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DEPOSITIONAL ENVIRONMENT AND PETROPHYSICAL EVALAUTION OF THE K CREEK OIL FIELD, NIGER DELTA BASIN, NIGERIA

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Abstract: This study integrated wireline log data with other supporting information such as formation well top and bottom to quantitatively determine the spatial variability of some important reservoir properties. The results obtained from the suite of gamma ray and resistivity well log analysis of the K creek oil field have been used to study and evaluate the petro-physical characteristics and hydrocarbon prospective of the well Formation. The value of Porosity ranges from 0.115 to 0.366 while the bulk volume of water of hydrocarbon-bearing zones ranges from 0.012 to 0.021. The bulk volume of hydrocarbon in the formation (BVH) ranged from 9.2% to 34.9%. Water saturation, mud filtrate saturation and hydrocarbon saturation ranged from 0.047 to 0.187; 0.543 to 0.715; 0.813 to 0.953 respectively. The percentage of movable hydrocarbon ranged from 49.6% to 52.8% and non-movable hydrocarbon ranged from 28.5% to 45.7%. The depositional environment showed coarse up and sharp top, even block with sharp top and base, saw teeth, hour glass that favor the accumulation of hydrocarbon within the reservoir.
Keywords: Depositional environment; Formation; Hydrocarbon; Petro-physical; Saturation

1 INTRODUCTION

The challenges associated with exploration uncertainty needs to be reduced for gainful exploration and exploitation of the hydrocarbon reserves. The field which consists of interstratified sandstones and shale units representing shore face to shelf deposition environment has recently been experiencing decline in oil production [1], while water production on the other hand is on the increase. Several petro-physical studies have been undertaken, especially to tackle production challenges associated with complex fields, usually presented with unpredictable stratigraphic and facies variation and oftentimes with related structural complexities. Material balance studies carried out on the reservoir as well as production decline curve plot which fits production data to the decline curve to estimate future production indicated undepleted reservoir [2]. The decision to increase production for the purpose of maximizing recovery initiated the need to evaluate the reservoir in order to be able to make informed decisions relating to placement of new wells for the purpose of optimizing reservoir activities and thus reduce water production. Well logs are largely used to evaluate reservoirs properties in sedimentary rocks. It is one of the most important tools for hydrocarbon research for oil companies [3-5].

Depositional environment or sedimentary environment describes the combination of physical, chemical and biological processes associated with the deposition of a particular type of sediment.

Sedimentary facies are characteristic of sedimentary rock linked to a distinct sedimentary environment in a given location where sediments are deposited within the reservoir [6]. The amount of kerogen present in sediments is a balance between bio-productivity, survival and dilution of inorganic grains. Physical characteristics and geographical location determines the type of sediment that will normally be deposited. The contained fluids are closely linked to the structural shape of the rock body. It is of importance to know whether the rock body corresponds, for example, to a small river bar of a minor meandering stream or a vast limestone plain. This will have an important impact on the estimates of reserves and the subsequent drilling for production.

Petro-physical and formation evaluation is essentially performed on a well-by-well basis. A number of measurement devices and interpretation techniques have been developed. They provide, principally, values of porosity and hydrocarbon saturation, as a function of depth, using the knowledge of local geology and fluid properties that is accumulated as a reservoir is developed. The internal surface area of the reservoir rock is used to evaluate the possibilities of producing fluids from the pore space. Because of the wide variety of subsurface geological formations, many different logging tools are needed to give the best possible combination of measurements for the rock type anticipated. Despite the availability of this rather large number of devices, each providing complementary information, the final answers derived are mainly three: the location of oil-bearing and gas-bearing formations, an estimate of their producibility, and an assessment of the quantity of hydrocarbon in place in the reservoir.

The Niger Delta basin has area coverage of about 75,000 km^2 and consists of an overall regressive clastic sequence which reaches a maximum thickness of about 12,000 m in the central part of the basin where there is maximum subsidence [7].

