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RESEARCH ARTICLE

SUBSURFACE MATRIX ARRANGEMENTS OF THE S-FIELD OIL RESERVOIR IN NIGER DELTA BASIN

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ABSTRACT

Evaluation of textural parameters were carried out to understand the arrangements of reservoir matrix (rocks). Well data were obtained from wells 001, 002 and 003 and used to generate suites of logs like gamma ray, density and sonic. Microsoft Excel was the software adequately used. The lithology was identified as sand for gamma ray information less than 75 API (or shale if this value is greater than 75 API). Gamma ray log and density log with respect to depth were generated. These results were used to obtain porosity; the average result of porosity estimated are approximately 17.42%, 29.98% and 17.53% from wells 001, 002 and 003 respectively. The outcomes of sorting, skewness and kurtosis are 9.09, 1.62 and 0.47 respectively for well 001; 1.52, 0.23 and 1.20 respectively for well 002 and lastly, corresponds to 4.76, 0.22 and 0.60 for well 003. The matrices making up the lithology are therefore extremely poorly sorted, very fine skewed and platykurtic for well 001; poorly sorted, coarse skewed indicating high energy environment and leptokurtic for well 002; poorly sorted, coarse skewed (high energy environment) and very platykurtic for well 003. Moreso, the porosity obtained is in the good class for wells 001 and 003 but excellent for well 002.

KEYWORDS

Matrix, S-Field, Reservoir, Porosity, Textural Parameters, Ogive

1. INTRODUCTION

Porosity is the void in the rock which is important for the build-up of fluids (oil, gas and water) and the basics in understanding the reservoir's matrix arrangement (Uko et al., 2013). The estimation of porosity from well log data is vital as it offers valuable indication about the capacity of reservoir rock to store and transmit fluids (Umoren et al., 2023). Some reservoirs have porosity in the range of 5-45% (Egeh et al., 2001; Atat et at., 2023a). It is a requirement needed to assess the potential volume of hydrocarbons availability (Akankpo et al., 2015). Porosity may be negligible if it is less than 0.05, poor if it is within 0.05 to 0.09, fair if its within the range of 0.10 to about 0.14; 0.15 to 0.24 is considered as good, 0.25 to almost 0.30 is very good and porosity values greater than 0.30 is excellent (Udo et al., 2017).

The use of statistical parameters is essential for environmental reconstruction as it helps to discriminate ancient environments. Textural parameter such as skewness is an environmental pointer. A well sorted lithology (matrix) is one in which the grains are of the same size. Poorly sorted sediment comprises a disordered mixture of different sizes of grain. Newton's first law is also applicable here. A matrix at rest will continue to be at rest and the one in motion with constant velocity will remain in motion with constant velocity except it is forced to change that position by forces acting on it. By his second law, this body will move in the direction in which the force acts. A greater energy is needed for a greater force to be applied to move sediment and where this energy cannot supply the minimum required force, the coarser matrices are deposited. In overall, coarser sediment are left behind by the transportation process and found closer to its source; fine ones are found farther away from the source (Atat et al., 2022).

Researchers, has worked on the Estimation of Porosity using Mechanical Specific Energy (MSE) approach; worked on the formation of Young's modulus using textural parameters such as (Kirkham, 2022; Atat et al., 2024a). Have used a novel approach for fracture porosity estimation of carbonate reservoirs where they developed a fracture porosity estimation method using empirical and analytical solutions based on the wire line data considering stress conditions (Sharifi et al., 2023). As conducted research on Percentile- Ogive approach determines the textural parameters of Xa Field Lithologies and the suitable technique for Porosity Estimates (Atat et al., 2022).

The study on the subsurface matrix arrangements of S-Field in Niger Delta Basin is significant as it makes available detailed understanding of the arrangements of reservoir rocks (matrix); provides understandings into the porosity and fluid flow patterns. The study will either encourage or discourage the development of oil wells within this Field. Oil reservoir in the Niger Delta basin faces challenges in improving oil production and maximizing recovery due to a lack of comprehensive understanding of its subsurface matrix and complex matrix arrangements.

