INTERNATIONAL JOURNAL FOR RESEARCH IN EMERGING SCIENCE AND TECHNOLOGY, VOLUME-5, ISSUE-4, APR-2018 E-ISSN: 2349-7610

A Comparative Study of the Methods of Determining Shale Volume in Radioactive Reservoirs of "AMA" Field, Niger Delta, Nigeria

Fadiya, S. L.[1], Alao, O. A.[2] and Adetuwo, A. M.[3]

[1]Lecturer, Department of Geology, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria
[1] fadiyalawrence@yahoo.co.uk
[2] Lecturer, Department of Geology, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria
[2]olade77@yahoo.com.com
[3]Graduate Student, Department of Geology, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria
[3]adetuwomichael@gmail.com

ABSTRACT

Shale effect in reservoir rocks is one of the most controversial problems in formation evaluation. The presence of highly-radioactive material in shaly sand reservoirs, overestimates the shale volume producing an overall pessimistic scenario of the reservoir quality. An accurate determination of shale volume impacts in the calculation of formation porosity and water saturation and therefore affects the original oil in place and reserves. This paper presents a comprehensive approach for handling this problem of radioactive shaly sand reservoirs. A combination method is provided to calculate the accurate value of shale volume for different scenarios from different shale volume computation methods. The study concluded that the combination method was the most reliable for estimating shale volume which fall within the acceptable range. It also concluded that the Clavier method was most reliable in oil bearing radioactive reservoirs while the resistivity method was most reliable in estimating shale volume in gas bearing radioactive reservoirs.

Index Term— Shale volume, Comparative, Radioactive, and Reservoirs

1. INTRODUCTION

Several investigations over the years ([8], [7], [9], [16]) 13 confirmed a wide geographical spread of radioactive sand in the Niger Delta. The occurrence of radioactive sands ranges from 10 to 100ft. In wells where they occur, they can account for as much as 55 – 70% of hydrocarbon zones. Also about 35-45% of hydrocarbon bearing reservoirs in the Niger Delta is believed to be radioactive.

Quartz, the principal component of the coarse-grained detrital rocks originally shows no radioactivity [14]. Sandstones therefore usually show low gamma ray values. However, if the sources of the sediments are near-by granitic highlands, implying that the detrital materials have not undergone sufficient transportation and weathering, then the parent minerals like feldspar (K), micas and heavy minerals would be retained in the sedimentary rock. In this case, the sands and gravel may be highly arkosic (high feldspar content), with high content of K^{40} or may contain zircon enriched with thorium. Petrophysical data is always the basis for understanding petroleum reservoirs and plays a very important role in oil and gas reservoirs/field management and development. The occurrence of radioactive minerals in hydrocarbon bearing formations presents to the petrophysicist a major challenge in the delineation, quantification and production of hydrocarbon resources [14]. The challenge that is posed in this case is how net sand is defined and what constitutes valid criteria for differentiating net reservoir from non-reservoir intervals. In order to accurately evaluate radioactive sands in the Niger Delta, two problems have to be solved:

 COPYRIGHT © 2018 IJREST, ALL RIGHT RESERVED

a) Accurate estimation of volume of shale (V_{sh}) for net sand computation

b) Accurate determination of porosity

The estimation of the V_{sh} in shaly reservoirs is conventionally done using the gamma ray log. However, the presence of a radioactive material like uranium and potassium that is not directly associated with shale can result in erroneous values of water saturation and effective porosity due to overestimation of the volume of shale that arises from the gamma ray log. Accurate and reliable estimation of the porosity, permeability and water saturation of shaly reservoirs is solely dependent on proper estimation of the V_{sh}.

Shaliness is known to affect both formation characteristics and logging tool response ([10], [6]). This has now placed much importance on V_{sh} calculation from logs because of its further influence on the computation of important petrophysical properties such as porosity and water saturation [3]. V_{sh} can be derived from log measurements using Gamma Ray (GR), Spontaneous Potential (SP), Neutron-Density Combination (N/D) and Resistivity Logs. Due to inaccurate prediction of V_{sh} from GR log when it encounters radioactive sand, A comparative analysis of all the methods in estimating V_{sh} in shaly sand units, taking into consideration the strengths and limitations of the logs is therefore necessary. For the purpose of this study, the V_{sh} was estimated using the gamma-ray, spontaneous potential, resistivity and the neutron-density combination logs in order to determine the true quality of the reservoir and the quantity of hydrocarbon present in the formation.

“AMA” Field is located in the shallow offshore region of the Niger Delta Basin. Figure 1 is the map of the Niger Delta showing the approximate location of the study area.