The basin consists of progradational, paralic sequences of Akata, Agbada and Benin Formations which builds southwards into the deep waters and this account for the Delta Complex in the Oligocene–Miocene times [8].

2 THE STUDY AREA

The study area includes those communities around the Creek where oil exploration activities are ongoing in Ogbia Local Government of Bayelsa State, Nigeria (Figure 1). The study area lies within latitudes 4^0 20' and 4^0 50'N and longitudes 6^0 20' and 6^0 18'E. Specific towns within the area include Imiringi, Otuasega, Elebe, Orom, and Ayom. The Agip pipeline, the Kolo Creek oil and gas field is located within Imiringi town and situated about 10km east of Yenagoa, Bayelsa State. The Kolo Creek field hosts some oil facilities including 46 oil wells one flow station, one manifold and one SPDC camp site. The other economic activities include subsistence agriculture, artisanal fishing, palm wine tapping and processing. The study used three wells data (A, B, & C) from the study area to ascertain the producibility and an assessment of the quantity of hydrocarbon in place in the reservoir.

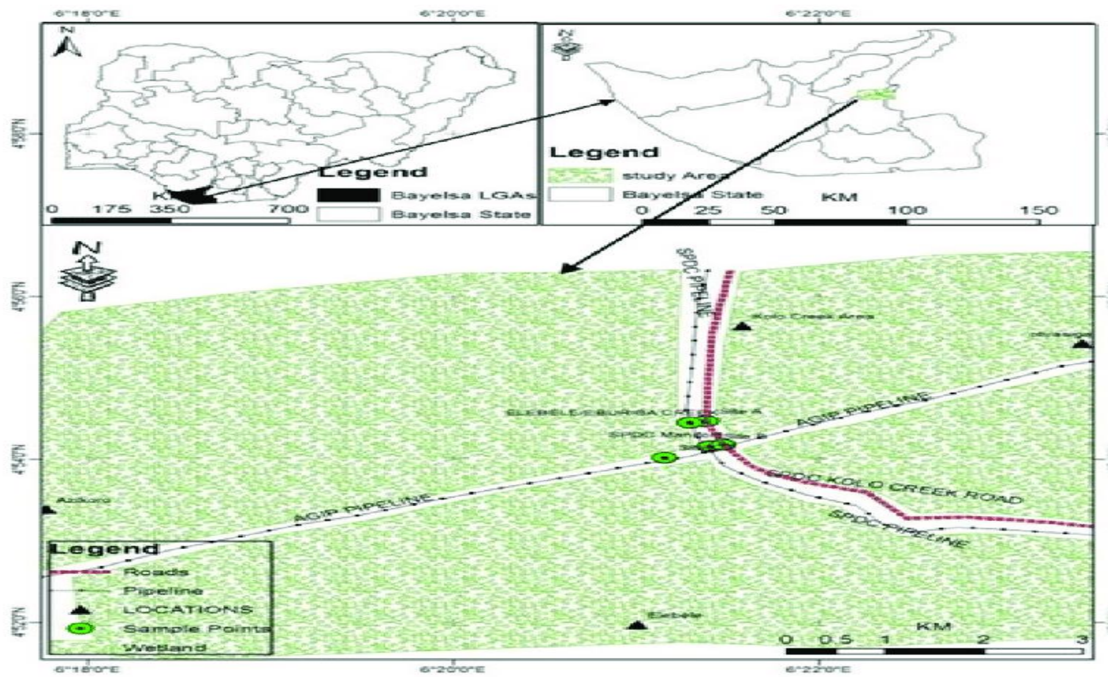

Figure 1 Map Showing Parts of the K Creek and its Environs [4].

3 MATERIALS AND METHODS

Well log data collection were obtained from Shell Petroleum Development Company (SPDC), Rumubiakani, through the Department of Petroleum Resources, Rivers State. A detailed petro-physical evaluation viz; shale volume, water saturation, mud filtrate saturation and into movable, non- movable hydrocarbon of the well was undertaken based on the wire line logs obtained from the K creek well. Guidance was obtained from the company representative on picking of sand tops and bases; and the use of cut-offs for determining pay.

