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RESEARCH ARTICLE

DETERMINATION OF THE RELATIONSHIP BETWEEN POROSITY AND PERMEABILITY USING SUITE OF CORE SAMPLES, IN NORTH-EASTERN NIGER DELTA, NIGERIA

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ABSTRACT

This study is aimed at determining the relationship between porosity and permeability using suite of core samples. Porosity and permeability values of a suite of core samples obtained at different depths from three different producing wells in North-Eastern Niger Delta, Nigeria were determined using routine core analysis. Only dry and clean core plugs were used for the measurement. This analysis entails the use of fluid saturation techniques for the determination of porosity values and passing fluid (synthetic oil) of known viscosity at a certain rate through the cores, measuring the resulting pressure drop across the cores for the determination of permeability. Each suite is comprised of 30 core samples and is represented by plots of permeability versus porosity and a written summary. Producing wells Apani-01 and Apani-03 showed a better relationship between porosity and permeability of the core samples compared to producing well Apani-02. Producing well Apani-01 has its highest porosity and permeability values (20.8% and 1393.6mD respectively) at the depth of 9756.64ft, while producing well Apani-03 has its highest porosity and permeability values (23.3% and 336mD respectively) at the depth of 8355.36ft. Producing well Apani-02 which showed a poor relationship has its highest porosity and permeability values (21.4% and 882.0mD) at the depth of 10087.34ft. The results of this study can be applied in exploration and production of hydrocarbon to identify potential and/or productive wells.

KEYWORDS

Overburden, Potentiality, Productivity, Borehole effect, Cap rock.

1. Introduction

Porosity and permeability of reservoir rocks are the most fundamental properties with respect to the storage and transmission of fluids. Accurate knowledge of these two properties for any hydrocarbon reservoir, together with fluid properties is required for efficient development, management and prediction of future performance of reservoir (Djebbar and Erle, 2016). Storage capacity gives information about how much fluid can be contained in the rock, and flow capacity gives information of how fast fluid can be produced or recovered from the reservoir (Fanchi and Christiansen, 2017). Any rock with sufficient high porosity and permeability may serve as a source rock provided that there is a source of petroleum, a structure and a tight cap rock. Porosity is an expression of the percentage fluid by volume compared to the total rock volume with fluid. Porosity is often expressed as a percentage, but in most calculations, it is easier to express it as a fraction. Permeability on the other hand, is an expression of the ease with which fluid flow through rocks.

It depends on the size of the pore spaces in the rocks and in particular the connections between the pore spaces (Knut, 2010). The flow of fluid through rock materials is governed by properties such as the porous nature, interconnectivity of the pores, as well as the properties of the flowing fluid (Saar, 1998). Porosity is either expressed as void ratio or, more frequently as a percentage, it may be measured in the following ways: directly from cores (core analysis), indirectly from geophysical well-logs, from seismic data or well testing (Salley, 1998). The core analysis porosity determination has the advantage that no assumption is made concerning mineral composition, borehole effect, hydrocarbon effect etc. However, since the volume of the core is less than that of the rock which is investigated by logging device, porosity values derived from logs are frequently more accurate in heterogeneous reservoir (Torsaeter and Abtahi, 2013).

Permeability is a tool for the recovery of hydrocarbon from the reservoir, as it aids in the determination of how much hydrocarbon can be produced from a reservoir (Halliburton, 2001). By definition, permeability is the measure of the ease with which a fluid of a given viscosity can pass or flow through the pore spaces of a rock. To evaluate the productivity of a reservoir, it is necessary to know how easily fluid can flow or pass through its pore system (Schlumberger, 1989). The unit of permeability is the Darcy (D), which is defined as the permeability that allows the flow of one cubic centimeter per second of a fluid of one centipoise viscosity through a cross sectional area of one square centimeter under a pressure gradient of one atmosphere per centimeter (Salley, 1998). High porosity implies high pore spaces whereas low porosity implies low pore spaces. Hence, the diameter of invasion will be greater in high porosity rocks, this is because low porosity rocks have less storage capacity or pore volume to be filled by the invading fluid and as a result, large number of pores in the rock formation will be affected (Schlumberger, 1989).

