis Of The Delineated Reserviors: Reservior R-1000: The reservoir has an average net to gross sand quotient of 0.8223, porosity of 27%, permeability of 159.974 mD , volume of shale of 15%, hydrocarbon saturation of 55% and bulk volume of water of 10% (table 3). The average porosity value is an indication of a very prolific reservoir as well as a good permeability according to Rider, 1996, Osisanya et al., 2021(Table 2) with its permeability ranging form 63-295mD across the five wells. The reservoir also has hydrocarbon saturation values of 64%, 34%, 47%, 71% and 59% from Geowil 01-05 which are indication of good oil.

The reservoir R-2000: The reservoir has an average net to gross of sand ratio of 0.6799, porosity of 27%, permeability of 126.19 mD, volume of shale of 19%, hydrocarbon saturation of 54% and bulk volume of water of 10% (table 4). It has a maximum net to gross ratio of 100% while its porosity ranges from 21 -30% which is a clear indication of very good porosity as well as good permeability values according to Rider, 1996, Osisanya et al., 2021(Table 2). It also contains large volume of sand than shale. The hydrocarbon saturation of the reservoir from well Geowil 01-05 are 77%, 27%, 41%, 90% and 35% respectively which also connotes an indication of good oil index.

The reservoir-3000: The petrophysical parameter revealed that reservoir-3000 (table 5) has an average net to gross of 78%, porosity of 25%, permeability of 162.02 mD, volume of shale of 16%, hydrocarbon saturation of 50% and bulk volume of water of 11% (table 5). The values obtained for the porosity and permeability index for R-3000 are rated very good and good respectively based on Rider, 1996. More so, the hydrocarbon saturation value are predicted to be prolific due to it good value index across the five wells.

*Volumetric Estimation***:** The result of the volume of hydrocarbon originally in place and the volume that can be recovered estimated is shown in Table **7**. The results revealed that R-1000 has STOIIP of 262.47MMSTB, R-2000 has 2.66MMSTB and R-3000 has 42.67MMSTB. The ultimate recovery for the three reservoirs is 19.31MMSTB, 1.19MMSTB, and 19.2MMSTB respectively (Tab. 7). The results show that the field has great potential for oil resources in considerable size. The result suggests that company can come up with further plan to increase and optimize efforts to increase production rates and proper field development planning.

Conclusion: Three hydrocarbon bearing sands were identified namely reservoir R-1000, R-2000 and R-3000 from the welllog data. The hydrocarbon saturation index obtained for all the three reservoir (55%, 54% and 50%) showed that they are all good indicator of prolific hydrocarbon accumulation. The result of the volume of hydrocarbon originally in place and the volume that can be recovered estimated revealed that R-1000 has STOIIP of 262.47MMSTB, R-2000 has 2.66MMSTB and R-3000 has 42.67MMSTB. The ultimate recovery for the three reservoirs is 19.31MMSTB, 1.19MMSTB, and 19.2MMSTB respectively. This implies that the reservoir has great potential for oil resources in considerable size. This research will aid the provision of reliable data for advance interpretation of Geowil field.

Table 3: Calculated parameter for reservoir R-1000

GEOWIL	Gross Thickness (ft)	Net Sand (ft)	NTG	Poros	Vsh	P-Eff	F	Swirr	K gas) (MD)	K oil) (MD)	Sh	BVW
01	253.75	217.82	0.8584	0.2932	0.143	0.2512	12.083	0.0777	2604.344	260.0594	0.644	0.089
02	225.32	175.83	0.7804	0.2465	0.142	0.2115	17.498	0.0935	639.3632	63.84425	0.34	0.1396
03	228.52	181.04	0.7922	0.2662	0.15	0.226	15.134	0.0870	1108.481	110.6885	0.47	0.1199
04	252.49	227.67	0.9017	0.29	0.12	0.255	11.684	0.0764	2955.261	295.1005	0.717	0.0722
05	219.42	170.12	0.7753	0.2581	0.171	0.214	17.067	0.0924	702.7648	70.17528	0.59	0.0877

Table 4: Calculated parameter for reservoir R-2000

GEOWIL	Gross Thickness (ft)	Net Sand (ft)	NTG	Poros	Vsh	P-Eff	F	Swirr	K gas) (MD)	K oil) (MD)	Sh	BVW
01	63.09	63.09	1	0.3039	0.1342	0.2631	10.94	0.0740	3790.8	378.5306	0.77	0.060517
02	19.63	9.03	0.4600	0.3048	0.24	0.2316	14.39	0.0848	1342.4	134.0433	0.27	0.169103
03	35.05	27.35	0.7803	0.239	0.17	0.1984	20.08	0.1002	379.3	37.87231	0.41	0.117038
04	16.42	6.31	0.3843	0.2196	0.23	0.1691	28.31	0.1190	103.2	10.30613	0.895	0.027496
05	219.42	170.12	0.7753	0.2581	0.171	0.214	17.07	0.0924	702.8	70.17528	0.35	0.10991

Table 5: Calculated parameter for reservoir R-3000

GEOWIL	Gross Thickness (ft)	Net Sand (ft)	NTG	Poros	Vsh	P-Eff	F	Swirr	K gas) (MD)	K oil) (MD)	Sh	BVW
01	285.22	246.36	0.8638	0.2639	0.1493	0.2245	15.391	0.0877	1039.746	103.8249	0.18	0.1841
02	140.47	101.61	0.7233	0.28	0.18	0.2296	14.67	0.0856	1248.646	124.6848	0.6	0.0918
03	284.5	284.5	1	0.2755	0.1	0.2479	12.43	0.0788	2336.608	233.3243	0.54	0.1141
04	336.98	296.8	0.8808	0.24	0.16	0.2016	19.397	0.0985	432.6295	43.20065	0.47	0.1068
05	110.16	50.08	0.4546	0.2	0.225	0.155	34.13	0.1306	50.78339	5.071026	0.722	0.0431

Table 6: Average Petrophysical Values of the reservoirs across the wells.

	GT	NST	NTG	Vsh	Por	EffP	F	Perm	Permoil	Pav	Sh	Sw
R-1000	235.9	194.496	0.8216	0.1452	0.2708	0.2316	14.693	1602.0	159.97	881.0081	0.5522	0.4478
R-2000	36.65	30.97	0.7249	0.1808	0.2737	0.2248	16.955	1852.5	184.98	1018.737	0.539	0.461
R-3000	231.47	195.87	0.7845	0.1629	0.2519	0.2117	19.204	1021.7	102.02	561.8518	0.5024	0.4976

Table 7: Volumetric Estimation Results of the three Reservoirs

Parameters	**Reservoir R-1000**	**Reservoir R-2000**	**Reservoir R-3000**
Area (Acres)	262.47153	133.2851	363.44031
Gross thickness(ft)	254	37	231
NTG	0.82	0.72	0.78
Effective porosity (ϕ_{eff})	0.23	0.22	0.21
S_w	0.45	0.46	0.50
STOIIP (MMSTB)	42.920043	2.666496	42.674529
UR (MMSTB)	19.314015	1.199923	19.203538

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