Using formation parameters generated from log data and basic regional information applicable to the Niger Delta Province (dispersed shaly sand structural and dispersed type of shale distribution).

Modelling for the depositional environment was carried out using the Schlumberger Petrel software and consequently the evaluation of the reservoir parameters were carried out using Interactive Schlumberger Petro-physical software and other established mathematical equations. This work presents a qualitative approach to the geological terrain of the studied area, which gives the visual inspection of the gamma ray log and resistivity log traces on each track. The well log traces (Figure 2), shows the interval coloured yellow is sand while the interval coloured dark grey is shale. The K Creek well data have been correlated and each divided into six reservoir according to their stratigraphic position, beginning from the bottom to the top. The reservoir zones were identified and labeled reservoir 1 to 6 in order to distinguish from one sand body to another; and which are separated from each other with certain thickness of shale beds. In the first reservoir, horizon 1 is the bottom while horizon 2 is the top. In the second reservoir, horizon 2 is the bottom while horizon 3 is the top. In the third reservoir, horizon 3 is the bottom while horizon 4 is the top. In the fourth reservoir, horizon 4 is the bottom while horizon 5 is the top. In the fifth reservoir, horizon 5 is the bottom while horizon 6 is the top. In the sixth reservoir, horizon 6 is the bottom while horizon 7 is the top. These horizons (top and bottom) characterization have been used across the three wells (Figure 3). Abrupt changes observed in the overall log patterns with associated change in individual log values were implied as change in the lithology or stratigraphic boundary.

Modelling for the depositional environment begins with the inspection of the shapes and trends of the curves in each track. Attribute maps extracted on top of key horizons were used for better visualization and for interpreting the morphological and reflectivity characteristics of the reservoir.

Qualitative analysis of the well logs resulted in characterization of the subsurface stratigraphy into well log facies of depositional environment. The gamma-ray (GR) and resistivity (Rt) logs from all wells were arranged into vertical profiles against common measured depths (in meters) to show systematic vertical variations of the sedimentary sequence across different log types at corresponding depths in each well.