2. Area of Study

The Niger Delta is bounded geographically by Latitudes 5˚00'N to 8˚00' N and Longitudes 4˚00'E to 6˚00'E of the Greenwich meridian as shown in Figure 1 (Reijers, 2011). The Apani field is situated in the east of the

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Greater Ughelli depobelt located in North-Eastern Niger Delta sedimentary basin. The lower marine shale package, the Akata formation, is the main source rock in the area, with production from the overlying sandstone facies of Agbada formation. The structural style in Apani field is a fault dependent closure. The major structural building faults are Southward dipping East-West trending faults.

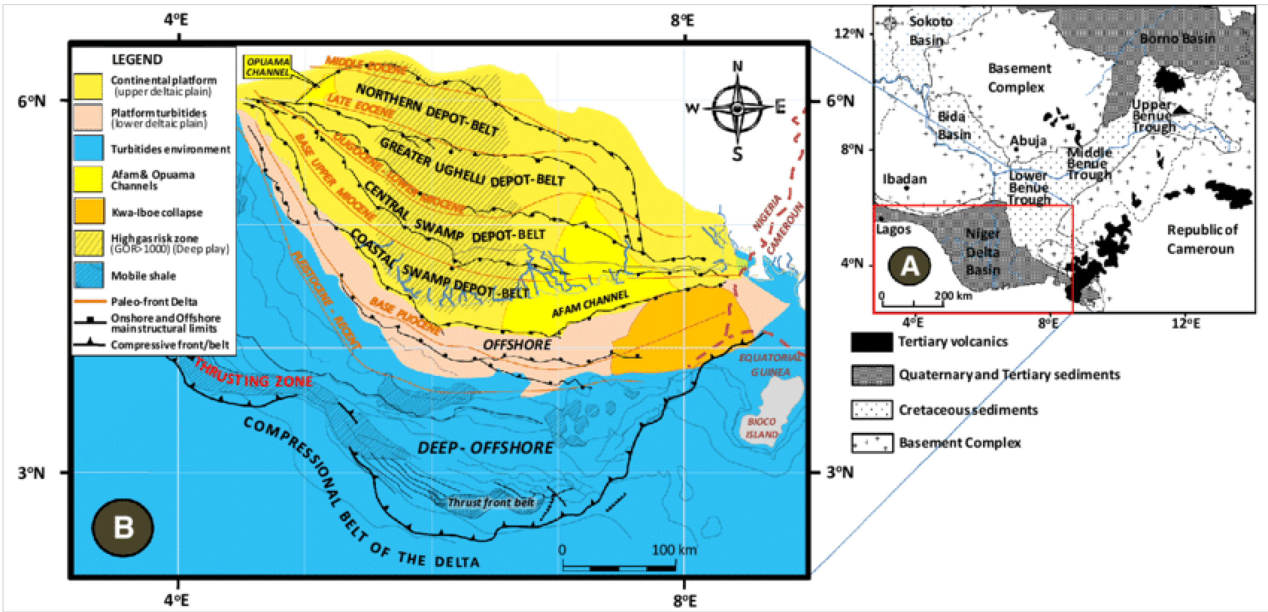

Figure 1: Map Showing the Study Area

3. Materials and Methods

3.1 Materials

Routine core analysis (laboratory measurement of core samples) was carried out to achieve the goal or aim of this study and the materials used include: callipers, metre rules, weigh balance, beakers, core holders, barometers (pressure gauge), stop watch, fluid injector and synthetic oil.

3.2 Methods

The methods used for this study are discussed in the following headings:

3.2.1 Determination of Porosity

Procedure: Porosity values of core samples were determined using fluid saturation technique which gave effective porosity of the core samples. The length, L and diameter, D of each of the core samples were measured using meter rule and calliper respectively. The mass, M of dry core samples were measured using a weigh balance. The cores samples were saturated with synthetic oil and weighed.

