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PETROPHYSICAL ANALYSIS OF WELL LOGS FOR RESERVOIR EVALUATION: A CASE STUDY OF THE 'BETA' FIELD, NIGER DELTA.

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Abstract – This study presents the result of the petrophysical analysis of the suite of well logs available from Beta field's, Niger-Delta. The analysis was carried out with the aim of determining and evaluating the field hydrocarbon prospect. The suites of well logs available are; Gamma ray (GR), Resistivity, Neutron and Density logs from two wells. Qualitative interpretations were carried out based on the log patterns to delineate reservoir and non-reservoir units while the fluid types were also identified. Quantitative analysis involving computation of petrophysical parameters for each identified reservoir was also done. Five sand units were delineated, three of which were correlated across the two wells available for the field. All the sand units are hydrocarbon bearing. The computed petrophysical parameters for the reservoir layers have porosity, $\emptyset$ range of 22.7% - 31.1% and hydrocarbon saturation of 49% - 77%. The reservoirs are encountered at the depth range of 2408 to 3244 meters. The result of the whole analysis suggests that the reservoir sand units of Beta field contain significant accumulation of hydrocarbon.

Keywords: Hydrocarbon, Petrophysical, Reservoir, Well logs, Wireline.

1.0 Introduction

Oil and gas exploration cannot proceed without a proper petrophysical analysis of the given field. The Niger-Delta basin has been analyzed using petrophysical methods in parts and portions ([2], [1], [8], [10]). It is also a routine task carried out in several other basins of the world. For example, Jadoon, et al. [5], did some petrophysical analysis work in the Cooper basin of Australia. Petrophysical analysis provides good information on pore system, fluid distribution and flow characteristics of hydrocarbon reservoirs which are properties employed in the evaluating them. The modelling and analysis of well logs is a fundamental part of the exploration and production process. The physical properties of the subsurface must be well understood before committing to a commercial venture. Hydrocarbon wells are logged by lowering measuring equipment (logging tools) on a 'Sonde' into them. A 'Sonde' can be said to be a 'container' unto which geophysical equipment are loaded. Manipulating data acquired from such an endeavor provides information on presence of reservoir structure, content of reservoir, and quality of reservoir available, before proceeding on the onerous task of drilling for oil and gas. The reservoir and fluid characteristics to be determined include thickness (bed boundaries), lithology, porosity, fluid saturations, fluid identification and characterization, permeability. etc.For this current study, logs including the Gamma ray, Resistivity logs, Neutronand density logs were obtained across two wells in the 'Beta' field of the Niger Delta. These were qualitatively and quantitatively analyzed for petrophysical information.

2.0 Location of the Study Area

The Niger Delta is a marginal sag basin located in thecontinental margin of the Gulf of Guinea in equatorialWest Africa, covering an area of about 75,000 km^2,with an average thickness of about 12 km and liesbetween latitudes 3° and 6° N and longitudes 5° and8° E [6].

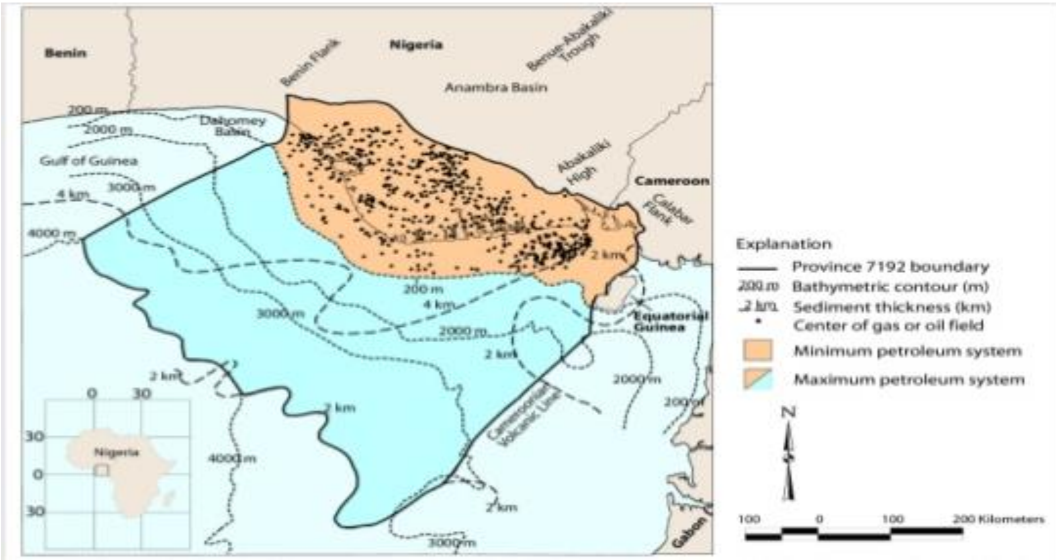

Fig. 1: Location Map of the Niger Delta (Adapted from Tuttle et al. [9])

