Evaluation of shale volume and effective porosity using Iarionov and Archie equations from wire-line logs, Niger delta Nigeria

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ABSTRACT

In Niger Delta region of Nigeria, reservoirs are mostly loose and unstratified sands to hold fluids. In this paper, three different wells in central Niger Delta were assessed for shale volume and actual porosity. The results of the analysis delineate the presence of sand, sand-shale and shale formations. Hydrocarbon prospecting was found to be strong in sand, moderate in sand-shale and shallow in shale respectively. However, existence of shale lessens effective porosity and water saturation of the rock formations. The extent of the formation extends from 1300 to 2500 m. Shale volume and actual porosity values extend from 0.00 to 0.302 dec and 0.047 to 0.302 dec which decrease with increasing depth. Comparably, the water saturation and water resistivity extend from 0.432 to 0.779 dec and 0.106 to 2.918 Ohm respectively. These values of actual porosity are strong in sand, moderate in sand-shale and shallow in shale formations. The results from this assessment prove well log a vital and easier tool in assessing of reservoir properties.

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1. INTRODUCTION

Reservoirs in the Niger Delta region of Nigeria indicate a variety of complexities in sandstones, shaly and shale depositions which are loose and unstratified. The presence of shale in the formation within this region has effects on both petrophysical properties and logging tool responses, which reduces effective porosity of the reservoir [1]. Shale are laminated or fissile clastic sedimentary rock with predominance of clay and silt as the detrital components [2, 3]. It is classified into effective and passive shales as clayey, silty or sandy shales on the basis of texture. Effective shale contains montmorillonite and bentonite while passive shale contains kaolinite and chlorite with zero cation exchange capacities which can be identified only by neutron tool [4]. Shale can be assigned in the formation in three ways: In the form of laminae between layers of sand which does not affect the porosity or permeability of the sand streaks. It can exist as grains or nodules in the formation matrix with similar properties of laminae shale and nearby massive shales. It can also be dispersed throughout the sand, partially filling the intergranular interstices. [5]. Porosity is a fraction of the volume of void over total volume between 0 and 1 or as a percentage between 0 and 100%. It is categorized as actual and total porosity. Actual porosity is portions of total void space that displace fluid. Total porosity is the percentage volume occupied by the pore space regardless of the type of fluid contained in the pore space. Information about core analysis technique is important in the assessment of reservoir parameters [6]. Problems such as low productivity of oil, well bore instability, decrease in depth formations and presence of clay particles in void space found unreliability in depositional settings [7]. The formation evaluation problems are as a result of inadequate knowledge of the shale volume and effective porosity evaluation [8]. However, core analyses of sample from formations have been routinely used by some researcher in this region.

This method did not give much areal coverage information and cannot be used in all the rock formations, and this leads to persistence cases of low productivity of oil, well bore instability and decrease in the depth formation due to its coverage limitation outside the coring locations. The current research therefore, based mostly on well logs using Larionov and Archie equations for better evaluation of prospective areas. On the other hand, aid other properties such as lithology, water and hydrogen saturations. Also, information through these well log approaches will aid better identification of reservoir, non-reservoir units and enhance quick decision making in geological setting of the area.

2. GEOLOGY OF THE STUDY AREA

The area under study is the central Niger Delta region of Nigeria. It is situated on the continental margins of the Gulf of Guinea in equatorial West Africa [9]. The region is about 7500km² as the largest delta extending between longitude 3⁰ and 9⁰ East and latitude 4⁰ and 6⁰ North [9-13]. The Niger Delta is classified as a tropical rainforest with ecosystems comprising of diverse species of flora and fauna both aquatic and terrestrial species. The region could be classified into four ecological zones; coastal inland zone, freshwater zone, lowland rainforest zone, mangrove swamp zone and this region is considered one of the ten most important wetlands and marine systems in the world [14, 15]. Three major stratigraphic units have recognized in the onshore and offshore province, namely: Benin, Agbada and Akata formations. Benin formation which the study is housed comprises sand, gravel and swamp deposit [3]. Agbada formation comprises alternating sandstones [16]. It constitutes the main hydrocarbon habitat in the Niger Delta. Akata formation Eocene to Recent is made up of a sequence of under compacted marine clays with minor study and silty beds [17].

3. MATERIAL AND METHOD

A total of three wire line logs data were analyzed, in order to evaluate lithology, shale volume and effective porosity respectively [18]. Fundamentally, high formation of gamma ray designates shale while low formation depicts sand [19]. However, lithology interpretation is the first step in well log analysis and very important in reservoir characterization.

3.1. Shale Volume (V_{sh})

Shale volume is the most important parameters in formation evaluation. It is expressed as shown in Larionov equations (1) to (3).