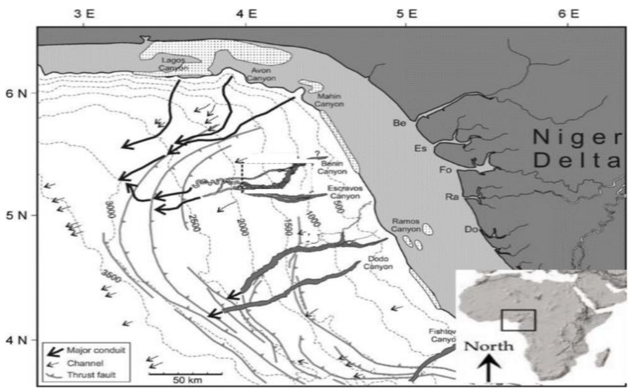

Fig-1: Map of Niger Delta Showing the Study Area (Modified from [12 Study Area

2. MATERIALS AND METHOD

The data used for this study were obtained from chevron Nigeria limited through the Department of Petroleum Resources, Nigeria. The sets of data included 3D seismic data, checkshot data, and a suite of borehole logs comprising Spontaneous Potential (SP), Gamma Ray (GR), Sonic (DT), Neutron (NPHI), Bulk Density (RHOB) and a number of Resistivity Logs. Figure 2 is the base map of the study area, with the well locations indicated with black dots.

High gamma ray values between 80-150 API units were classified as shale intervals while values lower than 80 API were interpreted as sand units. In the Niger Delta, the sand units are regarded as the reservoir units because shale is not porous and permeable enough to host, retain and release fluid. The lithology logs (SP and GR) were used together only because they compensate for each other, if a deflections does not show the same pattern on both logs, then we can infer that there must have been a radioactive effect or lithological change.

In the sand units delineated, differentiation between reservoir fluids (hydrocarbon and water) was done using the resistivity log. Since the resistivity of hydrocarbon is higher than that of the formation water [16], hydrocarbon sand units were inferred from high resistivity values observed from the resistivity readings.

The neutron-density combination log was also used to identify gas bearing formations. The checkshot data was used in the conversion of time values to depth, and for well to seismic tie. The seismic section was used for overall sub-surface appraisal of structural features, and for tracking lateral variation and changes in lithofacies. The entire interpretation was done using the Schlumberger Petrel Software. The evaluation study was carried out in two Phases; Petrophysical data analysis and Seismic data interpretation.

 COPYRIGHT © 2018 IJREST, ALL RIGHT RESERVED

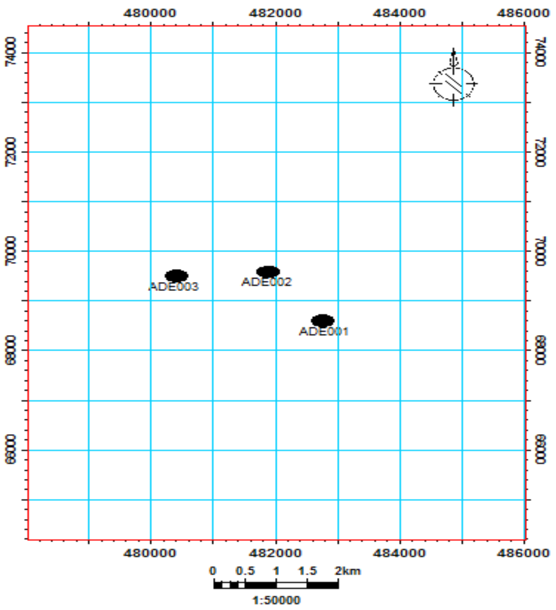

Fig-2: Base Map of the Study Area Showing the Well Locations

2.1. Volume of Shale (V_{sh}) Determination

The volume of shale in the radioactive reservoirs was computed using the conventional gamma ray, resistivity, spontaneous potential and neutron-density combination log. A Linear estimation from the GR log (I_{GR}) and a non-linear estimate was done using the conventional Larionov method. The Steiber and Clavier methods were also used to estimate V_{sh};

2.1.1. Linear formula from [5]

$$V_{sh}=I_{GR} = \frac{GR_{log}-GR_{min}}{GR_{max}-GR_{min}} \quad \ldots\ldots\ldots\ldots (1)$$

Where the I_{GR} = Linear volume of shale estimation (Gamma-ray Index)

GR_{log} = Gamma Ray reading of the zone of interest

GR_{min} = Minimum Gamma Ray reading

GR_{max} = Maximum Gamma Ray reading

2.1.2. Reference [15] Tertiary rocks method (non-linear)

$$V_{sh} = 0.083(2^{(3.7\times I_{GR})} - 1)\ldots\ldots\ldots\ldots (2)$$

Where:

$V_{sh} = volume\ of\ shale$

2.1.3. Volume of shale from sp log

$$V_{sh} = 1.0 - \frac{PSP}{SSP} \quad \ldots\ldots\ldots\ldots (3)$$

2.1.4. V_{sh} for neutron-density combination log method utilized the Crain's neutron-density chart (Figure 3)

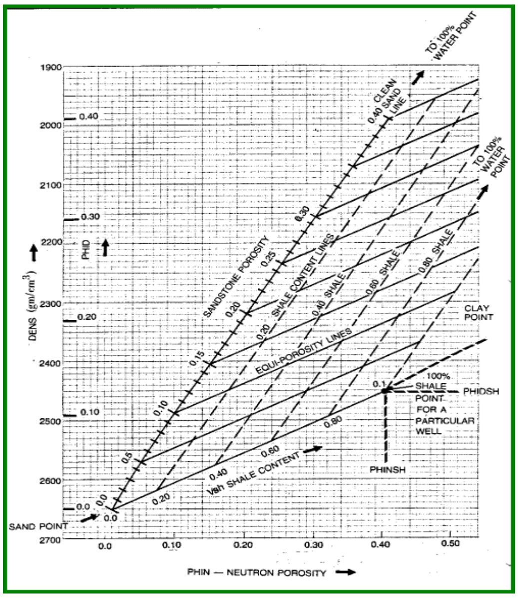

Fig-3: Neutron-Density Cross Plot [4]

2.1.5. Volume of shale from resistivity log according to [2]

$$V_{sh}\ RESISTIVITY = \frac{\log(RESD) - \log(RESD_{CLN})}{\log(RESD_{SHL}) - \log(RESD_{CLN})} \ldots (4)$$

Where;

RESD = Resistivity log reading from zone of interest

$RESD_{CLN}$ = resistivity log reading from clean sand

$RESD_{SHL}$ = resistivity log reading from adjacent shale

2.2. Porosity Determination

2.2.1. Total porosity

The Density log was used to calculate porosity.

Density-derived porosity (porosity from density log), $\emptyset_d$ is computed using the equation:

$$\emptyset_d = \frac{\rho_{ma}-\rho_b}{\rho_{ma}-\rho_f} \quad \ldots\ldots\ldots\ldots (5)$$

Where;

 COPYRIGHT © 2018 IJREST, ALL RIGHT RESERVED

ρ_{ma} = Density of matrix material (2.648 gm/cc for sandstone)

ρ_b = Bulk density (read from the density log)

ρ_f =Density of the drilling fluid (0.85 gm/cc for oil based mud)

2.2.2. Effective porosity

The formula used to compute the effective porosity is shown below:

$$\emptyset_{eff} = \emptyset_{total} \times (1 - V_{sh}) \quad (6)$$

Where;

V_{sh} = Volume of Shale

$\emptyset_{total}$ = Total Porosity

$\emptyset_{eff}$ = Effective Porosity

2.4 Determination of Water Saturation

Water saturation was estimated using the Simandoux equation. The Simandoux equation has been proven to be more effective especially in shaly sand units as reported by [11] after comparing the Archie's equation and the Simandoux equation. R_w was estimated in a clean water-bearing interval where S_w = 1, using deep resistivity reading. S_w was thereafter estimated using the computed R_w and $\emptyset_{eff}$.

The Simandoux equation ([11]) for water saturation is expressed as;

$$S_w = \frac{C \times R_w}{\emptyset^2{}_{eff}}\left[\sqrt{\frac{5\emptyset^2 e}{R_w \times R_t} + \left(\frac{V_{sh}}{R_{sh}}\right)^2} - \frac{V_{sh}}{R_{sh}}\right] \quad (7)$$

Where;

C = 0.40 for sand and 0.45 for carbonate

V_{sh} = Volume of shale

R_t = Deep resistivity (corrected for invasion)

R_{sh} = Deep resistivity reading in adjacent shale

ϕ_{eff} = Effective porosity

S_w = Water Saturation

3. RESULTS AND DISCUSSION

The V_{sh} was estimated using seven different methods; Linear GR log, Larionov, Steiber, Clavier, Resistivity, Neutron-Density combination and Spontaneous Potential logs. In order to establish a control for the proper determination of true V_{sh} values, the radioactive sand units were classified as acceptable, fair and unacceptable based on the following volume of shale cut-offs;

i. < 12% implies an acceptable value [13]
ii. 12 - 34% implies a fair result
iii. >35% implies an unacceptable value [1].