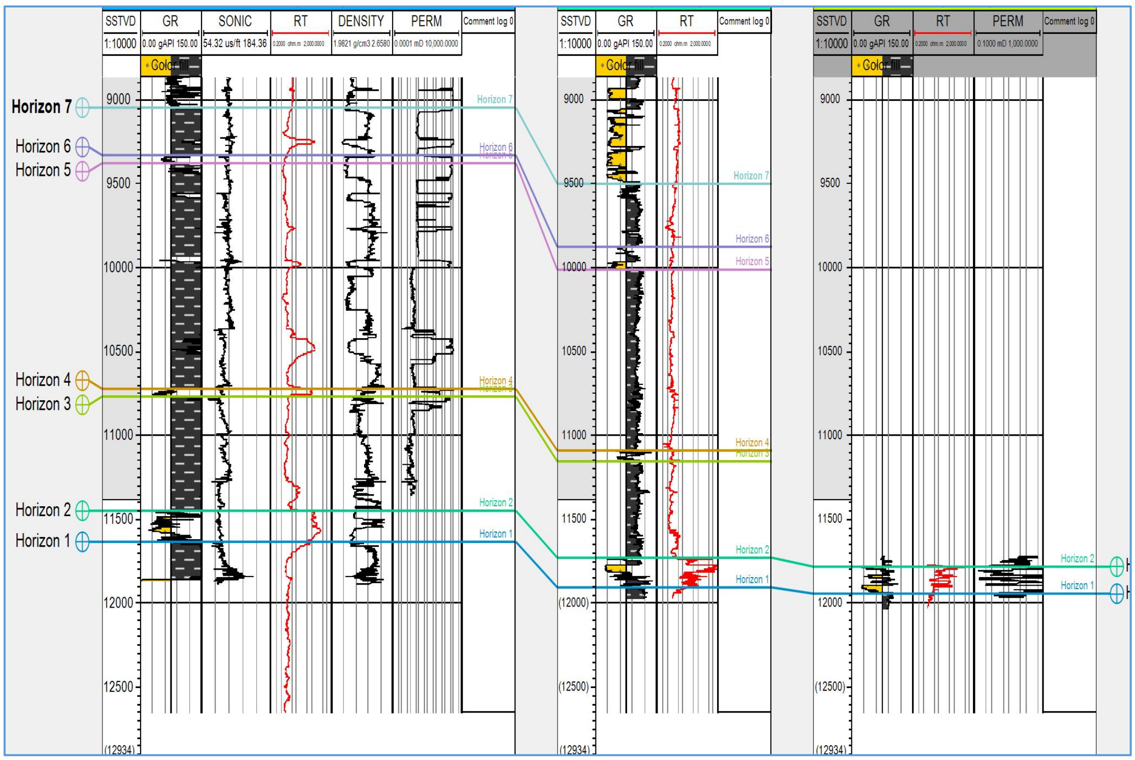

Figure 2 Showing Well Log Traces Correlation for the Three Wells

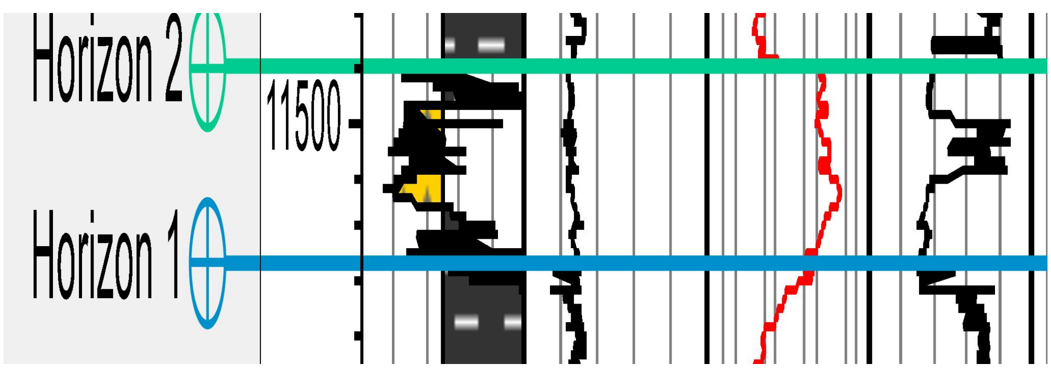

Figure 3 Model (Well A) Depositional Environment for Reservoir 1

The following petro-physical parameters were determined using the equations according to Simandous (1963), Bardon and Pied (1969), Thomas and Stieber (1975), Telford (1990) [9-12]:

$$\text{Formation factor (F)} = \frac{1}{\Phi^2} \tag{1}$$

$$\text{Tortuosity } (\tau) = \frac{1}{\Phi} \tag{2}$$

where Φ is the porosity

$$\text{Hydrocarbon saturation } S_h = 1 - S_w \quad (3)$$

$$\text{Bulk volume of water (BVW)} = \Phi S_w \quad (4)$$

where S_w is the water saturation

$$\text{Bulk volume of hydrocarbon (BVH)} = \Phi(S_h) \quad (5)$$

Schlumberger (2005) and Akpan et al. (2017) gives the equation for the mud filtrate saturation, movable hydrocarbon and non- movable hydrocarbon as [5, 13]:

$$\text{Mud filtrate saturation } S_{xo} = \sqrt[5]{S_w} \quad (6)$$

$$S_{hnon\text{-}movable} = 1 - S_{xo} \quad (7)$$

$$S_{hmovable} = S_h - S_h \text{ non-movable} \quad (8)$$

where, $S_{hnon\text{-}movable}$ is the non- movable hydrocarbon and $S_{hmovable}$ is the movable hydrocarbon.