It is bounded in the western –north western part by the Okitipupa Hinge line; in the north by the Benin Flank; inthe north eastern part by the Abakaliki High; and in the eastern – south eastern part by the Calabar Flank. The basin formed during the separation of Africa from South America and the consequent opening of the South Atlantic in Mid Cretaceous times ([4], [3]).

3.0 Aim and objectives

The aim of the study is to determine and evaluate the hydrocarbon prospect of the study area and the specific objectives include:

a. Delineate reservoir units within the study area.
b. Determine the fluid content within the reservoirs.
c. Compute petrophysical parameters essential to exploitation of Oil and gas.

4.0 Methodology

A qualitative inspection of the gamma ray logs (Fig. 2) is used to delineate reservoir units since the gamma ray measures natural radioactivity in formations.

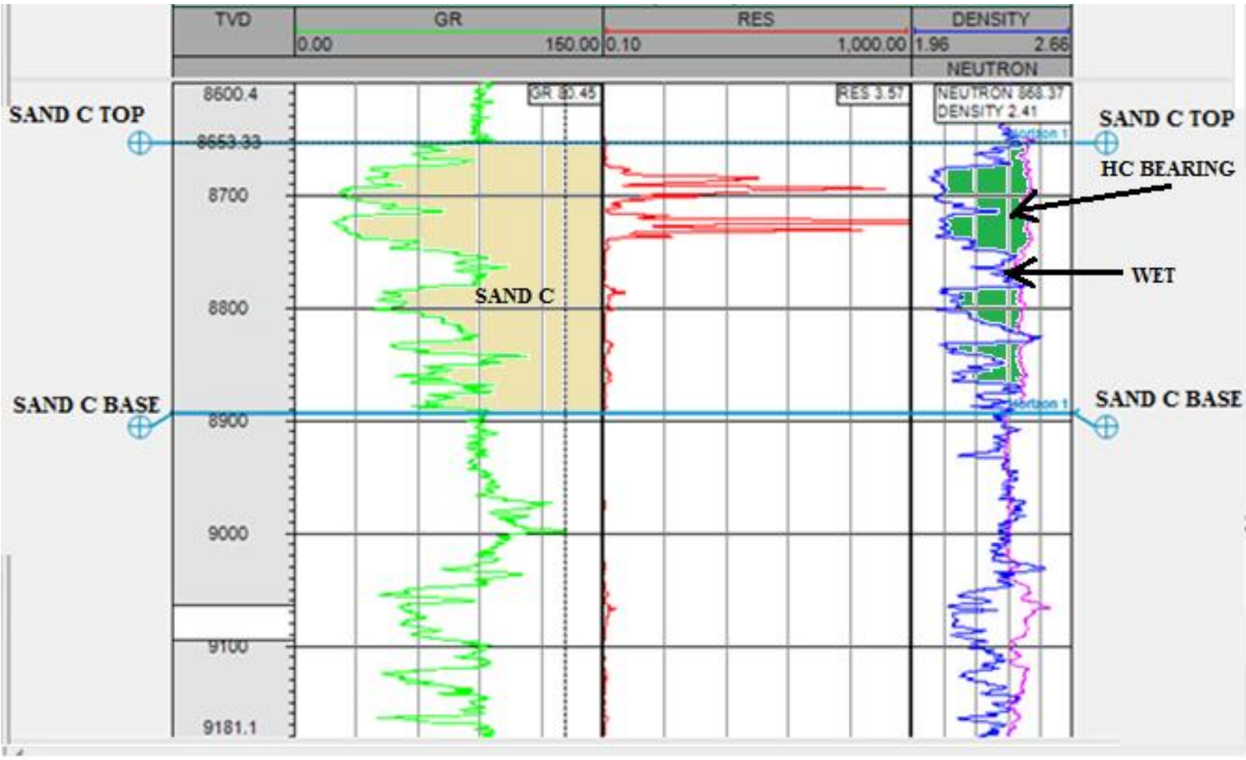

Fig. 2: Beta 1 logs showing Reservoir Sand C

Clean sands which are essentially shale free have low concentration of radioactive materials and therefore result into a deflection on the gamma ray track. At the zones of shale inclusions however, the deflection is high. Thus, a gross reservoir thickness is first estimated and then a sum of the shale thicknesses is then subtracted from this value to obtain the net reservoir thickness.