1.1 Geology and location

According to the article written, the Niger Delta Basin (Figure 1) is situated between latitude 3°N and 6°N and longitude 5°E and 8°E (Reigers et al., 1996; Akpabio et al., 2023a; 2023b; Atat et al., 2023b). Also agreed with this information (Eyibio et al., 2023; Umoren et al., 2019); Atat and Umoren, 2016). The Niger Delta Province contains Akata–Agbada petroleum system (Ekweozor and Daukoru, 1994). The region experiences wet and dry seasons annually (Atat et al., 2020a; George et al., 2017; Ejoh et al., 2023; Benjamin et al., 2022). The S-Field is a major oil and gas field located in the Niger Delta Basin. This Field is characterized by a complex

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subsurface matrix arrangement. The Niger Delta is the most prolific hydrocarbon-producing basin in Africa (Umoren et al., 2020). The deposit of crude oil is really large (Atat et al., 2023c). Reservoirs in this field generally consist of sandstone and shale layers, affecting the distribution and flow of hydrocarbons (Short and Stauble, 1967). Thick Sedimentary formations of late Tertiary and Holocene ages are seen and the surface is about 1.76 x 10^2m above sea level (Atat et al., 2020b; Atat et al., 2021a).

Figure 1: Map of the Study Area (Umoren et al., 2023)

2. THEORETICAL BASIS

2.1 Few words on density

Density is the mass of a unit volume of a material substance. In Geophysics terms, density is the intrinsic unit mass of a material. Bulk density (matrix density and pores fluid density) is a very important physical property that is used as main parameter to estimate physical characteristics (porosity, water and hydrocarbons saturation, shale volume and many others). In order to obtain density from well log; parameters such as compressional wave velocity, density and gamma ray data from the well has to be available. Density is one of the critical parameters used in petrophysics and geophysics to characterize and understand the composition and properties of rock formations (Umoren et al., 2024).

The accurate density information is significant for characterization of reservoir. Equation 1 is the most suitable expression for density determination from Gardner's model but with local fit constants obtained since the case study is Niger Delta by (Atat et al., 2020a; 2020c).

$$\rho = bV_p^n \tag{1}$$

Where V_p is compressional wave velocity

b and n are local fit constants for sand and shale lithology

ρ is density.

The major findings resulting from the local fit for sands and shales differentiated from the work done, indicates b and n from compressional wave velocity as 0.23 and 0.27 by (Atat et al., 2020a; 2020d).

The density log is a continuous record of a formation bulk density. The density log measures the apparent density of the formation by means of the interaction between the gamma logs. The density log measures the apparent density (RHOB) of the formation by means of the interaction between the gamma rays emitted by a radioactive source and the rock. It allows the measurement of the bulk density in subsurface formations. Density logging is a well logging tool that can provide a continuous record of a formation bulk density along the length of a borehole. It is one of the three well logging tools that are commonly used to calculate porosity; the other two being sonic logging and neutron porosity logging. A low-density formation decreases the GR less than a zone with high density (Atat et al., 2024b; Akpabio et al., 2023b)

2.2 Porosity

The behaviour of fluids in the voids of a rock is fundamental to the study of many of the problems of oil-field development and production. For it is by virtue of these openings between grains that oil and gas can move through the rock, to be contained by the rock, and to pass from the rock into the well (Fraser, 1935).

The number of internal spaces in a given volume of rock is a measure of the amount of fluid a rock will hold. The amount of void space interconnected, and able to Transmit fluids is called Effective Porosity while a void space that is connected and not Connected is called Total Porosity. Porosity can be primary or secondary. Primary porosity is that which a rock possesses at the end of its depositional phase. Secondary porosity is that which is due to post depositional processes such as solution and fracturing (Pettijohn, 1975). Porosity of the formation is important in evaluation of fluid content, potentiality of fluids flow. It is determination is possible with Equation 2 or Equation 3 (Atat et al., 2024c).

$$\emptyset = \frac{\rho_{ma}-\rho_b}{\rho_{ma}-\rho_f} \tag{2}$$

where: ∅ = porosity

ρ_{ma}= grain matrix density

ρ_b= bulk density recorded by the log

ρ_f= fluid density

$$\emptyset = \frac{C_{r(t-t_{ma})}}{t} \tag{3}$$

The value C_r of can vary between 0.625 and 0.700 depending upon local conditions. The most widely accepted value is 0.670; it is taken as 0.60 for gas reservoirs. The porosity of a formation can also be estimated from density log.