A total of three radioactive hydrocarbon bearing sand units were identified and correlated across three wells (ADE 001, ADE 002 and ADE 003) in "AMA" field, Niger Delta. Volume of shale estimation was carried out on the three identified radioactive sand units using seven different methods (Linear Gamma Ray (GR) Measurement, Larionov, Steiber, Clavier, Resistivity, Neutron-Density and SP logs).

For the purpose of the results discussion, Sand 003 will be used as a reference reservoir. The V_{sh} estimates from Linear Gamma-Ray, Larionov, Steiber, Clavier, and Neutron-Density Combination logs have average values of 32, 26.3, 53, 17.7 and 17% respectively for Sand 03, while the V_{sh} estimates from Resistivity and Spontaneous Potential Logs methods have average values of 4.6 and 54.3% respectively (Figure 4). The results showed that the GR direct linear measurement overestimates V_{sh} in radioactive sand units, as discovered from comparison with established volume of shale cut-offs from previous studies, used to classify the V_{sh} values as acceptable, unacceptable and fair. The V_{sh} estimated from other methods, showed a reduction

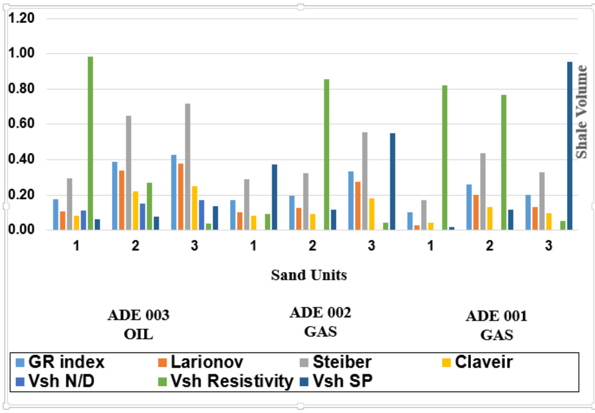

Fig-4: V_{sh} Distribution for the Seven Different Methods

in the V_{sh} values relative to the linear method, except for the Steiber method that further overestimated V_{sh} values. This result is an indication that the Steiber method overestimates V_{sh} in radioactive sand units. Results were also generated for the combination method adopted for this research work which

 COPYRIGHT © 2018 IJREST, ALL RIGHT RESERVED

finds the average of results from the two most feasible of the seven methods.

The resistivity method presented an erroneously low V_{sh} of 4% from Sand 03 in ADE 003. This low value was however attributed to the fluid type (Table I). The study revealed an average effective porosity of 21% for the Larionov method, while the combination method has a higher average effective porosity value of 25% in the hydrocarbon bearing reservoirs. The permeability values ranged from 118.04 – 879.47 md and 856.98 – 2710.25 md for the conventional and the combination methods respectively, indicating that the identified reservoirs are of very good to excellent quality (Tables II and III).

Table I: V_{sh} Results for the Seven Different Methods

Well Identity	Reservoir Identity	Gross Thickness (ft)	Net Thickness (ft)	V_{sh} IGR	V_{sh} Larionov	V_{sh} Steiber	V_{sh} Clavier	V_{sh} Resistivity	V_{sh} N/D	V_{sh} SP
ADE 001	SAND 01	89.18	72.62	0.10	0.03	0.17	0.05	0.82		0.02
	SAND 02	39.02	25.23	0.26	0.20	0.44	0.13	0.77		0.12
	SAND 03	119.85	75.61	0.20	0.13	0.33	0.10	0.06		0.95
ADE 002	SAND 01	89.57	59.17	0.17	0.10	0.29	0.08	0.09		0.37
	SAND 02	20.47	13.36	0.19	0.13	0.32	0.09	0.85		0.12
	SAND 03	90.04	73.43	0.33	0.28	0.55	0.18	0.04		0.55
ADE 003	SAND 01	55.69	38.13	0.18	0.11	0.30	0.08	0.98	0.11	0.06
	SAND 02	14.99	8.23	0.39	0.34	0.65	0.22	0.27	0.15	0.08
	SAND 03	96.39	71.56	0.43	0.38	0.72	0.25	0.04	0.17	0.13