Quantitative determinations were done by reading values off the logs. Some of the parameters estimated include:

Gamma ray index also known as % Shale using the relationship below:

$$I_{GR} = \frac{Gr_{log} - Gr_{min}}{Gr_{max} - Gr_{min}} \times \frac{100}{1} \quad (1)$$

Where,

Gr_{log}= Gamma ray reading of formation
Gr_{max}= Minimum gamma ray
Gr_{min}= Maximum gamma ray
% Sand was easily estimated by subtracting the value of % Shale from 100.

Porosity values were also obtained through the use of density logs. After taking the bulk density (ρ_b) reading off the log, the following relationship was employed.

$$\emptyset_d = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (2)$$

Where,

$\rho_{ma} = Matrix\ density$

$\rho_f = Fluid\ Density\ (0.85\ for\ Oil)$

$\rho_b = Formation\ bulk\ density$

Formation factor values were computed using the equation:

$$Formation\ Factor, F = \frac{a}{\emptyset^m} \qquad (3)$$

Where a = 1 (For Sandstone); m = 2

R_t values which are true resistivity of formation values were read from maximum deflection of resistivity log on the reservoir.

For Water Saturation this is employed:

$$S_w = \sqrt[n]{\frac{FR_w}{R_t}}, \qquad (4)$$

where R_w is $Resistivity\ of\ Water = \frac{R_o}{F}$. (5)

R_o is read off the resistivity log.

Hydrocarbon Saturation, $S_{hc} = 100 - S_w$ (%). (6)

Finally, the permeability is also calculated using:

Permeability, $k = \left[\frac{250 \times \emptyset^3}{S_{wirr}}\right]^2$, (7)

where S_{wirr} is irreducible water of saturation and is given by:

$$S_{wirr} = \left(\frac{F}{2000}\right)^{1/2} \qquad (8)$$

5. Results and Discussions

The reservoirs are encountered at the depth range of 2408 to 3244 m all of which are hydrocarbon bearing. E.g. Sand E (Fig. 3) deducible from the gamma ray (GR) track from the deflection. A cross-over point between sand and shale is indicated at about 100 units by a dotted line. This served as a guide in delineating the sand lithologies which are the reservoirs. The resistivity track shows resistivity values ranging from the lowest 0.10 unit to 1000 units. The strong spikes to the right side of the track indicate high resistivity which confirm that the reservoirs are hydrocarbon bearing.

The last track which is the neutron-density track showed good 'ballooning' in the reservoir region resulting from the deflection of the two logs in these track from each other. This firstly confirms the presence of hydrocarbon and gives an insight on the hydrocarbon type that is present. The rule of thumb is that where the deflection is wide, the hydrocarbon form is gas and where narrow, it is oil.