2.3 Textural Parameters

Statistical/textural parameters which include mean (M) which is may be obtained using Equation 4, standard deviation (SD), skewness (S) and kurtosis (S_K) are needed for grain size and statistical spreading. Textural parameters such as Standard Deviation, Sorting, Skewness, and Kurtosis can be computed by means of Equations 5 to 8 respectively (Adedoyin et al., 2022; Gandhi and Raja, 2014; Folk and Ward, 1957). It relates with the velocity of the medium accountable for the transportation and deposition of sediment (or sand-shale lithology in this research) (Atat et al., 2018; Atat et al., 2024b). Table 1 highlights the interpretation.

$$M = \frac{1}{3}(\emptyset_{16} + \emptyset_{50} + \emptyset_{84}) \tag{4}$$

Standard deviation is a measure of sorting. The sorting of a given population is a measure of the range of grain-size present and the magnitude of these sizes around the mean sizes. Sorting can be homogenous [if it occurs when there is a very negligible level of deviation from the mean] or heterogeneous [if there is high deviation from the mean].

$$SD = \frac{1}{4}(\emptyset_{84} - \emptyset_{16}) \tag{5}$$

$$S = \frac{\emptyset_{84}-\emptyset_{16}}{4} + \frac{\emptyset_{95}-\emptyset_5}{6.6} \tag{6}$$

Skewness measures the symmetry of a curve by marking the position of the mean in relation to the median. A given size population that has a tail of excess fine particles is said to be positively skewed while one with tail excess is said to be negatively skewed. Negatively skewed (which is coarse skewed) defines high energy environment and positively skewed (which is finely skewed) corresponds to low energy environment.

$$S_K = 0.5\left(\frac{\emptyset_{84}+\emptyset_{16}-\emptyset_{50}}{\emptyset_{84}-\emptyset_{16}} + \frac{\emptyset_5+\emptyset_{95}-\emptyset_{50}}{\emptyset_{95}-\emptyset_5}\right) \quad (7)$$

Kurtosis measures the sorting ratio at the extremes of the distribution. If kurtosis is defined as platykurtic, its value is negative excess kurtosis (that is, opposite situation to the case of leptokurtic); if it is mesokurtic, kurtosis curve is observed to have uniform sorting in both tails and central position and finally leptokurtic, if its value is positive excess kurtosis (tail is better sorted than central portion). It is a quantitative measure used to describe the departure from normality of distribution. It signifies the ratio between sorting in tails and central portion of the curve.

$$K_S = \frac{\emptyset_{95}-\emptyset_5}{2.44(\emptyset_{75}-\emptyset_{25})} \quad (8)$$

Table 1: Classification of Textural Parameters (Atat et al., 2022; Atat et al., 2021b; Atat et al., 2024a)

S/N	Parameters	Range of values	Interpretation/Classification
1	Sorting	Less than 0.35	Very well sorted
2	Sorting	0.35 to 0.50	Well sorted
3	Sorting	0.51 to 0.70	Moderately well sorted
4	Sorting	0.71 to 1.00	Moderately sorted
5	Sorting	1.01 to 2.00	Poorly sorted
6	Sorting	2.01 to 4.00	Very poorly sorted
7	Sorting	Greater than 4.00	Extremely poorly sorted
8	Skewness	Less than - 0.30	Very coarse skewed
9	Skewness	- 0.30 to - 0.11	Coarse skewed
10	Skewness	- 0.10 to +0.10	Near symmetrical
11	Skewness	+0.11 to +0.30	Fine skewed
12	Skewness	Greater than +0.30	Very fine skewed
13	Kurtosis	Less than 0.67	Very platykurtic
14	Kurtosis	0.67 to 0.90	Platykurtic
15	Kurtosis	0.91 to 1.11	Mesokurtic
16	Kurtosis	1.12 to 1.50	Leptokurtic
17	Kurtosis	1.51 to 3.00	Very leptokurtic
18	Kurtosis	Greater than 3.00	Extremely leptokurtic