4 RESULTS AND DISCUSSION

A number of measurement devices and interpretation techniques have been developed. They provide the values of porosity and hydrocarbon saturation, as a function of depth, using the knowledge of local geology and fluid properties that is accumulated as reservoir is developed.

After carefully applying cut-off < 0.5 for water saturation, > 0.1 for porosity and < 0.5 for volume of shale to define the net pay and other petro-physical parameters, the results from the study conform to these standards to give accurate interpretation of our findings. The value of Porosity ranges from 0.115 to 0.366. Porosity depends on degree of uniformity of grain size, the shape of the grains, the method of deposition, the manner of packing and the effects of completion during or after deposition. Bulk volume of water of hydrocarbon-bearing zones ranges from 0.012 to 0.021, the grain size of the sand is fine to very fine-grain [14].

Facies distribution which correspond to different log traces such as symmetrical, serrated, funnel and cylindrical shapes across the reservoir was used to analyze gamma ray response to variation in grain [15]. These facies distribution clearly reveal the hydrocarbon accumulation potentiality of the reservoir source rocks.

For Well A, reservoir 1, the depositional environment shows both serrated and symmetrical GR shape as illustrated in (Figure 3) the context of a model section, through varying log shape classification geometry. The serrated with saw teeth showed aggrading with fluvial flood plain, storm dominated shelf and distal deep marine slope while the symmetrical with hour glass showed a corresponding prograding and retrograding with reworked of shore bar regressive to transgressive shore face Delta that favour the accumulation of hydrocarbon within the reservoir.

Reservoir 3, the depositional environment showed symmetrical GR shape as illustrated in (Figure 4) the context of a model section, through varying log shape classification geometry. The symmetrical with hour glass show a corresponding prograding and retrograding with reworked of shore bar regressive to transgressive shore face Delta that favour the accumulation of hydrocarbon within the reservoir.

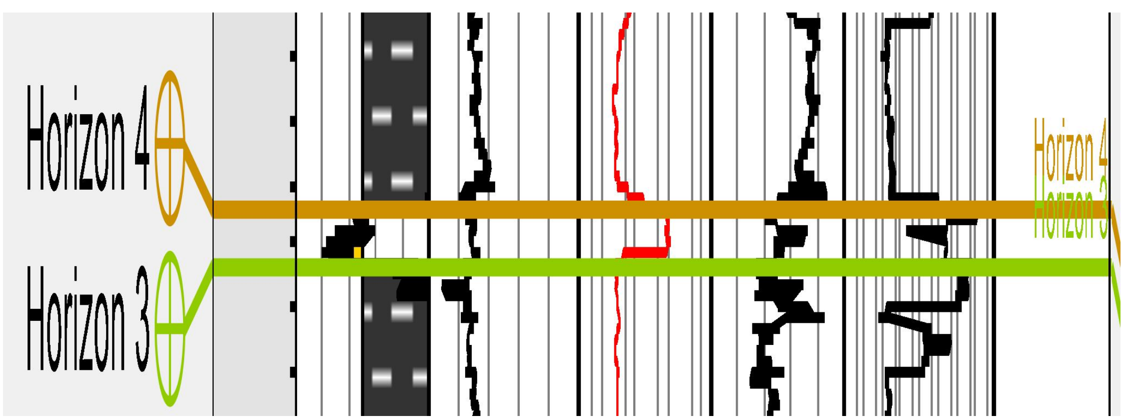

Figure 4 Model (Well A) Depositional Environment for Reservoir 3

Reservoir 5, the depositional environment showed symmetrical GR shape as illustrated in (Figure 5) the context of a model section, through varying log shape classification geometry. The symmetrical with hour glass show a corresponding prograding and retrograding with reworked of shore bar regressive to transgressive shore face Delta that favour the accumulation of hydrocarbon within the reservoir.