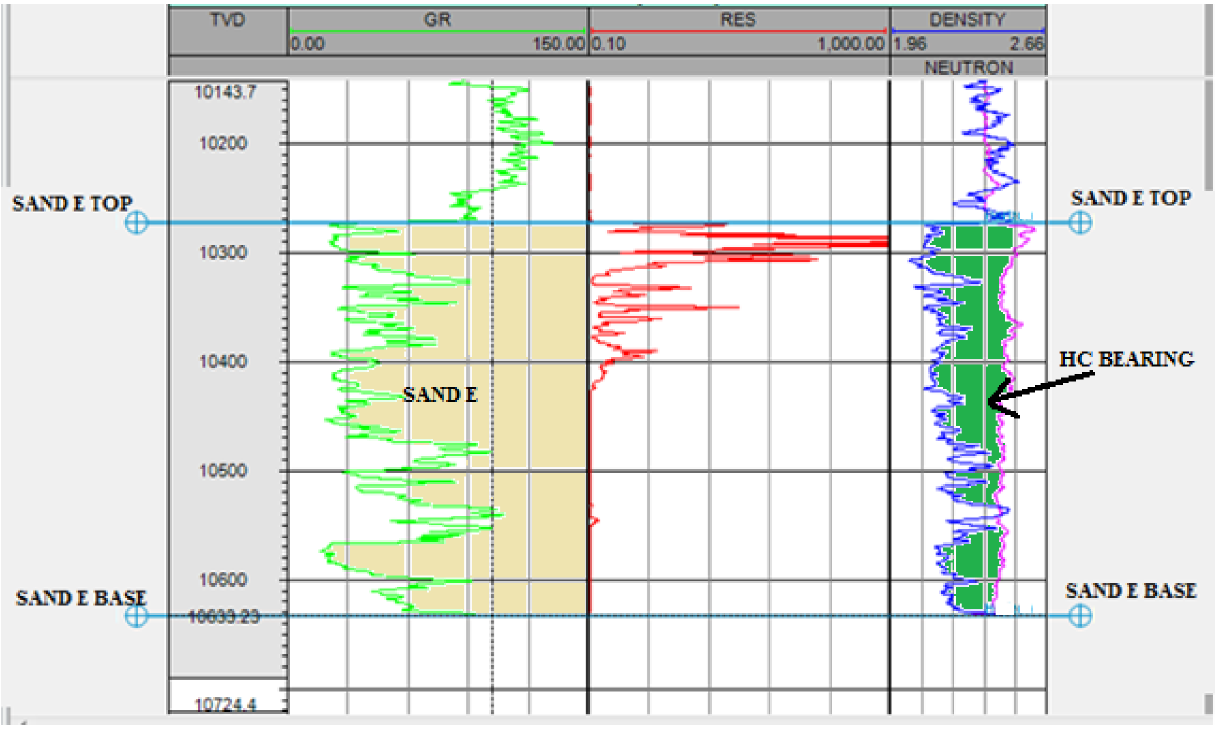

Fig. 3: Beta 3 Logs showing reservoir Sand E

Table 1: Petrophysical properties of Well Beta 1 reservoirs

Beta 1	**NRT(ft)**	**NTG (%)**	**I_{GR} (%)**	**% Sand (%)**	**Ø(%)**	**F**	**R_t**	**S_{hc}(%)**	**K(md)**
Sand A	53.36	75	24.8	75.51	30.5	10.7	92.3	66.1	10267.93
Sand B	80.42	86	21.3	78.7	28.3	12.5	42.6	49	5143.75
Sand C	188.17	78.5	34.1	65.9	22.8	19.27	298.88	50	102906.2
Sand D	293.46	91.7	14.8	85.16	22.7	18.9	369.79	77	979.29
Sand E	252.22	70	10	90	29.4	11.57	446.3	76.4	6987.74

The Net Reservoir thicknesses (NRT) within the wells were estimated by subtracting the depth values of the reservoir bases from the depth value of the reservoir tops (Fig. 3). The Net to Gross (NTG) ratio was estimated by summing the thicknesses of actual sand layers within individual reservoirs and finding the percentage of the ratio. Other parameters such as the Gamma ray Index (I_{GR}), Porosity (Ø), Permeability (k), Formation factor (F), True resistivity (R_t), % Sand (sand content) were all estimated using appropriate formulae.

Reservoirs Sand A to Sand E have sand volume that range from 65.9% to 90% providing a good habitat for hydrocarbon. Their porosity values range from 22.7% to 30.5% all which are indicative of ‘Good’ to ‘Exceptional’ reservoirs going by the work of Levorsen, 1967. The values of the Hydrocarbon Saturation, S_{hc} , also supports the viability of the prospects.