Calculation and Report:

$L = Length\ of\ core\ sapmle$

$D = Diameter\ of\ core\ sapmle$
$M_{dry} = Mass\ of\ dry\ core\ sample$

$M_{sat} = Mass\ of\ saturated\ core\ sample$

$\rho_o = Density\ of\ oil\ used$

Mass of oil, M_o is determined thus,

$$M_o = M_{sat} - M_{dry} \quad (1)$$

Volume of oil V_o is determined thus,

$$V_o = \frac{M_o}{\rho_o} \quad (2)$$

Volume of oil, V_o = Volume of pore, V_p

Bulk volume of core sample is then determined thus,

$$V_b = \frac{\pi D^2 L}{4} \quad (3)$$

Effective porosity Φ_e is then determined using

$$\Phi_e = \frac{V_p}{V_b} \quad (4)$$

3.2.2 Determination of Permeability

Permeability values of the core samples were determined by flowing fluid (synthetic oil) of known viscosity (0.25cp) at a certain rate through the core samples and then measuring the resulting pressure drop across the core sample.

Procedure: Core sample are mounted on the core holder, synthetic oil is injected into the core sample at a steady rate using the fluid injector, pressure at both ends of the core sample is measured using the pressure gauge and fluid flow time is measured using the stop watch.

Calculation and Report:

$V = Volume\ of\ fluid\ used$

$R = Probe\ radius\ of\ core\ sapmle$

$\mu = Viscosity\ of\ fluid$

$\Delta t = Fluid\ flow\ time$

$\Delta P = Pressure\ gradient$

$C = Fluid\ flow\ shape$

Fluid flow rate Q is determined thus,

$$Q = \frac{\Delta V}{\Delta t} \quad (5)$$

Absolute permeability values, K of the core samples is then determined using the empirical relation:

$$K = 5660\frac{Q\mu}{\Delta P} \quad (6)$$

3.2.3 Relationship Between Porosity and Permeability

A plot of permeability values against porosity values using cross-plots as shown in Figures 2 – 4 were used to establish the relationship between porosity and permeability.

4. Results and Discussion

4.1 Results

Porosity and permeability values of core samples obtained at different depths from three different producing wells are presented in Tables 1 – 3 for producing wells Apani-01, Apani-02 and Apani-03 respectively. Permeability values plotted against porosity values using cross plots are shown in Figures 2 – 4 for producing wells Apani-01, Apani-02 and Apani-03 respectively.

Table 1: Porosity and Permeability Values of Core Samples from Producing Well Apani-01

S/N	Depth, d (ft)	Porosity, Φ (%)	Permeability, K (mD)
1	9034.43	20.6	114.50
2	9066.15	18.8	0.47
3	9092.91	14.9	0.86
4	9129.63	11.0	0.10
5	9161.23	20.4	189.10
6	9193.04	17.2	37.10
7	9195.22	20.2	153.10
8	9203.87	20.5	115.80
9	9209.78	16.7	22.30
10	9214.17	20.0	50.60
11	9218.61	18.4	23.30
12	9220.55	18.8	34.30
13	9252.07	7.1	38.20
14	9264.10	18.4	52.90
15	9315.76	21.3	69.30
16	9347.28	12.2	0.07
17	9378.59	11.6	0.05
18	9410.09	9.3	0.02
19	9441.69	12.9	85.30
20	9473.21	20.6	805.60
21	9504.46	12.4	116.20
22	9535.97	15.6	199.70
23	9567.29	17.3	468.50
24	9598.82	20.6	821.80
25	9630.37	12.7	80.10
26	9662.03	15.9	236.30
27	9693.59	18.7	444.60
28	9725.14	20.1	716.90
29	9756.64	20.8	1393.60
30	9788.15	20.4	285.40

Table 2: Porosity and Permeability Values of Core Samples from Producing Well Apani-02