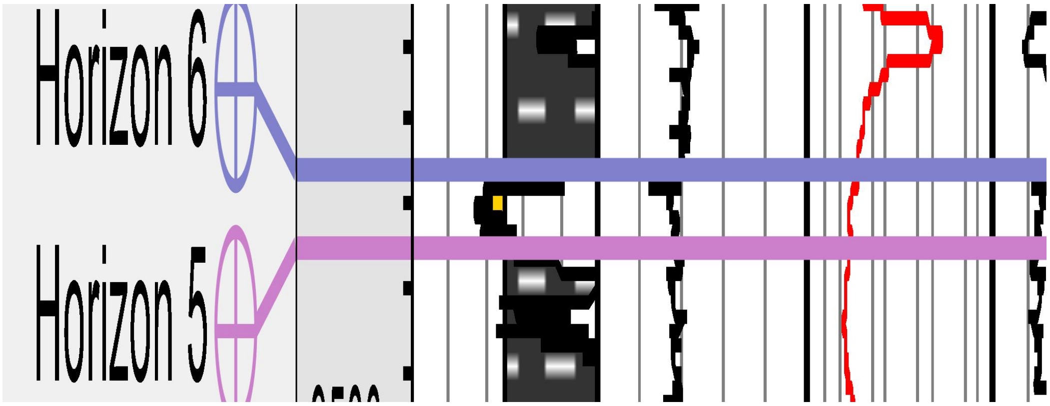

Figure 5 Model (Well A) Depositional Environment for Reservoir 5

For well B, reservoir 1, the depositional environment showed both cylindrical and serrated GR shape as illustrated in (Figure 6) the context of a model section, through varying log shape classification geometry. The cylindrical shape as even block with sharp top and base showed aggrading which correspond to the eolian, braided fluvial, distributary channel-fill, submarine canyon-fill, carbonate shelf-margin and evaporate fill of basin. The serrated shape with saw teeth showed aggrading with fluvial flood plain, storm dominated shelf and distal deep marine slope that favour the accumulation of hydrocarbon within the reservoir.

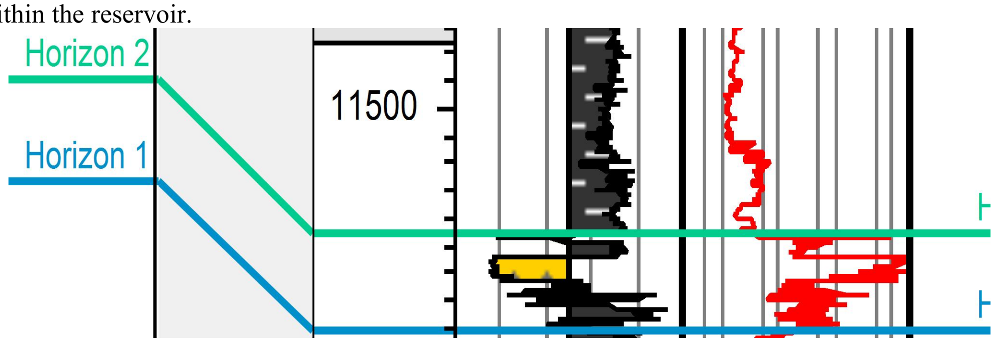

Figure 6 Model (Well B) Depositional Environment for Reservoir 1

Reservoir 5, the depositional environment showed serrated GR shape as illustrated in (Figure 7) the context of a model section, through varying log shape classification geometry. The serrated shape with saw teeth showed aggrading with fluvial flood plain, storm dominated shelf and distal deep marine slope that favour the accumulation of hydrocarbon within the reservoir.