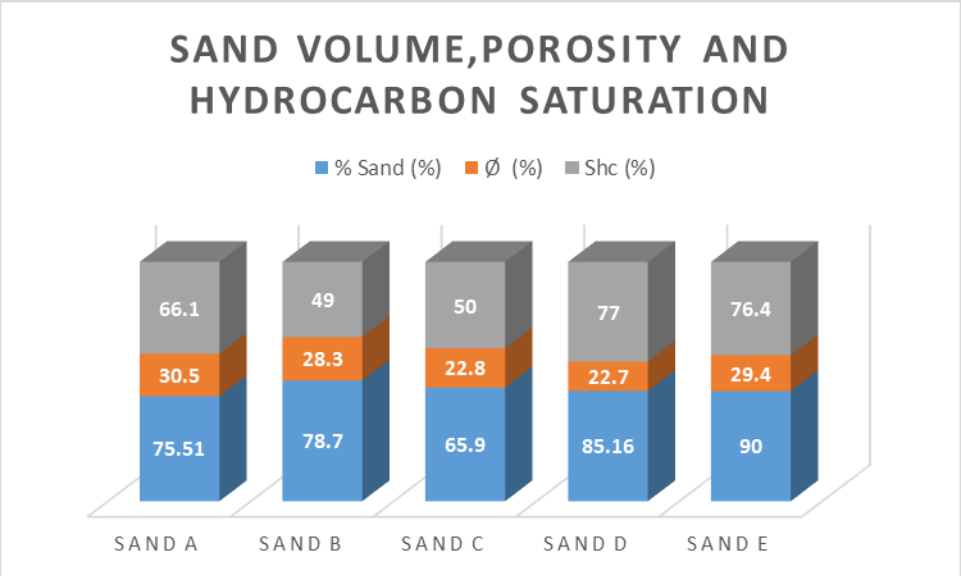

Fig. 4: Well Beta 1 petrophysical parameters

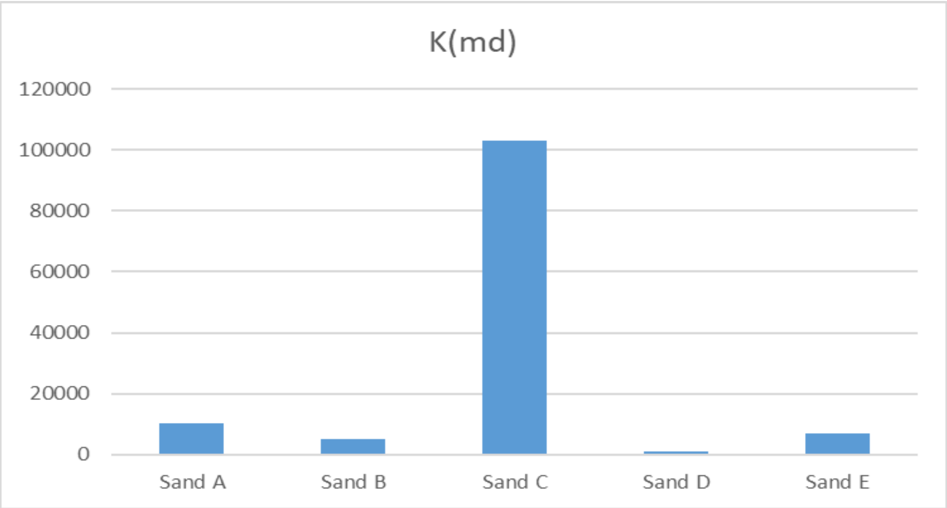

Fig. 5: Well Beta 1 permeability plot

The permeability values for this well indicates that they are 'exceptional' reservoirs ([7]).

Table 2: Petrophysical properties of Well Beta 2 reservoirs

Beta 2	**NRT(ft)**	**NTG (%)**	**I_{GR} (%)**	**% Sand (%)**	**Ø(%)**	**F**	**R_t**	**S_{hc} (%)**	**K(md)**
Sand A	302.28	85.8	16.5	83.5	31.1	10.33	39.1	59.3	10969.67
Sand B	298.32	94	13.7	86.24	29.4	11.56	42.2	62.8	6987.7
Sand C	148.97	53	25	75	26.7	14.03	37	63	3232.18