Oil Bearing **Gas Bearing**

Table II: Petrophysical Parameters for the Combination Method

Well Identity	Reservoir Identity	Net-Gross Thickness (ft)	V_{sh} cb	Porosity	Effective Porosity	S_{wirr}	K(md)	S_w	S_h	BVW
ADE 001	SAND 01	0.81	0.03	0.26	0.25	0.08	2465.06	0.89	0.11	0.22
	SAND 02	0.65	0.13	0.30	0.26	0.08	3398.72	0.87	0.13	0.22
	SAND 03	0.63	0.08	0.24	0.22	0.09	903.28	0.61	0.39	0.14
ADE 002	SAND 01	0.66	0.09	0.25	0.22	0.09	1024.36	0.32	0.68	0.07
	SAND 02	0.65	0.11	0.26	0.24	0.08	1580.73	0.86	0.14	0.20
	SAND 03	0.82	0.11	0.27	0.24	0.08	1840.65	0.15	0.85	0.04
ADE 003	SAND 01	0.68	0.07	0.25	0.23	0.08	1418.04	0.87	0.13	0.20
	SAND 02	0.55	0.18	0.31	0.25	0.08	2710.25	0.34	0.66	0.09
	SAND 03	0.74	0.21	0.28	0.22	0.09	856.98	0.07	0.93	0.01

Oil Bearing **Gas Bearing**

Table III: Petrophysical Parameters for the Larionov Method

Well Identity	Reservoir Identity	Net-Gross Thickness (ft)	I_{GR}	V_{sh}	Porosity	Effective Porosity	S_{wirr}	K (md)	S_w	S_h	BVW
ADE 001	SAND 01	0.81	0.10	0.03	0.26	0.25	0.08	2596.58	0.87	0.13	0.22
	SAND 02	0.65	0.26	0.20	0.30	0.24	0.08	1650.04	0.88	0.12	0.21
	SAND 03	0.63	0.20	0.13	0.24	0.21	0.10	545.72	0.89	0.11	0.18
ADE 002	SAND 01	0.66	0.17	0.10	0.25	0.22	0.09	879.47	0.88	0.12	0.19
	SAND 02	0.65	0.19	0.13	0.26	0.23	0.09	1316.08	0.88	0.12	0.20
	SAND 03	0.82	0.33	0.28	0.27	0.20	0.10	348.15	0.89	0.11	0.17
ADE 003	SAND 01	0.68	0.18	0.11	0.25	0.22	0.09	1027.96	0.88	0.12	0.20
	SAND 02	0.55	0.39	0.34	0.31	0.21	0.10	500.13	0.89	0.11	0.18
	SAND 03	0.74	0.43	0.38	0.28	0.17	0.12	118.04	0.90	0.10	0.15

Oil Bearing **Gas Bearing**

The combination method was thereafter used to estimate the V_{sh} in Sand 03 which revealed an average value of 13% (Table IV and Figure 5). The V_{sh} results generated through the combination method revealed values that fell within the acceptable range of the established cut-offs for this study, except for Sand 02 and Sand 03 in ADE 003 which were classified as fair to good. However, all other methods did not give values within the established cut-offs in Sand 03 except for the resistivity method.

Table IV: V_{sh} Values Derived from Linear Gamma Ray, Larionov and the Combination Methods

Well Identity	Reservoir Identity	Gross Thickness (ft)	Net Thickness (ft)	V_{sh} IGR	V_{sh} Larionov	V_{sh} cb
ADE 001	SAND 01	89.18	72.62	0.10	0.03	0.03
	SAND 02	39.02	25.23	0.26	0.20	0.13
	SAND 03	119.85	75.61	0.20	0.13	0.08
ADE 002	SAND 01	89.57	59.17	0.17	0.10	0.09
	SAND 02	20.47	13.36	0.19	0.13	0.11
	SAND 03	90.04	73.43	0.33	0.28	0.11
ADE 003	SAND 01	55.69	38.13	0.18	0.11	0.07
	SAND 02	14.99	8.23	0.39	0.34	0.18
	SAND 03	96.39	71.56	0.43	0.38	0.21

Oil Bearing **Gas Bearing**

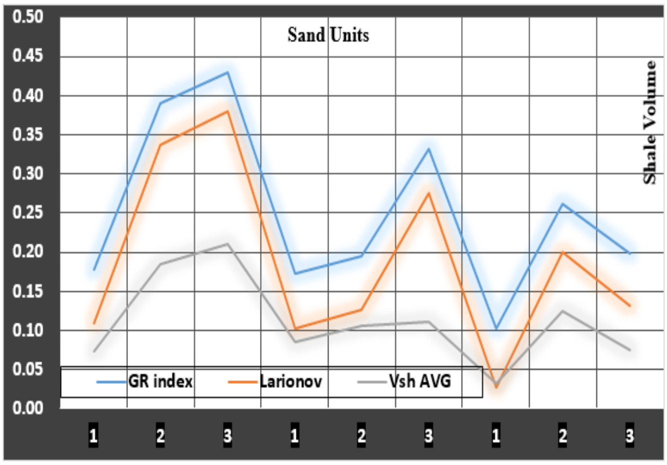

Fig-5: Line Chart of V_{sh} for the Linear GR Measurement, Larionov and the Combination Method (V_{sh} AVG).