Tertiary rocks:

$$V_{Sh} = 0.083(2^{3.7I_{GR}} - 1) \quad (1)$$

Older rocks:

$$V_{Sh} = 0.33(2^{2I_{GR}} - 1) \quad (2)$$

$$I_{GR} = \frac{GR_{Log} - GR_{Min}}{GR_{Max} - GR_{Min}} \quad (3)$$

3.2. Porosity (Φ)

Porosity measures the total amount of void space accessible from the surface. It is expressed as shown in Archie equations (4) and (5).

$$\Phi = \frac{Sonic \log \text{valu} \cdot .5}{189 \cdot .5} \quad (4)$$

$$\Phi = \frac{\rho_{ma} \cdot \rho_b}{\rho_{ma} \cdot \rho_{fl}} \quad (5)$$

3.3. Effective Porosity

Effective porosity is the pore volume in rock or sediments that contributes to permeability in a reservoir. It is expressed as shown in Archie equations (6) to (8).

Sand reservoir:

$$\Phi_e = \Phi_t - V_{sh} \times \Phi_{sh} \quad (6)$$

Shale reservoir:

$$\Phi_e = \Phi_t - V_{sh} \times \Phi_t \quad (7)$$

Shale-bound water:

$$\Phi_e = \Phi_t - V_{cbw} \quad (8)$$

4. RESULT AND DISCUSSION

Sand and shale were the prevalent lithologies in Niger Delta region with staunch credibility significance parameters such as permeability, water and hydrocarbon saturation. In order to achieve this goal, three wells namely, wells 1, 2 and 3 were delineated into three zones, namely: 1, 2 and 3 which were modeled appropriately. Sand, sand-shale and shale were identified from the wells as shown in Figure 1 to Figure 3. Table 1 to Table 3 show the evaluation of petrophysical properties within the three wells; 1, 2 and 3 while Table 4 and Table 5 show the ranges of evaluated parameters and characterization of the well formations. In each of the well, three reservoirs were identified. In well 1, the result showed moderate values of the shale volume of 0.347 dec and effective porosity of 0.138 dec, with other parameters such as: mean porosity of 0.211 dec, permeability of 4.324 darc, water saturation and a resistivity value of 0.623 dec and 1.715 Ohmm with moderate hydrocarbon potential from sand-shale formation. In well 2, the result showed high values effective porosity of 0.302 dec and 0.0dec of shale volume with other parameters such as: mean porosity of 0.302 dec, permeability value of 3.847 darc, water saturation and resistivity of 0.432 dec and 2.18 Ohmm respectively. This indicates a high presence of hydrocarbon accumulation from sand formation. In well 3, the result showed high values of shale volume of 0.740 dec and low effective porosity of 0.047 dec with other parameters such as: mean porosity of 0.182 dec, permeability value of 6.454 dec, water saturation and resistivity of 0.799 dec and 2.985 Ohmm respectively. This indicates a low hydrocarbon accumulation from shale formation. However, it is observed that the value of the effective porosity and shale volume ranged from 0.047 to 0.302 dec and 0.182 to 0.302 dec. On the other hand, a higher hydrocarbon potential is allotted to sandy deposition found in well 2 with zero shale volume, bright spot formations. Moderate potential is allotted to sandy-shaly area found in well 1 while moderately potential is allotted to shaly area, less porosity and a higher shale volume found in well 3 depict clay sediments particles. Comparing the evaluated value with core sample analysis delineated much difference in core sample analysis values. This is due to the analytical and conservation sampling approaches compared with the standard values than that of evaluated approaches. However, the foregoing comparison of evaluated approaches with core sample values affirms accuracy and applicability approaches using Larionov and Archie Equations in the study.

Table 1. Well 1

Curves	Units	Upper Values	Lower Values	Difference Values	Minimum Values	Maximum Values	Mean Values
BVW	Dec	1223.05	3040.698	1817.702	0.000	0.411	0.105
CAL	Inch	0	3519.7	3520.551	-999.250	24.299	-340.605
GR_NM	API	0	3519.7	3520.551	-999.250	134.423	36.216
K	Darc	1223.05	3040.698	1817.702	2.053	25.646	4.324
LL9D	gm/cc	0	3519.7	3520.551	-999.250	357.436	-101.946
NPHI	Dec	0	3519.7	3520.551	-999.250	52.006	-478.577
PHI	Dec	1223.05	3040.698	1817.702	0.000	0.600	0.211
RHOB	gm/cc	0	3519.7	3520.551	-999.250	2.589	-346.624
RWapp	Ohmm	1223.05	3040.698	1817.702	0.000	47.022	1.715
SONIC	us/ft	0	3519.7	3520.551	-999.250	170.338	-279.431
SW	Dec	1223.05	3040.698	1817.702	0.046	1.000	0.623
V _{SH}	Dec	1223.05	3040.698	1817.702	0.119	0.876	0.347