3. Materials and Methods

3.1 Materials

Onshore S-field data was acquired from the Niger Delta basin. The data include well location and raw well data. Microsoft Excel and Paint Package of Windows 10 were used for data loading, processing, plots, diagrams, and computations.

3.2 Method

The three wells were studied and suites of log such as depth, gamma ray, and density were generated from the offered data set. These data were analysed using Microsoft Excel. Figure 2 outlines the steps taken to attain the research goal.

The raw data were analysed to create suites of logs as illustrated in Figures 3 to 5 which includes Density Log (red), Gamma Ray Log (blue) and Porosity (green) with respect to depth. Gamma ray log was used to identify the Lithologies (sand stones and shale) since we need this information to identify the reservoir for each well. It was marked as sand when gamma ray log is less than 75API and marked as shale when the gamma ray log is greater than 75API. The information obtained from gamma ray log led to the appropriate well reservoir thickness of each well. The results of porosity (green curves) estimates were obtained using Equation 2 and illustrated in Figure 6 for all the wells.

In order to deduce the ogive, class intervals were obtained and ogives were plotted as shown in Figures 7 to 9; percentile deduction were deduced as well. Equations 4 and 5 were used to determine the Mean and Standard Deviation respectively. Other textural parameters such as sorting, skewness and kurtosis were computed using Equations 6, 7 and 8 respectively for all the wells. The result on porosity estimates obtained using Equation 2 are shown in Figure 6 for well 001, well 002 and well 003 respectively.

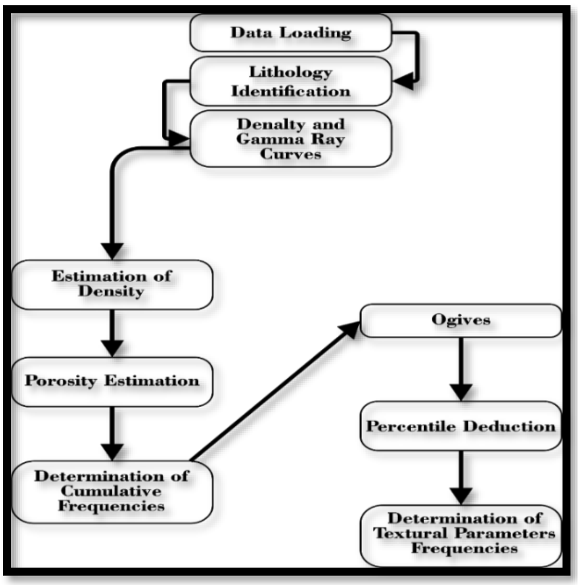

Figure 2: Work Flow of the Study

4. RESULTS AND DISCUSSION

4.1 Results

The study on the subsurface matrix arrangement has been conducted. The research outcomes of porosity estimates are presented in Figures 3 to 6. In order to obtain textual parameters, ogive curves were obtained (Figures 7 to 9). Tables 2 and 3 present the percentile outcomes and interpretations respectively.