S/N	Depth, d (ft)	Porosity, Φ (%)	Permeability, K (mD)
1	9526.18	9.9	0.07
2	9558.08	9.1	0.02
3	9589.48	9.6	0.22
4	9621.48	7.4	0.01
5	9653.11	20.7	226.10
6	9684.71	21.1	488.20
7	9716.27	8.0	0.001
8	9747.24	17.4	15.10
9	9778.24	15.3	12.30
10	9809.18	21.2	86.10
11	9840.17	18.3	36.10
12	9871.16	20.7	132.20
13	9902.15	17.8	48.40
14	9933.14	15.1	68.30
15	9964.13	19.9	185.00
16	9994.93	19.9	110.00
17	10025.74	22.4	561.70
18	10056.54	20.1	706.70
19	10087.34	21.4	882.00
20	10118.18	22.2	375.70
21	10148.98	16.6	169.70
22	10179.97	22.3	169.70
23	10210.89	19.9	135.90
24	10241.91	15.8	6.17
25	10272.90	16.0	132.80
26	10303.68	18.9	60.70
27	10334.66	21.5	115.10
28	10365.63	21.1	72.60
29	10396.60	21.2	110.70
30	10427.55	21.3	105.30

Table 3: Porosity and Permeability Values of Core Samples from Producing Well Apani-03			
S/N	**Depth, d (ft)**	**Porosity, Φ (%)**	**Permeability, K (mD)**
1	8196.56	18.2	26.80
2	8228.23	19.5	38.30
3	8259.96	18.5	25.70
4	8291.78	20.4	61.60
5	8323.57	13.0	19.10
6	8355.36	23.3	336.60
7	8387.08	22.2	200.00
8	8418.84	19.1	40.50
9	8450.60	22.6	182.30
10	8482.41	16.5	24.30
11	8514.18	20.1	126.10
12	8545.91	20.1	172.20
13	8577.69	19.7	94.4
14	8609.47	20.4	110.20
15	8641.25	20.1	69.10
16	8673.06	19.3	108.70
17	8704.83	19.3	56.40
18	8736.62	16.8	20.30
19	8768.39	20.7	110.50
20	8800.18	12.3	0.08
21	8831.94	18.4	51.30
22	8863.68	20.4	77.20
23	8895.46	12.8	0.37
24	8927.28	14.6	4.44
25	8958.94	8.5	0.22
26	8990.72	13.9	0.51
27	9022.39	12.9	0.21
28	9054.10	11.5	4.07
29	9085.87	11.9	0.26
30	9117.59	11.9	0.05

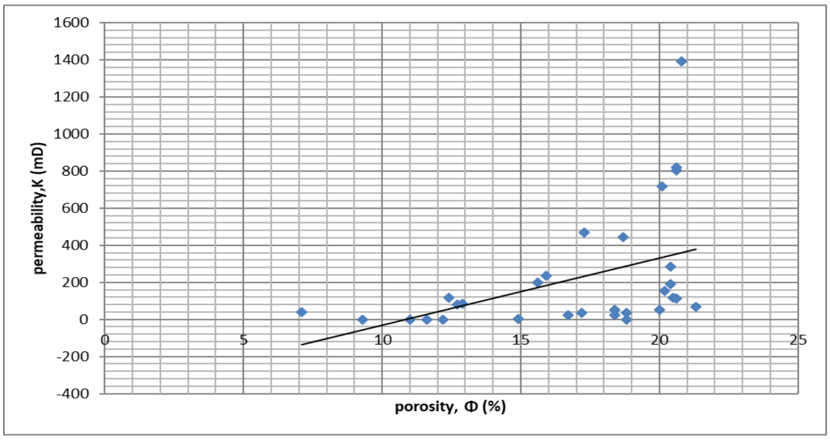

Figure 2: Plot of Permeability versus Porosity for producing well Apani-01.