Figure 7 Model (Well B) Depositional Environment for Reservoir 5

For Well C, the depositional environment showed both serrated and funnel GR shapes as illustrated in (Figure 8) the context of a model section, through varying log shape classification geometry. The serrated shape with saw teeth showed aggrading with fluvial flood plain, storm dominated shelf and distal deep marine slope. The funnel shape with coarse up and sharp top showed crevasse splay, river mouth bar, Delta front, shoreface, submarine fan lobe, change from clastic to carbonate which favour the accumulation of hydrocarbon within the reservoir. The reservoir is sufficient for oil and gas exploration. These findings are equally in agreement with the work of Oboh (1993) on the investigation of sedimentological and microfossil data that shows seven deltaic sub environments of deposition which include the distributary channel fill [16], lagoon/tidal flat, coastal barrier and delta fringe sub environments, prodelta, lagoonal and flood tidal deltas.

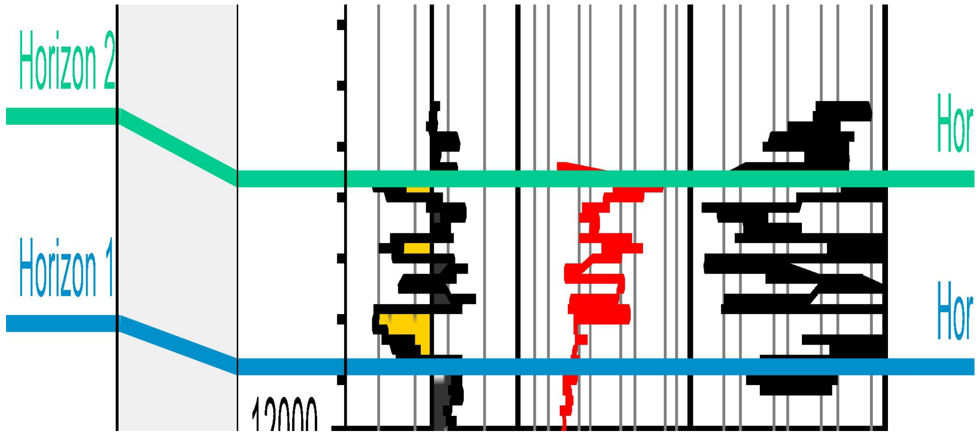

Figure 8 Model (Well C) Depositional Environment for Reservoir 1

The petro-physics approach has been used to evaluate well properties. Table 1, gives the summary of the hydrocarbon potentiality of each of the three wells. The properties include depth, gross pay thickness, net pay thickness, Net to gross ratio, shale volume, porosity, bulk volume of water, bulk volume of hydrocarbon, water saturation and mud filtrate saturation. These properties were used to estimate the hydrocarbon potentialities and distinguish between the movable and non-movable hydrocarbons. The volume of shale values were low within the hydrocarbon- bearing zones. The reservoir petro-physical features are good indicators of hydrocarbon accumulation, especially the oil bearing zone with low water saturation. The result from the wells shows that Well C is more hydrocarbon productive with hydrocarbon saturation of 95% at a depth of 3591 m as compared to the other two wells (Figure 9; Figure 10). Well B was the least productive with hydrocarbon saturation of 81% at a depth of 3451 m (Table 1). This result fairly agrees with that obtained by Akpan et al. (2017) when a hydrocarbon saturation of 68% was obtained at depths of 3533 to 3850 m [13]. The result is equally in agreement with Emudianugbe and Timi-Odiase (2022) with hydrocarbon saturation that ranged between 60% to 76% using well log and seismic data [17].

Table 1 Showing Petro-Physical Parameters of the K Creek Well

Well	Depth (m)	Gross Pay Thickness (m)	Net Pay Thickness (m)	Net/Gross Ratio Thickness (m)	V_{sh}	Porosity (ϕ)	S_w	S_h	S_{xo}	$S_{hmov.}$ (%)	$S_{hnon-mov.}$ (%)	BVW	BVH	τ	F
A	3044	3871	1962	0.507	0.008	0.219	0.057	0.943	0.564	50.7	43.6	0.012	0.207	4.6	20.9
B	3451	3660	49	0.013	0.124	0.113	0.187	0.813	0.715	52.8	28.5	0.021	0.092	8.8	78.3
C	3591	2222	51	0.023	0.18	0.366	0.047	0.953	0.543	49.6	45.7	0.021	0.349	2.7	7.5