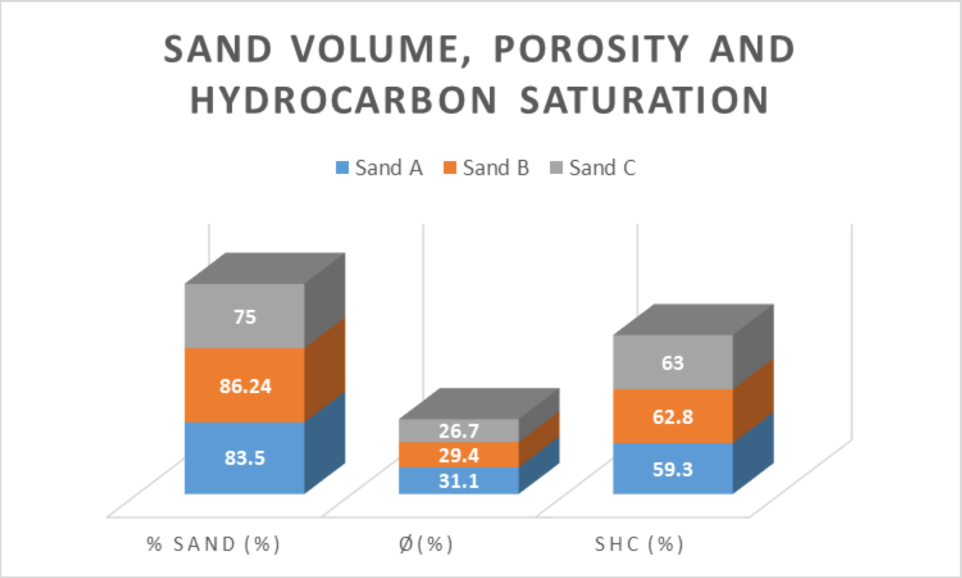

Fig. 6: Well Beta 2 petrophysical parameters

Reservoirs Sand A to Sand C have sand volume that range from 75% to 86.24% also providing a good habitat for hydrocarbon. Their porosity values range from 26.7% to 31.1% all which are similarly indicative of 'Good' to 'Exceptional' reservoirs (Levorsen, 1967). The hydrocarbon content range suggests that the prospect is good.

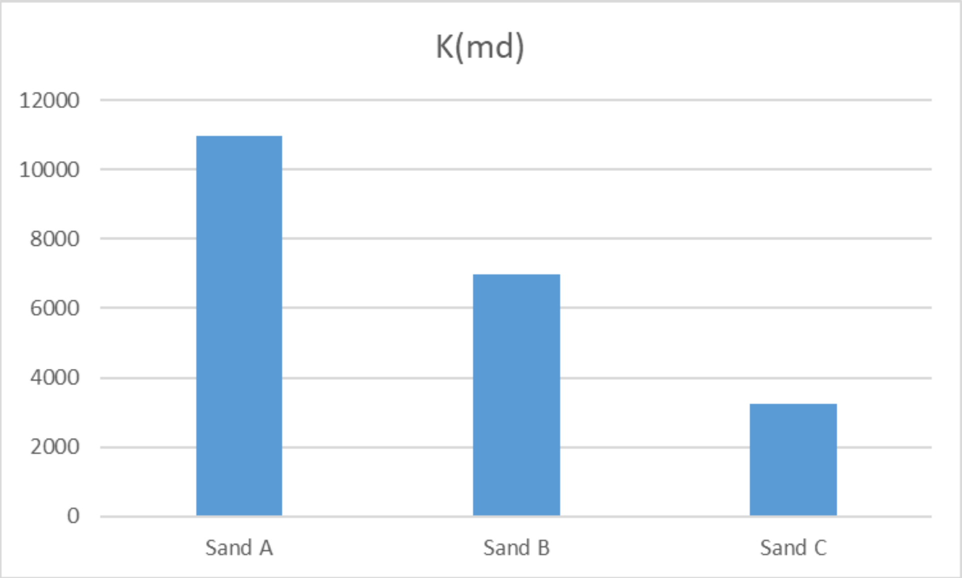

Fig. 7: Well Beta 2 permeability plot

The permeability values here are also 'exceptional' [7].

6. CONCLUSION

The porosity and permeability values of reservoirs are the most essential petrophysical parameters in determining the viability of a prospect. The porosity, $\emptyset$ values of this field from the studied wells range from 22.7% - 31.1%. Reservoir with porosity values greater than 20% are considered good. When they are above 25%, they are exceptional. The permeability values also ranged from 979.29 md to 102906.2 md. This correlates with the range of reservoirs considered to be 'very good' to 'exceptional'.
The sand volume, porosity, permeability and hydrocarbon saturation values of the reservoirs analyzed in the 'Beta' field of the Niger-Delta are all indicative of good quality and very productive reservoirs. With further investigations such as the seismic exploration of the field and after estimating the actual reserve, it may be advised that production should progress.

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