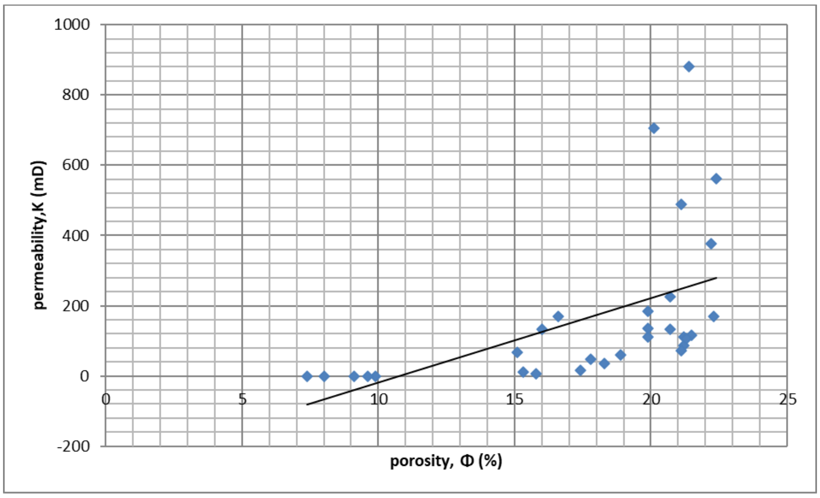

Figure 3: Plot of Permeability versus Porosity for producing well Apani-02.

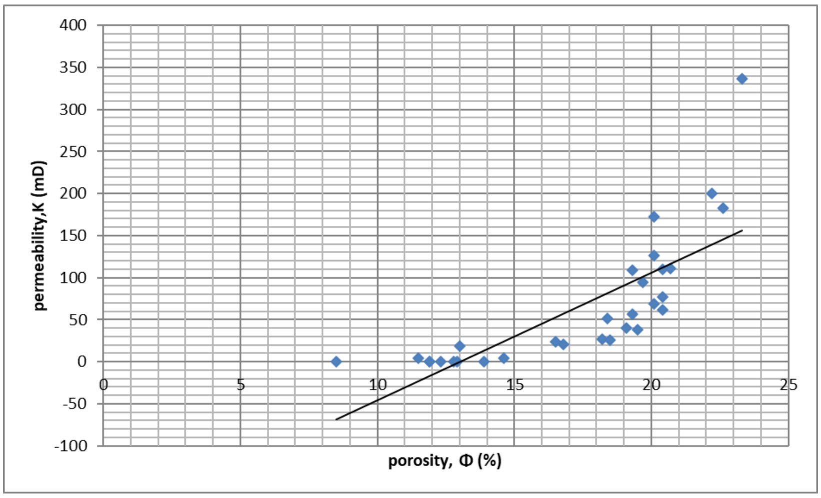

Figure 4: Plot of Permeability versus Porosity for producing well Apani-03.

4.2 Discussion

Under ideal situation, porosity decreases with depth as a result of the effect of compaction resulting from overburden (geostatic pressure). A producing well can be porous but may not necessarily be permeable if the pore spaces are not interconnected whereas a producing well that is permeable must be porous. Porosity indicates potentiality while permeability indicates productivity of a well. Values of porosity and permeability obtained are dependent on geostatic pressure and compaction of the formation as a function of depth. But due to pressure difference (sore pressure and over pressure) or equivalent pressure, there is variation or equality in porosity as well as permeability values of the core samples. From Figure 2 of producing well Apani-01 data, the scatter decreases as permeability and porosity values decreases indicating a decrease in the productivity and potentiality of the well. From Figure 3 of producing well Apani-02, the scatter is high at high permeability values but low at low porosity values, signifying higher productivity and low potentiality of the well. From Figure 4 of producing well Apani-03, linearity in permeability and porosity values is observed. Thus, leading to a progressive decrease in permeability and porosity values, indicating a decrease in productivity and potentiality of the well.

5. Conclusion

From the results of this study, the following conclusions are reached:

The porosity values of producing well Apani-01 ranges from 7.1% to 20.8%, while its permeability values ranges from 0.2mD to 1393.6mD.

The porosity values of producing well Apani-02 ranges from 7.4% to 21.4%, while permeability values ranges from 0.001mD to 882.0mD.

The porosity values of producing well Apani-03 ranges from 8.5% to 23.3%, while permeability values ranges from 0.22mD to 336.6mD.

Potentiality increases from producing well Apani-01 to Apani-02, then to Apani-03 whereas productivity increases from producing well Apani-03 to Apani-02, then to Apani-01.

Producing well Apani-03 is more porous but less permeable, thus is said to be more potential and less productive because the pore spaces are less interconnected, hence has low fluid flow rate.

Producing well Apani-01 is less porous but more permeable, therefore, is said to be less potential but more productive because its pore spaces are more interconnected, hence has a high fluid flow rate.

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