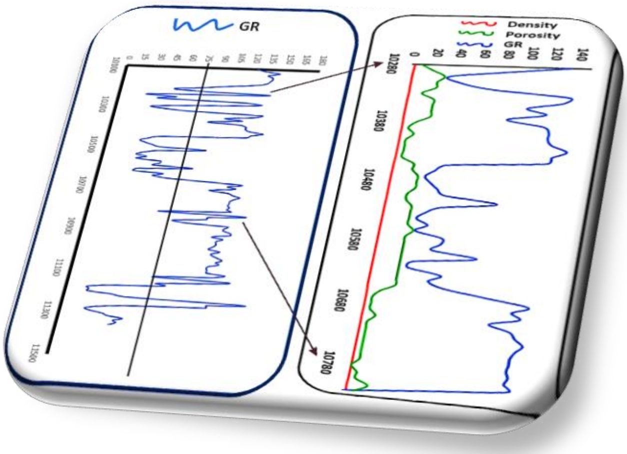

Figure 3: The generated suites of log with depth for gamma (blue), porosity (green), density (red) indicating sand/shale base line for well 001.

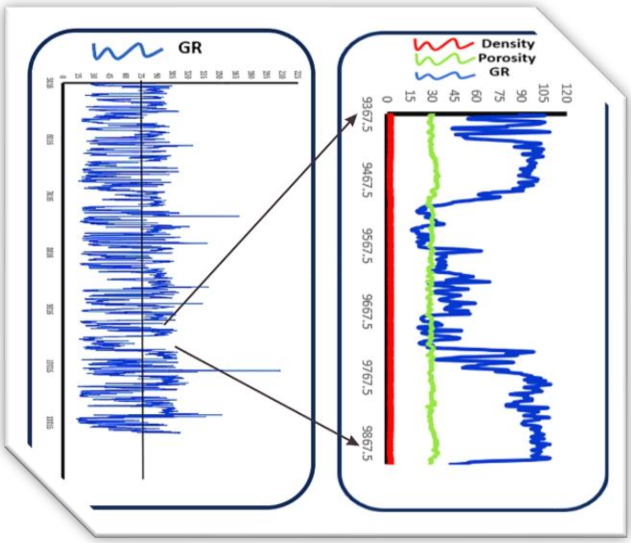

Figure 4: The generated suites of log with depth for gamma (blue), porosity (green), density (red) indicating sand/shale base line for well 002**.**

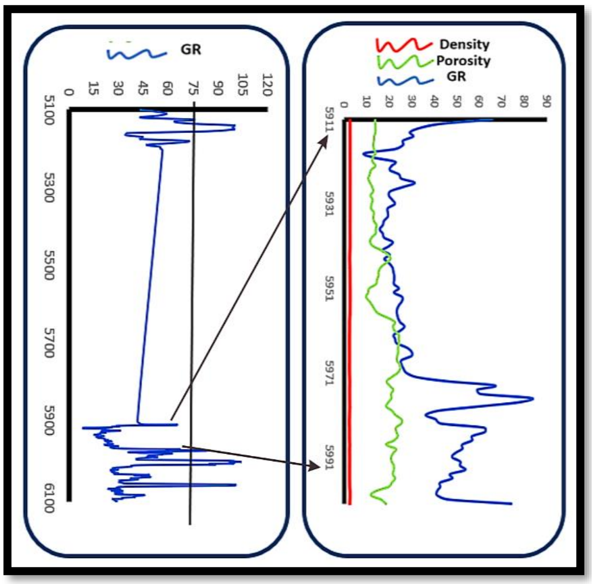

Figure 5: The generated suites of log with depth for gamma (blue), porosity (green), density (red) indicating sand/shale base line for well 003**.**