Table 2. Well 2

Curves	Units	Upper Values	Lower Values	Difference Values	Minimum Values	Maximum Values	Mean Values
BVW	Dec	1200.023	2499.933	1300.080	0.021	0.348	0.124
CAL	Inch	1200.023	2499.933	1300.080	11.750	17.813	12.333
LL9D	gm/cc	1200.023	2499.933	1300.080	1.745	2.568	2.152
GR_NM	API	1200.023	2499.933	1300.080	26.702	120.198	50.013
K	Darc	1200.023	2499.933	1300.080	2.221	20.688	3.847
NPHI	Dec	1200.023	2499.933	1300.080	0.409	0.409	0.409
PHI	Dec	1200.023	2499.933	1300.080	0.050	0.549	0.302
RHOB	Ohmm	1200.023	2499.933	1300.080	0.750	224.111	28.872
RWapp	Ohmm	1200.023	2499.933	1300.080	0.010	24.366	2.918
SONIC	us/ft	1200.023	2499.933	1300.080	58.200	152.800	114.916
SW	Dec	1200.023	2499.933	1300.080	0.064	1.000	0.432
V _{SH}	Dec	1200.023	2499.933	1300.080	0.000	0.307	0.000

Table 3. Well 3

Curves	Units	Upper Values	Lower Values	Difference Values	Minimum Values	Maximum Values	Mean Values
BVW	Dec	2176.633	2499.627	323.141	0.019	0.204	0.140
CAL	Inch	2176.633	2499.627	323.141	12.344	18.031	13.350
LL9D	gm/cc	2176.633	2499.627	323.141	2.034	2.464	2.197
GR_NM	gAPI	2176.633	2499.627	323.141	26.361	106.837	59.466
K	Darc	2176.633	2499.627	323.141	3.996	52.884	6.454
NPHI	Dec	2176.633	2499.627	323.141	0.128	0.481	0.295
PHI	Dec	2176.633	2499.627	323.141	0.019	0.282	0.182
RHOB	Ohmm	2176.633	2499.627	323.141	1.175	12.407	2.985
RWapp	Ohmm	2176.633	2499.627	323.141	0.002	0.842	0.106
SONIC	us/ft	2176.633	2499.627	323.141	57.625	142.750	113.352
SW	Dec	2176.633	2499.627	323.141	0.241	1.000	0.799
V _{SH}	Dec	2176.633	2499.627	323.141	0.717	0.773	0.740

Where:

BVW = Bulk volume of water,

CAL = Caliper log,

GR_NM = gamma ray neutron meter,

NPHI = Neutron porosity, PHI = porosity,

RHOB = Resistivity density,

RW_{app} = Apparent water resistivity,

SONIC = Sonic log,

SW = Water saturation,

HS = Hydrogen saturation,

V_{SH} = Volume of shale,

K= Permeability

Table 4. Ranges of the evaluated shale volume, effective porosity and other parameters

Parameter	Well 1	Well 2	Well 3
K (darc.)	0.347	0.000	0.740
K (darc.)	0.211	0.302	0.182
Φ _e (dec)	0.138	0.302	0.047
S _w (dec)	0.623	0.432	0.799
K (darc.)	4.324	3.847	6.454
R _{Wapp} (Ohmm)	1.175	2.180	2.985

Table 5. Characterization of the well formations

Wells	Characteristics	Formations
1	Fair Fairly effective porosity, moderate shale volume and hydrocarbon accumulation	Sand- Shale
2	Good Highly porous and good accumulation	Sand
3	Weak highly shale volume and less accumulation	Shale

Figure 1. Well log interpretation of Well 1

Figure 2. Well log interpretation of Well 2

Figure 3. Well log interpretation of Well 3

5. CONCLUSION

The research and analysis carried out from three well delineate in central Niger Delta using Larionov and Archie equations. The result depicts three reservoirs extents 1300 to 2500m, Shale volumes and effective porosity extents 0.00 to 0.740dec and 0.047 to 0.302 dec. Comparably, water resistivity extent 0.432 to 0.779 dec. The evaluated shale volume and effective porosity were compared to core analysis data which give good agreement of the result. Also, prove the method a useful approach for assessment from wire line log data.