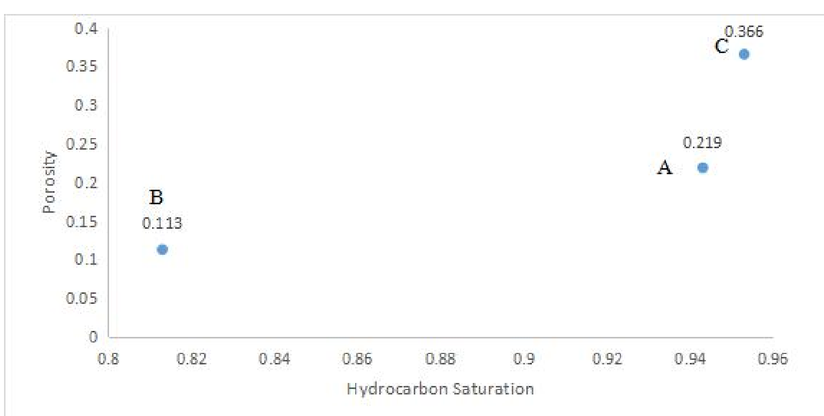

Figure 9 Plot of porosity with Hydrocarbon Saturation (Well A, B and C)

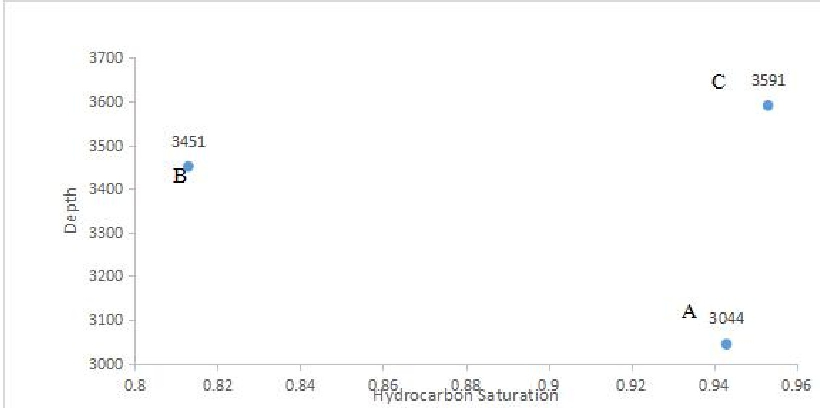

Figure 10 Plot of Depth With Hydrocarbon Saturation (Well A, B and C)

5 CONCLUSION

The application of well log data provided a powerful tool in modelling for the depositional environment and evaluation of the reservoir parameters of the K Creek oil field. The bulk volume of hydrocarbon in the formation (BVH) ranged from 9.2% to 34.9%. Water saturation, mud filtrate saturation and hydrocarbon saturation ranged from 0.047 to 0.187; 0.543 to 0.715; 0.813 to 0.953 respectively. The percentage of movable hydrocarbon ranged from 49.6% to 52.8% and non-movable hydrocarbon ranged from 28.5% to 45.7%. The depositional environment showed coarse up and sharp top, even block with sharp top and base, saw teeth, hour glass that favor the accumulation of hydrocarbon within the reservoir. The results of lithology showed hydrocarbon of varying proportion. It could therefore be concluded that the zones are potential for oil and gas production. This result is similar to that of Aigbadon et al., (2022) on Depositional Environment and facies analysis of Useni- 1 [18], Niger Delta Basin, using well logs, core data. It is also in agreement with that obtained by Obidike and Chiazor (2023) on Petrophysical Evaluation and Depositional Environments of Reservoir Sands in an Oil Producing Field [19], Onshore Niger Delta, Nigeria.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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