The Simandoux equation was adopted to estimate the water saturation after estimating V_{sh} using the combined method; this was done to further ensure proper estimation of the water saturation as the Archie's equation has been proven to overestimate water saturation in shaly sand units. The average values derived for water saturation are 82 and 42% in the conventional Larionov and the combination methods respectively.

Time and depth structural contour maps were produced for the two horizons mapped, namely H1 (Reservoir Sand 001) and

 COPYRIGHT © 2018 IJREST, ALL RIGHT RESERVED

H3 (Reservoir Sand 003) (Figures. 6, 7, 8 and 9). The time and depth structure maps showed similar structural configuration, which is an indication that the time-depth conversion is good. The time and depth structure contour maps showed similar relationship in terms of the behavior of the two regional growth faults, which are dipping to the south and quite extensive covering about 85% of the entire breadth of the mapped area. Synthetic faults are seen to occur almost at the edge (NE) of the mapped area. Two faults (F1 and F2) seen on the map: give a fault dependent structure favorable for hydrocarbon accumulation with most of the wells drilled within the field located there. The original oil in place and the original gas in place were also estimated as 11,235,206.78 (bl) and 63,083,991.65 (scf) respectively for the Conventional Larionov method while 88,565,833.31 (bl) and 497,283,797.2 (scf) were