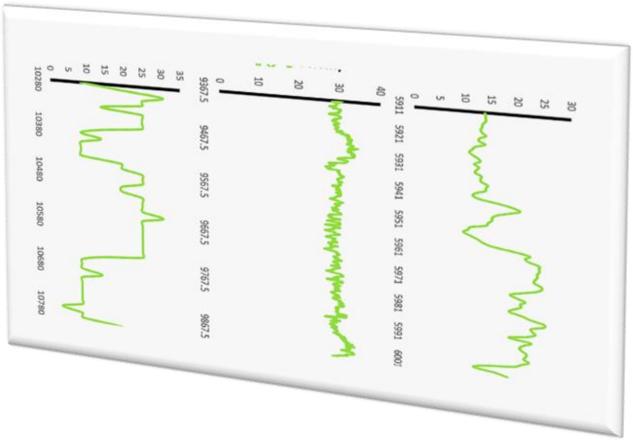

Figure 6: Porosity curve for well 001, well 002 and well 003 respectively

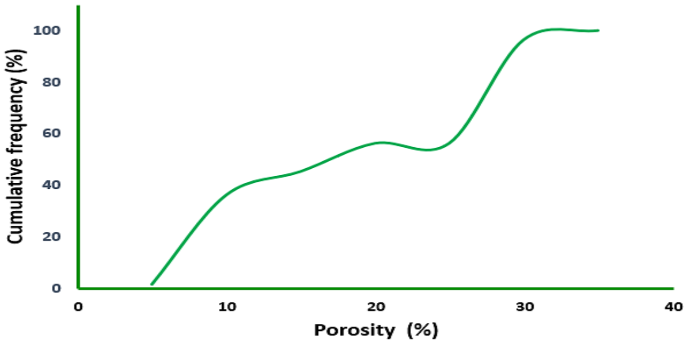

Figure 7: Ogive outcome of well 001

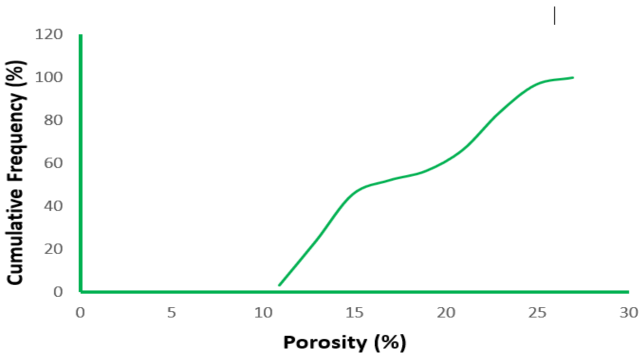

Figure 8: Ogive outcome of well 002

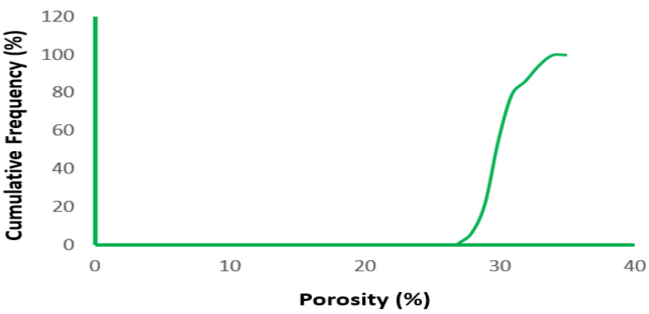

Figure 9: Ogive outcome of well 003

Table 2: The Percentiles. Standard Deviation and Mean outcomes

	PERCENTILES								
WELLS	$Ø_5$	$Ø_{16}$	$Ø_{23}$	$Ø_{50}$	$Ø_{75}$	$Ø_{85}$	$Ø_{95}$	SD	MEAN
001	5.4	6.7	7.9	17.2	27.7	28.3	29.3	5.4	17.4
002	28.1	28.7	29.9	29.9	31.2	31.4	33.7	0.675	30
003	11.2	12.2	13.1	16.4	22.4	22.0	24.8	2.7	17.2

Table 3: Result of textural parameters and interpretations

WELLS	M	SD	Sr/ Interpretation	Sk/Interpretation	Ks/Interpretation
001	7.4	5.4	9.0969697/Extremely poorly sorted	1.62287492/Very fine skewed	0.47619048/Very platykurtic
002	30	0.675	1.52348485/poorly sorted	0.23412698/Fine skewed	1.20793788/Lepto kurtic
003	17.2	2.7	4.76060606/Extremely poorly sorted	0.22875817/Fine skewed	0.59933016/ Very platykurtic

4.2 Discussion

The 5th, 16th, 25th, 50th, 75th, 84th and 95th percentiles were deduced from each cumulative curve. The criteria for classifying porosity include; porosity values less than 5% are negligible, between 5% and 10% is poor, greater than 10% but less than 30% is very good and porosity by value from 30% above is excellent. Table 2 shows the percentiles deduction and other statistical results. These were used to investigate the statistical and textural parameters such as mean (M), standard deviation (SD), sorting (S), graphic kurtosis (Ks), and graphic skewness (Sk). The Equations employed for calculations are Equations 4 to 8. Table 3 has information on the textural percentiles obtained.