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REFERENCES

- [1] I. O. Akpabio, C. I. Johnson, E. Okechukwu and T. Odunayo, "Petrophysical Characterization of Eight Wells from Wire line logs, Niger, Delta, Nigeria," *Asian journal of Applied Science*, vol. 2(2), pp. 105-109, 2014.
- [2] G. E. Archie, "Classification of Carbonate Reservoir Rocks and Petrophysical Consideration," *American Association of Petroleum Geologist, Bulletin*, vol. 4(2), pp. 10-18, 1952.
- [3] M. Mehana and I. El-Monier, "Shale Characteristics impact on Nuclear Resonance (NMR) fluid typing methods and correlations," *Petroleum*, vol. 2(2), pp. 138-147, 2016.
- [4] N. T. Inyang, I. O. Akpabio, and O. E. Agbasi, "Shale Volume and Permeability of the Miocene Unconsolidated Turbidities Sands of Bonga Oil field, Niger Delta, Nigeria," *International journal of Advanced Geosciences*, vol. 5(1), pp. 37-45, 2017.
- [5] K. J. Weber and E. M. Daukoru, "Petroleum Geology of the Niger Delta (9th World)" *Petroleum Congress Proceeding: Tokyo, Japan*, vol. 6(2), pp. 209-221, 1985.

- [6] M. Siyamak, M. Mohammed, K. G. Mohammed, and H. Elaheh, "Determination of Shale Volume Distribution Patterns and Effective Porosity from Well Log Data Based on Cross Plot," *World Multidisciplinary Earth Science Symposium*, vol. 44, 2016.
- [7] O. A. Olafuyi and O. O. Omole, "A Study of Formation Resistivity Factor- Porosity Relationship in the Central Offshore of Niger Delta," *Journal of Economics and Engineering*, 2010.
- [8] N. J. Inyang, E. E. Okwueze, and O. E. Agbasi, "Detection of Gas Sands in the Niger Delta by Estimation of Poisson Damping Factor (PDF) Using Wire Line Log Data," *Geosciences*, vol. 5(1), pp. 46-51, 2015.
- [9] L. F. Awosika, "Impact of Global Climate change and Sea level rise on Resources and Energy Development in Nigeria. In: umolu. J.C., (Ed) Global Climate Change," *Impact on energy development DAMTECH Nigeria limited*, vol. 62(4), pp. 5-11, 1995.
- [10] C. B. Powell, S. A. White, D. O. Ibiebele, M. Bara, B. Dut Kwiez, M. Isoun, and F. U. Oteogbu, "Oil Spill Environmental Impact: Effect on Aquatic Biology, Paper Presented at NNPC/FMHE," *International Seminar on Petroleum Industry and the Nigerian Environment, Kaduna, Nigeria*, vol. 2(6), pp. 168-178, 1985.
- [11] CLO: Civil Liberties Organization, "Blood Trail: Repression and Resistance in the Niger Delta," *Ikeja Country Analysis Brief*, vol. 4(2), pp. 9-14, 2002.
- [12] B. Anifowose, "Assessing the Impact of Oil and Gas Transport on Nigeria's Environment," *U21 Postgraduate Research Conference Proceedings 1*, University of Birmingham UK, vol. 10(2), pp. 40-46, 2008.
- [13] C. Chinweze and G. Abiolu- Oloke, "Women Issues, Poverty and Social Challenges of Climate Changes in the Nigerian Niger Delta," *Context 7th International Conference on the Human Dimension of Global Environmental Changes UN Campus, Bonne Germany*, vol. 11(10), pp. 14-20, 2009.
- [14] FME: Federal Ministry of Environment, "Niger Delta Natural Resources Damage Assessment and Restoration Project, Phase 1 Scoping Report," *Abuja: Federal Ministry of Environment*, vol. 5(2), pp. 10-15, 2006.
- [15] ANEEJ, "Oil of Poverty in the Niger Delta," *A publication of the African Network for Environment and Economic Justice*, vol. 4(2), pp. 53-59, 2004.
- [16] B. D. Evamy, J. Harembource, and P. Kamerly, "Hydrocarbon Habit of Tertiary Niger Delta," *American Association of Petroleum Geologist. Bulletin*, vol. 6(2), pp. 1-29, 1978.
- [17] M. U. Igbokwe, R. V. Gurundha, and E. E. Okwueze, "Groundwater flow modeling of Kwa Ibo River Watershed," *South Eastern Nigeria Hydroelectric Process*, vol. 3(11), pp. 1523-1531, 2008.
- [18] G. Asquith and Gibson, "Basic Well Log Analysis for Geologists," *American Association of Petroleum Geologist. Methods for Exploration Series*, vol. 2(3), pp. 12-18, 1982.
- [19] R. E. Chapman, *The logging of Boreholes: Petroleum Geology. Concise Study*, Elsevier, Amsterdam, pp. 107-157, 1983.