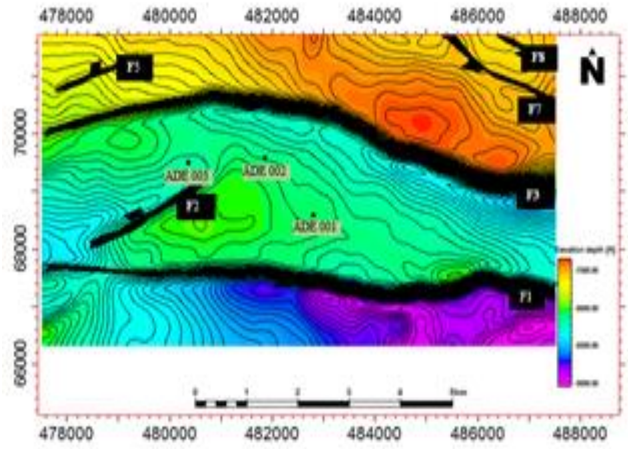

Fig-6: Sand1 Time Map Displaying Fault Polygon

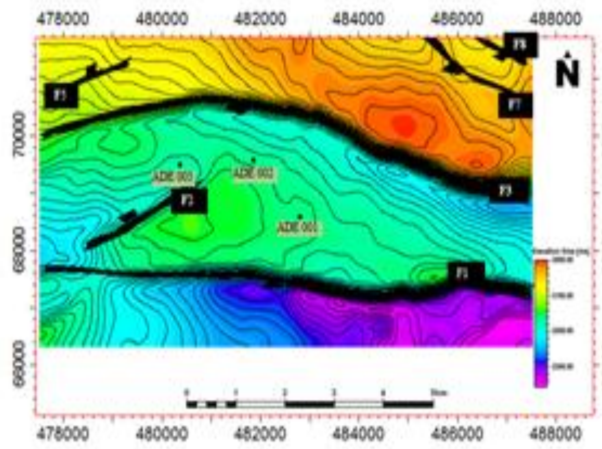

Fig-7: Sand1 Depth Map Displaying Fault Polygon

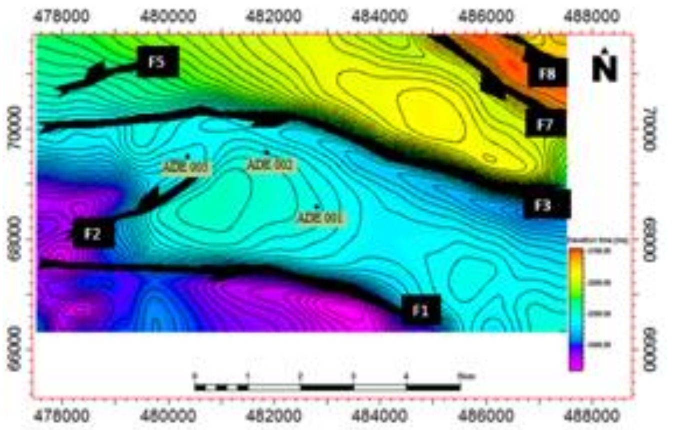

Fig-8: Sand 3 Time Map Displaying Fault Polygon

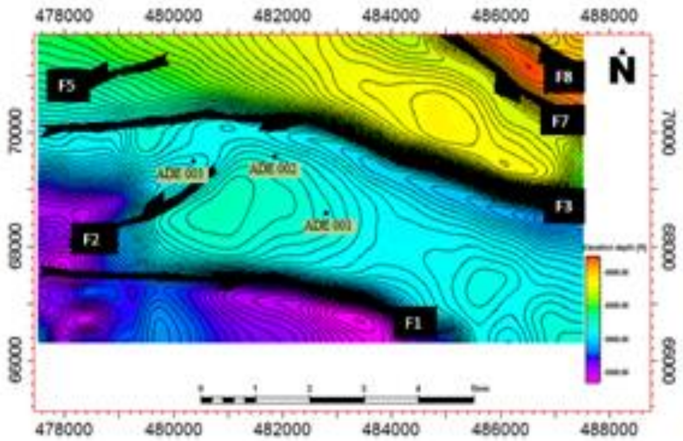

Fig-9: Sand 3 Depth Map Displaying Fault Polygon

the values estimated for the Combination method in Sand 03. Figures 10 and 11 are column charts displaying the variations in the volume of oil and gas for both methods in Sands 003 and 001 respectively.

Figure 12 shows the S_w values for both conventional and the combination methods. The results from the combination method revealed an improved hydrocarbon potential and a much lower V_{sh} values which showed a fair to good range relative to the standard cut-offs adopted for this study. The original oil in place and the original gas in place were estimated as 5,655,055.54 (bl) and 31,752,284.01 (scf) respectively for the conventional Larionov method while 14,595,577.65 (bl) and 81,951,967.31 (scf) were the values estimated for the Combination method in Sand 01.

 COPYRIGHT © 2018 IJREST, ALL RIGHT RESERVED

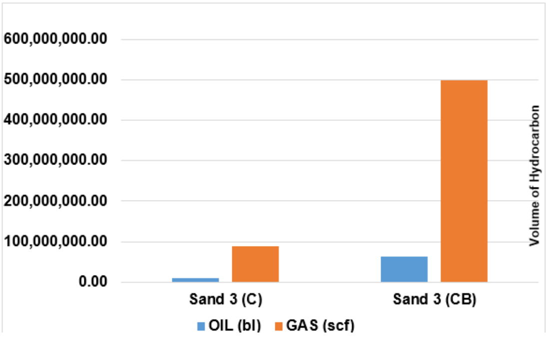

Fig-10: Column Chart Displaying the Variation in the Volume of Oil and Gas for Both Methods in Sand 3 (R3)

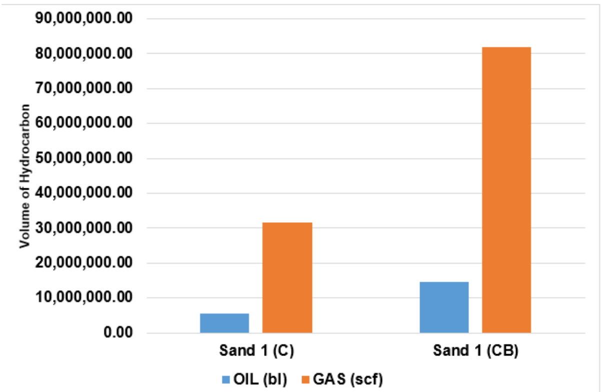

Fig-11: Column Chart Displaying the Variation in the Volume of Oil and Gas for both methods in Sand 1 (R1)

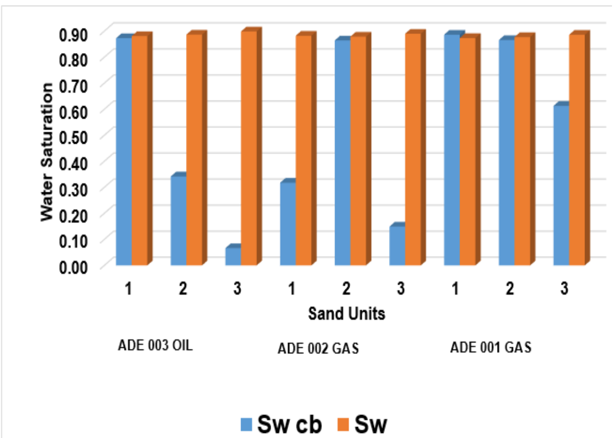

Fig-12: Shows the S_w Distribution for both Conventional and the Combination Methods

4. CONCLUSIONS

The study concluded that, using a combined method like the combination method proves to be more effective in estimating V_{sh}. The Clavier method showed the most acceptable V_{sh} results in oil bearing radioactive reservoirs, resistivity log method showed most acceptable results in gas bearing radioactive reservoirs. This study however recommends an extensive research work on radioactive reservoirs involving the use of shale volume estimation derived from core data relative to shale volume computation from log interpretation.