4.2.1 For well 001

The sand/shale lithology investigated a thickness of 540ft from 10280ft and 10820ft. Gamma ray log and density log with respect to depth were generated. These results were used to obtain porosity of the reservoir. The result on porosity shows that the porosity ranges from 8.0% to 20.5%. The average result of porosity estimated is approximately 17.42% which is classified as good.

Table 3 defines the reservoir matrix as extremely poorly sorted, very fine skewed and very platykurtic. As extremely poorly sorted signifies that the rocks (matrix) are composed of a wide variety of grain sizes and shapes. The fine skewness suggests a low energy environment that can hinder fluid flow. The very platykurtic signifies very flat distribution *(*Oladipo *et al.,* 2018). The fine skewness suggests a potential for low permeability which can hinder fluid flow; the very platykurtic signifies very flat frequency distribution (Folk, 1968).

4.2.2 For well 002

The sand/shale lithology investigated a thickness of 531.5ft from 9367.5ft and 9899ft. In this well, density is estimated using Equation 1. Gamma ray log and density log with respect to depth were generated. These results were used to obtain porosity of the reservoir. The result on porosity shows that the porosity ranges from 26.59% to 34.57%. The average result of porosity estimated is approximately 29.98% which is classified as excellent.

Table 3 defines the reservoir matrix as poorly sorted, fine skewed, and leptokurtic. As poorly sorted signifies that the rocks (matrix) are composed of a wide variety of grain sizes and shapes. The fine skewness suggests a low energy environment that can hinder fluid flow. The leptokurtic signifies highly peaked distribution (Folk, 1968).

4.2.3 For well 003

The sand/ shale lithology investigated a thickness of 91ft from 5911ft and 6002ft. Gamma ray log and density log with respect to depth were generated. These results were used to obtain porosity of the reservoir. The result on porosity shows that the porosity ranges from 9.83% to 24.38%. The average result of porosity estimated is approximately 17.53% which is classified as good. Table 3 defines the reservoir matrix as extremely poorly sorted, fine skewed, and very platykurtic. As extremely poorly sorted signifies that the rocks (matrix) are composed of a wide variety of grain sizes and shapes. The fine skewness suggests a low energy environment that can hinder fluid flow. The very platykurtic signifies very flat distribution (Oladipo *et al.,* 2018).

It should be noted that the porosity information was used to generate the ogives and percentiles were deduced. The interpretation of textural parameters from the percentiles yields the goal of this research. The class of porosity noted are good, excellent and good for wells 001. 002 and 003 respectively. The subsurface matrix arrangements are defined as extremely poorly sorted, very fine skewed and very platykurtic for well 001; poorly sorted, fine skewed and leptokurtic for well 002 and extremely poorly sorted, fine skewed and very platykurtic for well 003. The wells analysed are porous and can accumulate high amount of hydrocarbon and it is strongly recommended for development and exploration of hydrocarbon.

5. Conclusion

The study on the arrangement of reservoir matrix has been conducted. The three wells are highly porous and well suited for storage and transmission of hydrocarbons. Well 001 and well 003 belong to the good class of porosity. The outcome of the average porosity obtained from well 002 indicates that the porosity is in the excellent class. The use of textural parameters has made it easier to define and understand the reservoir matrix arrangement.

Compliance with Ethical Standards

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Disclosure of Conflict of Interest

No conflict of interest to be disclosed.

Statement of Informed Consent

The Authors consent to take part in the research project and the outcome of our study result is this article. The involvement of the Authors is voluntary and they have agreed to publish this finding in Malaysian Journal of Geosciences (MJG) as a research article.

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