ACKNOWLEDGEMENTS

The authors would like to appreciate Chevron Nigeria Limited, Directorate of Petroleum Resources, Schlumberger and Exxon Mobil Nigeria for making available for use, the data set, Petrel Software and the workstation computers in the Department of Geology, Obafemi Awolowo University, Ile-Ife.

We also thank the Department of Geology, Obafemi Awolowo University, Ile-Ife for accessibility to these resources.

REFERENCES

[1] A. A. Adepelumi, O. A. Alao and T. F. Kutemi. “Reservoir characterization and evaluation of depositional trend of the Gombe sandstone, southern Chad basin Nigeria”. Journal of Petroleum and Gas Engineering, Vol. 2(6): p. 118-131. 2011.

[2] A. Poupon, C. Clavier, J. Dumanoir, R. Gaymard and A. Misk. “Log Analysis of Sand-Shale Sequences. A Systematic Approach”. Journal of Petroleum Technology, Vol. 22(7): p. 867-881. 1970.

[3] D. Adeyemo, J. P. Logan and S. Saha. “Enhanced clay characterization and formation evaluation with wire line spectroscopy tool”. In the Proceedings of the 2005 SPWLA Annual Logging Symposium, held in New Orleans, Louisiana, United States, p. 1-12. 2005.

[4] E. R. Crain. Crain’s Petrophysical Handbook; 3rd Millennium Edition: 2001. http://www.spec2000.net/11-vshnd.htm [accessed March 24, 2017].

[5] G. B. Asquith and C. R. Gibson. “Basic Well Log Analysis for Geologists”. American Association of Petroleum Geologists, ISBN-10: 0891816526; ISBN-13: 978-0891816522, p216. 1983.

[6] I. Aigbedion, and S. E. Iyayi. “Formation Evaluation of Oshioka Field Using Geophysical Well Logs”. Middle-East Journal of Scientific Research, Vol. 2(3-4): p. 107-110. 2007.

COPYRIGHT © 2018 IJREST, ALL RIGHT RESERVED

[7] K. C. Short and J. Stauble. “Outline of Geology of Niger Delta”. American Association of Petroleum Geologists Bulletin, Vol. 51: p. 761-779. 1967.

[8] K. J. Weber. “Sedimentological aspect of oil fielding the Niger Delta”. Geol. Minjbouw, Vol. 50: p. 559-576. 1971.

[9] K. J. Weber and L. C. Van Geuns. “Framework for Construction Clastic Reservoir Simulation Models”. Journal of Petroleum Technology, Vol. 42, p. 1248-1297. 1990.

[10] L. Adeoti, E. A. Ayolabi, and P. L. James. “An Integrated Approach to Volume of Shale Analysis: Niger Delta Example, Orire Field”. World Applied Sciences Journal, Vol. 7(4): p. 448-452. 2009.

[11] L. Adeoti, , A. A. Ojo, O. B., Olatinsu, O. O. Fasakin, and O. Y. Adesanya. “Comparative Analysis of Hydrocarbon Potential in Shaly Sand Reservoirs Using Archie and Simandoux Models: A Case Study of “X” Field, Niger Delta, Nigeria”. Ife Journal of Science, Vol. 17(1), p. 15-29. 2015.

[12] M. E. Deptuck, Z. Sylvester, C. O. Pirmez and C. Byrne. “Migration-aggradation history and 3-D seismic geomorphology of submarine channels in the Pleistocene Benin-major Canyon, western Niger Delta slope”. Marine and Petroleum Geology 24, 406-433. 2007.

[13] O. A. Alao and T. E. Oludare. “Classification of Reservoir Sand-Facies Distribution Using Multi-Attribute Probabilistic Neural Network Transform in “Bigola” Field, Niger Delta, Nigeria”. Ife Journal of Science, Vol. 17(3), p. 579-589 2015.

[14] O. Chudi and S. Roya. “Petreophysical Characterization of Radioactive Sands – Integrating Well Logs and Core Information – A Case Study in the Niger Delta”. Society of Petroleum Engineers, 163020: p. 1-8. 2012.

[15] V. V. Larionov. “Borehole Radiometry”. Moscow, U.S.S.R., Nedra: p. 115-121. 1969.

[16] Schlumberger Log Interpretation, Principles and Application: Schlumberger Wireline and Testing, Houston, Texas: 1989.

 COPYRIGHT © 2018 IJREST, ALL RIGHT RESERVED